United States
Environmental Protection
Agency

Office of Water
(4303)

EPA-821-R-02-003
February 12, 2004

EPA

Regional Analysis Document for the Final Section 316(b) Phase II Existing Facilities Rule

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U.S. Environmental Protection Agency
Office of Science and Technology
Engineering and Analysis Division

Washington, DC 20460
February 12, 2004

ACKNOWLEDGMENTS AND DISCLAIMER

This document was prepared by the Office of Water staff. The following contractors provided assistance and support in performing the underlying analysis supporting the conclusions detailed in this document.

Stratus Consulting Inc.
Abt Associates Inc.
Tetra Tech
Science Applications International Corporation

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Table of Contents

Introduction

Part A: Evaluation Methods

Chapter A1: Ecological Risk Assessment Framework

Chapter A2: Everything You Ever Wanted to Know About Fish

Chapter A3: Other Vulnerable Aquatic Organisms

Chapter A4: Direct and Indirect Effects of CWIS on Birds

Chapter A5: Methods Used to Evaluate I&E

Chapter A6: Uncertainty

Chapter A7: Entrainment Survival

Chapter A8: Impingement & Entrainment by Waterbody Type

Chapter A9: Economic Benefit Categories and Valuation

Chapter A10: Methods for Estimating Commercial Fishing Benefits

Chapter A11: Estimating Benefits with a Random Utility Model

Chapter A12: Non-Use Meta-Analysis Methodology

Chapter A13: Threatened & Endangered Species Analysis Methods

Chapter A14: Discounting Benefits

Chapter A15: Habitat Based Methodology for Estimating Non-Use Values

Appendix A1

Part B: California

Chapter B1: Background

Chapter B2: Evaluation of Impingement and Entrainment in California

Chapter B3: Commercial Fishing Valuation

Chapter B4: RUM Analysis

Chapter B5: Non-Use Benefits

Chapter B6: Threatened and Endangered Species Analysis

Appendix B1: Life History Parameter Values Used to Evaluate I&E in the Northern and Southern California Regions

Appendix B2: Valuing Water Use Foregone

Appendix B3: Special Status Species Population Estimates

Part C: North Atlantic

Part D: Mid-Atlantic Region

Chapter D1: Background

Chapter D2: Evaluation of Impingement and Entrainment in the Mid-Atlantic Region

Chapter D3: Commercial Fishing Valuation

Chapter D4: RUM Analysis

Chapter D5: Non-Use Benefits

Chapter D6: Habitat Based Analysis

Appendix D1: Life History Parameter Values Used to Evaluate I&E in the Mid-Atlantic Region

Part E: South Atlantic

Chapter E1: Background

Chapter E2: Evaluation of Impingement and Entrainment in the South Atlantic Region

Chapter E3: Commercial Fishing Valuation

Chapter E4: RUM Analysis

Chapter E5: Non-Use Benefits

Part F: Gulf of Mexico

Chapter F1: Background

Chapter F2: Evaluation of Impingement and Entrainment in the Gulf of Mexico

Chapter F3: Commercial Fishing Valuation

Chapter F4: RUM Analysis

Chapter F5: Non-Use Benefits

Appendix F1: Life History Parameter Values Used to Evaluate I&E in the Gulf of Mexico Region

Part G: The Great Lakes

Chapter G1: Background

Chapter G2: Evaluation of Impingement and Entrainment in the Great Lakes Region

Chapter G3: Commercial Fishing Valuation

Chapter G4: RUM Analysis

Chapter G5: Non-Use Benefits

Chapter G6: Habitat Based Analysis

Appendix G1: Life History Parameter Values Used to Evaluate I&E in the Great Lakes Region

Appendix G2: Scaling Habitat Restoration

Part H: The Inland Region

Chapter H1: Background

Chapter H2: Evaluation of Impingement and Entrainment in the Inland Region

Chapter H3: Commercial Fishing Valuation

Chapter H4: Recreational Benefits Analysis

Chapter H5: Non-Use Benefits

Appendix H1: Life History Parameter Values Used to Evaluate I&E in the Inland Region

Part I: National Benefits

Chapter I1: National Benefits

Glossary

References

Introduction

This Regional Analysis Document presents the methods used by EPA for its section 316(b) Phase II benefits analysis and study results. Part A of the document provides details of the methods used. Parts B-H present reports for each of seven regions evaluated. Finally, Part I presents national level estimates. The following sections provide an overview of the study design and a summary of the contents of each part of the document.

CONTENTS

EPA defined seven regions for its analysis based on similarities among the affected aquatic species and characteristics of commercial and recreational fishing activities in the area. These regions and the water body types within each region are described below. Maps showing the facilities in each region that are in scope of the Phase II rule are provided in the introductory chapter of each regional report (Parts B-H of this document).

1-1 REGIONAL STUDY DESIGN

1-1.1 Coastal Regions

Coastal regions are fisheries regions defined by National Atmospheric and Oceanic Administration (NOAA) Fisheries. Table 1-1 presents these geographic areas and the number of facilities included in each region. The North Atlantic region includes all estuary/tidal river and ocean facilities in Maine, New Hampshire, Massachusetts, Connecticut, and Rhode Island. The Mid-Atlantic region includes all estuary/tidal river and ocean facilities in New York, New Jersey, Pennsylvania, Maryland, the District of Columbia, Delaware, and Virginia. The South Atlantic region includes all estuary/tidal river and ocean facilities in North Carolina, South Carolina, Georgia, and the east coast of Florida. The Gulf of Mexico region includes all estuary/tidal river and ocean facilities in Texas, Louisiana, Mississippi, and Alabama and the west coast of Florida. The California region includes all estuary/tidal river and ocean facilities in California.

Table 1-1: Definition of Costal Regions

Region	Geographic Area	Number of Estuarine Facilities	Number of Ocean Facilities	Total Number of Facilities
North Atlantic	Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut	20	2	22
Mid-Atlantic	New York, New Jersey, Delaware, Maryland and Virginia	43	1	44
South Atlantic	North Carolina, South Carolina, Georgia, East Florida	15	1	16
Gulf of Mexico	West Florida, Alabama, Missouri, Louisiana, Texas	21	3	24
California	All California Counties	8	12	20
Total number of estuarine and ocean facilities[a]		107	19	126

[a] In addition, there are 3 ocean facilities in Hawaii that are not included in the NOAA Fisheries regions.

1-1.2 Great Lakes Region

The Great Lakes region includes all facilities located on the shoreline of a Great Lake or on a waterway with open passage to a Great Lake and within 30 miles of a lake in Minnesota, Wisconsin, Illinois, Michigan, Indiana, Ohio, Pennsylvania, and New York. This definition is based on EPA's estimate of the extent of the spawning habitat of Great Lakes fish species, including spawning habitat in rivers and tributaries of the Great Lakes. The distance each species may travel upstream to spawn varies depending on both the species and the waterway, and is influenced by obstacles such as dams. However, after consultation with local fisheries experts, EPA determined that inclusion of waters within 30 miles of the Great Lakes is likely to encompass spawning areas of Great Lakes fishes. EPA used GIS to determine which facilities are on a water body that has unobstructed passage to the Great Lakes and is within 30 miles of a Great Lake. Data from the Lake Huron Project were used for areas encompassed by that project. For areas not covered by the Lake Huron Project, this was done using the ERF1 streams coverage (available at http://water.usgs.gov/lookup/getspatial?erf1), the national dams coverage (available at http://data.geocomm.com/catalog/US/group7.html), and a basic US states coverage. No facilities drawing from other lakes or reservoirs were included among the Great Lake facilities unless the water bodies were connected to the Great Lakes.

1-1.3 Inland Region

The Inland region includes all facilities located on freshwater rivers or streams and lakes or reservoirs, in all states, with the exception of facilities located in the Great Lakes region (defined above in section 1-1.2).

1-2 PART A: STUDY METHODS

1-2.1 Evaluation of I&E

Chapter A5 of Part A of this Regional Analysis Document describes the methods used to evaluate facility I&E data. Chapter A6 discusses uncertainties in the analysis. Data from a total of 46 facilities were evaluated. To obtain regional I&E estimates, EPA extrapolated loss rates from these facilities to all other in-scope facilities within the same region. These results were then summed to develop national estimates.

1-2.2 Economic Benefits

Chapters A9-A14 of Part A of this document describe the methods that EPA used for its analysis of the economic benefits of the Phase II rule. As discussed in Chapter A9, EPA considered the following benefit categories: recreational fishing benefits, commercial fishing benefits, and non-use benefits. The analysis of use benefits included benefits from improved commercial fishery yields and benefits to recreational anglers from improved fishing opportunities. Chapters A10 and A11 provide details on the methods used for these analyses. Chapter A14 discusses discounting of recreational and commercial benefits. Non-use benefits included benefits from reduced I&E of forage species, threatened and endangered species, and the non-landed portion of commercial and recreational species. Non-use methods are described in Chapters A12 and A13.

1-3 PARTS B-H: REGIONAL REPORTS

Parts B-H of this Regional Analysis Document are reports of results for each study region. Chapter 1 of each report provides background information on the facilities in the region and a map showing facility locations. Chapter 2 provides I&E estimates. Benefits estimates are presented in Chapters 3, 4, and 5. Chapter 3 presents estimates of commercial fishing benefits, Chapter 4 presents recreational fishing benefits, and Chapter 5 presents non-use benefits. In addition, Chapter B6 presents an analysis of benefits to threatened and endangered species from reducing I&E at California facilities, and Chapter 6 in Parts C, D, and G summarizes results of a habitat-based valuation of baseline I&E losses and the benefits of reducing these losses under the final option. An appendix to each regional report indicates the life history data and data sources used for the species evaluated in the region.

Part A

Evaluation Methods

Chapter A1: Ecological Risk Assessment Framework

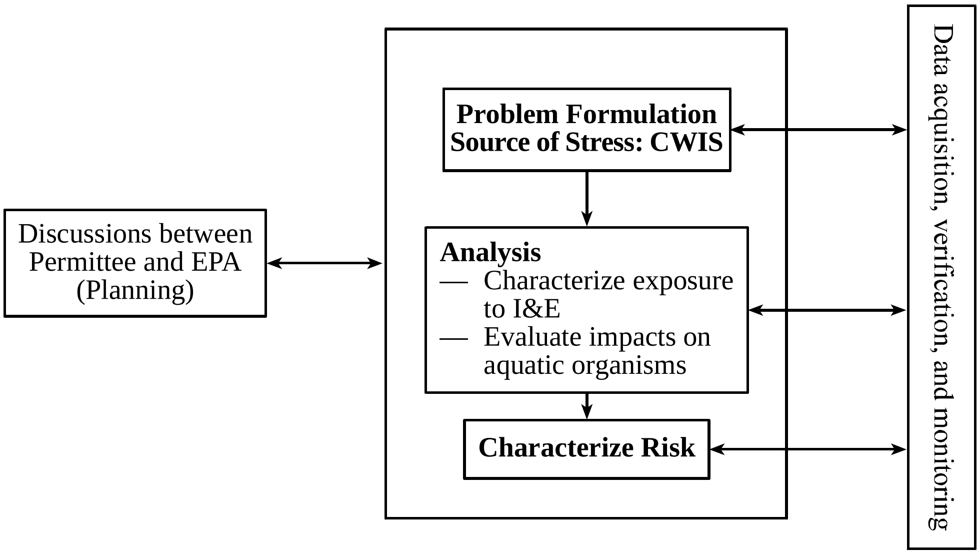
INTRODUCTION

CHAPTER CONTENTS

EPA has defined ecological risk assessment as “a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors” (U.S. EPA, 1998a). It is an approach to impact assessment that involves explicit evaluation of the data, assumptions, and uncertainties associated with an impact analysis. Risk assessments range in level of analysis and data requirements, depending on management goals, data availability, and stakeholder concerns.

In the context of evaluating the impacts of cooling water intake structures (CWIS) under section 316(b), the primary stressors of interest for an ecological risk assessment are the impingement and entrainment (I&E) of aquatic organisms. The following sections outline the three phases of ecological risk assessment (problem formulation, analysis, and risk characterization) as they apply to section 316(b) (see Figure A1-1).

Figure A1-1: EPA’s Framework for Ecological Risk Assessment Applied to Section 316(b)



Adapted from U.S. EPA, 1998a.

A1-1 PROBLEM FORMULATION

The problem formulation phase of an ecological risk assessment defines the problem to be evaluated and develops a plan for analyzing available data and characterizing risk (U.S. EPA, 1998a). This involves formulating a conceptual model of the relationships between stressors and receptors, selecting assessment and measurement endpoints, and developing a plan for the analysis of exposure and risk. In the context of section 316(b), the primary stressors associated with CWIS are I&E and the receptors are the aquatic organisms that are exposed to I&E. Figure A1-2 is a conceptual model indicating the primary and secondary ecological effects that result from the exposure of aquatic organisms to I&E.

An assessment endpoint is any ecological entity of concern to stakeholders (U.S. EPA, 1998a). Ecological entities to be assessed may include one or more entities across a range of levels of biological organization, including individuals, subpopulations, populations, species, communities, or ecosystems. Measurement endpoints are the attributes of an assessment endpoint that are evaluated in a risk assessment. Attributes of concern may include individual survival, population recruitment, species abundance, species diversity, or ecosystem structure and function. Ideally, assessment endpoints should include all species directly and indirectly affected by a CWIS. However, most facility studies only report direct losses of fish and shellfish species, and therefore EPA's analysis is limited to consideration of these species only.

A1-2 ANALYSIS

The analysis phase of an ecological risk assessment focuses on the characterization of (1) exposure to one or more stressors and (2) the ecological effects that are expected to result from exposure (U.S. EPA, 1998a).

A1-2.1 Characterization of Exposure of Aquatic Organisms to CWIS

Exposure characterization describes the potential or actual co-occurrence of stressors and receptors (U.S. EPA, 1998a). In the case of CWIS, characterization of exposure involves description of facility characteristics that influence rates of I&E, and the physical, chemical, and biological characteristics of the surrounding ecosystem that influence the intensity, time, and spatial extent of contact of aquatic organisms with a facility's CWIS.

Exposure of aquatic organisms to I&E depends on factors related to the location, design, construction, capacity, and operation of the facility's CWIS (U.S. EPA, 1976; SAIC, 1994; SAIC, 1995; SAIC, 1996a and b). Table A1-1 lists facility characteristics as well as characteristics of species and the surrounding environment that influence when, how, and why aquatic organisms may become exposed to and experience adverse effects of CWIS. These characteristics are described in the following sections based on information provided in EPA's 1976 section 316(b) development document (U.S. EPA, 1976) and background papers developed for EPA's section 316(b) rulemaking activities by Science Applications International Corporation (SAIC) (SAIC, 1994; SAIC, 1995; SAIC, 1996a and b).

a. Intake location

Two major components of a CWIS's location that influence the relative magnitude of I&E are (1) the type of waterbody from which a CWIS is withdrawing water, and (2) the placement of the CWIS relative to sensitive biological areas within the waterbody. Considerations in siting include intake depth and distance from the shoreline in relation to the physical, chemical, and biological characteristics of the source waterbody. In general, intakes located in nearshore areas (riparian or littoral zones) will have greater ecological impacts than intakes located offshore, since nearshore areas are usually more biologically productive and have higher concentrations of aquatic organisms.

Figure A1-2: Conceptual Model Indicating Some Primary and Secondary Effects of Impingement and Entrainment by CWIS

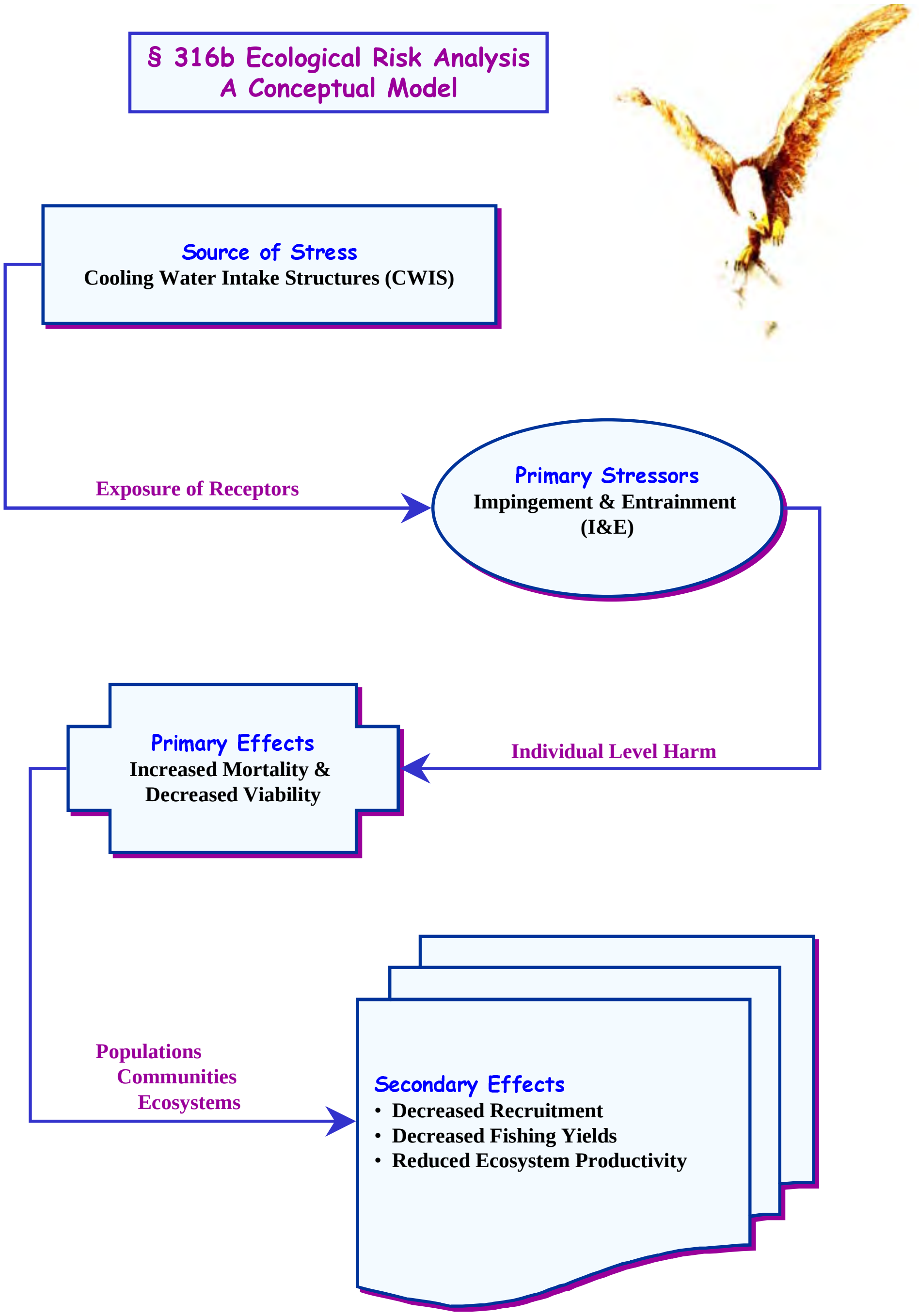


Table A1-1: Partial List of CWIS Characteristics and Ecosystem and Species Characteristics Influencing Exposure to I&E

CWIS Characteristics	Ecosystem and Species Characteristics
▸ Depth of intake ▸ Distance from shoreline ▸ Proximity of intake withdrawal and discharge ▸ Proximity to other industrial discharges or water withdrawals ▸ Proximity to an area of biological concern ▸ Type of intake structure (size, shape, configuration, orientation) ▸ Through-screen velocity ▸ Presence/absence of intake control and fish protection technologies a. Intake screen systems b. Passive intake systems c. Fish diversion/avoidance systems ▸ Water temperature in cooling system ▸ Temperature change during entrainment ▸ Duration of entrainment ▸ Use of intake biocides and ice removal technologies ▸ Scheduling of timing, duration, frequency, and quantity of water withdrawal ▸ Mortality of aquatic organisms ▸ Displacement of aquatic organisms ▸ Destruction of habitat (e.g., burial of eggs deposited in stream beds, increased turbidity of water column) ▸ Type of withdrawal - once through vs. recycled (cooling water volume and volume per unit time) ▸ Ratio of cooling water intake flow to source water flow	**Ecosystem Characteristics (abiotic environment)**: ▸ Source waterbody type (marine, estuarine, riverine, lacustrine) ▸ Water temperatures ▸ Ambient light conditions ▸ Salinity levels ▸ Dissolved oxygen levels ▸ Tides/currents ▸ Direction and rate of ambient flows **Species Characteristics (physiology, behavior, life history)**: ▸ Density in zone of influence of CWIS ▸ Spatial and temporal distributions (e.g., daily, seasonal, annual migrations) ▸ Habitat preferences (e.g., depth, substrate) ▸ Ability to detect and avoid intake currents ▸ Swimming speeds ▸ Body size ▸ Age/developmental stage ▸ Physiological tolerances (e.g., temperature, salinity, dissolved oxygen) ▸ Feeding habits ▸ Reproductive strategy ▸ Mode of egg and larval dispersal ▸ Generation time

Critical physical and chemical factors related to siting of an intake include the direction and rate of waterbody flow, tidal influences, currents, salinity, dissolved oxygen levels, thermal stratification, and the presence of pollutants. The withdrawal of water by an intake can change ambient flows, velocities, and currents within the source waterbody, which may cause organisms to concentrate in the vicinity of an intake or reduce their ability to escape a current. Effects vary according to the type of waterbody and species present.

In large rivers, withdrawal of water may have little effect on flows because of the strong, unidirectional nature of ambient currents. In contrast, lakes and reservoirs have small ambient flows and currents, and therefore a large intake flow can significantly alter current patterns. Tidal currents in estuaries or tidally influenced sections of rivers can carry small, passive organisms past intakes multiple times, thereby increasing their probability of entrainment. If intake withdrawal and discharge are in close proximity, entrained organisms released in the discharge can become re-entrained.

The magnitude of I&E in relation to intake location also depends on biological factors such as species' distributions and the presence of critical habitats within an intake's zone of influence. Species with planktonic (free-floating) early life stages have higher rates of entrainment because they are unable to actively avoid being drawn into the intake flow.

b. Intake design

Intake design refers to the design and configuration of various components of the intake structure, including screening systems (trash racks, pumps, pressure washes); passive intake systems; and fish diversion and avoidance technologies (U.S. EPA, 1976). After entering the CWIS, water must pass through a screening device before entering the power plant. The screen is designed, at a minimum, to prevent debris from entering and clogging the condenser tubes. Screen mesh size and velocity characteristics are two important design features of the screening system that influence the potential for impingement and entrainment of aquatic organisms that are withdrawn from the waterbody with the cooling water (U.S. EPA, 1976).

Approach velocity has a significant influence on the potential for impingement (Boreman, 1977). Approach velocity is the velocity of the current in the area approaching the screen and is measured at the screen upstream of the screen face in feet per second (fps). Approach velocity is directly related to the area of the screen and the size of the intake structure (U.S. EPA, 1976). The biological significance of approach velocity depends on species-specific characteristics such as fish swimming ability and endurance. These characteristics are a function of the size of the organism and the temperature and oxygen levels of water in the area of the intake (U.S. EPA, 1976). The maximum velocity protecting most small fish is 0.5 fps, but lower velocities will still impinge some fish and entrain eggs and larvae and other small organisms (Boreman, 1977).

Conventional traveling screens have been modified to improve fish survival of screen impingement and spray wash removal (Taft, 1999). However, a review by SAIC of steam electric utilities indicated that alternative screen technologies are usually not much more effective at reducing impingement than the conventional vertical traveling screens used by most steam electric facilities (SAIC, 1994). An exception may be traveling screens modified with fish collection systems (e.g., Ristroph screens). Studies of improved fish collection baskets at the Salem Generating Station showed increased survival of impinged fish (Ronafalvy et al., 2000).

Passive intake systems (physical exclusion devices) screen out debris and aquatic organisms with minimal mechanical activity and low withdrawal velocities (Taft, 1999). The most effective passive intake systems are wedge-wire screens and radial wells (SAIC, 1994). A new technology, the filter fabric barrier system (known commercially as the Gunderboom) consists of polyester fiber strands pressed into a water-permeable fabric mat, has shown promise in reducing entrainment of ichthyoplankton (free-floating fish eggs and larvae) at the Lovett Generating Station on the Hudson River (Taft, 1999).

Fish diversion/avoidance systems (behavioral barriers) take advantage of natural behavioral characteristics of fish to guide them away from an intake structure or into a bypass system (SAIC, 1994; Taft, 1999). The most effective of these technologies are velocity caps, which divert fish away from intakes, and underwater strobe lights, which repel some species (Taft, 1999). Velocity caps are used mostly at offshore facilities and have proven effective in reducing impingement (e.g., California's San Onofre Nuclear Generating Station, SONGS).

Another important design consideration is the orientation of the intake in relation to the source waterbody (U.S. EPA, 1976). Conventional intake designs include shoreline, offshore, and approach channel intakes. In addition, intake operation can be modified to reduce the quantity of source water withdrawn or the timing, duration, and frequency of water withdrawal. This is an important way to reduce entrainment. For example, larval entrainment at the San Onofre facility was reduced by 50% by rescheduling the timing of high volume water withdrawals (SAIC, 1996a).

c. Intake capacity

Intake capacity is a measure of the volume of water withdrawn per unit time. Intake capacity can be expressed as millions of gallons per day (MGD), or as cubic feet per second (cfs). Capacity can be measured for the facility as a whole, for all of the intakes used by a single unit, or for the intake structure alone. In defining an intake's capacity it is important to distinguish between the design intake flow (the maximum possible) and the actual operational intake flow.

The quantity of cooling water needed and the type of cooling system are the most important factors determining the quantity of intake flow (U.S. EPA, 1976). Once-through cooling systems withdraw water from a natural waterbody, circulate the water through condensers, and then discharge it back to the source waterbody. Closed-cycle cooling systems withdraw water from a natural waterbody, circulate the water through the condensers, and then send it to a cooling tower or cooling pond before recirculating it back through the condensers. Because cooling water is recirculated, closed-cycle systems reduce intake water flow substantially. It is generally assumed that this will result in a comparable reduction in I&E (Goodyear, 1977). Systems with helper towers reduce water usage much less. Plants with helper towers can operate in once-through or closed-cycle modes.

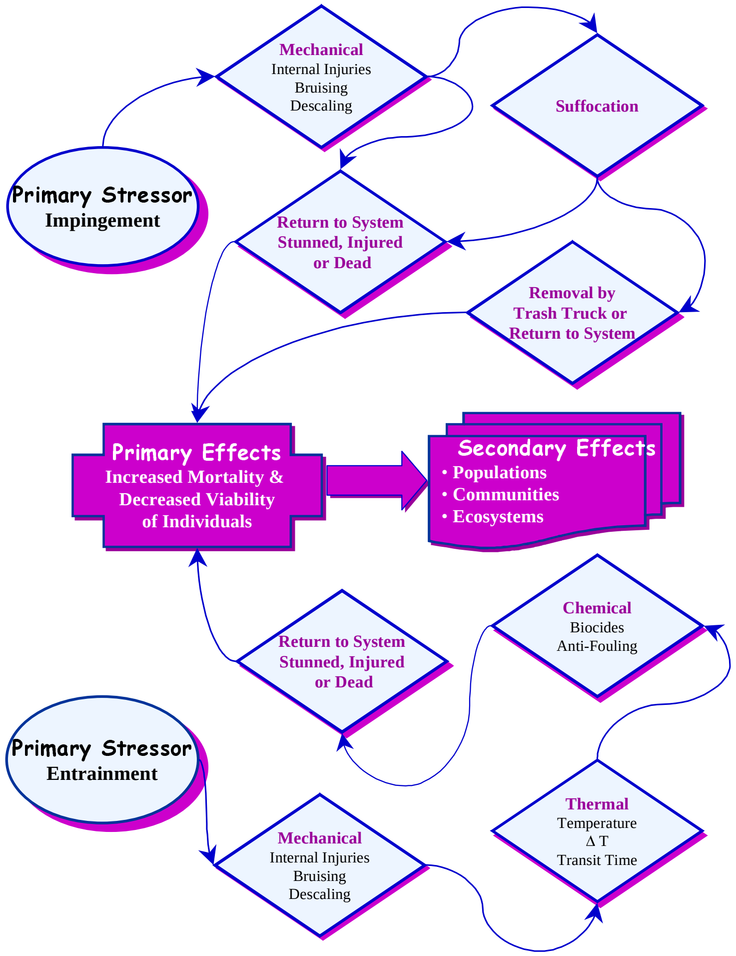
Circulating water intakes are used by once-through cooling systems to continuously withdraw water from the cooling water source. The typical circulating water intake is designed to use 1.06-3.53 cfs (500-1500 gallons per minute, gpm) per megawatt (MW) of electricity generated (U.S. EPA, 1976). Closed cycle systems use makeup water intakes to provide water lost by evaporation, blowdown, and drift. Although makeup quantities are only a fraction of the intake flows of once-through systems, quantities of water withdrawn can still be significant, especially by large facilities (U.S. EPA, 1976).

If the quantity of water withdrawn is large relative to the flow of the source waterbody, a larger number of organisms is more likely to be affected by a facility's CWIS. Thus, the proportion of the source water flow supplied to a CWIS is often used to derive a conservative estimate of the potential for adverse impact (e.g., Goodyear, 1977). For example, withdrawal of 5% of the source water flow may be expected to result in a loss of 5% of planktonic organisms based on the assumption that organisms are uniformly distributed in the vicinity of an intake. Although the assumption of uniform distribution may not always be met, when data on actual distributions are unavailable, simple mathematical models based on this assumption provide a conservative and easily applied method for predicting potential losses (Goodyear, 1977).

A1-2.2 Characterization of Ecological Effects

The characterization of ecological effects involves describing the effects resulting from the stressor(s) of interest, linking effects to assessment endpoints, and measuring endpoints to evaluate how effects change as a function of changes in stressor levels (U.S. EPA, 1998a). For EPA's section 316(b) regional studies, measures of ecological effects included measures of both primary and secondary effects (Figure A1-3). Losses of impinged and entrained organisms are measures of primary effects and are the most direct measure of the effects of CWIS on aquatic organisms. It is necessary to fully evaluate primary effects in order to evaluate the consequences of these losses for fishery yields, ecosystem production, or other measures of indirect or secondary effects. The measurement endpoints evaluated for the section 316(b) regional studies are discussed in detail in Chapter A4.

Figure A1-3: Stressor-Effects Pathway



A1-2.3 Cumulative Effects

Impingement and entrainment impacts have cumulative impacts on aquatic ecosystems that are usually not considered in section 316(b) demonstration studies. Cumulative impacts refer to the temporal and spatial accumulation of changes in ecosystems that can be additive or interactive. Cumulative impacts can result from the effects of multiple facilities located within the same waterbody and from individually minor but collectively significant impingement and entrainment impacts taking place over a period or time. In many locations (especially estuary and coastal waters), fish species migrate long distances and therefore regional stocks of these species are subject to impingement and entrainment from a large number cooling water intake structures. EPA's regional analysis is designed to take into consideration such cumulative impacts.

A1-3 RISK CHARACTERIZATION

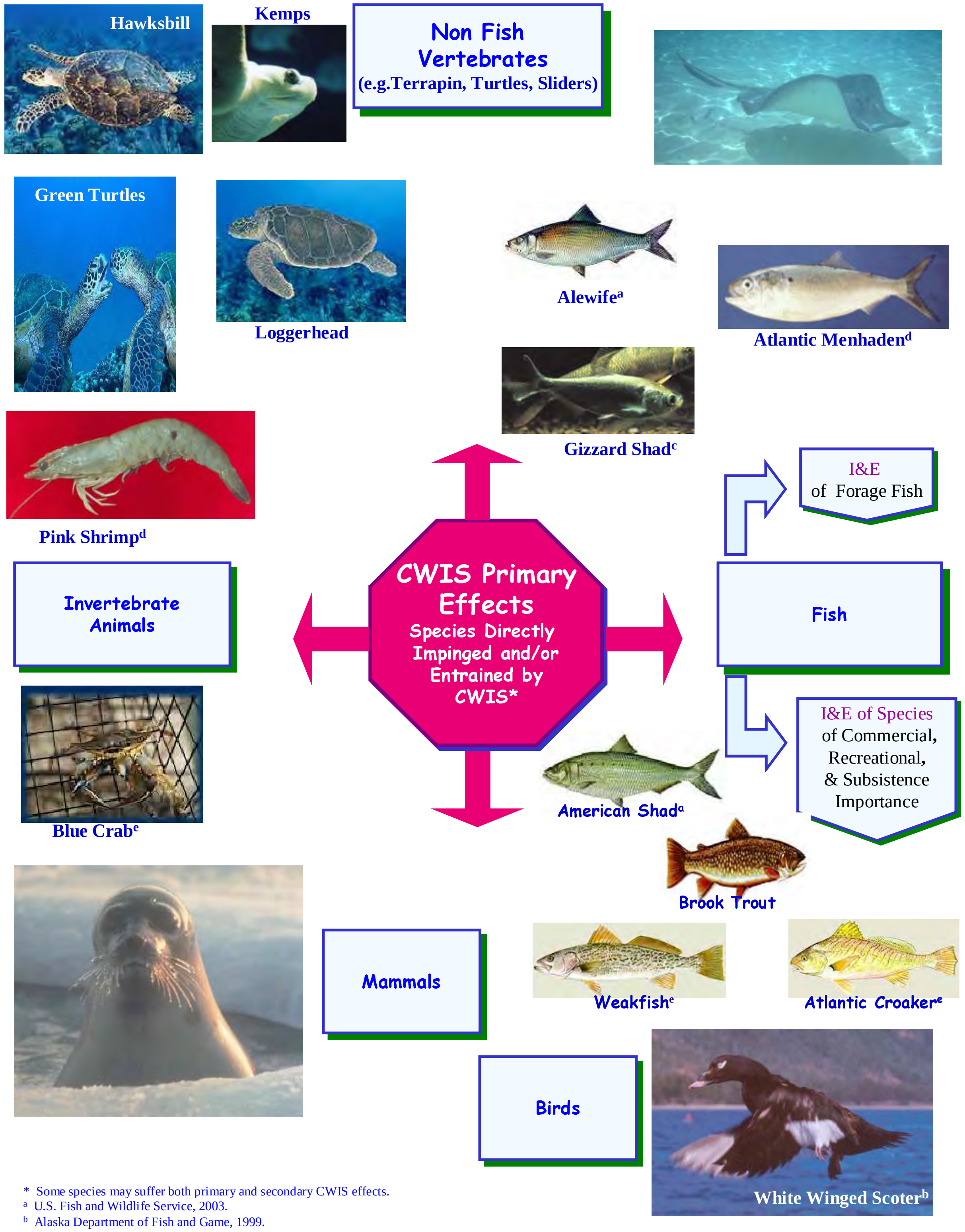
The final step of an ecological risk assessment is the characterization of risk (U.S. EPA, 1998a). Risk refers to the likelihood of an undesirable ecological effect resulting from the stressor of concern. Because of the intrinsic variability and inevitable uncertainty associated with the evaluation of ecological phenomena, ecological impacts cannot be determined exactly, and thus only the probability (or risk) of an effect can be assessed (Hilborn, 1987; Burgman et al., 1993).

Risk can be defined qualitatively or quantitatively, depending on factors such as the goals of a risk manager and data availability (U.S. EPA, 1998a). Qualitative assessments usually involve best professional judgment. Quantitative assessments involve calculation of the change in risk (Ginzburg et al., 1982; Akçakaya and Ginzburg, 1991). The ecological risk assessments for EPA's section 316(b) regional studies used available facility data to quantitatively evaluate impingement and entrainment risks to aquatic organisms.

A1-3.1 Cumulative Impacts

Cumulative impacts are usually not considered in I&E monitoring programs and so it is usually not possible to account for potential cumulative impacts in characterizing risks to aquatic organisms subject to impingement and entrainment. Cumulative impacts are the temporal and spatial accumulation of changes in ecosystems, which can be additive or interactive. Cumulative impacts can result from the combined effects of multiple facilities located within the same waterbody, or from individually minor but collectively significant I&E impacts taking place over many years. For example, in many locations (especially estuaries and coastal waters), species migrate over long distances and are subject to I&E from many cooling water intake structures.

Figure A1-4: Examples of Species Directly Affected by CWIS



* Some species may suffer both primary and secondary CWIS effects.
[a] U.S. Fish and Wildlife Service, 2003.
[b] Alaska Department of Fish and Game, 1999.
[c] University of Minnesota, 2003.
[d] South Carolina Department of Natural Resources, 2001.
[e] Chesapeake Bay Program, 2003.

Chapter A2: Everything You Ever Wanted to Know About Fish

INTRODUCTION

Fish are the most numerous and diverse of all vertebrate groups. They go back more than 400 million years and make up over half of all vertebrate species. About 24,600 species in 482 families live in the world today. Experts think that thousands more species are yet to be found.

Fifty-eight percent of the world's fish species live in the sea and 41 percent live in freshwater. This number is striking, since the volume of freshwater is only 1/7,500th that of the oceans. One percent, just over 200 species, move between freshwater and the sea. Most of these 200 species are anadromous, i.e., they reproduce in freshwater but mature at sea. A few species are catadromous, spawning in the sea but maturing in freshwater.

More than three quarters of marine species live on or along the shallow continental shelves. The deep waters beyond, which comprise most of the oceans, have only about 2,900 fish species.

This chapter provides general information on the distribution, anatomy, physiology, and ecology of fish based on information in Wetzel (1983), Nelson (1994), Ross (1995), Moyle and Cech (1996), and Helfman et al. (1997).

CHAPTER CONTENTS

A2-1 FISH DIVERSITY AND ABUNDANCE

A2-1.1 Biological Diversity

The behavior, physiology, and morphology of fish are very diverse. Fish eat all conceivable plant or animal food items. Some species form large schools; others have territorial or solitary lifestyles. Fish migrate over short or long distances looking for food or areas to mate. Extreme examples are some species of Pacific salmon, which swim more than 1,880 miles (3,000 km) up the Yukon River to reproduce; or the giant blue tuna, which swims throughout the world's oceans seeking food. Some species can also walk on land or glide in the air.

Most fish are cold-blooded, but some are partially warm-blooded. Most species use gills to get oxygen, but some supplement gill breathing by gulping air. A few will drown if they cannot breathe air. Some fish make venom, electricity, sound, or light. Most fish release sperm and eggs into the water or the bottom with little parental care; others build nests, are live bearers, or mouth brooders. Most fish have fixed sexual patterns, i.e., they are either male or female for their entire lives. A surprising number switch sex at some point in their lives. The majority of species reproduce many times over a lifetime; some die after the first mating.

Fish live from one year to over a century. Adult fish range from a 0.4 inch (10 mm) marine goby to the giant 39.4 ft (12 m) whale shark. Fish shapes range from snake-like to ball-like, saucer-like, or torpedo-like, with many forms in-between. Some species are sleek and graceful; others are ungainly or grotesque. Fins may be missing or are changed for use as sexual organs, suction cups, pincers, claspers, lures, or to serve other functions. Fish can be highly-colored to drab grey. Finally, approximately 50 species lack eyes.

A2-1.2 Distribution and Zoogeography

Fish live in all possible aquatic habitats on the planet. Most are found in "normal" habitats, such as lakes, rivers, tidal rivers, estuaries, and oceans. Within those habitats, fish are found at elevations of up to 17,000 ft (5,200 m) in Tibet, and depths of over 3,300 ft (1,000 m) in Lake Baikal and 23,000 ft (7,000 m) below the ocean surface. Fish live in water ranging from essentially pure freshwater with salt levels close to that of distilled water, to hyper-saline lakes with salt levels over three times that found in the sea. Their habitats extend from caves or springs to the entire ocean, from hot soda lakes in Africa with water temperatures up to 44 ˚C (111 ˚F) to deep-sea hydrothermal vents in the eastern Pacific, and the Antarctic ocean where water temperatures drop to -2 ˚C (28 ˚F).

a. Freshwater

Freshwaters support most of the world's fish species, when one considers the volume of available water. This disparity arises from greater productivity, and isolation.

- Freshwaters are quite shallow on average. Sunlight, which stimulates photosynthesis and increases algal growth, can reach a relatively large part of their volume. In contrast, the oceans have a mean depth of 12,100 ft (3,700 m). Much of the water column is too deep and dark for photosynthesis and stays unproductive. The shallower continental margins, which support most marine species, are an exception.

- Freshwater habitats easily break up into isolated water bodies, creating many distinct "islands" of water over the terrestrial landscape. This isolation promotes the formation of new species over time. Droughts, volcanos, earthquakes, landslides, glaciation, and river course adjustments break up habitats. In contrast, marine habitats are unbroken over great distances and volumes. They are less likely to form barriers, except on a trans-oceanic scale.

In North America, from the Arctic to the Mexican Plateau, freshwaters belong to a zoogeographic region called the Nearctic. This area has approximately 950 known fish species, classified into 14 families. The most species-rich families are the Cyprinids (minnows and related species), Catostomids (suckers and related species), Ictalurids (catfish and related species), Percids (darters and related species), and Centrarchids (sunfish and related species).

The Nearctic region in North America is divided into two subregions, each with many "provinces":

- The *Arctic-Atlantic subregion* includes the Mississippi-Missouri drainage basins, the Great Lakes-Saint Lawrence drainage basin, the rivers that drain the Atlantic seaboard, the Hudson Bay drainage basin, the rivers that drain into the Arctic Ocean, and the Rio Grande drainage basin.

- The *Pacific subregion* contains the Pacific drainages from the Yukon river to Mexico, and the interior drainages west of the Rocky Mountains.

b. Oceans

The distribution of marine fish in the world's oceans suggests four major marine regions, two of which are associated with North America:

- The *Western Atlantic Region* includes the temperate shores of the Atlantic seaboard, the Gulf of Mexico, the tropical shores of the Caribbean Sea, and the tropical and temperate shores of the Atlantic ocean along South America. Most of the 1,200 fish species in this region live in the West Indian coral reefs.

- The *Eastern Pacific Region* is split from the rest of the Pacific Ocean by the expanse of water between the continent and the Pacific islands. The fish diversity is less than that of the Western Atlantic, mainly because this region has fewer coral reefs. Several species in the Eastern Pacific Region are closely related to species in the Western Atlantic Region, since these two regions were once connected until the Isthmus of Panama formed a barrier around 3 million years ago.

Most fish species live in coral reefs. Speciation drops in temperate or polar regions, even though the number of individual fish within a species may be quite high. Many species also have relatively small ranges, resulting in a high degree of endemism (i.e., confinement to relatively small geographic areas). Global distribution of marine fish is hampered by physical barriers (e.g., land and mid-ocean barriers). Distribution of freshwater fish is limited by land and salt water barriers.

A2-1.3 Habitat Diversity

Different variables determine where fish can live and reproduce. These variables include dissolved oxygen levels, water temperature, turbidity, salinity, currents, substrate type, competition, and predation. Lake-dwelling species may prefer deep, cold, nutrient-poor lakes versus shallow, warmer, nutrient-rich lakes. Species within lakes may seek out open water areas, the shallow or deep benthic zone, or in-shore areas. A similar pattern exists in streams and rivers: some fish prefer swifter waters, whereas others seek pools or quiet backwaters. Regional species assemblages differ between the cooler, swifter, and clear headwaters and warmer, slower, more turbid low-land stretches.

Habitat use changes seasonally or throughout the life of a fish: a species may have eggs and larvae that are pelagic, juveniles that seek inshore nursery habitat, and adults that live in deep, cool, open water. Some fish are flexible enough to thrive in different habitats: trout, sunfish, minnows, or smallmouth bass are equally successful in lakes and streams, as long as conditions are acceptable. Others, such as sculpins, are more selective, and only tolerate a relatively narrow range of conditions.

A2-2 INFLUENCE OF FISH ON AQUATIC SYSTEMS

Fish are an intrinsic part of aquatic food webs due to their numbers and functional diversity, and their effects as competitors, predators, and prey. Studies show that fish have direct effects on the structure and function of aquatic ecosystems: their presence causes changes in habitat use, prey population structure, population dynamics, and nutrient flows. Large shifts can occur when fish are removed or eliminated.

A fish’s lifecycle starts as a fertilized egg. The egg hatches in days, weeks, or even months, based on the species and on water temperature. Larvae are called sac fry for the first several days or weeks of their life until they consume all their yolk. In their first year, they are called yearlings or age 0+ fish. The term juvenile is more generic and refers to sexually immature fish. The age of first reproduction is species-specific: small, shorter-lived species such as minnows mature in one or two years. Larger or longer-lived species such as sharks, sturgeons, or tarpon can take ten or more years to reproduce.

Each fish plays a role in aquatic food webs based on its size, feeding habits, or habitat needs. The term “game fish” refers to species wanted by recreational fishers; these fish have high value in a benefits analysis because they are highly valued by mankind. The term, even though not based on biology, normally refers to fish that are predators near or at the top of aquatic food chains. Examples of game fish include pike, largemouth bass, salmon, bluefish, snook, or tarpon.

The term “forage fish” or “prey fish” is vague because all fish in their younger life stages are eaten by bigger fish and other organisms. Forage fish often refers mainly to smaller species that feed on plant material or small animals (zooplankton, fish eggs or sacfry, small crustaceans, etc.) and are themselves eaten, even as adults. Examples of forage fish include anchovies, rainbow smelt, bluegill sunfish, and numerous minnow species. Their value to humankind in a benefits analysis is less than that of game fish, but their biological value to the ecosystem is even more important, because without them, there wouldn’t be any game fish.

Many predators eat fish. Invertebrate predators include diving beetles, dragonfly larvae, jellyfish, sea anemones, squids, cone shells, crabs, and others. Amphibian predators include bullfrogs and other large frog species. Reptilian predators include water snakes, aquatic lizards, turtles, and crocodiles or alligators. Bird predators include albatrosses, auks, cormorants, eagles, egrets, gannets, goldeneye ducks, herons, kingfishers, loons, mergansers, murres, ospreys, pelicans, petrels, penguins, seagulls, skimmers, spoonbills, storks, terns, and many others. Finally, mammal predators include dolphins, seals, sea lions, bears, otters, mink, and raccoons, among others.

This great predatory pressure affects fish distribution. Wading birds, for instance, feed in shallows along weedy edges or quiet backwaters. Small fish measuring less than 1.6 inches (< 4 cm) are safe there, because they can hide among stems, leaves, rocks, debris, or other structures. In contrast, larger prey fish avoid shallows and seek deeper water out of the reach of wading birds. The deeper water is a relatively safe alternative, because the piscivorous fish that live there are usually gape limited (i.e., limited by the size of prey fish they can swallow because their mouths can open only so wide).

A2-2.1 Responses by Different Aquatic Receptors to Fish

❖ *Aquatic plants*

Grazing by fish (and other organisms) affects plants, by altering plant biomass and productivity, changing the species composition of the vegetation, and causing plants to invest energy in growth instead of reproduction to replace parts lost to grazing. Less than 25 percent of fish species in temperate streams are true herbivores, compared with 25 percent to 100 percent in tropical streams. In temperate seas, only 5 to 15 percent of species are herbivores, compared with 30 percent to 50 percent in coral reefs.

❖ *Zooplankton*

Fish predation in lakes, ponds, and reservoirs can affect zooplankton by forcing changes in their daily vertical migrations. During the day, zooplankters hide at depth, on the bottom, or in dense vegetation, to avoid being eaten by fish. The zooplankters rise to the surface at night to feed. These migration patterns become less pronounced when the number of planktivorous fish drops.

❖ *Benthic invertebrates*

Benthic invertebrates live on or in the substrate. The population dynamics and behaviors of the benthos can change in response to fish predators. Studies have shown that these changes are subtler than for the more exposed zooplankton. Aggressive benthic feeders, such as bluegill sunfish in lakes or creek chubs in streams, can depress local populations of benthic invertebrates. More often, the presence of benthic feeders causes behavioral changes in prey to reduce predation. For example:

- insect larvae move from the surface of rocks to less desirable (but more protective) spots underneath the same rocks;
- crayfish — a favorite bass prey — move less and hide over bottom types that match their colors and make them less visible when bass are present;
- the amount of benthic invertebrate drift drops when fish predators are present.

A2-2.2 Ecosystems are Complex — Fish Predation and Trophic Cascades

The effects described above show that predators and prey are linked. The next sections show that fish do not live in a biological vacuum, but interact at different levels with other organisms.

a. Trophic cascades and their effects on biological responses

- A trophic cascade is a kind of "ripple effect" that occurs when the numbers of organisms at different levels within a food web change as a result of the addition or deletion of predators or prey. For example, fewer zooplanktivores are consumed when top predators are removed, and therefore the number of zooplanktivores rises. In turn, the increased numbers of zooplanktivores deplete populations of zooplankton, reducing predation on phytoplankton and increasing algal blooms. The opposite response can occur if top predators are added (for example, by stocking) or zooplanktivores are removed (for example, by commercial fishing, disease, or I&E).

Such responses have been seen in freshwater systems, as shown by the following experiments:

- A lake contained the trophic cascade of redear sunfish — snails — epiphytes (i.e., algae that grow on submerged plants) — submerged plants. When the sunfish were removed from test plots in the lake, the snail population grew and ate more epiphytes. The absence of epiphytes afforded more light for the plants, which grew better than in areas of the lake where sunfish were present.
- A similar situation occurred in rivers. This trophic cascade included piscivorous fish (large roach and steel head trout) — predators of benthic invertebrates (damselfly nymphs and fish fry) — herbivorous benthos (midges) — filamentous algae. The number of nymphs and fish fry increased when roaches and steel head trout were removed

from test plots. The predation rate on midges went up and reduced their population levels. The resulting growth of the filamentous algae was better than that seen in areas where the roaches and trout remained.

b. Trophic cascades and their effects on physical parameters

Big changes in physical variables can result from the presence or absence of fish predators. Lakes or reservoirs with hard waters and high pH levels can have “whiting events” in the summer. Lake Michigan is such a lake. These events occur when photosynthesis by phytoplankton is very high in the warm surface layers. This activity removes dissolved CO_2, raises the pH of the water even further and causes calcium carbonate ($CaCO_3$) to precipitate (the solubility of $CaCO_3$ goes down as pH goes up) and turns water into a milky, white color. Whiting affects zooplankton feeding, decreases primary productivity, and causes nutrients to sink to the bottom.

In the 1970s, salmonids were stocked in Lake Michigan. By 1983, these fish ate so many zooplanktivorous alewives that predation pressures on zooplankton fell. The lower pressure increased the number of phytoplankton-eating cladocerans and led to more grazing on the phytoplankton. As a result, photosynthetic activity dropped, the rise in pH during the summer was lower than normal, little or no $CaCO_3$ precipitated out of solution, and no whiting event took place in 1983.

The absence of zooplankton-eating fish can affect temperature regimes in small lakes (< 20 km^2). Compared to similar lakes with piscivorous fish, such lakes have many zooplankton, which keep the phytoplankton in check. The clarity of the water column increases, light goes deeper, and water temperatures are higher at greater depth. Trophic cascades have been used to control eutrophication in lakes because they can generate strong biological and physical responses. Piscivorous fish are stocked to lower the number of zooplanktivores, enhancing the populations of herbaceous zooplankters who control the algal blooms.

A2-2.3 Effects of Fish on the Cycling and Transport of Nutrients

Fish can affect nutrient cycling. Phosphorus (P) is generally the limiting nutrient for plants in lakes and reservoirs. Fish excrete P as soluble reactive phosphorus (SRP) through their gills or feces. SRP is easily taken up by algae. Studies show that fish excretion is an important source of SRP to lakes and reservoirs and may have direct impacts on primary productivity in those systems.

Fish are found in different trophic levels and feeding groups. They are highly mobile organisms that move nutrients among compartments. In lakes, bottom feeders such as suckers, carp, or catfish stir up sediments while looking for food. Nutrients are resuspended in the water and support algal growth. Some fish species that live in lakes make daily vertical migrations; they transport N and P from the deeper, colder layers to the surface, and release these nutrients through excretion and defecation in areas where most algal growth occurs.

Fish are also major nutrient reservoirs. In certain lakes, up to 90 percent of the P is tied up in bluegill sunfish. This value shows the importance of fish to primary productivity, at least in nutrient-deficient waters: nutrients in fish are released to the water by the gills or feces, or during fish decomposition after death. Studies in a clear, deep lake showed that P released by roaches represented around 30 percent of the P budget of the epilimnion during summer stratification. Fish removal experiments in lakes can also lead to drops in N and P in the water, presumably because the fish increase nutrient levels. Fish biomass loss from emigration, fishing, or other ways (including I&E) can affect nutrient balances, hence primary productivity.

Fish tie different ecosystems together, particularly species that spend part of their lives in freshwater and part at sea. Such fish move large amounts of nutrients when they migrate between habitats. Prolific species, such as menhaden or herring, are prey for larger piscivorous fish in coastal areas and are major sources of nutrients. The gulf menhaden, an abundant species in Gulf estuaries, is a case in point. The fish spawn off-shore in late winter. Their larvae enter estuaries to feed. Juveniles grow by a factor of 80 over a nine-month period; they return to the Gulf in late fall to mature. Each year, an estimated 5 to 10 percent of the primary productivity in the salt marshes and estuaries is exported into the Gulf in the form of menhaden. Up to 50 percent of the total N and P lost annually from these habitats does so in the form of migrating menhaden. The loss in one habitat is a gain for another, because menhaden are a major source of prey. The carbon in these fish represents 25 to 50 percent of off-shore production in the Gulf. Other fish species with similar lifecycles all along our coastal habitats help move energy, nutrients, and carbon across aquatic ecosystems.

In conclusion, the links and feedback loops in aquatic food webs make it difficult to predict what effects could result from the loss of fish from such systems. The examples above remind us that every action leads to a reaction, some of which are unpredictable but can have large effects. Thus, losses of impinged and entrained organisms from the local population can have cascading effects throughout the food web.

A2-3 EXTERIOR FISH ANATOMY

Most people can recognize a fish. Its external shape, the structure and position of its mouth, the location of fins, or the presence of spines are a few of the characteristics that vary among species. The long evolutionary history of fish has led to many changes that help fish use all aquatic environment habitats. Some basic patterns are present in the exterior anatomy of most fish species. These are discussed below.

The external shape of a fish reflects its lifestyle and habitat use. For example, the lifestyles of tuna and flounders have changed the "typical" fish body shape. Tuna migrate and hunt throughout the world's oceans. They have streamlined bodies with strong muscles and a specially-shaped tail to swim fast and catch prey. The largest members of this group, such as the bluefin tuna, are even partially warm-blooded to raise their endurance and speed. Flounders, on the other hand, are flat and move less: they spend much time on the ocean floor buried in the sand. They catch molluscs, worms, or fish that swim by.

Figure A2-1: Exterior Fish Anatomy

Figure A2-1 details a fish's exterior anatomy and the rest of Section A2-3 describes the major elements of exterior fish anatomy. The section focuses on those elements that may be important to impingement or entrainment. A basic knowledge of scales, for example, may help in understanding survival in fish that have lost their scales from I&E.

A2-3.1 Fish Shapes

The "typical" fish is long and cigar-like. Six general body shapes have developed around this basic design depending on the species' lifestyle and habitat preferences:

- **Rover-predators** are streamlined, with well-spaced fins along the body to provide stability and maneuverability. These fish are always mobile looking for prey. Examples include bluefin tuna and pelagic sharks.
- **Lie-in-wait predators** have long bodies, flattened heads, and large mouths. Their dorsal fins and anal fins are located far back on the body and their caudal fin is large. The size and place of most of their fins provide quick, forward thrust needed to catch prey. Their colors and secretive behavior make them blend into their surroundings. These fish lie in ambush and capture prey by quick-burst swimming. A typical example of a lie-in-wait predator is the pike.
- **Surface-oriented fish** are smaller, with an upward-pointing mouth, a flattened head, large eyes, and a dorsal fin located toward the tail. Their shape lets them capture small prey living below the water surface. Examples of surface-oriented fish include mosquito fish and brook silversides.
- **Bottom-dwelling fish** generally have a small or nonexistent air (e.g., swim) bladder. They spend much time foraging or resting on the bottom. Examples are rays and skates, which are flattened dorso-ventrally; and flounders, which lie on their sides.
- **Deep-bodied fish** are usually flattened sideways, with a body depth measuring at least one-third of their length. Their dorsal and anal fins are long and the pectoral fins are placed high on the body, directly above the pelvic fins. Deep-bodied fish tend to have a protrusible mouth, large eyes, and a short snout. Many have spines that increase their ability to escape predators, but at the expense of speed. Sunfish are examples of deep-bodied fish.

- **Eel-like fish** have long bodies, blunt or wedge-shaped heads, and tapered or rounded tails. Their pelvic fins are small or missing. Such fish are well adapted to entering small crevices and holes in reefs or rock formations. Examples include the American eel and the murray eel.

A2-3.2 Skin and Scales

Skin covers the entire body of a fish. It protects against micro-organisms and helps regulate water and salt balances. It also has the pigment cells that give fish their colors. The outer skin layer is the epidermis: it is thin and lacks blood vessels but is replaced as it wears off. The dermis is the inner, thicker layer, from which the scales grow. Much mucus is released by mucus glands in the dermis. Mucus covers the fish with a protective layer: it cleans body surfaces, prevents the entry of pathogens, helps regulate salt balances, and reduces friction.

Most fish are covered with scales. Some fish are scaleless, others are partially covered. Differences may be big even in closely-related species: the leather carp is scale-less, the mirror carp is partly covered with scales, and the common carp is fully covered with scales. Scale-less species generally have a tough, leathery skin to compensate.

Scales are thin, calcified plates that grow out of the dermis and protect the skin. They usually overlap like roof shingles and are known as imbricate scales. Another type of scale, mosaic scales, fit closely together like a mosaic but do not overlap; adjacent scales may touch, or they may be separated by a small space. The scale structure also varies by fish group: sharks, skates, and rays are covered with placoid scales (or dermal denticles), which give these fish the rough feel of sandpaper. Higher, bony fish, such as sunfish or minnows, are covered by smoother leptoid scales. Scale and mucus loss make fish more vulnerable to infections.

Scales are colorless; color comes from cells called chromatophores found in the dermis. Some of these cells contain pigments that produce the bright colors seen in fish. Others create various color hues (such as the typical “metallic” coloration in some fish species) by scattering or reflecting light.

Mechanical injuries from impingement and entrainment can abrade the epidermis, dermis and scales, removing them. This causes increased susceptibility to infection and osmotic stress. Freshwater fish will suffer from excessive water uptake, while saltwater fish will lose water (Rottmann et al., 1992). Abrasion can also cause a reduction in the lethal shear threshold of a fish, creating a greater susceptibility to injury or mortality from the shear forces created by spatial differences in the velocity of moving water (Marcy et al., 1978).

A2-3.3 Fins

Swimming is a challenge because water is not a solid material, but flows upon impact. Deep-bodied fish tend to fall over on their side, because the water provides no support. The body of a fish also shifts sideways as it swims. Fish have developed several strategies, including fins, to lend stability and maneuverability for swimming more efficiently through the water. Fins are bony or cartilaginous rays projecting from the fish’s body, and which are connected by a thin membrane. Some of those rays are articulated and are called soft rays. Others are stiff and are known as spines. Many fish incorporate soft rays and spines in their fins to provide flexibility and protection. Some species also have poison glands attached to the base of hollow spines to protect against predators.

Fins have many roles: they are used to swim and maneuver but also serve as rudders, balancers, defensive weapons, feelers, sexual structures, sucking disks, and prey or mate attractors. They have many shapes, colors, and lengths, and are found in different locations on the body. Fins come in two varieties: paired fins and vertical (or median) fins.

a. Paired fins

Paired fins include the pectoral fins and pelvic fins, which are ventral fins found at the bottom of the body (compared to dorsal fins, found on top of the body). Pectoral and pelvic fins resemble the four limbs of the higher vertebrates: the pectoral fins are the forelimbs and are attached to the shoulders; the pelvic fins represent the hind limbs. Neither fin type plays a major role in locomotion; they prevent the body from pitching and rolling and to help to brake forward motion.

❖ *Pectoral fins*

Pectoral fins are located behind the gill openings. They provide maneuverability, but also balance the body at low swimming speeds. Pectorals can have different shapes and functions: flying fish have large pectoral fins to help them soar in the air;

mudskippers have modified pectoral fins for crawling on land; and sea robins use the three front rays of their pectoral fins as feelers.

❖ *Pelvic fins*

Pelvic fins are located on the underside of the body but vary in their placement: they may be found in front of the pectorals (e.g., in cods, pollock, or winter flounder), below the pectorals (e.g., in largemouth bass, Atlantic croakers, or darter goby), or in the middle of the body (e.g., in salmon, American shad, herring, or striped mullet). The pelvic fin is used to stop, hover, maneuver, and balance. Pelvic fins can become specialized. Some species have fused pelvic fins, which form a suction disk for clinging to rocks and coral. In male sharks, the pelvic fins form claspers, which serve as sperm cell conduits.

Either one of these fin types may be absent in fish. Eels lack pelvic fins but have fused dorsal, caudal, and anal fins (see discussion below). Lampreys lack pectoral fins. Generally, however, pelvic fins are much more likely than pectoral fins to be absent.

b. Vertical fins

Vertical fins are found along the centerline of the body, at the top, bottom, and back of a fish. Dorsal fins, anal fins, and caudal fins are vertical fins found on most fish. Their roles include locomotion, protection, and balance.

❖ *Dorsal fins*

Dorsal fins are found on top of the body and consist of one or two (and rarely three) separate fins. They help prevent the fish from turning over in the water. Many species incorporate stiff spines in their dorsals to protect against predators. The dorsal fin may be followed by the adipose fin, a fleshy outgrowth with no rays, typically found in salmonids and catfish. Mackerel-like fish have small, detached finlets consisting of a single ray behind their dorsal (and anal) fins. Other species have highly modified dorsal fins: remoras have a sucker disk used for attaching to sharks, sea turtles, and other large marine animals. Angler fish have a modified dorsal fin ray that bears a fleshy, moving lure used for attracting prey.

❖ *Anal fin*

The anal fin is found on the belly of the fish behind the vent, or anus. It is usually a single fin (rarely two) used in balance. Many species include stiff, sharp spines to protect against predators. The anal fin is absent in rays and skates, which move about and feed close to the bottom. (Contrary to rays and skates, which have a depressed body shape, flatfish actually lie on their sides and have normal anal fins.) Anal fins also serve other purposes; in male mosquitofish, the anterior rays of the anal fin have joined into a single structure used to transfer sperm to the female.

❖ *Caudal fin*

The caudal fin is at the back of the fish and serves mainly to aid in locomotion. Swimming behavior shapes the caudal fin. Some rover-predators, such as tuna and marlin, have a stiff, quartermoon-shaped forked tail attached to a narrow caudal peduncle. The deeper the fork, the more active the fish. Deep-bodied fish and most surface- and bottom-oriented fish have rounded, square, or only slightly-forked tails. A few fish, such as sea horses, lack a caudal fin.

A2-3.4 Mouth and Dentition

The shape, size, and position of the mouth and teeth reflect the fish's habitat and diet. The mouths of bottom-feeding fish, such as carps, suckers, or catfish, generally point downward. In extreme cases, the mouth is tucked underneath the fish, as in rays, skates, and sturgeons. The mouth of surface-oriented fish, such as killifish, mosquitofish, and Atlantic silversides, points upwards. Most fish, however, have a terminal mouth. Mouths can become highly specialized, with shapes ranging from long, tube-like, probing structures to large, parrot-like beaks.

Fish do not chew their food; their teeth grab and hold prey until it can be crushed, torn apart, or positioned to be swallowed. Predators, such as sharks, barracudas, and piranhas, have rows of highly-developed teeth. Most species have teeth that look alike and are packed along the inner rim of the lower and upper jaw. Teeth typically point inward to prevent prey from fleeing after capture. Some predators, including pikes and pickerels, also have teeth on their tongues, gill arches, throats, and the roofs of their mouths. Fish that strain the water for plankton or eat plants have few well-developed teeth. Species that crush coral or clams have fused teeth in the form of a cutting edge, crushing plates, or broad, blunt teeth arranged like cobblestones. These species include parrot fish or skates and rays. The number of teeth in fish varies greatly and ranges from 0 to more than 10,000.

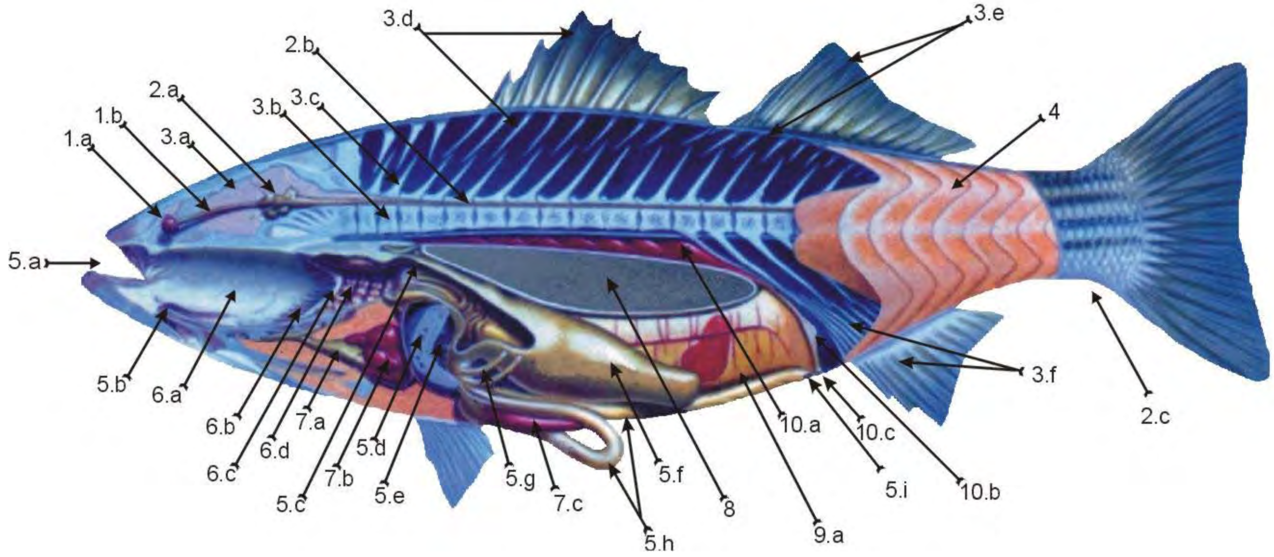
A2-4 INTERIOR ANATOMY

Section A2-4 discusses various components of the interior anatomy of a fish. Terms in this section refer to Figure A2-2 which diagrams many of the internal organs of the striped bass.

The internal anatomy of fish varies less than their external anatomy. All vertebrates share many structures, such as a central nervous system or an internal skeleton. Other structures are unique to fish [e.g., air or swim bladders (Figure A2-2) for buoyancy control and internal gills for gas exchange and salt regulation]. This section outlines basic features of the internal anatomy of fish. Rather than in-depth review, this section provides a basic understanding of the structure and function of the major organ systems in fish.

This knowledge is important because the systems discussed here may play a role during impingement or entrainment. For example, (1) impinged fish may suffocate if they cannot pass water over their gills due to high water pressures;
(2) anadromous fish adjusting to different salt levels in the water during migrations may be more vulnerable than resident species to the stresses of impingement; and (3) the air or swim bladder of larval fish may be damaged when they undergo rapid pressure changes within the cooling system.

Figure A2-2: Interior Fish Anatomy



Source: EPA, based on a drawing by Jack J. Kunz, National Geographic Society, 1969.

1. Olfactory System
    - 1.a Nasal Capsule
    - 1.b Olfactory Nerve

2. Nervous System
    - 2.a Brain
    - 2.b Spinal Column
    - 2.c Lateral Line

3. Skeletal System
    - 3.a Cranium/Skull
    - 3.b Vertebra/Backbone
    - 3.c Neural Spines
    - 3.d 1st Dorsal Fin Spines & Pterygiophore
    - 3.e 2nd Dorsal Fin Spines & Pterygiophore
    - 3.f Anal Fin Spines and Support

4. Muscle Segment (myomere)

5. Digestive System
    - 5.a Mouth
    - 5.b Tongue
    - 5.c Esophagus
    - 5.d Liver
    - 5.e Gall Bladder
    - 5.f Stomach
    - 5.g Pyloric Caeca
    - 5.h Intestines
    - 5.i Anus

6. Respiratory System
    - 6.a Buccal Cavity
    - 6.b Gill Rakers
    - 6.c Gill Arches
    - 6.d Branchial Cavity

7. Circulatory / Cardiovascular System
    - 7.a Ventral Aorta
    - 7.b Heart
    - 7.c Spleen

8. Air Bladder

9. Reproductive System
    - 9.a Ovary

10. Excretory System
    - 10.a Kidney
    - 10.b Bladder
    - 10.c Urinary Duct/Urogenital Opening

A2-4.1 Skeletal System

The internal skeleton holds together and protects the soft, internal organs, helps maintain the proper body shape, and serves as an attachment or leverage point for striated (i.e., skeletal) muscles.

a. Types of skeletons

Fish belong to three broad groups, based on skeletal differences:

❖ *Agnathans*

Agnathans, the jawless fish, are the most primitive of all fish. Most species became extinct 350 million years ago, except for the eel-like hagfish and lampreys. Hagfish live in the ocean and scavenge dead fish or other vertebrates. Lampreys live both in marine and freshwater environments; some species parasitize other fish. Agnathans lack jaws; they also lack a true vertebral column, ribs, scales, paired appendages, and other skeletal features typically found in more modern fish. Instead of true hollow vertebrae (Figure A2-2), hagfish and lampreys have a flexible notochord, a long, cartilaginous rod that acts like a primitive backbone.

❖ *Chondrichthyes*

Chondrichthyes, the cartilaginous fish, include sharks, rays, skates, and the less familiar but striking Chimaeras. These fish do not have true bone; instead, their skeletons are made of cartilage combining hardness and elasticity. Unlike bone, cartilage usually does not mineralize (there are exceptions), but instead consists of a flexible matrix made of fibers meshed in a protein-like material. Typical Chondrichthyes are also distinct from bony fish for other reasons, including: (1) lack of a air/swim bladder; (2) presence of a solid braincase instead of one with many pieces of bone; (3) individual external gill openings instead of a single combined opening; (4) primitive fin structure; and (5) tooth-like scales.

❖ *Osteichthyes*

Osteichthyes, the bony fish, include all other living fish species. The Osteichthyes have a bony skeleton; notable exceptions include primitive bony fish, such as sturgeons or paddlefish, which have only partly ossified skeletons. Bony fish have gills in a common chamber covered by a movable bony operculum (see Figure A2-1), and fins supported by bony rays radiating from the fin base. They usually have a gas bladder to provide buoyancy. The teleosts are the most successful bony fish; most aquarium, commercial, and recreational species belong to this group. Teleosts comprise more than 30,000 species and subspecies.

b. Major components

The major components of the internal skeleton in modern fish include the following:

- The **backbone** replaces the notochord of the jawless fish and consists of interlocking hollow vertebrae that run from the back of the skull (Figure A2-2) to the tail. The spinal cord (Figure A2-2), which starts in the brain and runs through the backbone, is also protected by it. The number of vertebrae range from 16 to more than 400, depending on the fish species. Each vertebra has an upward-projecting spine called the neural spine (Figure A2-2). The vertebrae found behind the abdominal cavity may also have one or more downward-pointing spines (the haemal spines).

- The **skull** is a complex structure in the head region. Its major part is the cranium (Figure A2-2), or braincase, which protects the brain and several sense organs. The skull is also an attachment point for the lower jaw, the backbone, and the shoulder and pelvic girdles. In sharks and related fish, the skull does not have sutures. The skull of bony fish consists of many fused bones.

- The **ribs** or spines (Figure A2-2) are loosely attached to the vertebrae and surround the fish's abdominal cavity. They are small projections in cartilaginous fish, but are fairly well-developed in bony fish. Unlike in terrestrial vertebrates, fish ribs play no part in breathing. They instead transmit muscle contractions during swimming and frame the body. Fish also lack a breastbone to create a rigid rib cage.

- The fin spines (Figure A2-2) are spine-like bones not directly connected to the rest of the skeleton. They anchor both dorsal and ventral fins into the muscles through connecting structure called pterygiophores that reach toward or may intertwine with both the neural and haemal spines of the vertebrae.

A2-4.2 Muscle System

Muscles comprise one-third to one-half of the mass of an average fish. The activity of the nervous system has little consequence except through its action on muscles, which are used both to swim and to aid digestion, nutrition, secretion, and circulation. Muscles exert their force by contracting. If a muscle is attached to different places on the skeleton, the contraction creates a pull, resulting in movement. Two major types of vertebrate muscle tissue exist:

- **Smooth muscle**, the simpler of the two, is under involuntary control. It is found in the lining of the digestive tract, where it provides the slow contractions needed to advance food. It is also found in the ducts of glands connected to the gut and the bladder, as well as in blood vessels, genital organs, and other locations (the heart consists of highly modified smooth muscle). Although it plays a major role in the well-being of fish, smooth muscle is not involved in swimming.

- **Striated muscle** (Figure A2-2), forming the “flesh” of the fish, is under rapid, voluntary control. These muscles are large, well-formed structures; their main role is in swimming. Striated muscles are also used to move eyes, jaws, fins, and gill covers.

The biggest muscle mass in fish is the axial musculature, which runs from head to tail on both sides of the body. It is arranged in repeating, W-shaped, overlapping segments called myomeres. A tough membrane connects each myomere to its neighbor. An additional membrane, called the horizontal septum, divides the myomeres into a dorsal and ventral half.

The fish creates a wave along its flanks by contracting opposite muscle segments (Figure A2-2). The wave gains speed as it travels backwards and causes the tail to thrust against the resistance of the water, thereby moving the fish forward. There is little specialization in the axial musculature. One exception are the muscles used for moving the pectoral and pelvic fins. Each fin has two opposing muscles: one extends the fin, the other depresses it.

A2-4.3 Major Sense Organs

The sense organs in fish have many uses, including orienting the animals and detecting electrical, mechanical, chemical, thermal, and electromagnetic signals from their surroundings. The nervous system is split into two main parts: the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS includes the brain and spinal cord. The PNS consists of paired nerves that run outward from the CNS and connect to other areas in the body. One function of the nervous system is to tie receptor cells, such as the eyes or lateral line, to effector cells, such as the skeletal muscles. Receptor cells detect outside signals; effector cells create a response. Another part, the visceral nervous system, serves the gut, circulatory system, glands, and other internal organs.

This section discusses the structure and function of the organs tied to olfaction, taste, equilibrium/hearing, vision, and the lateral line.

a. Olfaction

Many fish have a keen sense of smell. Certain shark species can detect the odor of blood over great distances in the ocean. The olfactory epithelium is found at the bottom of specialized holes called nasal pits located in the snout. Unlike the noses of terrestrial vertebrates, the pits do not open into the buccal cavity (Figure A2-2). Each olfactory cell connects to the olfactory bulb of the brain via nerves. The olfactory cells project rod-like extensions into the nasal pit. These extensions detect the odor molecules. Little is known about the exact processes that generate the sense of smell in fish.

b. Taste

The taste cells are grouped in clusters called taste buds. Each cluster has 30 to 40 taste cells connected to nerve fibers. Taste buds are usually found in small depressions. Each sensory cell has a hair-like projection, which may extend to the surface of the epithelium via the taste pore and detect taste. Fish can detect sourness, saltiness, bitterness, and/or sweetness.

All fish do not experience taste in the same way. Most have taste buds in their mouth and pharynx, and can therefore taste to one degree or another. Some, like the bullhead catfish, also have tastebuds over their entire body surface. Others, such as sturgeons and carp, have taste buds on oral feelers to facilitate finding food in mud or murky waters. Still others have taste buds covering their heads.

c. Equilibrium and hearing

Fish do not have the features of hearing found in terrestrial vertebrates (i.e., ear lobes, ear canals, ear drums, ear ossicles). The basic ear structure in fish and all higher vertebrates is the inner ear, a paired sensory organ found in the skull. This structure originally evolved as an organ of equilibrium and is still used as such by all terrestrial and aquatic vertebrates. The ability to hear evolved later.

The inner ear in fish consists of sacs and canals that form a closed system containing a liquid called an endolymph. Some of the internal surfaces of the sacs and canals are lined by a tissue called the macula. The sensory cells that make up the macula resemble the neuromasts found in the lateral line system discussed below. These cells connect to auditory nerves in the brain. Calcium carbonate crystals are deposited on top of the macula and combine to form ear stones called otoliths. Depending on the tilt of the head, the acceleration, or the rate of turning, the otoliths contact the sensory cells in different ways, causing specific patterns of nerve firings. The CNS interprets these signals and provides data to the fish on its orientation and movement through space.

The inner ear also captures sound waves. Sound waves carry farther in water than in air and are therefore a source of information to fish. Whereas cartilaginous fish (e.g., sharks, ray, skates) respond only to very low vibrations, most bony fish hear a range of sounds. Fish do not have external hearing structures; sound is believed to pass through the skull into the inner ear. The vibrations cause the otoliths to shake, generating the effect of hearing.

Sound must generate head vibrations for fish to hear. Some fish have “hearing aids” to better capture sounds. These aids rely on the gas in air/swim bladders to amplify the vibrations of sound in water. The swim bladder in herrings has an extension that reaches forward and carries vibrations directly to the inner ear. Catfish and carp use a different method: bony processes of the anterior vertebrae form a chain called the Weberian ossicles, which connect the swim bladder to the head region. These modifications show the importance of sound to fish.

d. Vision

The basic anatomy of fish eyes resembles that of other vertebrates. The cornea is the outermost layer, through which light enters the eyeball. The cornea is followed by a lens, which serves to bend and focus the light rays on the retina in the back of the eye. Muscles attached to the lens allow fish to focus on nearby or far away objects. Ocular fluid fills the interior of the eye and the space between the cornea and lens. Fish have evolved a tapetum to let the eye catch more light. This is a highly reflective tissue that mirrors the light back onto the eye. Unlike terrestrial vertebrates, fish lack a pupil to control the intensity of the incoming light.

The retina in fish is composed of rods and cones, which are light-gathering cells containing visual pigments. Rods have more pigments than cones and are more sensitive to dim light. Cones work only at higher light levels and are usually missing in fish that live in low-light habitats, such as the deep sea. Different pigments have distinct molecular structures and are sensitive to specific wavelengths. When light hits visual pigments, a chemical reaction is started that results in nerve impulses. These are carried by the optic nerve to the brain for processing.

Fish have adapted to deal with the unique optics of water and the different light conditions that exist in aquatic environments.

❖ *Refraction*

Refraction refers to the bending of light as it passes from one medium to another, such as from air to water or from water to tissue. The cornea and ocular fluids of fish do not refract light. Fish lenses are good at bending light, and make images free of aberrations or distortions by changing the refractive properties of the tissues within the lens. Light passing through the lens follows curved paths to form sharp images on the retina.

This arrangement is a problem when fish need to focus on nearby or far away objects. Mammals focus by changing the curvature of the lens. Fish cannot do that. Most fish move the lens toward or away from the retina along the optical axis. As a general rule, freshwater species accommodate less than do marine species; useful vision is more limited in the more turbid waters of lakes and rivers, compared to ocean water.

❖ *Light absorption*

Water’s light absorption properties change with depth. Longer wavelengths (reds and greens) are quickly removed at the surface; only shorter wavelengths (blues) go farther down. Deep water fish have visual pigments sensitive to blue light. A change in spectral quality with depth affects fish that move between the seas and inland waters. Adult salmon in the ocean, for example, have rod pigments that best absorb in blue end of the spectrum. As the fish migrate into shallower freshwater, their pigments are gradually replaced by new ones that are more sensitive to the redder end of the spectrum.

❖ ***Color vision***

Fish can see colors if they live in relatively shallow or clear water. Consequently, numerous tropical fish species display brilliant colors.

e. Lateral line

Most fish have a "lateral line" (Figure A2-2) running along their flanks from head to tail. The lateral line provides spatial and temporal information. It is so sensitive that blinded fish can locate fish or other nearby objects. A fish can also feel the motion of its own body relative to the surrounding water: as it approaches an object, the pressure waves around the fish's body are slightly distorted. The lateral line detects these changes and enables the fish to swerve. Low frequency sound waves generate pressure waves in the water column, which are also detected by the lateral line.

The lateral line can be single, double, or forked, consisting of thousands of tiny sensory organs that lie on the skin surface within small pits. These sensory organs connect to the brain. At the bottom of each pit is a neuromast, a small structure that detects vibrations and water movement around the fish. The neuromast consists of sensory hairs enclosed in a gel-filled capsule that protrudes into the water. The neuromasts send out electrical impulses to the brain. The enclosed sensory hairs bend when a pressure wave distorts the gelatinous caps. This movement either increases or decreases the frequency of nerve impulses depending on the bending. It is this change in frequency which is sensed by the fish.

A2-4.4 Circulatory System

The circulatory system transports and distributes various substances including oxygen, nutrients, salts, hormones, or vitamins to cells throughout the body; and removes waste products such as carbon dioxide, nitrogenous wastes, excess salt, or metabolic water. The circulatory system also maintains proper physiological conditions within the body, fights diseases, heals wounds, and serves as an accessory to the nervous system through the endocrine (i.e., hormone) system.

The major parts of the circulatory system are the blood and the circulatory vessels.

a. Blood

Blood fills the circulatory system vessels. Blood's liquid "matrix," called blood plasma, contains several cell types:

- Red blood cells are packed with hemoglobin, which contains iron atoms to carry oxygen to the cells and carbon dioxide away from the cells.
- White blood cells fight infections and other diseases.
- Thrombocytes help the blood to clot.

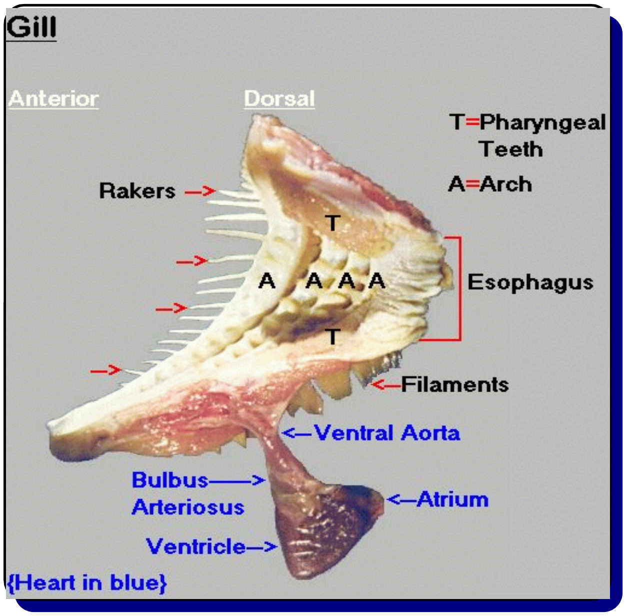
The life span of blood cells ranges from hours to months, depending on cell type. The body must therefore make new cells to replace old ones. Blood-forming tissue in fish is found in one or more of the: spleen (Figure A2-2), kidneys (Figure A2-2), gonads (sex organs), liver (Figure A2-2), and heart (Figure A2-2 and Figure A2-3). Bone marrow does not form blood cells in fish.

b. Circulatory vessels

The circulatory system includes the heart, arteries and veins, capillaries, and the lymphatics.

The heart of a typical fish, a modified tube with four sequential chambers, is found close to the gills. Oxygen-poor blood enters the sinus venosus, and is pumped through the atrium and ventricle into the bulbous (Figure A2-2) or conus arteriosus. From there, it is pumped out of the heart, into the ventral aorta. The ventricle does most of the pumping. One-way valves prevent blood from flowing backward. The ventral aorta runs toward the gills and branches into parallel aortic arches that run through each gill. After the blood is re-oxygenated, the blood vessels rejoin into one large dorsal aorta, which carries the blood to the organs.

Figure A2-3: Gill and Heart Anatomy



Arteries carry higher-pressure, oxygen-rich blood. When they reach their target organs, the arteries split into smaller branches called arterioles. These enter the organ and continue to divide until they become so narrow that red blood cells can pass through them only single-file. At this point, the blood vessels are called capillaries. The microscopic capillaries are the most important part of the circulatory system. Whereas blood is simply carried through the arteries and veins, blood in the capillaries releases oxygen and nourishment to the cells and picks up carbon dioxide and other wastes. The capillaries rejoin and form larger venules. The venules merge into veins, which carry the oxygen-poor blood out of the organs and back to the heart. The venous system is at a lower pressure than the arterial system because pressure is lost as blood passes through the capillaries.

Bony fish also have a lymphatic system, a network of vessels running parallel to the venous system, returning excess fluids from the tissues to the heart. The lymphatics are not connected to the arterial blood supply, but instead arise from their own dead-end capillaries within the tissues. The excess fluid is captured as lymph and returned to the venous system.

A2-4.5 Respiratory System

Fish are aerobic, i.e., they must breathe oxygen. Most fish obtain their oxygen from the water. Extracting oxygen from water is difficult because (1) water is a thousand times denser and 50 times more viscous (at 68 ˚F [20 ˚C]) than air; (2) when saturated, water contains only 3 percent of the oxygen found in an equal volume of air; and (3) oxygen solubility in water decreases with increasing temperature. Fish expend much energy moving water over their gills; they have evolved efficient gills to maximize oxygen uptake while minimizing the cost of breathing.

a. Basic gill anatomy

Gills are similar among groups of fish. The paired gills are internal and located in the pharyngeal region, specifically the branchial cavity. They are supported by flexible rods called gill bars. The number of gill bars ranges from four to six. On the side facing the pharynx, the gill bars carry stiff strainers called gill rakers (Figure A2-2 and Figure A2-3). Though not used in breathing, some species use gill rakers to strain out food particles. A typical gill bar has two large gill filaments (Figure A2-2 and Figure A2-3), which point outward (i.e., away from the pharynx and into the branchial cavity). Each gill filament supports many gill lamellae, where the gases are exchanged.

An average of 20 lamellae are found on each mm of gill filament. Lamellae are covered by tissue one cell layer thick to optimize gas exchange. Those of adjacent gill filaments usually touch or mesh together, which favors contact between the gills and water. The gill surface area varies by a factor of 10 (on a per weight basis) and depends on the animal's activity. Active swimmers like white shark or tuna have larger gill surface areas than do sedentary fish like sunfish or carp. A fish such as a 44-pound sea bass has a respiratory surface of about 60 ft^{2}.

b. Gas exchange

When the fish opens its mouth to breathe, the branchial cavity is closed by a stiff operculum (in bony fish) or a series of flap-like gill septa (in cartilaginous fish) to prevent oxygen-depleted water from re-entering the branchial cavity. The operculum and septa also help keep a negative pressure in the buccal cavity when the mouth opens, forcing water to rush in. As the fish closes its mouth, the buccal cavity becomes smaller and water is forced backward over the gills.

Breathing water has drawbacks, partly due to its low oxygen content. Gills increase oxygen uptake using a countercurrent exchange mechanism. The gill lamellae face the incoming water, which always moves from the buccal cavity to the branchial cavity. Blood flows through the lamellae in the opposite direction. When blood first enters the lamellae, it encounters water low in oxygen (the "upstream" gill lamellae have already removed some oxygen). The blood entering the lamellae contains even less oxygen. This difference lets the small amount of oxygen still present in the water move into the blood. The oxygen content of blood flowing into the incoming water goes up, but so does that of the ever "fresher" water. A nonstop oxygen flow in favor of the blood all along the lamellae results. Oxygen keeps moving into the bloodstream until the blood leaves the lamella. Through this process, fish remove up to 80 percent of the oxygen from the water. Carbon dioxide moves in the opposite direction based on the same principle.

c. Other gill functions

The central role of gills is to take up oxygen and release carbon dioxide. Gills also have other functions due to their large surface area and close contact with water.

❖ *Osmoregulation*

Gills, together with kidneys, are used in osmoregulation: the control of salt and water balances. The internal fluids of freshwater fish are "saltier" than the surrounding water. When blood moves through the gills, salt diffuses from the blood into the water, whereas water tends to move into the body. The kidneys release the extra water as dilute urine to keep a proper internal water balance. Freshwater fish also drink little or no water. Any salt loss is made up by chloride cells located in gill filaments and lamellae. These cells move salts from the water into the blood to make up for the loss. Mucus covers the gills, which protects them from injuries but helps in osmoregulation.

This situation reverses in marine bony fish: their internal fluids are less "salty" than their surroundings: water in the blood moves out of the body, but salts move in. These fish drink freely to make up for water loss. Drinking sea water brings salts into the body; these salts are excreted by both the gill chloride cells and the kidneys.

✤ Osmoregulation is a vital physiological need for fish and other aquatic organisms. This is particularly true for anadromous fish, which move from the ocean into freshwater habitats to spawn, and whose offspring migrate back into the ocean to mature. These species undergo profound physiological changes over relatively short periods of time to adapt to and survive in drastically different osmotic environments. Some species may be less able to survive physical shock or extreme stress during this transitional period, and could therefore be more susceptible to mortality from impingement.

Cartilaginous fish (and some primitive bony fish) also live in salt water but maintain their water balance differently. These fish keep high levels of urea in their blood, which causes their internal fluids to be saltier than seawater. Some water enters the gills, and the kidneys produce moderate amounts of urine. These fish need little or no additional water and drink infrequently.

❖ *Heat exchange*

Most fish are cold-blooded: their body temperature equals that of the water. Internal heat created by muscle activity is lost to the environment when the fish's blood passes through the gills to extract oxygen from water. Pelagic fish, such as certain tuna and sharks, are exceptions. These fish have countercurrent heat exchangers in their muscles to keep much of the heat inside and prevent it from being lost through the gills. Their body temperatures can be up to 20-25 ˚F (-6.7 to -3.9 ˚C) higher than that of the surrounding water.

❖ *Excretion*

Freshwater and marine bony fish release their nitrogenous wastes through their gills. Blood moves the waste, in the form of urea, to the gills. There, urea changes into toxic ammonia, which quickly diffuses into the water. Cartilaginous fish (i.e., Chondrichthyes) keep high levels of urea in their blood and lose very little of it through their gills to help in osmoregulation.

❖ *Predation*

Gills have evolved to catch prey in plankton feeders, which swim with their mouths open. These fish have numerous, fine, and long gill rakers that strain plankton. Examples include the paddlefish (*Polyodon spathula*), the gizzard shad, and the Atlantic herring (*Clupea harengus*).

A2-4.6 Air/Swim Bladder

Buoyancy is the tendency of an object to float or rise in water, and depends on the object's density versus that of water. An aquatic organism with a density like water is weightless, neither rising or sinking. Less effort is needed to keep it from sinking or to move about. Most fish regulate their density to reach neutral buoyancy.

a. Strategies to increase buoyancy

Fat is less dense than water. One way to reduce body density, and increase buoyancy, is to increase body fat. About one-third of a fish's body weight needs to be fat to make the fish weightless in seawater. Several shark species increase buoyancy in this manner: they have huge livers full of squalene, a fatty substance that provides buoyancy, being much less dense than seawater. Buoyancy is also attained by storing gases within the body. Many bony fish have an air/swim bladder for this purpose.

The amount of body volume that must be in the form of gas to achieve "weightlessness" depends on the saltiness of the water. Freshwater contains less salt than seawater; it is therefore less dense and provides less buoyancy. Swim bladders in freshwater fish range from 7 to 11 percent of body volume, while those of marine fish range from 4 to 6 percent of body volume.

b. Structure and function

Fish would be neutrally buoyant at only one depth, if air/swim bladders had a fixed amount of gas. Water pressure increases as water depth increases. When a fish swims to a lower depth, the increased pressure compresses the gas in the swim bladder, lowering its volume and increasing the density of the fish. The fish must swim more actively to compensate for this to prevent its denser body from sinking further. Water pressure decreases expanding the volume of gas in the swim bladder, when a fish swims toward the surface. Without the ability to change the amount of air in the swim bladder, a fish becomes less dense and rises to the surface like a cork.

The volume of gas in an air/swim bladder, and hence its pressure, needs adjusting as a fish changes depths. Most fish have an air/swim bladder that is isolated from the outside of the body and air pressure within the bladder varies when gas moves from the bladder to nearby blood vessels and back again. In some species, such as carp, a pneumatic duct joins the air/swim bladder with the esophagus. This connection acts as a " valve" to release extra gas as the fish swims toward the surface, or to take up gas by gulping air at the surface before swimming toward the bottom.

It is simple to remove gas from an expanding air/swim bladder: the pressure forces the gas into the surrounding blood capillaries, which carry it away. Filling up a bladder is more difficult because it is done against the high pressures already in the bladder.

In most bony fish (i.e., Osteichthyes), gas enter the air/swim bladder through the red body. The name comes from a structure known as the rete mirabile (the "marvelous net"), a dense bundle of capillaries arranged side by side in countercurrent fashion. Blood leaving the area carries gases at the same pressure found in the air/swim bladder. The gas pressure of blood coming into the area is much lower, similar to that in the surrounding water. Gases move from the outgoing blood to the incoming blood, not unlike the gas exchange process in the gills. The red body boosts the process by releasing compounds that raise the incoming blood's oxygen level. When the gas pressure in the red body exceeds that within the swim bladder, gas moves into the latter. Gas uptake and release is not immediate; swim bladders can burst when fish caught at great depth come to the surface too fast.

c. Effect of entrainment on the swim bladder

Changes in pressure can have a dramatic and often lethal effect on fish with swim bladders. Cooling water systems contain both positive and negative pressure differentials. A large positive pressure change will cause the swim bladder to implode. The effects of negative pressure changes appear to be more damaging. Negative pressure changes can cause the swim bladder to explode if the pressure across the membrane cannot be equalized fast enough. Pressure effects may be the leading cause of mortality in larvae of bluegill, carp, and gizzard shad. Gas disease may also result from a negative pressure change. Gas becomes more soluble in a negative pressure system, and following the release of pressure, hemorrhaging of blood vessel walls may occur around the eyes, gills, fins, and kidneys.

A2-4.7 Digestive System

The digestive system processes ingested food to meet the energy needs of fish.

The digestive system of fish has four major functions:

- **Transportation:** Swallowed food moves through the various gut sections for handling. Solid wastes must be removed at the end.
- **Physical treatment:** Food must be reduced in size by muscular action before it can broken down by digestive chemicals. Fluids are added to turn the food into a soft, pasty pulp.
- **Chemical treatment:** Food is turned into simpler compounds in the "digestive" phase.
- **Absorption:** The products of digestion are absorbed through the intestinal wall and either distributed as fuel or stored for later use.

The digestive system starts at the mouth (Figure A2-2), which captures prey. Food is passed through the buccal cavity into the muscular pharynx, where it is swallowed into the tube-like esophagus (Figure A2-2). The esophagus uses smooth muscle to transport food to the stomach (Figure A2-2) [note that some fish such as chimaera, lungfish, and certain teleosts do not have a stomach; the esophagus connects directly to the intestine (Figure A2-2)]. In many fish, a muscular sphincter exists where the esophagus meets the stomach. The stomach, when present, can be either a "U"- or "V"-shaped tube or a straight, cigar-shaped organ. Its internal wall is deeply folded and rich with mucus-secreting glands. Other glands release digestive acids, and enzymes such as pepsin and lipases, to break down protein and fats. At the end of the stomach, many bony fish have extensions called pyloric caeca (Figure A2-2), which may help digest and absorb food.

The pancreas is a major source of digestive enzymes, that form an "intestinal juice" to break down fats, proteins, and carbohydrates into simpler molecules. The intestine has glands which produce more digestive enzymes, or mucus to lubricate food passage. Intestinal contractions move the food along. The inner lining of the intestine is deeply folded to increase the surface area for absorption. All Chondrichthyes and some primitive bony fish have an intestinal spiral valve, which looks like an auger enclosed in a tube. This valve increases the surface area of the gut because the food must twist through the intestine instead of moving straight through. The length of the intestine in bony fish varies: herbivores have long, coiled intestines, but carnivores have short, straight intestines. After digestion is complete, the wastes pass through the rectum and are excreted via the anus (Figure A2-2).

The liver (Figure A2-2) is not directly tied to digestion but is associated with it. This organ produces bile and bile salts, which help pancreatic enzymes split and absorb fats. Bile collects in the gall bladder (Figure A2-2) before it enters the intestine. The liver is a major storage organ. Blood leaving the intestines passes through the liver; fats, amino acids (building blocks for protein), and carbohydrates (simple sugars) are removed and stored there. The simple sugars are stored as glycogen and released to the blood when a burst of energy is needed.

Chapter A3: Other Vulnerable Aquatic Organisms

INTRODUCTION

CHAPTER CONTENTS

Chapter A2 focused specifically on fish species. Fish are of particular concern in the context of section 316(b) because of their importance in aquatic food webs and their commercial and recreational value. However, numerous others kinds of aquatic organisms are vulnerable to cooling water intake structures (CWISs), including diverse planktonic organisms, macroinvertebrates such as crabs and shrimp, and aquatic vertebrates such as sea turtles. These other organisms are discussed briefly in this chapter based on information compiled for EPA's section 316(b) rulemaking activities (SAIC, 1995).

A3-1 PLANKTON

Plankton includes microscopic organisms, plant or animal, that are suspended in the water column and are neutrally buoyant. Because of their physical characteristics, most planktonic organisms are incapable of sustained mobility against the flow of water. Consequently, plankton drift passively in prevailing currents and have limited ability to avoid CWIS.

A3-1.1 Phytoplankton

Phytoplankton are free-floating plants, usually microscopic algae, which are primary producers in many aquatic environments. Primary productivity can be reduced by passage of phytoplankton through CWIS, especially during summer. In warm climates, a greater portion of the year may be affected. Some plants in lower latitudes may decrease primary productivity to some extent throughout the year.

Losses of phytoplankton rarely occur beyond the immediate vicinity of the CWIS. Possible exceptions include areas where mixing within non-entrained water is limited or slow, such as in enclosed bays or waters where substantial portions of water are withdrawn for cooling. In these cases, the effects of entrainment on algal primary productivity and biomass may persist and be apparent beyond the vicinity of CWIS.

A3-1.2 Zooplankton

Zooplankton are free-floating planktonic animals. Most zooplankton species have relatively short population regeneration times (from days to weeks), and therefore zooplankton populations are able to recover from entrainment losses relatively rapidly.

Source: USGS, 2001a.

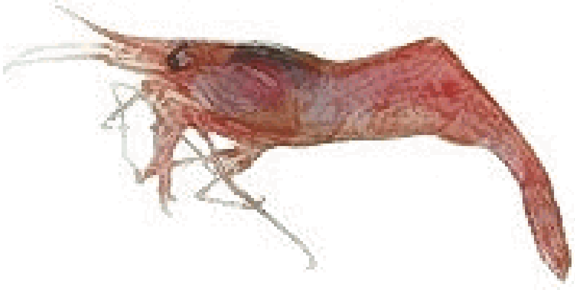
A3-1.3 Ichthyoplankton

Ichthyoplankton includes egg and larval stages of fish species. When egg and larval stages are pelagic, vulnerability to entrainment is high. In contrast, eggs that are demersal and attach to plants or sediments are rarely entrained.

A3-2 MACROINVERTEBRATES

Macroinvertebrates are invertebrate organisms that are large enough to be seen with the naked eye. Macroinvertebrates include many familiar crustaceans, such as lobsters, crayfish, crabs, shrimp, and prawns. Such organisms live in sediments, the surface of sediments, hard surfaces (e.g., rock pilings), or the water column itself. It is not uncommon for macroinvertebrate species to use different habitats at different parts of their life cycle. Macroinvertebrates such as shrimps are quite mobile and capable of moving throughout the water column in large schools, increasing their susceptibility to I&E. On the other hand, crabs and lobsters live on the bottom and typically do not swim in the water column. However, early life stages of these species are frequently planktonic, and can be susceptible to entrainment.

Comparatively few studies have been devoted to CWIS effects on macroinvertebrates. Available information suggests that macroinvertebrates with hard exoskeletons (e.g., blue crab) have relatively high survival rates following impingement. However, molting individuals are often found dead in impingement samples. Sessile adults of species such as clams and oysters are not typically entrained. However, because such species are often broadcast spawners with planktonic egg and larval stages, population abundance can be reduced by CWIS. In addition, because many macroinvertebrates serve as important prey items for many freshwater and marine fishes, declines as a result of CWIS can adversely affect aquatic food webs.



Source: NOAA, 2002.

A3-3 SEA TURTLES AND MARINE MAMMALS

Some CWIS facilities impinge sea turtles, including several species that are currently State- or Federally-listed as threatened or endangered. Sea turtles, seals, and other large aquatic vertebrates can die if they are impinged and trapped against intake screens.

Source: NMFS, 2001b.

A3-4 CONCLUSIONS

Although most I&E studies focus on fish species, it is important to bear in mind that many other kinds of aquatic organisms are vulnerable to I&E, either during early development or throughout their life cycle, depending on factors such as size, swimming ability, reproductive strategy, and other life history characteristics.

It is also important to note that in addition to direct harm from I&E, most aquatic organisms are also susceptible to indirect impacts as a result of the impingement or entrainment of prey items. Unfortunately, few studies consider how CWIS impacts may disrupt aquatic food webs. However, an estuarine trophic dynamics model by Summers (1989) indicated that production of valuable fishery species, such as striped bass (*Morone saxatilis*), bluefish (*Pomatomus salatrix*), and weakfish (*Cynoscion regalis*), can be significantly reduced if there are high entrainment losses of forage species, including bay anchovy (*Anchoa mitchilli*) and Atlantic silversides (*Menidia menidia*).

Such indirect effects on fish species whose prey are impinged or entrained are generally acknowledged, though rarely quantified. In addition, there has been little consideration of indirect effects of CWIS on non-fish species. In an effort to address this knowledge gap, Chapter A4 discusses CWIS effects on bird species.

Chapter A4: Direct and Indirect Effects of CWIS on Birds

INTRODUCTION

Chapter A2 focused specifically on fish species that are vulnerable to impingement and entrainment (I&E). Chapter A3 discussed other aquatic organisms vulnerable to I&E, including macroinvertebrates such as crabs and shrimp and aquatic vertebrates such as sea turtles. In this chapter we discuss potential direct and indirect effects on birds that prey on impinged and entrained fish and shellfish species.

CHAPTER CONTENTS

A4-1 DIRECT EFFECTS ON BIRDS

Although most direct effects of cooling water intake structures (CWIS) are on fish and shellfish, there are occasional cases of direct harm to birds. For example, the U.S. Fish and Wildlife Service in Green Bay, Wisconsin has recorded direct mortality of nestling double-crested cormorants (*Phalacrocorax auritus*) at the Point Beach Nuclear Power Plant (Stromborg, 1993). During one incident in September and October of 1990, 74 cormorants were impinged at the facility. According to the U.S. Fish and Wildlife Service, this number represents 3.2 percent of the total potential productivity of the species. It was concluded that the geographic extent of the impact was much larger than a single colony in Wisconsin because the losses were nestlings that otherwise would have entered the free-flying population. Another incident of avian impingement occurred at the Seabrook Station in 1999. Between February 20 and March 16, twenty-nine white-winged scoters were impinged at the facility's cooling water intake structures. The intake structures are located at a depth of approximately 40 feet below the surface, and mussels often attach to the structures. It is believed that after diving down to feed on the mussels on the intake structures, the scoters were drawn into the cooling system (North Atlantic Energy Service Corporation, 1999).

A4-2 INDIRECT EFFECTS ON FISH-EATING BIRDS

Although direct mortality of birds can occur, most effects are indirect as a result of losses of fish and shellfish that provide food for birds. For some fish-eating birds, such as cormorants, kingfishers, grebes, ospreys, and terns, fish are a necessary component of the diet. For others, such as gulls, fish are a regular but less essential dietary component. More than 50 bird species out of the 600 in North America fall into the former category, and 20 fall into the latter (Tables A4-1 and A4-2). The birds listed in Tables A4-1 and A4-2 usually obtain their fish prey from freshwater ecosystems such as lakes, ponds, marshes, or rivers (e.g., ospreys and kingfishers), or from estuarine or coastal marine environments (e.g., loons and cormorants). Many species such as grebes and auks spend part of the year (typically the breeding season) in freshwater environments, but winter on the coast. These birds while in their summer or winter ranges may occupy areas that could be affected by existing or future CWIS. Some birds (e.g., shearwaters) depend on fish prey from offshore marine areas. Since these prey are unlikely to be affected by CWIS located inland or on the coast, these birds are not considered in this chapter. Also, most birds are relatively flexible and opportunistic in their choice of prey, and some birds may consume fish, but only rarely; these birds (e.g., red-winged blackbirds) are not included in the tables.

In addition to birds that depend largely on fish for their diet, many species consume aquatic invertebrate prey, such as crustaceans, annelids, mollusks, etc. Bird species that are at least partially dependent on aquatic invertebrates from freshwater wetlands or coastal marine and estuarine habitats for at least part of their annual cycles are shown in Table A4-3. These

White winged scoters (*Melanitta fusca*) are one of the 15 species of sea ducks found in North America. They spend most of the year in costal marine waters and migrate inland to nest and raise their young as do most sea ducks. White wings nest on freshwater lakes in the boreal forests of interior Alaska and western Canada and winter in large bays and estuaries along the Pacific and Atlantic coasts.

Source: Alaska Department of Fish and Game, 1999.

Photo source: Alaska Department of Fish and Game, 1999.

The double-crested cormorant is a bird of salt, brackish and fresh waters. It breeds mainly along the coasts, but also around inland lakes. As soon as they return from their wintering grounds on the U.S. east coast south to the Gulf of Mexico, they appear throughout the St. Lawrence system. They are particularly fond of islands for nesting. The nest is made of a mass of branches which they build in a tree, on a ledge or on a clifftop.

Cormorants are 61-92 cm (2 to 3 ft) long, with thick, generally dark plumage and green eyes. The feet are webbed, and the bill is long with the upper mandible terminally hooked. Expert swimmers, cormorants pursue fish underwater. The young are born blind, and the parents feed the nestlings with half-digested food which is dropped into the nests. Later, the young birds poke their heads into the gullet of the adults to feed. Cormorants are long-lived; a banded one was observed after 18 years.

Average clutch size is three or four eggs. After being incubated by both parents for 24 to 29 days, the chicks hatch unprotected by any down. They grow rapidly and fledge when the are five to six weeks old. Cormorants are diving bird and feed mainly on fish caught close to the bottom. The double crested's diet consists of fish such as Capelin, American Sand Lance, gunnels, Atlantic Herring and sculpins, as well as crustaceans, molluscs and marine worms.

Source: Environment Canada, 2001.

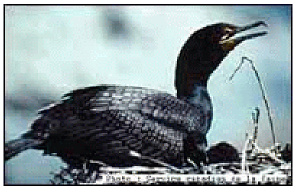


Photo source: Environment Canada, 2001.

species may be vulnerable to the secondary effects of CWIS since the planktonic life stages of their prey may be impacted and the local adult communities eventually affected. However, they are probably less vulnerable than the piscivorous birds listed in Tables A4-1 and A4-2 since, unlike fish, it is less likely that most adult invertebrates, which are typically bottom-dwelling, will be directly affected by intake structures.

While at their breeding, migration, or wintering sites, the birds listed could be close to one or more existing or planned CWIS, and could be affected by the operation of these facilities. CWIS have the potential to adversely affect these bird populations indirectly by reducing their available food supply (eggs, larvae, juveniles and/or adult fish and invertebrates) through impingement and entrainment (I&E).

Table A4-1: North American Birds that Eat Fish as a Major Dietary Component

Major Dietary Component	
Species	**Distribution**[a]
Red-throated loon	summer: lakes in arctic Canada and Alaska; winter: Atlantic and Pacific coasts south to California and Georgia
Pacific loon	summer: lakes in arctic Canada and Alaska; winter: Pacific coast south to California
Arctic loon	summer: lakes in Alaska; winter: Pacific coast south to California
Common loon	summer: lakes in Canada and northern U.S.; winter: Atlantic and Pacific coasts south to Texas and California
Horned grebe	summer: freshwater wetlands in Canada and north-western U.S.; winter: Atlantic and Pacific coasts south to Texas and California
Pied-billed grebe	resident in freshwater wetlands throughout U.S.
Red-necked grebe	summer: freshwater wetlands in Canada and northern Great Lakes; winter: Atlantic and Pacific coasts south to California and Georgia
Clark's grebe	summer: freshwater wetlands in western U.S.; winter: Pacific coast
Western grebe	summer: freshwater wetlands in Canada and western U.S.; winter: Pacific coast
American white pelican	summer: lakes in Canada and western U.S.; winter: California and Gulf of Mexico coasts
Brown pelican	resident: Pacific and Atlantic coasts from Washington and New York south to California and Gulf of Mexico
Anhinga	resident: Atlantic coastal wetlands from South Carolina south to southern Texas
Neotropic cormorant	resident: coastal wetlands in Texas
Great cormorant	summer: maritime east Canada; winter: Atlantic coast south to South Carolina
Double-crested cormorant	summer: lakes in Great Lakes, west U.S. and north-east U.S.; winter: entire Pacific and Atlantic coasts
Brandt's cormorant	resident: Pacific coast from Canada to California
Pelagic cormorant	summer: Alaskan coast; winter: Pacific coast from southern Alaska to California
Least bittern	summer: freshwater wetlands from east coast of U.S. to midwest States; winter: Gulf coast and south Florida
American bittern	summer: freshwater wetlands throughout Canada and U.S.; winter: wetlands on both coasts south to California and Texas
Green heron	summer: freshwater wetlands from Atlantic coast to midwest States and Oregon and Washington; winter: California, gulf of Mexico and Florida coastal wetlands
Tricolored heron	resident: Atlantic coastal wetlands from New York south to Florida and Gulf of Mexico
Little blue heron	summer: freshwater wetlands in Gulf of Mexico States; resident: coasts of Gulf Coast and Florida north to New York
Reddish egret	resident: coastal wetlands in Florida and Gulf Coast
Snowy egret	summer: freshwater wetlands in western States; winter: California coast; resident: coastal wetlands from Massachusetts south to Gulf Coast States
Great egret	summer: freshwater wetlands in Mississippi Valley States; resident: Atlantic coastal States from Mid-Atlantic south to Gulf of Mexico; winter: California coast
Great blue heron	summer: freshwater wetlands in northern U.S. States and Canada; winter and resident: wetlands in inland southern States and both coasts of Canada and U.S. south to California and Gulf of Mexico

Table A4-1: North American Birds that Eat Fish as a Major Dietary Component

Major Dietary Component	
Species	**Distribution**[a]
Wood stork	resident: coastal wetlands in Florida and Gulf of Mexico
Roseate spoonbill	summer and resident: coastal wetlands in Florida and Gulf of Mexico
Common merganser	summer: lakes in Canada and north-west U.S.; winter: lakes and rivers in interior and coastal U.S. south to California and North Carolina
Red-breasted merganser	summer: lakes in Canada; winter: Atlantic and Pacific coasts from Canada south to California and Gulf of Mexico
Hooded merganser	summer: lakes and rivers in Canada and Great Lakes States; winter: Pacific coast from Canada south to California and from New York south to Gulf of Mexico. Also winters in interior States of south-east U.S.
Osprey	summer: inland and coastal wetlands from Canada south to Great Lakes, Pacific Northwest, and Florida and Gulf of Mexico; resident: Florida and Gulf Coast States
Bald eagle	summer: lakes and rivers in Canada, Great Lakes, north-eastern U.S., Pacific Northwest, and some western States; winter: Midwestern and western States and both coasts south to Mexican border
Sandwich tern	Atlantic coastal areas from Mid-Atlantic States south to Gulf of Mexico
Elegant tern	summer: Southern California coast
Royal tern	summer and resident: Atlantic coasts from Mid-Atlantic States south to Gulf of Mexico; winter: southern California coast
Caspian tern	summer: Canadian wetlands, Great Lakes, and some western States; winter: Florida and Gulf of Mexico coasts, southern California coast
Roseate tern	summer: coasts of Newfoundland south to New York
Forster's tern	summer: inland wetlands in central Canada and western States of U.S. Also summers on coastal marshes in Gulf of Mexico; winter: southern California and south Atlantic coasts south to Florida and Gulf of Mexico
Common tern	summer: inland lakes of Canada and northern U.S. States and coastal Atlantic from Newfoundland south to North Carolina
Arctic tern	summer: tundra in Arctic Canada and arctic coasts south to Newfoundland and Maine
Least tern	summer: Atlantic and California coastal dunes south to Florida and Gulf of Mexico. Also rivers in Mississippi Valley
Black skimmer	summer: inland and coastal wetlands in southern California; resident and winter: Atlantic coast from New York south to Florida and Gulf of Mexico
Common murre	winter: Atlantic and Pacific coasts south to New York and California
Razorbill	winter: Atlantic coast south to Mid-Atlantic States
Black guillemot	resident: Atlantic coast from arctic south to New England
Pigeon guillemot	resident: Pacific coast from Arctic south to California
Marbled murrelet	resident and winter: Pacific coast south to California
Rhinoceros auklet	resident and winter: Pacific coast south to California
Atlantic puffin	resident and winter: Atlantic coasts from Newfoundland south to New England
Horned puffin	resident and winter: Pacific coasts from Alaska south to Washington
Tufted puffin	resident and winter: Pacific coasts from Alaska south to California
Belted kingfisher	summer: lakes and rivers throughout Canada; resident and winter: lakes and rivers throughout U.S.

Note: Excluded are species that are rare or have highly restricted distributions, that feed mainly offshore, or that eat fish only very rarely.

[a] These distributions are approximate. For more detailed representations see, for example, Kaufman, 1996.

Source: Kaufman, 1996.

Table A4-2: North American Birds that eat Fish as a Frequent Dietary Component

	Frequent Dietary Component
Species	**Distribution**[a]
Clapper rail	resident: Atlantic coastal marshes from New England south. Also San Francisco Bay
King rail	summer: inland marshes from Atlantic coast to midwest; resident and winter: Coastal marshes from Mid-Atlantic States south to Florida and Gulf of Mexico
Whooping crane	winter: Texas coast
Heerman's gull	all year: Oregon and California coasts
Laughing gull	resident: Atlantic coasts from New England south to Gulf of Mexico
Franklin's gull	summer: prairie wetlands in central Canada and northern U.S.
Bonaparte's gull	summer: forested wetlands across Canada; winter: Atlantic and Pacific coasts from Canada south to California and Gulf of Mexico
Ring-billed gull	summer: lakes in central Canada, Great Lakes and Maritime Provinces; winter: Atlantic coast from New England south to Mexico, Pacific coast from Canada south to Baja, and interior southern States of U.S.
Mew gull	summer: freshwater wetlands in western Canada; winter: Pacific coast from Canada south to California
California gull	summer: lakes in central Canada and western U.S.; winter: Pacific coast from Washington south to California
Herring gull	summer: inland and coastal lakes across Canada; winter: Pacific and Atlantic coasts from Canada south to Mexican border
Glaucous gull	summer: arctic; winter: Atlantic and Pacific coasts south to Mid-Atlantic States and California
Iceland gull	summer: arctic; winter: Atlantic coast from Canada south to New York
Thayer's gull	summer: arctic; winter: Pacific coast from Alaska south to California
Western gull	resident: Pacific coast from Canada south to Baja
Glaucous-winged gull	resident: Pacific coast of Canada; winter: Pacific coast of U.S.
Great black-backed gull	resident and summer: Maritime provinces south to Mid-Atlantic States
Black tern	summer: prairie and forested wetlands across Canada and in Midwestern and western States of U.S.
Ancient murrelet	summer: Alaska winter: Pacific coast from Alaska south to California
American dipper	resident: rivers throughout western States of U.S.

Table A4-3: North American Birds that Eat Mainly Aquatic Invertebrates

Species	Distribution[a]	Species	Distribution[a]
Eared grebe	summer: freshwater wetlands in western Canada and U.S.; winter: Pacific coast from Vancouver south to southern California	Piping plover	summer: coast, lake and river beaches in northern Midwest and New England; winter: Atlantic coastal beaches from New England south to Mexico
Black-crowned night-heron	summer: inland and coastal wetlands in southern Canada and across whole of U.S.; winter and resident: coast of Florida and Gulf of Mexico	American oystercatcher	resident: Atlantic coastal beaches from New England south to Texas
Yellow-crowned night-heron	resident and summer: visitor to interior and coastal wetlands in south-eastern States of U.S.	Black oystercatcher	resident: Pacific coastal beaches from Canada south to California
White ibis	resident: south east Atlantic coast from South Carolina to Texas	Black-necked stilt	summer: alkaline marshes in western States; winter: California, Florida and Gulf of Mexico coasts
Glossy ibis	resident and winter: coastal marshes on Atlantic coast from New England south to Texas	Greater yellowlegs	summer: northern Canada; winter: Atlantic coast from New York south to Mexico
White-faced ibis	summer: lakes in some western States of U.S.; winter: Gulf of Mexico and coastal and interior California	Lesser yellowlegs	summer: northern Canada; winter: Atlantic coast from New York south to Mexico
Roseate spoonbill	resident: Florida and Gulf Coast coastal wetlands	Willet	summer: wetlands in some western States and saltmarshes on Atlantic coast from New England south to Mexico; winter: Atlantic coast from New England south to Mexico and California coast
Greater scaup	winter: throughout Atlantic and Pacific coasts of U.S.	Spotted sandpiper	summer: inland wetlands throughout Canada and mid and northern U.S. States; winter: Florida and Gulf of Mexico coasts
Lesser scaup	summer: prairie wetlands in western States; winter: wetlands in southern States and Pacific and Atlantic coasts from Canada south to Mexico	Long-billed curlew	winter: Texas and California coasts
Common eider	winter: New England coast	Marbled godwit	summer: wetlands in northern prairies; winter: Atlantic and Pacific coasts from Delaware to Texas and California
King eider	winter: New England coast	Ruddy turnstone	winter: Atlantic coast south of New England
Harlequin duck	summer: rivers in western Canada and Pacific Northwest; winter: Atlantic and Pacific coasts as far south as California and New England	Surfbird	winter: Pacific coast from Canada to California
Oldsquaw	summer: arctic; winter: Pacific and Atlantic coasts south to California and Texas	Red knot	winter: Florida coast
Black scoter	winter: Pacific and Atlantic coasts south to California and Texas	Sanderling	winter: Atlantic and Pacific coasts from New York south to Texas and Vancouver to Baja
Surf scoter	summer: northern Canada; winter: Pacific and Atlantic coasts south to California and Texas	Western sandpiper	winter: Atlantic and Pacific coasts from New York south to Texas and Vancouver to Baja
White-winged scoter	summer: northern Canada; winter: Pacific and Atlantic coasts south to California and Texas	Least sandpiper	winter: Atlantic and Pacific coasts from New York south to Texas and Vancouver to Baja
Common goldeneye	winter: freshwater and coastal wetlands throughout U.S.	Purple sandpiper	winter: Atlantic coast from Canada south to Mid-Atlantic States
Barrow’s goldeneye	summer: rivers in northern Rocky Mountain States; winter: Rocky Mountain States	Rock sandpiper	winter: Pacific coast from Canada south to California
Bufflehead	summer: Canadian wetlands; winter: freshwater and coastal wetlands throughout U.S.	Dunlin	winter: Atlantic coast from New York to Texas and San Francisco Bay

Table A4-3: North American Birds that Eat Mainly Aquatic Invertebrates

Species	Distribution[a]	Species	Distribution[a]
Limpkin	resident: Florida wetlands	Dowitcher species	winter: Atlantic and Pacific coasts from Northern U.S. south to Baja and Mexico
Black-bellied plover	winter: Pacific and Atlantic coasts south to Mexico		
Snowy plover	summer: alkali lakes in western U.S.; resident: coastal wetlands in California and Gulf Coast		
Wilson's plover	resident: Atlantic coast wetlands from New York south to Gulf Coast		
	summer: arctic; winter: Pacific and Atlantic coast wetlands from Canada south to California and Mexico		

[a] These distributions are approximate. For more detailed representations see, for example, Kaufman, 1996.

Generally, the larger the bird, the larger its prey. Ospreys or bald eagles may take fish that weigh a few pounds. However, many North American fish- and invertebrate-eating birds typically exploit smaller prey species or the younger age groups of larger fish. For example, common terns breeding in Massachusetts feed their young the age groups of species such as sandeels or silversides that are typically less than 6 inches long (Galbraith et al., 1999). CWIS could potentially reduce the availability of the birds' fish or invertebrate prey either directly, by reducing the densities of the larval and older organisms that the birds exploit (through I&E), or indirectly, by reducing the numbers of eggs or larvae to the extent that the density of the older age groups that larger birds rely on is reduced locally. Also, fewer larger fish or adult invertebrates (i.e., the breeding stock) could affect the availability of small prey in the next generation. These cause-effect interactions are displayed in Figure A4-1.

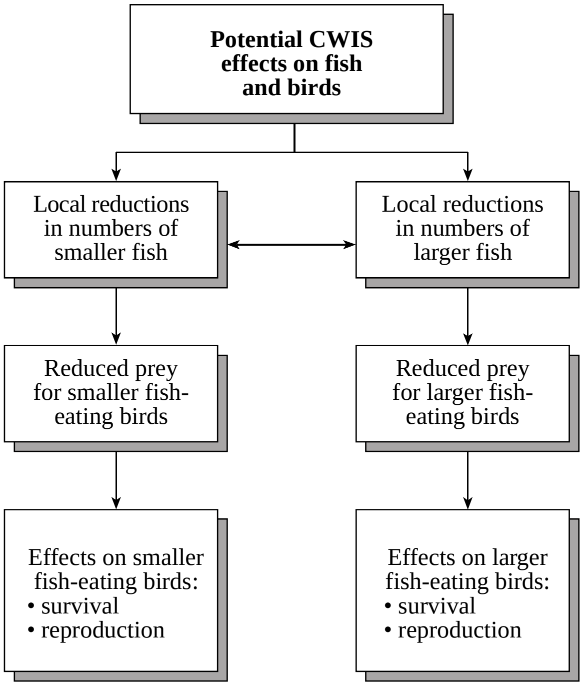


Figure A4-1: Potential CWIS Effects on Fish-Eating Birds and Their Prey

A4-3 UNDERSTANDING THE EFFECTS OF FOOD REDUCTION ON BIRD POPULATIONS

Many scientific studies have confirmed the link between the abundance of available food and the viability of bird populations. EPA reviewed recent papers published in the peer-reviewed literature that describe effects of food shortages on fish-eating birds. One of the goals of these studies was to identify linkages between food shortages and adverse impacts on birds, irrespective of the underlying cause of the shortage.[1] While EPA's review of these studies did not reveal any documented linkages between I&E and effects on bird populations, the principle remains the same: independent of the stressor, a reduction in the food supply can adversely affect bird populations. Table A4-4 summarizes a sample of the reviewed studies, and Boxes A4-1 and A4-2 describe the findings of two studies in greater detail. Several broad conclusions can be drawn from this body of literature:

- Chicks of fish-eating birds can starve and quickly die (in a few days) if food is scarce or unavailable during a short window of natal development.
- The amount of food that is available before and during the birds' breeding seasons can affect courtship and initiation of breeding, number of eggs laid, chick survival, frequency of renesting, and other important reproductive factors.
- Insufficient amounts of food may force parents to forage farther and wider, resulting in fewer and smaller feeds per chick per day. This may increase the risk of starvation.
- Food shortages can result in increased food theft, as chicks and adults steal food from each other.
- Food shortages during the breeding season usually affect chicks and fledglings before the adults.
- Inadequate nutrition during development can have significant physiological consequences (e.g., calcium deficiencies and poor skeletal development).
- Super-abundant food can lead to increased breeding success.

Table A4-4: Examples of Studies Showing Relationships between Quantity and Quality of Fish Prey and Survival, Behavior, and Reproductive Success of Fish-Eating Birds

Country	Waterbody	Target Species	Study Description	Summary	Reference
USA	Laboratory	Belted kingfisher	Effect of food supply on reproduction	Extra food resulted in earlier nesting, heavier chicks, and greater frequency of second clutches	Kelly and Van Horne, 1997
USA	Reservoir	Double-crested cormorant	Identification of factors associated with densities of cormorants	Fish availability correlated with cormorant density	Simmonds et al., 1997
Spain	Ebro Delta	Audouin's gull	Availability of trawler discards and kleptoparasitism	Reduced discards led to increased rates of kleptoparasitism	Oro, 1996
The Netherlands	Inland waters	Black tern	Impacts of acidification on fish stocks and chick growth and survival	Reduced fish stocks led to calcium deficiencies and increased mortality	Beintema, 1997
Northern Ireland	Lough Neagh	Great cormorant	Identification of factors associated with densities of cormorants	Fish availability correlated with cormorant density	Warke et al., 1994
France	Rhone Delta	Little egret	Food abundance and reproductive success	Increased food led to increased reproductive success and fledgling survival	Hafner et al., 1993

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[1] Causes of food shortages included spawning failure in fish, shifting weather patterns, effects of pollutants, and other factors.

Table A4-4: Examples of Studies Showing Relationships between Quantity and Quality of Fish Prey and Survival, Behavior, and Reproductive Success of Fish-Eating Birds

Country	Waterbody	Target Species	Study Description	Summary	Reference
Norway/Russia	Barents Sea	Kittiwakes, murres, puffins	Fish availability and reproduction of birds	Reductions in fish stocks impaired breeding success	Barrett and Krasnov, 1996
USA	Pacific Ocean	Kittiwakes, gulls, and puffins	Diets and breeding success	Diet switching led to reduced breeding success	Baird, 1990
Germany	North Sea	Common tern	Food supply and kleptoparasitism	Reduced food supply caused increased kleptoparasitism	Ludwigs, 1998
Germany	North Sea	Common tern	Food supply and chick survival	Reduced food caused increased chick mortality	Becker et al., 1997
South Africa	Indian Ocean	African penguin, Cape gannet, Cape cormorant, swift tern	Prey availability and breeding success	Reductions in anchovy stocks resulted in reduced breeding success	Crawford and Dyer, 1995
UK	Atlantic Ocean	Arctic tern	Fish abundance and breeding success	Reduced fish stocks lowered egg volume, clutch size, and breeding success	Suddaby and Ratcliffe, 1997

Box A4-1: Fish Availability Affects Breeding Success in Arctic Terns.

The arctic tern is a small, circumpolar, fish-eating bird that typically obtains its prey in the inshore marine environment. Unlike the closely related common tern, arctic terns do not generally breed or feed in freshwaters.

In the United Kingdom, the Shetland Islands are one of the strongholds of the species. Large breeding colonies of thousands of pairs of birds can be found there. Such large breeding colonies require an abundant and predictable food supply. In the Shetlands the most important food species is the sandeel, which occurs in vast shoals in the inshore waters. Before the 1980's, sandeels were largely ignored by the UK fishing industry. However, beginning in the late 1970's, they became an increasingly sought after catch as their value as fodder for farm animals was recognized. This led to a huge sandeel fishing industry that, since it was largely unregulated, resulted in the 1980s in massive depletion of the fish stocks. This study by Monaghan et al. (1989) investigated the effects of this stock depletion on the breeding biology of arctic terns in the Shetlands (where the sandeels were overfished) and at Coquet Island in England (where food supplies were not reduced).

Of the interesting differences found in the breeding biology of the terns from the two colonies, many could be ascribed to the reduction in prey availability at the Shetland colony. The Shetland birds delivered smaller sandeels to their nests than did the Coquet birds, indicating that the fishing industry had removed the larger (and more nutrient- and energy-rich) fish. Also, because of this, the chicks in the Shetland colony grew at a slower rate than the Coquet chicks and the majority of the chicks in the colony died a few days after hatching. The Coquet chicks had more rapid growth rates and far better survival.

The adult birds were also affected by the reduced sandeel stocks. During the breeding season, the adults in the Shetland colony lost weight and became lighter than the adults at Coquet, suggesting a food shortage effect.

This study clearly demonstrates the importance of having an adequate and predictable fish food supply for arctic terns during the breeding season and on their ability to raise chicks.

Box A4-2: Oceanic Currents, Human Fisheries, Anchovy Abundance, and the Abundance of Peruvian and Chilean Seabird Populations.

Several fish-eating seabirds breed in extremely large colonies on islands off the coasts of Peru and Chile. The breeding populations of these cormorants and boobies probably number several million in a typical year. These huge populations are made possible by an extremely rich supply of anchovies, which, in turn, depend on upwelling associated with the Humboldt current bringing nutrient-rich cold water to the surface close to the nesting islands (Harrison, 1983). In typical years, these birds can easily raise their young by exploiting the rich fish prey base.

However, every 10 or so years an El Niño event forces the upwelling south and deprives the seabirds of their anchovy prey. In these years, the birds may have reduced reproductive success or may fail to breed at all. Further, the birds may desert their normal ranges and spread north and south along the Pacific coast into areas where they are not normally seen (Murphy, 1952).

In the last few decades a new factor has complicated this pattern. The human anchovy fishery has now reduced the numbers of fish to the extent that even in good years the numbers of breeding birds and their success may be reduced.

The sensitivity of these seabirds to temporal and spatial disturbances in the dependability of their food supply highlights the critical relationship between the availability of fish prey and their population status.

This information shows that the responses of fish-eating birds to food shortages can range from behavioral changes (e.g., greater foraging efforts or increased food theft) to more dramatic responses (e.g., clutch abandonment, chick mortality, failure to attempt to breed). It is not likely that I&E by CWIS has resulted in such large-scale die-offs and reproductive failures. Such obvious responses would have been observed and reported. CWIS I&E effects are, therefore, likely to be more subtle. However, even these types of responses could have longer-term population impacts.

The studies reported in Table A4-4 show that chicks in particular are prone to rapid starvation and increased mortality during early development. During that period, sufficient amounts of high quality food (i.e., nutritionally and energetically rich) must be available to ensure successful fledging. The potential effects of I&E could be magnified if the depletion of a localized high quality fish resource forces parents to switch to a lower quality food or to forage further afield, resulting in a decrease in the rate of food delivery to the chicks and an increased starvation risk. Alternatively, I&E effects on local food supplies could affect bird populations when they are under stress from some other factor (e.g., severe weather or contaminants). Thus, the potential effects of I&E on bird populations, though perhaps subtle, cannot be discounted.

Even when enough food is available to allow a "normal" reproductive event, any additional food can increase the survival rate of nestlings and increase overall breeding success (Hafner et al., 1993; Suddaby and Ratcliffe, 1997). This at least partly rebuts the commonly used argument that surplus fish production has no ecological value and can therefore be removed without affecting the local ecosystem. It also suggests that even though the I&E of large numbers of fish might not actually adversely affect birds, the removal of that extra food resource could just as easily prevent them from realizing their full reproductive potential.

Even if a bird species can switch to another food source, significant effects are still possible if the replacement food has lower caloric or nutritional quality (Beintema, 1997). Recently hatched chicks can be particularly vulnerable to changes in food availability, starving and dying in a short time. Such risks may be of particular concern if the CWIS removes large numbers of fish or other aquatic prey in bird foraging areas during the breeding season.

In conclusion, this review of the ornithological literature underscores the link between adequate food supplies and survival and reproductive success in fish-eating birds. In particular, the low degree of behavioral flexibility combined with severe food shortages can result in reduced survival or increased reproductive failure. As the data shown in Table A4-4 suggest, localized food shortages caused by I&E are likely to affect bird populations differently depending on their dietary requirements. Species that can readily switch to an alternative prey may be less vulnerable, and those others that are entirely dependent on fish stocks may be more vulnerable. This leads to two conclusions: 1) any impacts associated with the removal of prey fish by I&E are likely to be species-specific, and 2) birds entirely dependent on fish (e.g., ospreys or loons) have a greater risk of being adversely affected compared to species with more flexible dietary requirements.

Chapter A5: Methods Used to Evaluate I&E

INTRODUCTION

This chapter describes the methods used by EPA to evaluate facility impingement and entrainment (I&E) data. Section A5-1 discusses the main objectives of EPA's I&E evaluation. Section A5-2 describes EPA's general approach to modeling fishery yield, the primary focus of its analysis, and the rationale for this approach. Section A5-3 describes the source data for EPA's I&E evaluations. Section A5-4 presents details of the biological models used to evaluate I&E. Finally, section A5-5 discusses methods used to extrapolate I&E rates from facilities evaluated to other facilities in the same region.

CHAPTER CONTENTS

A5-1 OBJECTIVES OF EPA'S EVALUATION OF I&E DATA

EPA's evaluation of I&E data had four main objectives:

- to develop a national estimate of the magnitude of I&E,
- to standardize I&E rates using common biological metrics so that rates could be compared across species, years, facilities, and geographical regions,
- to estimate changes in these metrics as a result of projected reductions in I&E under the Phase II rule, and
- to estimate the national economic benefits of reduced I&E.

Three loss metrics were derived to standardize I&E loss rates of all life stages: (1) foregone age-1 equivalents, (2) foregone fishery yield, and (3) foregone biomass production. The methods used to calculate these metrics are described in section A5-4. Age-1 equivalent estimates were used to quantify losses of individuals in terms of a single life stage. Losses of commercial and recreational species were expressed as foregone fishery yield. Estimates of production foregone were used to quantify the contribution of forage species to the yield of harvested species. The following section discusses EPA's rationale for evaluating the impingement and entrainment of harvested species in terms of foregone yield.

A5-2 RATIONALE FOR EPA'S APPROACH TO EVALUATING I&E OF HARVESTED SPECIES

Harvested species were the main focus of EPA's analysis, primarily because of the availability of economic methods for valuing these species (see Chapters A9 through A14 for a discussion of all of the economic methods used by EPA to estimate benefits of the Phase II rule). EPA's approach to estimating changes in harvest assumed that I&E losses result in a reduction in the number of harvestable adults in years after the time that individual fish are killed by I&E and that future reductions in I&E will lead to future increases in fish harvest. The approach does not require knowledge of population size or the total yield of the fishery; it only estimates the incremental yield that is foregone because of the number of deaths due to I&E.

As discussed in detail in section A5-4.2, EPA's yield analysis employed a specific application of the Thompson Bell model of fisheries yield (Ricker, 1975) to assess the effects of I&E on net fish harvest. This model is a relatively simple yield-per-recruit (YPR) model that provides estimates of yield (a.k.a. "harvest" or "landed fish") that can be expected from a cohort of fish that is recruited to a fishery. The model requires estimates of size-at-age for particular species and stage-specific schedules of natural mortality (M) and fishing mortality (F). All of the key parameters used in the yield model, F, M, and size-at-age, were assumed to be constant for a given species regardless of changes in I&E rates. Because these parameters are held static for any particular fish stock, YPR is also a constant value. With this set of parameters fixed, the Thompson Bell model holds that an estimate of recruitment is directly proportional to an estimate of yield.

EPA recognizes that the assumption that the key parameters are static is an important one that is not met in reality. However, by focusing on a simple interpretation of each individual I&E death in terms of foregone yield, EPA concentrated on the simplest, most direct assessment of the potential economic value of eliminating that death. EPA believes that this approach was warranted given the (1) scope and objectives of its analysis of harvested species, (2) data available, and (3) difficulties in distinguishing the causes of population changes. Each of these factors is discussed in the following sections.

A5-2.1 Scope and Objectives of EPA's Analysis of Harvested Species

The simplicity of EPA's approach to modeling yield was consistent with the need to examine the dozens of harvested species that are vulnerable to I&E throughout the country (see Table A5-1) and the overall objective of developing regional- and national-scale estimates. This approach is not necessarily the best alternative for studies of single facilities for which site-specific details on local fish stocks and waterbody conditions might make possible the use of more complex assessment approaches, including some form of population model.

Table A5-1: Number of Facilities In Scope of Phase II, Facilities Evaluated, and Species with I&E Data in Each Region

Region	# Facilities In Scope	# Facilities Evaluated	# Species with I&E Data
California	20	18	305
North Atlantic	22	4	128
Mid-Atlantic	44	6	63
South Atlantic	16	0	N/A[a]
Gulf of Mexico	24	4	160
Great Lakes	56	3	84
Inland	358	11	106

[a] I&E estimates for this region were extrapolated from rates for Mid-Atlantic and Gulf of Mexico.

A5-2.2 Data Availability and Uncertainties

Although EPA's approach to modeling yield requires estimates of a large number of stage-specific growth and mortality parameters, the use of more complex fish population models would rely on an even larger set of significant data uncertainties and would require numerous additional and stronger assumptions about the nature of stock dynamics that would be difficult to defend with available data. Additional data uncertainties of population dynamics models include the relationship between stock size and recruitment, and how growth and mortality rates may change as a function of stock size and other factors. Obtaining this information for even one fish stock is time-consuming and resource intensive; obtaining this information for the many species subject to impingement and entrainment nation-wide was not possible for EPA's national benefits analysis.

It is also important to note that information on stock status is generally only available for harvested species, which represent less than 2% of I&E losses. Even for harvested species, stock status is often poorly known. For example, only 20 of a total of 92 distinct species that are impinged and entrained by northern California facilities are harvested species with fishery management plans, and the stock status for all but one of these is unknown or undefined (Leet et al., 2001). While the number of species with known status is better in some regions than others, a similar problem exists in all of the regions included in EPA's benefits analysis. In fact, only 23% of U.S. managed fish stocks have been fully assessed (U.S. Ocean Commission, 2002).

In addition to a lack of data, there are numerous issues and difficulties with defining the size and spatial extent of fish stocks. As a result, it is often unclear how I&E losses at particular cooling water intake structures can be related to specific stocks. For example, a recent study of Atlantic menhaden (*Brevoortia tryannus*), one of the major fish species subject to impingement and entrainment along the Atlantic Coast of the U.S., indicated that juveniles in Delaware Bay result from both local and long distance recruitment (Light and Able, 2003). Thus, accounting only for influences on local recruitment would be insufficient for understanding the relationship between recruitment and menhaden stock size.

Another difficulty is that fisheries managers typically define fish stocks by reference to the geographic scope of the fishery responsible for landings. However, landings data are reported state by state, which is generally not a good way to delineate the true spatial extent of fish populations.

A5-2.3 Difficulties Distinguishing Causes of Population Changes

Another difficulty in developing more complex models of harvested species is that it is fundamentally difficult to demonstrate that any particular kind of stress causes a reduction in fish population size. All fish populations are under a variety of stresses that are difficult to quantify and that may interact. Fish populations are perpetually in flux for numerous reasons, so determining a baseline population size, then detecting a trend, and then determining if a trend is a significant deviation from an existing baseline or is simply an expected fluctuation around a stable equilibrium is problematic. Fish recruitment is a multidimensional process, and identifying and distinguishing the causes of variance in fish recruitment remains a fundamental problem in fisheries science, stock management, and impact assessment (Hilborn and Walters, 1992; Quinn and Deriso, 1999; Boreman, 2000). This issue was beyond the scope and objectives of EPA’s section 316(b) benefits analysis.

A5-3 SOURCE DATA

A5-3.1 Facility I&E Monitoring Data

The inputs for EPA’s analyses included the empirical I&E monitoring expressed as counts reported by facilities and species life history characteristics such as growth rates, natural mortality rates, and fishing mortality rates. The general approach to I&E monitoring was similar at most facilities, but investigators used a wide variety of methods that were specific to the individual studies, e.g., location of sampling stations, sampling gear, sampling frequency, and enumeration techniques.

Impingement monitoring typically involves sampling impingement screens or catchment areas, counting the impinged fish, and extrapolating the count to an annual basis. Entrainment monitoring typically involves intercepting a small portion of the intake flow at a selected location in the facility, collecting fish by sieving the water sample through nets or other collection devices, counting the collected fish, and extrapolating the counts to an annual basis.

To the extent possible, EPA considered and evaluated facility-specific monitoring and reporting procedures, as described in EPA’s individual regional reports (see Parts B-H of this Regional Study Assessment). EPA used life stage-specific annual losses for assessment of entrainment losses. However, in most cases, the size or life stage of impinged fish were not reported. The EPA modeling procedure requires the age (or life stage) of the killed fish. Therefore, the age of impinged fish was assumed to range from the juvenile stage to age 5, so the total impingement losses as reported were divided into age groups using proportions corresponding to the expected life table dictated by species-specific mortality schedules.

EPA adjusted annualized loss rates at some facilities as needed to reflect the history of technological changes at the facility. The purpose of the adjustments was to interpret loss records in a way that best reflects the current conditions at each facility. So, for example, if a facility was known to have installed a protective technology subsequent to the time that I&E loss rates were recorded, EPA reduced the loss rates in an amount corresponding to the presumed effectiveness of the protective technology.

Loss rates recorded at each facility were expressed as an annual average rate, regardless of the number of years of sampling data available. All information regarding species, life stage, and loss modality (I or E) was retained just as they were originally reported, with the exception of some species aggregation that is described below. The annual total among the facilities evaluated was then the subject of the detailed modeling procedure described in section A5-4. Once this analysis was completed, estimates of total losses, by region, were generated using the extrapolation procedures described in section A5-5.

A5-3.2 Species Groups Evaluated

To evaluate I&E, EPA organized species into groups and then conducted detailed analyses of I&E rates for each species group. Species groups were based on similarities in life history characteristics and the groupings used by the National Marine

Fisheries Service (NMFS) for landings data. An appendix to each regional report in Parts B-H of this document provides details on the species groups and life history data that were used.

A5-3.3 Species Life History Parameters

The life history parameters used in EPA's analysis of I&E data included species growth rates, the fraction of each age class vulnerable to harvest, fishing mortality rates, and natural (nonfishing) mortality rates. Each of these parameters was also stage-specific. For the purpose of this assessment, EPA uses the terms "age" and "stage" interchangeably. For fish age 1 and older, a stage corresponds directly to the age of the fish. For fish younger than age one, a stage corresponds to specific early life developmental stages. Early developmental stages may occur at different ages, and may have different durations for different species. All of the modeling procedures and parameterization are expressed on a stage-wise basis.

EPA obtained life history parameters from facility reports, the fisheries literature, local fisheries experts, and publicly available fisheries databases (e.g., FishBase). To the extent feasible, EPA identified region-specific life history parameters, and all I&E losses within a region were modeled with a single set of parameters. Detailed citations are provided in the life history appendix accompanying each regional report (Parts B-H of the Regional Study Document).

For most species in most regions a reasonable set of life history parameter values was identified. However, in a few cases where no information on survival rates was available for individual life stages, EPA deduced survival rates for an equilibrium population based on records of lifetime fecundity using the relationship presented in C.P. Goodyear (1978) and below in Equation (1):

$$S_{eq} = 2/fa \qquad \text{(Equation 1)}$$

where:

S_{eq} = the probability of survival from egg to the expected age of spawning females
fa = the expected lifetime total egg production

Published fishing mortality rates (F) were assumed to reflect combined mortality due to both commercial and recreational fishing. Basic fishery science relationships (Ricker, 1975) among mortality and survival rates were assumed, such as:

$$Z = M + F \qquad \text{(Equation 2)}$$

where:

Z = the total instantaneous mortality rate
M = natural (nonfishing) instantaneous mortality rate
F = fishing instantaneous mortality rate

and

$$S = e^{(-Z)} \qquad \text{(Equation 3)}$$

where:

S = the survival rate as a fraction

A5-4 Methods for Evaluating I&E

The methods used to express I&E losses in units suitable for economic valuation are outlined in Figure A5-1 and described in detail

A5-4.1 Modeling Age 1 Equivalents

The Equivalent Adult Model (EAM) is a method for expressing I&E losses as an equivalent number of individuals at some other life stage, referred to as the age of equivalency (Horst 1975a; C.P. Goodyear, 1978; Dixon, 1999). The age of equivalency can be any life stage of interest. The method provides a convenient means of converting losses of fish eggs and larvae into units of individual fish and provides a standard metric for comparing losses among species, years, and regions. For the section 316(b) regional case studies, EPA expressed I&E losses at all life stages as an equivalent number of age 1 individuals.

The EAM calculation requires life-stage-specific impingement and entrainment counts and life-stage-specific mortality rates from the life stage of impingement or entrainment to the life stage of equivalence. The cumulative survival rate from age at impingement or entrainment until age 1 is the product of all stage-specific survival rates to age 1. For impinged fish that are older than age 1, age 1 equivalents are calculated by modifying the basic calculation to inflate the loss rates in inverse proportion to survival rates. In the case of entrainment, the basic calculation is:

$$S_{j,1} = S_j^* \prod_{i=j+1}^{j_{\max}} S_i \qquad \text{(Equation 4)}$$

where:

$S_{j,1}$ = cumulative survival from stage j until age 1
S_i = survival fraction from stage i to stage $i + 1$
S^*_j = $2S_j e^{-\log(1+S_j)}$ = adjusted S_j
$j_{\max}$ = the stage immediately prior to age 1

Equation 4 defines $S_{j,1}$, which is the expected cumulative survival rate (as a fraction) from the stage at which entrainment occurs, *j*, through age 1. The components of Equation 4 represent survival rates during the different life stages between life stage *j*, when a fish is entrained, and age 1. Survival through the stage at which entrainment occurs, *j*, is treated as a special case because the amount of time spent in that stage before entrainment is unknown and therefore the known stage specific survival rate, S_j, does not apply because S_j describes the survival rate through the entire length of time that a fish is in stage *j*. Therefore, to find the expected survival rate from the day that a fish was entrained until the time that it would have passed into the subsequent stage, an adjustment to S_j is required. The adjusted rate S^*_j describes the effective survival rate for the group of fish entrained at stage *j*, considering the fact that the individual fish were entrained at various specific ages within stage *j*.

Age-1 equivalents are then calculated as:

$$AE1_{j,k} = L_{j,k}\, S_{j,1} \qquad \text{(Equation 5)}$$

where:

$AE1_{j,k}$ = the number of age-1 equivalents killed during life stage *j* in year *k*
$L_{j,k}$ = the number of individuals killed during life stage *j* in year *k*
$S_{j,1}$ = the cumulative survival rate for individuals passing from life stage *j* to age 1 (equation 4)

The total number of age-1 equivalents derived from losses at all stages in year *k* is then given by:

(Equation 6)

$$AE1_k = \sum_{j=j_{\min}}^{j_{\max}} AE1_{j,k}$$

where:

$AE1_k$ = the total number of age-1 equivalents derived from losses at all stages in year *k*

A5-4.2 Modeling Foregone Fishery Yield

Foregone fishery yield is a measure of the amount of fish or shellfish (in pounds) that is not harvested because the fish are lost to I&E. EPA estimated foregone yield using the Thompson-Bell equilibrium yield model (Ricker, 1975). The model provides a simple method for evaluating a cohort of fish that enters a fishery in terms of their fate as harvested or not-harvested individuals. EPA's application of the Thompson-Bell model assumes that I&E losses result in a reduction in the number of harvestable adults in years after the time that individual fish are killed by I&E and that future reductions in I&E will lead to future increases in fish harvest.

The Thompson-Bell model is based on the same general principles that are used to estimate the expected yield in any harvested fish population (Hilborn and Walters, 1992; Quinn and Deriso, 1999). The general procedure involves multiplying age-specific harvest rates by age-specific weights to calculate an age-specific expected yield (in pounds). The lifetime expected yield for a cohort of fish is then the sum of all age-specific expected yields, thus:

(Equation 7)

$$Y_k = \sum_j \sum_a L_{jk} S_{ja} W_a (F_a / Z_a)\left(1 - e^{-Z_a}\right)$$

where:

Y_k = foregone yield (pounds) due to I&E losses in year *k*
L_{jk} = losses of individual fish of stage *j* in the year *k*
S_{ja} = cumulative survival fraction from stage *j* to age *a*
W_a = average weight (pounds) of fish at age *a*
F_a = instantaneous annual fishing mortality rate for fish of age *a*
Z_a = instantaneous annual total mortality rate for fish of age *a*

The model assumes that:

- the yield from a cohort of fish is proportional to the number recruited,
- annual growth, natural mortality, and fishing mortality rates are known and constant, and
- natural mortality includes mortality due to I&E

The assumption that fishing mortality, F, remains constant despite possible reductions in I&E is central to the modeling approach used to estimate changes in fishery yield. This assumption implies that fishing activity and fishing regulations will adapt to increases in fish stock in a manner that leads to harvest increases in direct proportion to the magnitude of increases in harvestable stock.

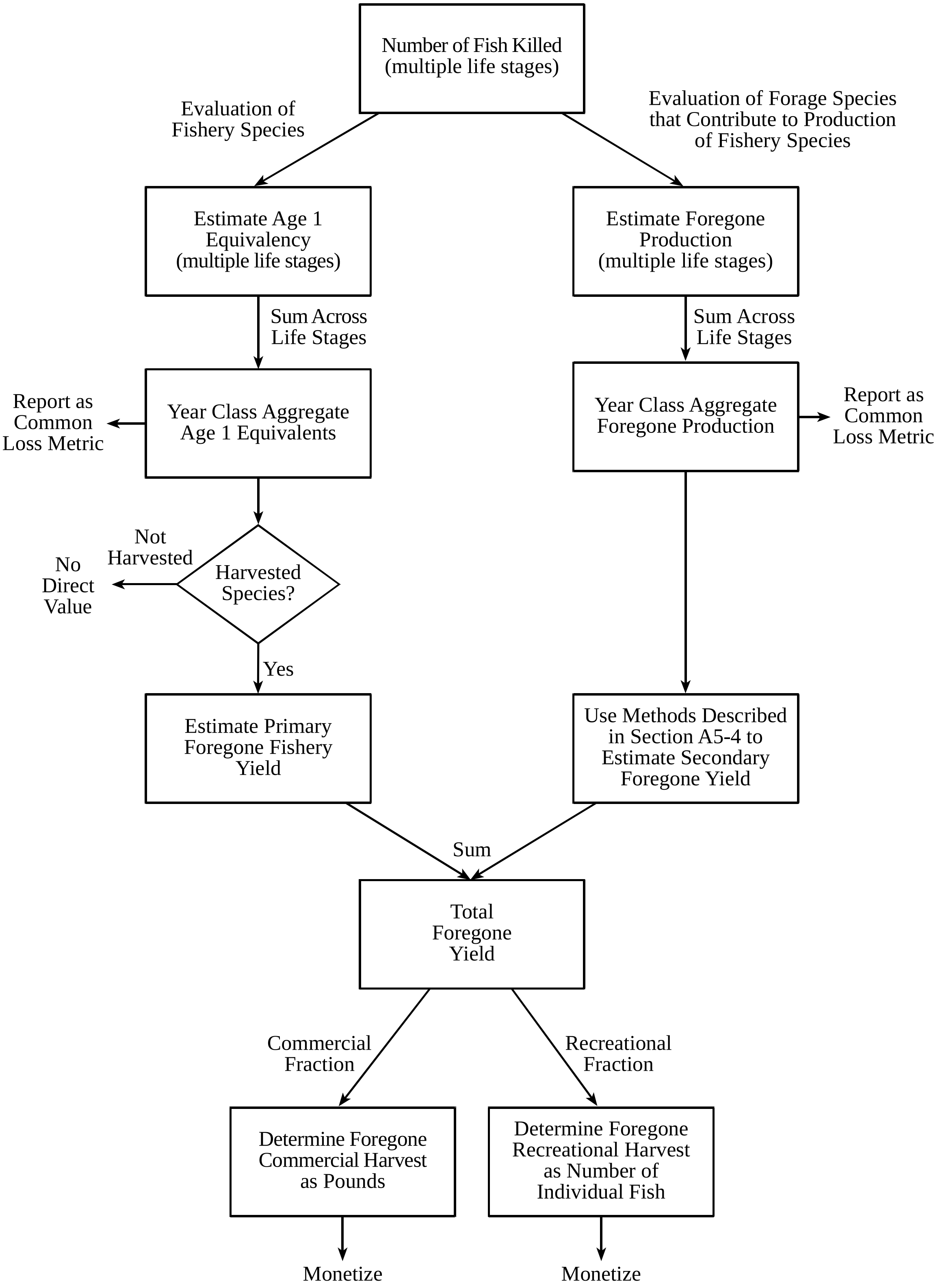
The assumption that M and F are constant is based on EPA’s assumption that:

- I&E losses are a relatively minor source of mortality in comparison to the total effects of all other sources of natural mortality (e.g., predation); and
- the scale of changes in I&E loss rates being considered will not lead to dramatically large increases in the size of harvestable stocks.

EPA acknowledges that in some cases the importance of I&E as a source of mortality in a fishery might be large enough that it would be unlikely that natural and fishing mortality would remain constant, but such cases are not expected to be the norm.

As indicated in Figure A5-1, EPA partitioned its estimates of total foregone yield for each species into two classes, foregone recreational yield and foregone commercial yield, based on the relative proportions of recreational and commercial state-wide aggregate catch rates of that species in that region. Pounds of foregone yield to the recreational fishery were re-expressed as numbers of individual fish based on the expected weight of an individual harvestable fish. Chapter A9 describes the methods used to derive dollar values for foregone commercial and recreational yields for the regional benefits analyses.

Figure A5-1: General Approach Used to Evaluate I&E Losses as Foregone Fishery Yield



A5-4.3 Modeling Production Foregone

In addition to expressing I&E losses as lost age 1 equivalents (and subsequent lost yield, for harvested species), I&E losses were also expressed as foregone production. Foregone production is the expected total amount of future growth (expressed as pounds) of individuals that were impinged or entrained, had they not been impinged or entrained.

Production foregone is calculated by simultaneously considering the stage-specific growth increments and survival probabilities of individuals lost to I&E, where production includes the biomass accumulated by individuals alive at the end of a time interval as well as the biomass of those individuals that died before the end of the time interval. Thus, the production foregone for a specified stage, *i*, is calculated as:

$$P_i = \frac{G_i N_i W_i (e^{(G_i - Z_i)} - 1)}{G_i - Z_i} \qquad \text{(Equation 8)}$$

where:

P_i = expected production (pounds) for an individual during stage *i*
G_i = the instantaneous growth rate for individuals of stage *i*
N_i = the number of individuals of stage *i* lost to I&E (expressed as equivalent losses at subsequent stages)
W_i = average weight (in pounds) for individuals of stage *i*
Z_i = the instantaneous total mortality rate for individuals of stage *i*

P_j, the production foregone for all fish lost at stage *j*, is calculated as:

$$P_j = \sum_{i=j}^{t_{\max}} P_{ji} \qquad \text{(Equation 9)}$$

where:

P_j = the production foregone for all fish lost at stage *j*
$t_{\max}$ = oldest stage considered

P_T, the total production foregone for fish lost at all stages *j*, is calculated as:

$$P_T = \sum_{j=t_{\min}}^{t_{\max}} P_j \qquad \text{(Equation 10)}$$

where:

P_T = the total production foregone for fish lost at all stages *j*
$t_{\min}$ = youngest stage considered

A5-4.4 Evaluation of Forage Species Losses

Foregone production of forage species due to I&E losses may be considered a reduction in the aquatic food supply, and therefore a cause of reduced production of other species, including harvested species, at higher trophic levels. I&E losses of forage species have both immediate and future impacts because not only is existing biomass removed from the ecosystem, but also the biomass that would have been produced in the future is no longer available as food for predators (Rago, 1984; Summers, 1989). The Production Foregone Model accounts for these consequences of I&E losses by considering losses of both existing biomass and the biomass that would have been transferred to other trophic levels but for the removal of organisms by I&E (Rago, 1984; Dixon, 1999). Consideration of the future impacts of current losses is particularly important for fish, since there can be a substantial time between loss and replacement, depending on factors such as spawning frequency and growth rates (Rago, 1984).

To evaluate I&E losses of forage species (i.e., species that are not targets of recreational or commercial fisheries) EPA translated foregone production among forage species into foregone production among harvested species that are impinged and entrained using a trophic transfer ratio, and then translated foregone production among these harvested species to foregone yield. These estimates of the foregone yield of impinged and entrained harvested species were distinct from the primary foregone yield of these species and are termed “secondary yield”. This procedure is illustrated in detail in Equation 11, Equation 12, and schematically in Figure A5-2.

The basic assumption behind EPA’s approach to evaluating losses of forage species is that a decrease in the production of forage species can be related to a decrease in the production of impinged and entrained harvested (predator) species based on an estimate of trophic transfer efficiency. Thus, in general,

$$P_h = k\,P_f \qquad \text{(Equation 11)}$$

where:

P_h = foregone biomass production of a harvested species h (in pounds)
k = the trophic transfer efficiency
P_f = foregone biomass production of a forage species f (in pounds)

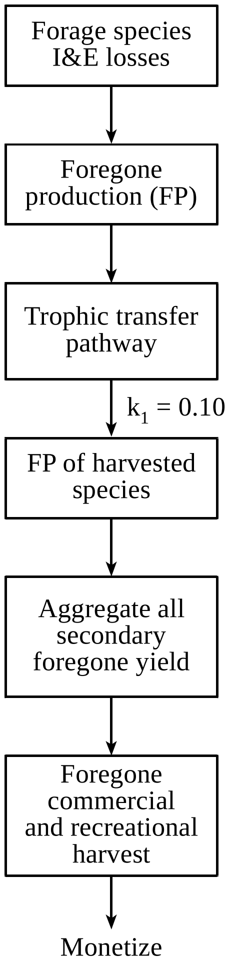
Equation 11 is applicable to trophic transfer on a species-to-species basis where one species is strictly prey and the other species is strictly a predator. For the section 316(b) regional studies, commercially or recreationally valuable fish were considered predators. The aggregate total secondary yield is estimated on a regional basis under the assumption that the trophic value of total foregone production among forage species is allocated equally among all harvested species that occur in the I&E losses, thus:

$$Y_{\sec} = \sum_{\substack{h \in all \\ harvested \\ species}} \left(\frac{k}{H} \sum_{\substack{f \in all \\ forage \\ species}} P_f \right) \left(Y_h \big/ P_h \right) \qquad \text{(Equation 12)}$$

where:

$Y_{\sec}$ = total secondary yield (as a generic predator species)
H = number of harvested species among regional loss estimates
Y_h = primary estimate of foregone yield for harvested species h
P_h = estimate of foregone production for harvested species h

Figure A5-2: Trophic Transfer Model for Valuation of Foregone Biomass Production (FP) of Forage Species by Estimating Consequential Reductions in Commercial and Recreational Harvest



It is difficult to determine, on a community basis, an appropriate value of *k* that relates aggregate forage production and aggregate predator production, since the actual trophic pathways are complicated. For the purposes of the regional case studies, EPA used the value of *k* = 0.10 (Pauly and Christensen, 1995).

A5-5 Extrapolation of I&E Rates

I&E data are not available for all facilities in scope of the Phase II rule. Therefore, EPA examined I&E losses, and the economic benefits of reducing these losses, at the regional level. The estimated benefits were then aggregated across all regions to yield a national benefit estimate. Extrapolation was necessary because not all in scope facilities within a given region have conducted I&E studies.

To obtain regional impingement and entrainment estimates, EPA extrapolated losses observed at the 46 facilities evaluated (facilities with suitable records of impingement and entrainment rates) to other in-scope facilities within the same region. EPA defined seven regions for its regional analysis based on similarities among the affected aquatic species and characteristics of commercial and recreational fishing activities in the area. The extrapolation was done separately for each region (North Atlantic, Mid-Atlantic, South Atlantic, Gulf of Mexico, Northern California, Southern California, Great Lakes and Inland). These regions and the water body types within each region are described in the Introduction to this Regional Analysis Document. Maps showing the facilities in each region that are in scope of the Phase II rule are provided in the introductory chapter of each regional report (Parts B-H of this document).

Impingement and entrainment data were extrapolated on the basis of operational flow, in millions of gallons per day (MGD), where MGD is the average operational flow over the period 1996-1998 as reported by facilities in response to EPA's section 316(b) Detailed Questionnaire and Short Technical Questionnaire. Operational flow at each facility was rescaled using factors reflecting the relative effectiveness of currently in-place technologies for reducing impingement and entrainment. Thus,

$$F_{f,e} = G_f\,(1-T_{f,e}) \qquad \text{(Equation 13)}$$

where:

$F_{f,e}$ = effective relative flow rate for entrainment at facility *f*
G_f = mean operational flow at facility *f* (10^6 gallons/day)
$T_{f,e}$ = fractional effectiveness of entrainment-reducing technology at facility *f* ($0<T_{f,e}<1$)

$$F_{f,i} = G_f\,(1-T_{f,i}) \qquad \text{(Equation 14)}$$

where:

$F_{f,i}$ = effective relative flow rate for impingement at facility *f*
G_f = mean operational flow at facility *f* (10^6 gallons/day)
$T_{f,i}$ = fractional effectiveness of impingement-reducing technology at facility *f* ($0<T_{f,i}<1$)

$$S_{r,e} = \sum_{\substack{f\,\in \text{All facilities} \\ \text{in region r}}} F_{f,e} \Bigg/ \sum_{\substack{f\,\in \text{All model facilities} \\ \text{in region r}}} F_{f,e} \qquad \text{(Equation 15)}$$

where:

$F_{f,e}$ = effective relative flow rate for entrainment at facility *f*
$S_{r,e}$ = scaling factor to relate total entrainment losses among model facilities to regional total entrainment losses

$$S_{r,i} = \sum_{\substack{f\,\in \text{All facilities} \\ \text{in region r}}} F_{f,i} \Bigg/ \sum_{\substack{f\,\in \text{All model facilities} \\ \text{in region r}}} F_{f,i} \qquad \text{(Equation 16)}$$

where:

$F_{f,i}$ = effective relative flow rate for impingement at facility *f*
$S_{r,i}$ = scaling factor to relate total impingement losses among model facilities to regional total impingement losses

$$L_{r,e} = S_{r,e} \sum_{\substack{f \in \text{All model facilities} \\ \text{in region r}}} L_{f,e}$$ (Equation 17)

where:

$S_{r,e}$ = scaling factor to relate total entrainment losses among model facilities to regional total entrainment losses
$L_{r,e}$ = estimated annual total entrainment losses at region *r*
$L_{f,e}$ = estimated annual total entrainment losses at facility *f*

$$L_{r,i} = S_{r,i} \sum_{\substack{f \in \text{All model facilities} \\ \text{in region r}}} L_{f,i}$$ (Equation 18)

where:

$S_{r,i}$ = scaling factor to relate total impingement losses among model facilities to regional total impingement losses
$L_{r,i}$ = estimated annual total impingement losses at region *r*
$L_{f,i}$ = estimated annual total impingement losses at facility *f*

The values of the regional scaling factors $S_{r,e}$ ranged from 1.0 to 11.7, and $S_{r,i}$ ranged from 1.0 to 12.1 (Table A5-2). The unweighted average values of $S_{r,e}$ and $S_{r,i}$ were 4.42 and 5.56, respectively, indicating that loss estimates derived from empirical records at the model facilities comprise roughly 23% and 18% of the estimates of national total entrainment and impingement, respectively.

Table A5-2: Regional Scaling Factors $S_{r,e}$ and $S_{r,i}$ Used to Extrapolate Total Annual I&E Losses Among Model Facilities to Total Annual I&E Losses Among All In-Scope Facilities Within Each Region

Region	S_{re}	S_{ri}
Inland	11.74	9.69
Mid Atlantic	5.14	12.11
North Atlantic	3.21	5.15
Northern California	1.00	1.00
Southern California	1.20	1.26
Great Lakes	5.15	4.44
Gulf of Mexico	3.52	5.25

There may be substantial among-facility variation in the actual I&E losses per MGD that results from a variety of facility-specific features, such as location and type of intake structures, as well as from ecological features that affect the abundance or species composition of fish in the vicinity of each facility. The accuracy of the extrapolation procedure relies heavily on the assumption that I&E rates recorded at model facilities are representative of I&E rates at other facilities in the region. Although this assumption may be violated in some cases, limiting the extrapolation procedure to particular regions reduces the likelihood that the model facilities are unrepresentative.

EPA believes that this method of extrapolation makes best use of a limited amount of empirical data, and is the only currently feasible approach for developing an estimate of national I&E and the benefits of reducing I&E. While acknowledging that an extrapolation necessarily introduces uncertainty into I&E estimates, EPA has not identified information that suggests that application of the procedure causes a systematic bias in the regional loss estimates (see Chapter A6 for additional discussion of uncertainty and bias).

The assumption that I&E is proportional to flow is consistent with other predictive I&E studies. For example, a key assumption of the Spawning and Nursery Area of Consequence (SNAC) model (Polgar, 1979) is that entrainment is proportional to cooling water withdrawal rates. The SNAC model has been used as a screening tool for assessing potential I&E impacts at Chesapeake Bay plants. As a first approximation, percent entrainment has been predicted on the basis of the ratio of cooling water flow to source water flow (Goodyear, 1978). A study of power plants on the Great Lakes (Kelso and Melburn 1979) demonstrated an increasing relationship (on a log-log scale) between plant "size" (electric production in MWe) and impingement and entrainment. There is scatter in these relationships, not just because there is variation in the cooling water intake for different plants having similar electric production, but also because of the imprecision (sampling variability) inherent in the usual methods of estimating impingement and entrainment. These relationships are nonetheless strong. EPA’s 1976 “Development Document for the Best Technology Available for the Location, Design, Construction and Capacity of Cooling Water Intake Structures for Minimizing Adverse Environmental Impact” concluded that “reduction of cooling water intake volume (capacity) should, in most cases, reduce the number of organisms that are subject to entrainment in direct proportion to the fractional flow reduction.”

Chapter A6: Uncertainty

INTRODUCTION

This chapter discusses sources of uncertainty in EPA's impingement and entrainment (I&E) analyses, and presents the preliminary results of an uncertainty analysis of the yield model used by EPA to estimate the benefits of reducing I&E of commercial and recreational fishery species. Section A6-1 discusses major uncertainties in EPA's I&E assessments, Section A6-2 briefly describes Monte Carlo analysis as a tool for quantifying uncertainty, Section A6-3 provides preliminary results of an uncertainty analysis by EPA of winter flounder yield estimates, and Section A6-4 discusses results of the uncertainty analysis.

CHAPTER CONTENTS

A6-1 TYPES OF UNCERTAINTY

Despite following sound scientific practice throughout, it was impossible to avoid numerous sources of uncertainty that may cause EPA's I&E estimates in the regional analysis to be imprecise or to carry potential statistical bias. Uncertainty of this nature is not unique to EPA's I&E analysis.

Uncertainty may be classified into two general types (Finkel, 1990). One type, referred to as structural uncertainty, reflects the limits of the conceptual formulation of a model and relationships among model parameters. The other general type is parameter uncertainty, which flows from uncertainty about any of the specific numeric values of model parameters. The following discussion considers these two types of uncertainty in relation to EPA's I&E analysis.

A6-1.1 Structural Uncertainty

The models used by EPA to evaluate I&E simplify a very complex process. The degree of simplification is substantial but necessary because of the limited availability of empirical data. Table A6-1 provides examples of some potentially important considerations that are not captured by the models used. EPA believes that these structural uncertainties will generally lead to inaccuracies, rather than imprecision, in the final results.

Table A6-1: Uncertainties Associated with Model Structure

Type	General Treatment in Model	Specific Treatment in Model
Generally simple structure	Species lost to I&E treated independently	Fish species grouped into two categories: harvested or not harvested (forage for harvested species)
Biological submodels	No dynamic elements	Life history parameters constant (i.e., growth and survival did not vary through time); growth and survival rates did not change in response to possible compensatory effects
Economic submodels	No dynamic elements	Ratio of direct to indirect benefits was static through time; market values of harvested species were inelastic (i.e., were fixed and thus not responsive to market changes that may occur due to increased supply when yield is higher)
	Fish stock	Landings of commercial and recreational fish associated with I&E losses assumed to be within the State where facility is located
	Angler experience	I&E losses at a facility assumed to be relevant to angler experience (or perception) and Random Utility Model (RUM) models of sport fishery economics.

A6-1.2 Parameter Uncertainty

Uncertainty about the numeric values of model parameters arises for two general reasons. The first source of parameter uncertainty is imperfect precision and accuracy of impingement and entrainment data reported by facilities and growth and mortality rates obtained from the scientific literature. This results from unavoidable sampling and measurement errors. The second major source of parameter uncertainty is the applicability of parameter estimates obtained from I&E or life history studies conducted at other locations or under different conditions.

Table A6-2 presents some examples of parameter uncertainty. In all of these cases, increasing uncertainty about specific parameters implies increasing uncertainty about EPA's point estimates of I&E losses. The point estimates are biased only insofar as the input parameters are biased in aggregate (i.e., inaccuracies in multiple parameter values that are above the "actual" values but below the "actual" values in other cases may tend to counteract). In this context, EPA believes that parameter uncertainty will generally lead to imprecision, rather than inaccuracies, in the final results.

Table A6-2: Parameters Included in EPA's I&E Analysis that Are Subject to Uncertainty

Type	Factors	Examples of Uncertainties in Model
I&E monitoring /loss rate estimates	Sampling regimes	Sampling regimes subject to numerous plant-specific details; no established guidelines or performance standards for how to design and conduct sampling regimes
	Extrapolation assumptions	Extrapolation of monitoring data to annual I&E rates requires numerous assumptions regarding diurnal/seasonal/annual cycles in fish presence and vulnerability and various technical factors (e.g., net collection efficiency; hydrological factors affecting I&E rates); no established guidelines or consistency in sampling regimes
	Species selection	Criteria for selection of species to evaluate not well-defined or uniform across facilities
	Sensitivity of fish to I&E	Through-plant entrainment mortality assumed by EPA to be 100 percent; some back-calculations required in cases where facilities had reported entrainment rates that assumed <100 percent mortality. Impingement survival included if presented in facility documents.
Biological/life history	Natural mortality rates	Natural mortality rates (M) difficult to estimate; model results highly sensitive to M
	Growth rates	Simple exponential growth rates or simple size-at-age parameters used
	Geographic considerations	Migration patterns; I&E occurring during spawning runs or larval out-migration; location of harvestable adults; intermingling with other stocks
	Forage valuation	Harvested species assumed to be food limited; trophic transfer efficiency to harvested species estimated by EPA based on general models; no consideration of trophic transfer to species not impinged and entrained.
Stock characteristics	Fishery yield	For harvest species, used only one species-specific value for fishing mortality rate (F) for all stages subject to harvest; used stage-specific constants for fraction vulnerable to fishery
	Harvest behavior	No assumed dynamics among harvesters to alter fishing rates or preferences in response to changes in stock size; recreational access assumed constant (no changes in angler preferences or effort)
	Stock interactions	I&E losses assumed to be part of reported fishery yield rates on a statewide basis; no consideration of possible substock harvest rates or interactions
	Compensatory growth	None
	Compensatory mortality	None
Ecological system	Fish community	Long-term trends in fish community composition or abundance not considered (general food webs assumed to be static); used constant value for trophic transfer efficiency; specific trophic interactions not considered. Trophic transfer to organisms not impinged and entrained is not considered.
	Spawning dynamics	Sampled years assumed to be typical with respect to choice of spawning areas and timing of migrations that could affect vulnerability to I&E (e.g., presence of larvae in vicinity of intake structure)
	Hydrology	Sampled years assumed to be typical with respect to flow regimes and tidal cycles that could affect vulnerability to I&E (e.g., presence of larvae in vicinity of CWIS)
	Meteorology	Sampled years assumed to be typical with respect to vulnerability to I&E (e.g., presence of larvae in vicinity of intake structure)

A6-1.3 Uncertainties Related to Engineering

EPA's evaluation of I&E was also affected by uncertainty about the engineering and operating characteristics of the study facilities. It is unlikely that plant operating characteristics (e.g., seasonal, diurnal, or intermittent changes in intake water flow rates) were constant throughout any particular year, which therefore introduces the possibility of bias in the loss rates reported by the facilities. EPA assumed that the facilities' loss estimates were provided in good faith and did not include any intentional biases, omissions, or other kinds of misrepresentations.

A6-2 Monte Carlo Analysis as a Tool for Quantifying Uncertainty

Stochastic simulation is among a class of statistical procedures commonly known as Monte Carlo modeling methods. Monte Carlo methods allow investigators to quantify uncertainty in model results based on knowledge or assumptions about the amount of uncertainty in each of the various input parameters. The Monte Carlo approach also allows investigators to conduct sensitivity analyses to elucidate the relative contribution of the uncertainty in each input parameter to overall uncertainty. Monte Carlo methods are particularly useful for assessing models where analytic (i.e., purely mathematical) methods are cumbersome or otherwise unsuitable. A thorough introduction to the statistical reasoning that underlies Monte Carlo methods, and their application in risk assessment frameworks, is provided in an EPA document "Guiding Principles for Monte Carlo Analysis" (U.S. EPA, 1997).

The characteristic feature of Monte Carlo methods is the generation of artificial variance through the use of pseudorandom numbers. The solution to the model of interest is recalculated many times, each time adding perturbations to the values of the model parameters. The types of perturbations are selected to reflect the actual uncertainty in knowledge of those parameters. Recalculations are conducted thousands of times, and the variation in the resulting solution is assessed and interpreted as an indicator of the aggregate uncertainty in the basic result.

A6-3 EPA's Uncertainty Analysis of Yield Estimates

A6-3.1 Overview of Analysis

As described in detail in Chapter A5 of this report, EPA estimated foregone yield using the Thompson-Bell equilibrium yield model (Ricker, 1975). The Thompson-Bell model is based on the same general principles that are used to estimate the expected yield in any harvested fish population (Hilborn and Walters, 1992; Quinn and Deriso, 1999). The general procedure involves multiplying age-specific weights by age-specific harvest rates to calculate an age-specific expected yield (in pounds). The lifetime expected yield for a cohort of fish is then the sum of all age-specific expected yields.

(Equation 1)

$$Y_k = \sum_j \sum_a L_{jk} S_{ja} W_a (F_a / Z_a)\left(1 - e^{-Z_a}\right)$$

where:

Y_k = foregone yield (pounds) due to I&E losses in year k
L_{jk} = losses of individual fish of stage j in the year k
S_{ja} = cumulative survival fraction from stage j to age a
W_a = average weight (pounds) of fish at age a
F_a = instantaneous annual fishing mortality rate for fish of age a
Z_a = instantaneous annual total mortality rate for fish of age a

Quantifying the variance in yield estimates resulting from uncertainty in the numeric values of L, S, W, F, and Z assists in the interpretation of results, gives a sense of the precision in yield estimates, provides insight into the sensitivity of predictions to particular parameter values, and indicates the contribution of particular parameters to overall uncertainty.

EPA evaluated uncertainty in yield estimates for winter flounder using I&E data for a facility located on a North Atlantic estuary. The I&E loss records and winter flounder life history parameters that were used are provided in the Phase II proposal docket as DCN # 4-2037.

EPA developed a custom program written in the S language to conduct the Monte Carlo analysis. Wherever possible, the simulation tool re-used the same code that was used to calculate yield for the original assessment. Graphical displays were used to confirm the behavior of random number generation and to examine results.

Selection of input distributions for parameters of interest are a key element of any Monte Carlo analysis. In the winter flounder test case, the input distributions were uniform distributions with a range defined as the initial, best estimate of the parameter +/- 15%. A uniform distribution was selected because of its simplicity and the 15% range was selected because this magnitude of variance is considered plausible.

EPA investigated sensitivity of the model to variations in parameters by grouping the parameters into five classes:

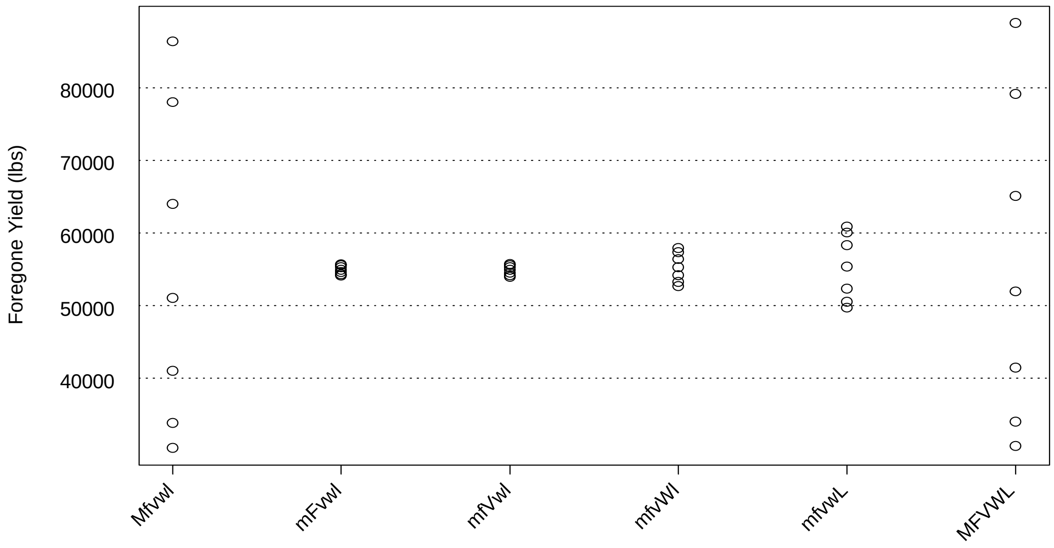
- natural mortality (M) at all life stages,
- fishing mortality (F) at all life stages,
- fraction vulnerable to fishing (V) at all life stages (i.e., age of recruitment to the fishery),
- weight at age (W), and
- the reported I&E loss rates (L).

The analysis consisted of repeating runs (n=10,000 in each run) of the model wherein each of the groups of parameters was either held constant at their best estimates or were varied stochastically according to the defined input distributions. The relative importance of these groups of parameters was assessed by comparing the relative amount of variation between each set of runs. Model sensitivity to individual parameters has not been examined.

A6-3.2 Preliminary Results

For entrainment losses, the analysis indicated that the yield model is most sensitive to uncertainty in natural mortality rates, followed by uncertainty in the I&E loss rates themselves (Figure A6-1). Age specific weights were the third most important group, followed by fishing mortality and age at recruitment, which were relatively insignificant sources of uncertainty.

Figure A6-1: Results of Preliminary Parameter Sensitivity Analysis of Estimates of Foregone Yield (pounds) of Winter Flounder Due to Entrainment by a Power Plant Located in a North Atlantic Estuary



Data points are plotted at the 5th percentile, 10th percentile, 25th percentile, median, 75th percentile, 90th percentile, and 95th percentile of 10,000 independent estimates of foregone yield within each parameter set. Groups are distinguished by uppercase letters designating which types of parameters were treated stochastically in the simulation and lowercase letters for types of parameters fixed at their best estimates. M = natural mortality rates; F = fishing mortality rates; V = age of recruitment to the fishery; W = weight at age; L = entrainment loss rates.

A6-4 CONCLUSIONS

This chapter includes a general discussion of uncertainty and describes a general approach that was tested by EPA as a way to quantify uncertainty associated with the yield model described in Chapter A5. Preliminary results of the uncertainty analysis suggest that uncertainty about natural mortality rates is a significant contributor to aggregate uncertainty in yield estimates. Unfortunately, as noted in a review article by Vetter (1987), “True rates of natural mortality, and their variability, are poorly known for even the great stocks of commercial fish in temperate regions that have been subject to continuous exploitation for decades” (Vetter, 1987, p. 39). As a result, the uncertainty in mortality parameters cannot be overcome. As Vetter (1987) noted, this is a difficulty shared by all models of fish stock dynamics. Nonetheless, through consultation with local fish biologists as well as the scientific literature, EPA expended considerable effort to identify reasonable mortality rates and other life history information for use in its yield analyses. These parameter values and data sources are presented in Appendix 1 of each regional study (Parts B-H of this report).

Chapter A7: Entrainment Survival

INTRODUCTION

CHAPTER CONTENTS

To calculate benefits associated with entrainment reduction, EPA used the assumption that all organisms passing through a facility's cooling water system would experience 100 percent mortality. This assumption was recommended in EPA's 1977 Guidance for Evaluating the Adverse Environmental Impact of Cooling Water Intake Structures on the Aquatic Environment: Section 316(b) P.L. 92-500 (U.S. EPA, 1977). This is also the basic assumption currently used in the permitting programs for section 316(b) in Arizona, California, Hawaii, Louisiana, Maine, Maryland, Massachusetts, Minnesota, Nevada, New Hampshire, Ohio and Rhode Island (personal communication, I. Chen, U.S. EPA Region 6, 2002; personal communication, P. Colarusso, U.S. EPA Region 1, 2002; personal communication, G. Kimball, 2002; personal communication, M. McCullough, Ohio EPA, 2002; McLean and Dieter, 2002; personal communication, R. Stuber, U.S. EPA Region 9, 2002).

In comments on the Proposed Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities; Proposed Rule, a few stated that this assumption may be incorrect and cited studies in which entrainment survival has been demonstrated. These entrainment survival studies were conducted by facilities to demonstrate that some organisms may survive the passage through the cooling water intake structure, and thus the assumption of 100 percent mortality may not be justified at their site.

EPA obtained 37 entrainment survival studies conducted at 22 individual power producing facilities and conducted a detailed review. Twenty of these facilities are in-scope for the section 316(b) Phase II rule for existing facilities. These facilities represent 3.7 percent of all section 316(b) Phase II existing facilities. EPA also reviewed a report prepared for the Electric Power Research Institute (EPRI) (EA Engineering Science and Technology, 2000) which summarized the results of 36 entrainment studies, 31 of which were the same studies reviewed by EPA. The intent of EPA's review was to determine the soundness of the findings behind the entrainment survival studies and to evaluate whether the assumption of 100 percent entrainment mortality is appropriate for use in the national benefits assessment for the section 316(b) Phase II rule to compare to the costs of installing the best technology available for minimizing adverse environmental impact.

A7-1 THE CAUSES OF ENTRAINMENT MORTALITY

A7-1.1 Fragility of Entrained Organisms

Cooling water intake structures entrain many species of fish, shellfish, and macroinvertebrates. These species are most commonly entrained during their early life stages, as eggs, yolk-sac larvae (YSL), post yolk-sac larvae (PYSL), and juveniles, because of their small size and limited swimming ability. In addition to having limited or no mobility, these early life stages are very fragile and thus susceptible to injury and mortality from a wide range of factors (Marcy, 1975). For these reasons, entrained eggs and larvae experience high mortality rates as a result of entrainment. The three primary factors contributing to the mortality of organisms entrained in cooling water systems are thermal stress, mechanical stress, and chemical stress

(Marcy, 1975). The relative contribution of each of these factors to the rate of mortality of entrained organisms can vary among facilities, based on the nature of their design and operations as well as the sensitivity of the species entrained (Marcy, 1975; Beck and the Committee on Entrainment, 1978; Ulanowicz and Kinsman, 1978). These three primary factors are discussed in more detail below.

A7-1.2 Thermal Stress

Facilities use cooling water as a means of disposing of waste heat from facility operations. Thus, organisms present in the cooling water are exposed to rapid increases in temperatures above ambient conditions when passing through the cooling water system. This thermal shock causes mortality or sublethal effects that affect further growth and development of entrained eggs and larvae (Schubel *et al.*, 1978; Stauffer, 1980). The magnitude of thermal stress experienced by organisms passing through a facility's cooling system depends on facility-specific parameters such as intake temperature, maximum temperature, discharge temperature, duration of exposure to elevated temperatures through the facility and in the mixing zone of the discharge canal, the critical thermal maxima of the species, and delta T (ΔT, i.e., the difference between ambient water temperature and maximum water temperature within the cooling system) (Marcy, 1975; Schubel *et al.*, 1978). The extent of the effect of thermal stress can also vary among the species and life stages of entrained organisms (Schubel *et al.*, 1978; Stauffer, 1980).

A7-1.3 Mechanical Stress

Entrained organisms are also exposed to significant mechanical stress during passage through a cooling system, which also causes mortality. Types of mechanical stress include effects from turbulence, buffeting, velocity changes, pressure changes, and abrasion from contact with the interior surfaces of the cooling water intake structure (Marcy, 1973; Marcy *et al.*, 1978). The extent of the effect of mechanical stress depends on the design of the facility's cooling water intake structure and the capacity utilization of operation. Some studies have suggested that mechanical stress may be the dominant cause of entrainment mortality at many facilities (Marcy, 1973; Marcy *et al.*, 1978). For this reason, it has been suggested that the only effective method of minimizing adverse effects to entrained organisms is to reduce the intake of water (Marcy, 1975).

A7-1.4 Chemical Stress

Chemical biocides are occasionally used within cooling water intake structures to remove biofouling organisms. Chlorine is the active component of the most commonly used biocides (Morgan and Carpenter, 1978; Morgan, 1980). These biocides are used in concentrations sufficient to kill organisms fouling the cooling system structures, and thus cause mortality to the organisms entrained during biocide application. The extent of the effect of chemical stress depends on the concentration of biocide and the timing of its application. Eggs may be less susceptible to biocides than larvae (Lauer *et al.*, 1974; Morgan and Carpenter, 1978). Tolerance to biocides may also vary according to species. However, most species have been shown to be affected at low concentrations, < 0.5 ppm, of residual chlorine (Morgan and Carpenter, 1978).

A7-2 FACTORS AFFECTING THE DETERMINATION OF ENTRAINMENT SURVIVAL

There are many challenges that must be overcome in the design of a sampling program intended to accurately establish the magnitude of entrainment survival (Lauer *et al.*, 1974; Marcy, 1975; Coutant and Bevelhimer, 2001). Samples are almost certain not to be fully representative of the community of organisms experiencing entrainment. Some species are extremely fragile and disintegrate during collection or when preserved, and are thus not documented when samples are processed (Boreman and Goodyear, 1981). This is particularly true for the most fragile life stages, such as eggs and yolk-sac larvae of many species. All sampling devices are selective for a certain size range of organisms, so a number of sampling methods would have to be employed to accurately sample the broad size range of organisms subject to entrainment. The relative ability of different organisms to avoid sampling devices also determines abundance and species composition estimated from samples (Boreman and Goodyear, 1981). This avoidance ability varies with the size, motility, and condition of the organisms. If dead or dying organisms tend to settle out, then sampling will be selective for the live, healthy specimens (Marcy, 1975). If, on the other hand, the healthy, more motile specimens are able to avoid sampling gear, the sampling will tend to be selective for dead or stunned specimens. The patchy distribution of many species (Day *et al.*, 1989; Valiela, 1995) creates difficulties in developing precise estimates of organism densities (Boreman and Goodyear, 1981). The patchier the distribution, the greater the number of samples required to reduce the uncertainty associated with the density estimates to an acceptable level.

The factors just discussed affect the ability to accurately establish the type and abundance of organisms present at the intake and discharge of a cooling water system. A second suite of factors, superimposed on the first, affects the ability to estimate the percentages of those organisms that are alive and dead at those two locations. The greatest challenge to be overcome is posed by the fragility of the organisms being studied. The early life stages of most species are so fragile that they may experience substantial mortality simply due to being sampled, both from contact with the sampling gear and in being handled for subsequent evaluation. For example, Marcy (1973) reported on the effects of current velocity on percent mortality of ichthyoplankton taken in plankton nets, and found sampling mortality of 18 percent at velocities of 0.3 to 0.6 m/sec. The loss or damage of organisms beyond identification during plant passage causes overestimations of the true fraction of live organisms in the discharge samples, because the disintegrated organisms are extruded from the sampling device (Boreman and Goodyear, 1981).

The entrainment survival studies addressed in this review quantified survival by estimating the percentage of organisms categorized as alive, stunned, or dead present in samples collected at the intake and discharge locations of a facility. In the studies reviewed, a variety of methods were used to determine the physiological state of sampled organisms, ranging from placing the sampled organisms in various types of holding containers for observation to the use of devices specifically designed for assessment of larval survival, such as a larval table. A variety of criteria was also used in these studies to categorize the physiological status of the organisms, such as opacity as an indicator of a dead egg, and movement of a larva in response to being touched as an indicator of being alive or stunned. The lack of standardized procedures applied for assessing physiological condition in all of the studies reviewed made comparisons of the study findings difficult.

When quantifying entrainment survival, these studies used the estimates of the percentage dead from samples collected at the intake as controls to correct the samples at the discharge for mortality associated with natural causes and with sampling and handling stress. The use of intake samples as controls requires the assumption that sampling- and handling-induced mortality rates be the same at the intake and discharge, which, in turn, requires that sampling methods and conditions be nearly identical in both locations (Marcy, 1973). This requirement is difficult to meet at most facilities because of the differences in the physical structures and hydrodynamic conditions at intakes and discharges (e.g., frequently high velocity, turbulent flow at discharges versus lower velocity, laminar flows at intakes). In many cases, the location and design of the cooling water intake and discharge structures may preclude use of the same type of sampling gear in both locations. Another assumption implicit in this approach is that mortality due to entrainment is entirely independent of mortality due to sampling and handling and that there is no interaction between these stresses, an assumption that is acknowledged but never proven in the studies reviewed.

The percent alive in the intake control is frequently well below 100 percent because these fragile organisms experience substantial mortality from stresses caused by being collected. An additional factor contributing to the less than 100 percent alive in intake samples is that some dead organisms may be present in the water column being sampled because of natural mortality or recirculation of water discharged from the cooling system. In many studies, the survival in the intake sample is extremely low; for example, the intake survival for bay anchovy was 0 percent in studies conducted at Bowline (Ecological Analysts Inc., 1978a), Brayton Point (Lawler, Matusky & Skelly Engineers, 1999), and Indian Point (Ecological Analysts Inc., 1978c; EA Engineering Science and Technology, 1989). The studies reviewed corrected their discharge survival estimates to account for the control sample mortality by using the percent alive in the intake control samples in the following manner. First, the proportion initially alive at the intake (P_I) and discharge (P_D) samples was determined, for each species in most cases, using the following equation:

$$P_I \text{ or } P_D = \frac{\text{Number of alive and stunned organisms}}{\text{Total number of organisms collected}}$$

Using the intake proportion as the control, initial percent entrainment survival (S_I) was then calculated using the following equation:

$$S_I = \left[\frac{P_D}{P_I}\right] \times 100$$

When latent mortality was studied, a sample of the alive and stunned organisms from the initial entrainment survival determination was observed for a given period of time. The latent survival rate calculated is the proportion of those that remained alive after a given period of time from only those that survived initially and not the total number sampled. The latent percent survival (S_L) was determined using the following equation:

$$S_L = 100 \times \left[\frac{\dfrac{\text{\# of alive organisms after a given time from discharge samples}}{\text{\# of organisms initially sampled alive or stunned indischarge samples}}}{\dfrac{\text{\# of alive organisms after a given time from intake samples}}{\text{\# of organisms initially sampled alive or stunned in intake samples}}} \right]$$

Entrainment survival was then calculated by adjusting the initial entrainment survival with latent entrainment survival using the following equation:

$$\text{Entrainment Survival (\%)} = S_I \times S_L$$

A variation of this formula, specifically Abbott's formula, is used for acute toxicity testing in the Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms (U.S. EPA, 2002d; EPA-821-R-02-012) and in testing of pesticides and toxic substances in Product Performance Test Guidelines OPPTS 810.3500 Premises Treatments (U.S. EPA, 1998b; EPA-712-C-98-413), to adjust mortality for the possibility of natural deaths occurring during a test. This formula is intended to account for acceptable levels of unavoidable control mortality in the range of 5 to 10 percent (Newman, 1995). Abbott's formula is as follows:

$$\text{Corrected mortality} = 1 - \left[\frac{1 - \text{proportion dead in treatment}}{1 - \text{proportion dead in control}} \right]$$

This method of correcting for control mortality is often used in toxicological experiments in which organisms in concurrent control and experimental samples experience identical conditions except for the stressor that is the subject of study, and, as already noted, this method is applied when control mortalities, from stress due to holding or sampling and from natural causes, are generally low (less than 10 percent). In entrainment survival studies, sampling conditions at the intake and discharge are seldom identical. Also, the initial mortalities in the intake samples are often much higher than 5 or 10 percent and sometimes higher than the mortality in the discharge samples.

In addition, the assumption that mortality due to entrainment is entirely independent of mortality due to sampling and handling with no interaction between these stresses is not true. The dead organisms observed in the intake samples comprise organisms that died before sampling from natural conditions, organisms that died from the stress of sampling and sorting, and possibly organisms that died from previous passages through the cooling water system at facilities where water is recirculated. The dead organisms observed in the discharge samples comprise organisms that died before passage through the facility from natural conditions, organisms that died from the stresses associated with entrainment as described above, and organisms that died from the stress of sampling and sorting. The fundamental difference between the extent of the effect of sampling stress in the intake and the discharge samples is that the discharge samples are exposed to sampling stress after they have been exposed to entrainment stress. Thus the most vulnerable organisms have already died because of entrainment and would not be alive at the time of sampling to die from that stress. By correcting discharge samples for sampling and natural deaths using the intake results, the assumption is made that the mortality in the discharge sample is the result of the same probability of death due to sampling as in the intake sample and only the additional mortality is due to the stress of entrainment. When intake survival (P_I) is less than discharge survival (P_D), the use of the equation for entrainment survival (S_I) results in a calculation of 100 percent survival even though the majority of organisms may be dead in both samples (EA Engineering Science and Technology, 2000). However, in the intake sample, much of the mortality may be due to sampling stress, whereas in the discharge sample, much of the mortality may be due to entrainment stress. Additionally, the initial survival estimates may be overestimations of survival due to the disintegration of entrained organisms and their subsequent extrusion through the sampling gear (Boreman and Goodyear, 1981). For all of the reasons described above, the applicability of this equation for determining entrainment survival by correcting discharge survival with intake survival is questionable. Also, the statistical attributes of these calculated mortality proportions are often not addressed. The higher and more variable the intake sample mortality percentages, the greater the degree of uncertainty that would be expected to be associated with the resultant entrainment survival estimates.

An additional factor that was not accounted for in all the studies reviewed was the fate of organisms discharged into receiving waters after passage through the cooling system. Latent mortality studies were intended to document delayed mortality of organisms that were lethally injured or stressed during entrainment but were not killed immediately. Some studies (e.g., Lauer *et al*, 1974) also reported that some fish larvae surviving entrainment behaved normally when maintained in laboratory conditions for extended periods of time, eating and growing normally. However, larvae that did not experience immediate mortality from lethal stresses were discharged into receiving waters under conditions substantially altered from the normal environment in which they were present before entrainment and under conditions very dissimilar to those experienced under laboratory conditions. Any naturally occurring vertical positioning of the organisms within the water column would be disrupted (Day *et al.*, 1989), and the turbulence and velocities present in discharge locations would be unlike the environmental conditions they experienced before entrainment. Under such altered conditions, their normal ability to feed or escape predation is compromised. In addition, thermal shock can disrupt further development of eggs and larvae even if they survive entrainment (Schubel *et al.*, 1978). The potential for such phenomena to occur and the magnitude the effect may have on any possible survival of entrained organisms would be nearly impossible to confirm or refute through field studies. However, were these phenomena to occur, they would result in mortalities beyond and in addition to the initial and latent mortalities that were calculated in the studies reviewed.

The factors discussed above served as the basis for EPA's review of the entrainment survival studies. Table A7-1 presents summary information collected directly from each of the original studies reviewed.

Table A7-1: Summary of Entrainment Survival Study Results

Facility	Sampling Period	Number of Samples and Days	Species	Number Sampled at Intake	Number Sampled at Discharge	Survival Study	Initial Discharge Survival	Latent Discharge Survival	Study Survival Estimate
Anclote	September - November 1985	120 samples 8 days	Fish larvae	109	474	initial and 24 hour latent	8 - 47%	-	27 - 62%
			Amphipods	5185	4662		29 - 58%	-	49 - 73%
			Chaetognatha	1549	1927		28 - 35%	-	67 - 72%
			Crab larvae	3007	6145		74 - 80%	-	21 - 100%
			Caridean shrimp	2728	1766		45 - 66%	-	64 - 81%
Bergum Power Station	April - June 1976	unknown # 6 days	smelt	unknown	322	initial	10 - 28%	-	10-41%
			perches	unknown	826		32 - 74%	-	39-82%
Bowline Point	June - July 1975	unknown # unknown days	striped bass	141	111	initial and 96 hour latent	74%	23%	70%
			white perch	122	168		68%	26%	100%
			bay anchovy	2134	1317		2%	0%	22%
Bowline Point	May - July 1976	unknown # 10 days	striped bass PYSL	118	207	initial and 96 hour latent	54%	23%	26 - 77%
			white perch PYSL	54	42		33%	21%	13 - 84%
			bay anchovy PYSL	148	1120		0%	0%	–
			herrings PYSL	46	83		20%	1%	0 - 80%
			Atlantic tomcod PYSL	54	17		29%	12%	54%
Bowline Point	March - July 1977	736 samples 46 days	striped bass larvae	228	452	initial and 96 hour latent	71 - 72%	55 - 66%	41 - 100%
			white perch PYSL	26	38		34%	69%	16 - 62%
			bay anchovy larvae	634	1524		0 - 2%	0%	–
			herrings PYSL	37	22		23%	5%	51%
			silverside PYSL	24	56		16%	0%	–
Bowline Point	March - October 1978	609 samples 40 days	striped bass PYSL	646	792	initial and 96 hour latent	52 - 63%	5 - 46%	76 - 100%
			white perch PYSL	190	301		19%	0-5%	52 - 68%
			bay anchovy PYSL	325	763		0 - 3%	0%	–
			herrings PYSL	271	51		23 - 63%	0%	–
Bowline Point	May - June 1979	435 samples 19 days	striped bass PYSL	77	155	initial and 96 hour latent	35 - 41%	8-20%	24 - 42%
			white perch PYSL	205	191		26 - 35%	5-8%	32%
			bay anchovy PYSL	181	89		0 - 4%	0%	–
			herrings PYSL	63	92		30 - 31%	0-3%	0 - 58%
Braidwood Nuclear	June - July 1988	68 samples 3 days	all species combined	191	103	initial	59%	-	100%
Brayton Point	April - August 1997 February - July 1998	6829 samples 41 days	winter flounder	49	965	initial and 96 hour latent	30 - 38%	-	90 - 100%
			tautog	34	401		4%	-	98 - 100%
			windowpane flounder	58	58		29 - 30%	-	65 - 67%
			bay anchovy	539	15896		0%	-	0%
			american sand lance	1091	2941		0%	-	100%
Cayuga Generating Plant	May - June 1979	80 samples 24 days	suckers	984	649	initial and 48 hour latent	75 - 92%	93 - 98%	87 - 98%
			carps and minnows	466	192		12 - 74 %	45 - 100%	25 - 86%
			perches	108	66		43 - 69%	44 - 61%	19 - 59%

Table A7-1: Summary of Entrainment Survival Study Results

Facility	Sampling Period	Number of Samples and Days	Species	Number Sampled at Intake	Number Sampled at Discharge	Survival Study	Initial Discharge Survival	Latent Discharge Survival	Study Survival Estimate
Connecticut Yankee	June - July 1970	102 samples 7 days	alewife blueback herring	unknown	unknown	initial	0-8%	-	0-25%
Connecticut Yankee	June - July, 1971 and 1972	30 samples 2 days	alewife blueback herring	273	795	initial	0 - 24%	-	0-26%
Contra Costa	April - July, 1976	unknown # 7 days	striped bass	637	329	initial	0 - 50%	-	0-95%
Danskammer Point Generating Station	May - November 1975	372 samples 29 days	striped bass PYSL white perch PYSL herrings PYSL	54 36 200	61 55 326	initial and 96 hour latent	39% 38% 20%	3% 4% 0%	95% 100% 80 - 87%
Fort Calhoun	October 1973 - June 1977	unknown # 89 days	Ephemeroptera Hydropsychidae Chironomidae	2221 3690 2646	2220 4964 2925	initial	18 - 32% 47 - 56% 43 - 66%	- - -	92% 92% 84%
Ginna Generating Station	June and August, 1980	255 samples 20 days	alewife larvae rainbow smelt larvae	54 31	95 17	initial and 48 hour latent	0% 0%	- -	- 0%
Indian Point	June and July, 1977	unknown # 7 days	striped bass PYSL white perch PYSL bay anchovy PYSL herrings PYSL	806 158 1254 100	518 67 704 65	initial and 96 hour latent	45 - 52% 15 - 43% 3 - 4% 10 - 11%	29 - 36% 15 - 30% 0% 0%	85 - 87% 73 - 89% 18 - 36% 40%
Indian Point	May - July, 1978	unknown # 22 days	striped bass PYSL white perch PYSL bay anchovy PYSL herrings PYSL	447 227 500 1046	1102 392 820 1104	initial and 96 hour latent	0 - 34% 0 - 37% 0% 0 - 8%	0-19% 6-15% 0% 0%	0 - 82% 0 - 58% 0% 0%
Indian Point Generating Station	March - August 1979	unknown # 40 days	Atlantic tomcod striped bass white perch herrings bay anchovy	266 127 195 254 457	212 153 147 186 485	initial and 96 hour latent	14 - 46% 62 - 77% 24 - 70% 28% 6%	15 - 75% 4 - 21% 18% 13% 4%	11 - 64% 59 - 75% 29 - 32% 22 - 31% 3 - 7%
Indian Point Generating Station	April - July 1980	unknown # 44 days	striped bass bay anchovy white perch	227 260 113	248 588 176	initial and 96 hour latent	50 - 81% 0 - 4% 0 - 90%	60-72% 0% 73%	55-81% 2-4% 50-90%
Indian Point Generating Station	May - June 1985	unknown # 49 days	bay anchovy PYSL	106	274	initial and 48 hour latent	6%	0%	0-24.3%
Indian Point Generating Station	June 1988	unknown # 13 days	striped bass larvae bay anchovy larvae	353 633	2710 7391	initial and 24 hour latent	62 - 68% 0 -2%	24 - 44% 0%	60-79% 0-25%
Indian River Power Plant	July 1975 - December 1976	46 samples 27 days	bay anchovy Atlantic croaker spot Atlantic menhaden Atlantic silverside	unknown	unknown	initial and 96 hour latent	unknown	unknown	0 - 100% 0 - 100% 25 - 100% 0 - 100% 0 - 100%
Muskingum River Plant	1979	no samples	none specified	0	0	none	intermediate to high potential	-	–
Northport Generating Station	April and July, 1980	162 samples 20 days	American sand lance winter flounder bay anchovy	29 13 7	782 17 11	initial and 48 hour latent	17% 35% 0%	2% 17% 0%	2% 10% –

Table A7-1: Summary of Entrainment Survival Study Results

Facility	Sampling Period	Number of Samples and Days	Species	Number Sampled at Intake	Number Sampled at Discharge	Survival Study	Initial Discharge Survival	Latent Discharge Survival	Study Survival Estimate
Oyster Creek Nuclear Generating Station	February - August 1985	28 samples 20 days	bay anchovy larvae winter flounder larvae	3396 3935	3474 2999	initial and 96 hour latent	0 - 71% 32 - 92%	0% 6 - 66%	0 - 68% 15 - 84%
Pittsburg Power Plant	April - July, 1976	unknown # 7 days	striped bass	196	266	initial	8 - 87%	-	12-94%
Port Jefferson	April 1978	94 samples 5 days	winter flounder sand lance fourbeard rockling American eel sculpin	36 249 216 107 22	26 191 144 96 17	initial and 96 hour latent	0 - 23% 12 - 40% 19 - 21% 94 - 96% 88%	50% 0 -10% - 71-96% -	65% 25 - 86% 73 - 100% 100% 75%
PG&E Potrero	January 1979	25 samples	Pacific herring	546	716	initial and 96 hour latent	16%	-	70%
Quad Cities Nuclear Station	June 1978	unknown # 5 days	freshwater drum minnows	378 278	916 307	initial and 24 hour latent	0 - 71% 2 - 75%	- -	2 - 62% 7 - 63%
Quad Cities Nuclear Station	April - June 1984	unknown # 8 days	freshwater drum carp buffalo	unknown unknown unknown	unknown unknown unknown	initial and 24 hour latent	unknown unknown unknown	- - -	63% 92 - 97% 94%
Roseton Generating Station	May - November 1975	672 samples 41 days	striped bass PYSL white perch PYSL herrings PYSL	100 77 471	172 97 833	initial and 96 hour latent	62% 29% 26%	6% 1% 0%	38% - -
Roseton Generating Station	June - July 1976	unknown # 27 days	striped bass PYSL white perch PYSL herring PYSL	93 401 1,054	80 349 645	initial and 96 hour latent	14 - 43% 6 - 42% 5 - 29%	- - 0%	19 - 58% 11 - 79% 10 - 59%
Roseton Generating Station	March May - July 1977	unknown # unknown days	striped bass PYSL white perch PYSL herring PYSL Atlantic tomcod YSL	427 251 880 1178	765 266 1344 1345	initial and 96 hour latent	3 - 29% 0 - 17% 0 - 5% 16%	18% 27% 0% 40%	6 - 58% 0 - 52% 0-19% 41%
Roseton Generating Station	March July - July 1978	256 samples 30 days	striped bass PYSL white perch PYSL herring PYSL Atlantic tomcod PYSL	123 395 1274 83	211 459 1089 153	initial and 96 hour latent	27 - 50% 0 - 35% 0 - 10% 33 - 45%	18% 10% 0% 36%	46% 56-96% 0% 39%
Roseton Generating Station	May - July 1980	1431 samples 42 days	striped bass PYSL white perch PYSL herring PYSL	245 194 812	425 366 1252	initial and 48 hour latent	46 - 61% 30 - 59% 7 - 31%	48 - 56% 27 - 62% 1 - 3%	88% 67% 23%
Salem Generating Station	1977-1982	640 samples, 38 days	spot herrings Atlantic croaker striped bass white perch bay anchovy weakfish	66 8 - - - - -	130 14 - - - - -	onsite and simulated studies	74.1 7.1 - - - - -	- 0 - - - - -	0 - 76% 2 - 74% 0 - 60% 32 - 46% 30 - 70% 2 - 3% 14 - 56%

A review of the data in Table A7-1 shows that the majority of the studies were conducted at facilities located in a limited geographical region of the country: 24 of the studies were conducted in the northeastern region of the United States. This may explain why these studies provide entrainment survival estimates for relatively few, only 24, species or families of fish. The majority of survival estimates in these studies were for striped bass, white perch, bay anchovy, and herrings. Also, the majority of these studies are over 20 years old, with 25 of the studies conducted in the 1970s. Thus, the results on species composition and abundance are not necessarily indicative of current conditions, with improved water quality due to the enactment of the Clean Water Act in 1972. Entrainment survival in these studies was also estimated with relatively short sampling periods, with the 15 studies using sampling periods of approximately two months long. Also, the sampling periods did not always correspond to peak egg and larval abundance in the waterbody. Twelve of these studies determined that sample sizes of fewer than 100 individuals for a particular species at the discharge station were sufficient to give an accurate estimation of entrainment survival. These small sample sizes are not be sufficient to provide accurate estimates of entrainment survival given that these facilities entrain organisms on the order of millions to billions per year. Also, small sample sizes in conjunction with the high variability of entrainment survival increase the uncertainty associated with these estimations. The small sample sizes allowed for limited study of latent survival, and no facility attempted to study latent physiological effects of entrainment on a species, such as the possible effects on growth rates, maturation, fertility, and vulnerability to natural mortality. The nature of the equation for entrainment survival results in estimates substantially higher than the proportion of survival in the discharge samples because of its use of a correction for mortality in the intake samples, which is often quite high. The fact that the existing studies are characterized by high uncertainty, high variability, and the potential for high bias (Boreman and Goodyear, 1981) complicates efforts to synthesize the various results in a manner that would provide useful generalizations of the results or application to other particular facilities. For these reasons, EPA believes that the reported results do not provide a clear indication as to the extent of entrainment survival significantly above 0 percent to be used as a defensible assumption to calculate benefits for this rule.

A7-3 DETAILED ANALYSIS OF ENTRAINMENT SURVIVAL STUDIES REVIEWED

The summary tables at the end of this chapter provide detailed summary descriptions of each of the 37 studies reviewed. EPA reviewed these studies to determine if they were conducted in a manner that provides adequate representation of the current probability of entrainment survival at the facility. The criteria EPA used to evaluate the studies focused on three main themes: the sampling effort of the study, the operating conditions of the facility during the study, and the survival estimates determined as the result of the study. Specifically, EPA asked the following questions:

Sampling:

- When were samples collected?
- With what frequency were samples collected?
- Were samples collected when organisms were spawning, or at peak abundance?
- What time of day were samples collected?
- What was the number of replicates per sampling date?
- Were the intake and discharge samples collected at the same time so the results can be compared?
- How long was each sample collected?
- What method was used to collect samples?
- At what depth were samples collected?
- What was the location of the samples collected at the intake and discharge?
- Which water quality parameters were measured?
- Were dissolved organic carbon (DOC) and particulate organic carbon (POC) measured?
- What was the velocity at the intake and at the discharge?

Operating conditions during sampling:

- How many generating units at the facility were in operation?
- How many pumps at the facility were in operation?
- What was the intake temperature range, the discharge temperature range, and the ΔT range to which organisms were exposed?
- Were biocides in use?

Survival estimation:

- How many sampling events occurred?
- What was the total number of samples collected?
- What was the total number of organisms collected?
- How many organisms are entrained each year at this facility?
- Did the study take into account fragmented organisms?
- Were the number of organisms collected at the intake and at the discharge comparable?
- What were the most abundant species collected?
- Were stunned larvae included with live larvae in survival estimates?
- Did the facility omit dead and opaque organisms from the count of dead organisms?

- How was latent survival studied?
- Were data sampled from all times and operating conditions combined to determine entrainment survival?
- What were the controls for the study?
- What was the range of intake survival determined by the study?
- What was the range of discharge survival determined by the study?
- How was entrainment survival calculated?
- Were confidence intervals or standard errors calculated?
- Were significant differences tested between intake and discharge survival?
- Was entrainment survival calculated for species with low sample sizes, such as fewer than 100 organisms?
- Was egg survival studied?
- Was there any trend evident in larval survival?
- Were the raw data provided to verify results?
- What was the trend of survival with regard to temperature?
- What was the extent of mechanical mortality?
- What quality control procedures were used?
- Was the study peer reviewed?

A7-4 DISCUSSION OF REVIEW CRITERIA

In this section, the criteria EPA used to review the entrainment survival studies are discussed in depth to give a better indication of the soundness of the science behind a facility's estimate of potential survival.

A7-4.1 Sampling Design and Method

These aspects of the sampling effort are relevant to whether the samples collected are representative of all organisms experiencing entrainment with regard to taxa and size classes, whether the estimates of densities and numbers are accurate and precise, and whether the survival estimates for the intake and discharge can be validly compared (Marcy, 1975; Boreman and Goodyear, 1981). Sampling should be carefully planned to minimize any potential bias (Marcy, 1975; Boreman and Goodyear, 1981). Studies should be conducted throughout the parts of the year when substantial numbers of organisms are entrained. Any possible survival may vary with factors that change seasonally, such as organism size and life stage and ambient water temperature. Most studies attempted to collect samples during times of peak abundance, although the sampling frequency may not have been sufficient to fully capture peak densities. Of those reviewed by EPA, six studies did not correspond with the timing of peak densities at that location.

Even if a study is limited to the early life stages of particular fish or shellfish, survival differences among sizes and life stages and seasonal or temperature-related changes in entrainment survival must be quantified. The timing of the sample collection for an entrainment survival study can influence results in a number of ways, such that results from studies collected during one period may not be representative of potential effects during other periods. For instance, samples collected when the intake temperatures are low or late in a spawning season when larvae are larger can produce estimates of entrainment survival that may be higher than at other times. Thus, studies need to be conducted throughout the entire spawning season to accurately characterize overall entrainment mortality if entrainment survival is found to vary with life stage or size of each species entrained. For the same reason, it may not be appropriate to develop average survival estimates from samples collected under different environmental conditions (in particular under different temperature regimes) and from only parts of a spawning period for a particular species. This was done in almost all the studies reviewed by EPA, which causes their results to be of questionable value. This also makes it difficult for EPA to synthesize the results of these studies into a meaningful average value of entrainment survival to be used in a national benefits assessment.

Many studies collected samples at night to ensure high numbers of organisms in their samples because larvae rise to the surface at night to feed and avoid predation (Marcy, 1975; Day *et al.*, 1989). This practice will bias results because the samples will contain a disproportionate number of live organisms than that which is actually present in the water column. There is evidence that dead organisms will sink to the bottom of the water column after entrainment (Marcy, 1975). Twenty-four studies indicated that most sampling took place at night. For many studies, the depth of sampling is not noted and thus it is unclear whether the samples were collected near the surface, at mid-depth, or near the bottom of the water column. Any potential for bias due to a higher percentage of alive organisms present near the surface could not be assessed.

The method of sampling should be selected to cause the least amount of mortality possible and the mesh size should be fine enough to capture disintegrated or fragmented organisms. Many studies sampled organisms using sampling instruments with mesh size greater than or equal to 500 μm. This may not be fine enough to capture disintegrated or fragmented organisms in the discharge. Attention should be given to the mesh size of sampling instruments to be sure that the targeted sample is not extruded through the mesh.

Intake and discharge sampling should be paired to be sure that the same population of organisms is sampled and subsequently compared. In 12 studies examined, it is unknown if the samples at the intake and discharge were paired. In some studies, samples were not collected at all locations during all sampling events. In other studies, twice as many samples were collected at the discharge than at the intake. Also, in many instances, the intake samples were collected at different generating units of the facility than the discharge samples. Average elapsed times for sample collection were given, and it is unclear if the same elapsed time was used at both locations to give an accurate depiction of organismal densities. The time elapsed during sample collection or the volume of water sampled should be identical in the paired intake and discharge samples to ensure valid comparisons of samples. It was not indicated in any of the studies reviewed whether the same volume of water was sampled in all the intake and discharge samples. If intake samples are to be compared to discharge samples, consistent sampling methods must be used at the two locations so that the samples contain the same density of organisms.

The location of the intake sampling is important because it may contain organisms that already died because of the changes in velocity near the intake. Two studies reviewed collected intake samples after the water had entered the cooling system. The location of the discharge sampling is also important. Samples collected from the end of the discharge canal may not contain organisms that died from passage through the facility because of the tendency of dead organisms to settle out of the water column in the discharge canal. Samples collected from the discharge pipe may not contain organisms that died from thermal effects of entrainment because the samples are collected before the full effects of thermal exposure were experienced. Fourteen studies reviewed collected discharge samples from the discharge pipe. It is also unknown if the samples collected in the discharge canal or from the receiving water contained organisms in the dilution water that bypassed the cooling water system. Five studies reviewed collected discharge samples in the receiving water downstream from the discharge canal, which can result in samples containing organisms that never passed through the cooling water system. The velocity at the intake and discharge should also be recorded to determine the potential to cause mortality. Fourteen of the studies noted the velocity at the intake, at the discharge, or both. For the ones that did not give both intake and discharge velocities, it is unknown whether the velocities at the two sampling sites were comparable, and thus whether the mortalities due to velocity-related sampling stress were comparable at the two locations.

Water chemistry conditions also need to be recorded to be sure conditions are similar at all sampling locations. Water quality parameters include measurements of dissolved oxygen, pH, and conductivity in the through-plant water, at the discharge point, and in the containers or impoundments in which the entrained organism are kept when determining latent mortality. Eighteen studies reviewed gave some indication that water quality parameters were measured. However, it is unclear whether measurements were collected at both the intake and the discharge, and only one study reviewed indicated that water quality parameters were measured in latent mortality studies (EA Engineering Science and Technology, 1986).

A7-4.2 Operating Conditions During Sampling

Mortality due to entrainment stress is affected by the operating characteristics of the power facility. The conditions under which the samples are collected are extremely important and, therefore, the results can be assumed to represent possible survival only when the facility is operating under those same conditions and at that time of year, and may not represent any potential for survival at all times. For example, results of studies conducted when the plant was not generating power (and thus not transferring heat to the cooling water) would not be applicable to impacts when it was in full operation. The magnitude of mechanical stress is dependent on the design of the facility’s cooling water intake structure. The physical and operating conditions of the facility must be recorded to determine the effect on entrainment survival. The percentage of the maximum load at which the facility is operating must be recorded at the time of sampling to indicate the extent to which organisms are exposed to stress. The number of generating units was highly variable or unknown in many of the studies reviewed. Only one study indicated that the facility operated at peak load to maximize temperature stress during the time of sampling. Eight studies indicated that power was generated during only a portion of time in the sampling period. To fully account for the effects of mechanical stressors on entrainment survival, the study must reflect the speed and pressure changes within the condenser, the number of pumps in operation, the occurrence of abrasive surfaces, and the turbulence within the condenser. In addition, it is important to note the number and arrangement of generating units, parallel or in sequence, which may expose organisms to entrainment in multiple structures. Survival should be studied under the range of facility conditions that may influence survival, for example, intake flow or capacity utilization and ambient (intake) water temperature and ΔT.

The effect of temperature can be species-specific since different fishes have different critical thermal maxima. The maximum temperature to which organisms may be exposed while passing through the facility may cause instant death in some species but not others. To assess the effect of thermal stressors on entrainment survival, the study must determine the temperature regime of the facility. Specifically, the study must record the temperature at both the intake and the discharge point for each component of the facilities system: temperature changes within the system, including the inflow temperature; maximum temperature; ΔT; rate of temperature change; and the temperature of the water to which the organisms are discharged. It is also important to measure the duration of time an organism is entrained and thus exposed to the thermal conditions within the condenser and in the mixing zone of the discharge canal. This information was not provided in the studies reviewed by EPA. Also, in those studies that attempted to relate survival to temperature stress, too few samples were collected at different temperature ranges to give an adequate representation of survival in that range. The EPRI report sorted larval entrainment survival data by discharge temperature and concluded that survivability decreased as the discharge temperature increased (EA Engineering Science and Technology, 2000). The lowest probability of larval survival occurred at temperatures greater than 33 °C. In the studies reviewed by EPA, a noticeable decline in survival estimates occurred at discharge temperatures above 30 °C. The amount of time that a facility discharges water in different temperature ranges and survival estimates at that temperature range should be weighted when attempting to determine the survival estimate throughout the year, rather than using an average survival during the sampling period, which may not adequately reflect operating conditions throughout the year.

To properly account for chemical stressors, the timing, frequency, methods, concentrations, and duration of biocide use for the control of biofouling must be determined. The extent to which biocides are routinely used is unknown. The studies reviewed by EPA were all conducted at times when biocides were not in use because the biocide use would be expected to kill all organisms. Thus, the results of these studies do not account for biocide impacts and only reflect other times when biocides are not in use at the particular facility. A reduced survival estimate for the proportion of time when biocides were in use would have to be incorporated into any estimation of annual mean entrainment mortality value for a facility for that estimate to be valid.

A7-4.3 Survival Estimates

Many of the entrainment survival studies reviewed did not account for the extent to which the fragile life stages are fragmented and disintegrated by both sampling and entrainment. Only six of the studies acknowledged that the entrainment survival estimates were indicative only of alive and stunned identifiable organisms out of all those sampled and enumerated that were at least 50 percent intact. In such circumstances, an important proportion of entrained dead (fragmented) organisms is omitted from the calculated estimate of survival. Entrainment survival studies should not limit their estimates of survival to include only those organisms that are either whole or 50 percent whole in the sample. For those studies that did not discuss the issue of fragmented organisms, it is unclear how the issue was treated. Several studies indicated that the majority of the sample was mangled or unidentifiable. There is potential for an extremely large number of dead organisms to be excluded from entrainment survival estimates because they are fragmented to the point of being unidentifiable. Studies should account for this fragmentation of organisms by measuring unidentifiable biomass in the samples from the intake and discharge stations. Without taking these organisms into account, entrainment survival estimates will be biased and the results will be higher than that which actually occurs. There are indications that the number of fragmented organisms, which are generally not included in survival estimates, may be high which results in an overestimation of entrainment survival if these fragmented organisms are more prevalent in the discharge. In the proceedings of a conference held in Providence, RI, on January 6, 1972, entitled *Pollution of the Interstate Waters of Mount Hope Bay and its Tributaries in the States of Massachusetts and Rhode Island*, the following regarding fragmentation was quoted "...in 1970 when we observed many small transparent larval menhaden in the intake. They were most readily noted by their black eyes. But in the effluent, all we found were eyes. They were torn to pieces" (U.S. EPA, 1972). Foam observed in the discharge (Thomas, 2002) may indicate that fragmentation is substantial. The data summary in Jinks *et al.* (1981) suggests that a substantial number of fish larvae may be fragmented by mechanical forces and become unrecognizable, contributing to a bias in estimates of survival. Ten of the studies reviewed by EPA reported finding fragmented organisms; others did not quantify evidence of disintegrated organisms. High rates of physical damage and abundant larval fish fragments were reported by Stevens and Finlayson (1978) at the Pittsburg and Contra Costa power plant discharges. Such losses can contribute to a bias (overestimation) of entrainment survival because the number of dead organisms are not properly enumerated. In addition, the low numbers of organisms sampled in the studies in relation to the high annual entrainment numbers give further indication that the sampling effort may not result in an adequate representation of the organisms entrained and therefore the survival estimates may not be representative of what occurs.

Including stunned larvae in the initial survival estimates also results in overestimations of survival, since the majority of these organisms died in the laboratory latent survival studies and even more will die in the natural conditions of the discharge canal because of predation or disrupted growth and development. Twenty-nine studies reviewed included stunned larvae in their initial survival estimates, and only a few of these indicated that this method will overestimate initial survival. The remainder of the studies reviewed did not discuss the treatment of stunned larvae. Many studies reviewed reported only initial acute mortality. Both initial mortality and extended or latent (96 hour) mortality should be studied and reported.

Dead and opaque organisms that may have died before entrainment should not be excluded from the enumeration of dead organisms. Several studies reviewed by EPA noted that dead organisms can turn opaque within an hour. This is the same amount of time that can elapse during sampling collection and sorting. Also, zero dead and opaque organisms were collected in the samples of one study when the facility was not generating power. Three studies omitted dead and opaque organisms from the dead classification used to estimate survival. This resulted in an elimination of up to 99 percent of the organisms in the samples of one study. Alternatively, one study counted only those organisms that were opaque as dead.

The study design should support unbiased estimation of survival, taking into account pertinent factors and the changing relative abundances of species and life stages. Because entrainment mortality changes with ambient and operating conditions, and because the numbers of various species and life stages entrained also change diurnally and seasonally, use of an average value for entrainment survival could be misleading. Organisms should be counted and sorted by species, life stage, and size. Entrainment survival should then be calculated separately for each life stage of each species. Entrainment survival estimates appears to vary markedly with fish larval size (EA Engineering Science and Technology, 1989); estimates of mortality are often higher for smaller larvae and lower for larger ones. Thus, survival measured for a heterogeneous mixture of sizes will apply only to that mixture under the same conditions, and cannot be used to accurately estimate survival for the species over the course of even part of a season. The approach of modeling survival in relation to size may be more promising (EA Engineering Science and Technology, 1989). The implication is that accurate assessment of entrainment survival requires frequent samples throughout a season, to reflect the changing size and species composition of the ichthyoplankton. In most of the studies all data from all samples collected under varied times and conditions were combined to give an average entrainment survival. However, bias could be introduced when a disproportionate number of samples are taken under a specific set of conditions that may not accurately reflect conditions throughout the year. Only 16 of the 37 studies reviewed estimated entrainment survival by sampling reported standard deviations or confidence intervals for the survival estimates. The apparent precision of estimates based on hundreds of organisms, and the estimates themselves, are deceptive. Such estimates are based on aggregated numbers that vary in size; however, larval fish survival is dependent on size (EA Engineering Science and Technology, 1989).

The volume of water sampled should always be reported with the number of organisms counted in the sampled volume. This allows estimates of the densities of organisms in the intake and the discharge water. Density estimates provide an important check on assumptions. When organism densities cannot be measured accurately, a useful check on disintegration of organisms that are never counted cannot be performed. Another check on loss of organisms by disintegration is a count of body parts, which was done in only one of the studies reviewed, but this will not account for organisms rendered unidentifiable or disintegrated. In some studies, the numbers of organisms in discharge samples were many times greater than the numbers of organisms in intake samples using the same sampling methods. In other studies, there were many times more organisms collected in the intake samples than in the discharge samples. Such large differences raise concerns about sampling methods and possible sources of bias that would need to be investigated.

Control samples taken to test the mortality associated with sampling gear should be taken as far away from the intake as possible. This will ensure that the rates of mortality determined will be solely from natural causes or sampling damage and not from potential damage due to increased velocity and turbulence near the intake. Sampling mortality should be reduced to the maximum extent possible, using modern sampling techniques (EA Engineering Science and Technology, 2000). When control survival is less than discharge survival, no attempts should be made to calculate entrainment survival; this would give an erroneous survival result of greater than 100 percent. That some studies reported entrainment survival estimates greater than 100 percent indicates that these studies' methods of calculating entrainment survival were flawed by methodological biases.

Calculating survival from the ratio of the fraction alive in discharge samples to the fraction alive in intake samples requires assumptions not supported by the same studies. These assumptions are that (1) no organisms are lost to counting by destruction in the cooling water system, in other words, the same density of organisms (dead or alive) is observed in the discharge as in the intake; and that (2) the sampling method causes the same rate of mortality in the discharge sample as in the intake sample. The first assumption is without doubt violated for many species and life stages. The second assumption is also questionable, because any organisms alive in the discharge have survived entrainment and may be more resistant to sampling-related mortality. Because the loss of organisms by disintegration is not measured, if a substantial number of organisms are destroyed and thus are not counted in the discharge, it is more likely that entrainment survival will be overestimated. The second assumption can be minimized if methods of sampling are used that reduce sampling mortality to a minimum (EA Engineering Science and Technology, 2000); such methods (e.g., rear-draw pumping methods, pumpless flume) were used in only 5 of the 37 studies reviewed. The formula commonly used (EA Engineering Science and Technology, 2000) to estimate entrainment survival, $S_I = P_{D/} P_I$, is appropriate in experimental situations in which the number of organisms at risk is verified to equal the number counted (alive and dead) at the end of the study. It can be applied in observational studies when it is known that the number at risk is conserved (i.e., no organisms are lost in sampling or destroyed so they cannot be counted). The biases that result from loss via sampling or destruction, and other causes, were illustrated by Boreman and Goodyear (1981). If Abbott' s correction for control mortality is applied, it requires the assumption that sampling mortality rate is the same for the intake and discharge samples. This source of bias was also considered by Boreman and Goodyear (1981). Abbott's correction may contribute to overestimation of entrainment survival because it attributes to entrainment only that mortality in excess of the mortality attributed to sampling. This may overestimate entrainment survival for two reasons: it is likely that sampling mortality and entrainment mortality are not entirely additive, and, as noted above, it is quite possible that the sampling mortality rate is less in the discharge sample than in the intake sample used as the control.

A7-5 APPLICABILITY OF ENTRAINMENT SURVIVAL STUDIES TO OTHER FACILITIES

Because of many factors, any potential for entrainment survival is most likely facility-specific. Therefore, EPA does not suggest that entrainment survival estimates be applied to other facilities, as was done in the Muskingum River Plant study (Ecological Analysts Inc., 1979a). To correctly transfer the results, the physical attributes of facilities would need to be identical. Specifically, the facilities would need to have similar numbers of cooling water flow routes; similar lengths of flow routes in terms of time and linear distance; similar mechanical features in terms of abrasive surfaces, pressure changes, and turbulence; and similar number and types of pumps used. In addition, there would need to be similarity and constancy of the flow rates, transit times, thermal regimes, and biocide regimes. The ecological characteristics of the environment around the facility would also need to be similar in terms of ambient water temperature, dissolved oxygen level, and the species and life stage of organisms present. Similarities or differences in these aspects may profoundly affect the applicability of the study across facilities. The studies reviewed by EPA were unsuitable for developing unbiased estimates of entrainment survival over the pertinent courses of time (diel and seasonal) and the typical environmental and operating conditions at the facilities conducting the studies, and thus cannot be used to estimate entrainment survival at section 316(b) facilities nationwide**.**

A7-6 CONCLUSIONS

EPA's review of the 37 entrainment survival studies revealed a number of limitations that challenge their use in assessing the benefits of the section 316(b) Phase II Existing Facilities Rule. The primary issue with regard to these studies is whether their results can support a defensible estimate of survival substantially different from the value of 0 percent survival assumed by EPA in assessing benefits of the rule. Given that live organisms can be found in the discharge canals of many cooling water intake systems, it may be true that not all organisms are necessarily killed as they pass through the cooling systems of all facilities under all operating conditions. However, the results of the 37 studies, summarized in Table A7-1, suggest that the proportion alive in the samples is highly variable and unpredictable among species and among facilities. The studies document that some species (e.g., herrings, bay anchovy) are very sensitive to entrainment and experience 0 percent survival with calculated mortality rates of 100 percent at most facilities. Other species (e.g., striped bass) may be more resistant to entrainment effects. However, even for these apparently hardy species, some studies yielded ranges of entrainment survival estimates that included zero and latent survival values very close to zero. Multiple studies at the same facility (e.g., Bowline Point, Indian Point) yielded survival values for some species (e.g., striped bass) that varied substantially among years, most likely due to a combination of changes in environmental conditions, changes in plant operations, and changes in sampling and testing procedures. The studies indicate that any survival is dependent on temperature, but the effect may vary greatly depending on intake water temperature, plant design, fish species, and life stages. Few of the studies could conclusively document and quantify the specific stressors causing the observed mortalities, and no rigorous, validated method or model was put forward that would allow survival rates to be accurately predicted. Another major constraint on the use of these findings in this rulemaking process is that they cover very few species, and primarily in a single geographical region of the country, thus providing no basis for prediction or projection of effects to other species in other parts of the country. These studies as well as other literature also show that findings from one facility cannot be considered to be valid for another facility, since many site-specific and facility-specific factors may affect the magnitude of mortality that occurs. The current state of knowledge would not support predictions of entrainment survival for the range of species, life stages, regions, and facilities involved in EPA's benefits estimates.

The potential usefulness of the findings of the studies reviewed is further compromised by the numerous factors that can influence the representativeness, accuracy, and precision of the survival estimates presented, and that are often not rigorously accounted for in the studies reviewed. These factors are described in section A7-2, and some of the deficiencies of the studies with regard to these factors are elaborated in section A7-3. The most frequent and serious deficiencies noted (e.g., high control mortalities, omission of fragmented or unidentifiable organisms, and uncertainty regarding post-discharge survival) compromise the accuracy and precision of the survival estimates. In many of the studies reviewed, the precision of the survival estimates was not rigorously assessed, and thus the uncertainty associated with the estimates is not known. If the factors addressed in this review were taken into account in an entrainment survival study, EPA believes that the estimates of survival that would result would not be substantially different from zero.

EPA acknowledges that some of the studies performed at some facilities were designed in a more rigorous manner than others in order to minimize the influence of factors that could compromise findings (e.g., the use of a larval table for assessing physiological condition) and included comprehensive sampling in an attempt to enhance the accuracy and precision of the survival estimates. However, while such studies may have provided estimates for the facility studied under the environmental and operational conditions that occurred at the time the study was performed, these studies do not provide a basis for generalizing specific survival rates for all or even the same species at other facilities or at the same facility in other years. In addition, there exists the possibility of additional post-discharge (latent) mortality when entrained organisms are returned to the receiving water body. Overall, the unreliability, variability, and unpredictability of entrainment survival estimates evident from EPA's review of the entrainment survival studies support the use of the assumption of 0 percent survival in the benefits assessment because there is no clear indication of any defensible estimate of survival substantially different from 0 percent to use to calculate benefits for this rule.

Summary Tables of Entrainment Survival Studies

Anclote Power Plant

Anclote River, FL

1985 Study

CCI Environmental Services, Inc., 1996

Sampling: Dates: Sept. 25 - 29, October 9 - 11, and November 1-2
Samples collection frequency: a few days per month
Times of peak abundance: autumn months when densities maybe not the highest
Time: mostly at night, some late afternoon to evening
Number of replicates: varied between 5 - 25 per month
Intake and discharge sampling: paired number, timing unknown
Elapsed collection time: 20 - 30 minutes
Method: 400 μm mesh net with 1 m diameter and 5 gallon plastic bucket with 500 μm mesh side panels
Depth: mid-depth and surface
Intake location: unknown
Discharge location: condenser discharge and point of discharge in canal
Water quality parameters measured: pH, DO, salinity
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: operated at peak load to maximize ΔT, 1 - 2 Units
Number of pumps in operation: varied due to sampling location, 0- 4 pumps
Temperature: Discharge temperature: 28.8 - 38.3 °C
ΔT average: 5.4 - 7.3 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 8
Total number of samples collected: 120
Total number of organisms collected: 41,196
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: approx. equal
Most abundant species: not classified to species level
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 24 hours
In several replicates, more organisms were counted after 24 hours in jar
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 64% for Fish larvae
73% for Amphipoda
44% for Chaetognatha
72% for crab larvae
72% for Caridean shrimp
Initial discharge survival range: 8 - 47% for Fish larvae
29 - 58% for Amphipoda
28 - 35% for Chaetognatha
74 - 80% for crab larvae
45 - 66% for Caridean shrimp
Calculation of Entrainment Survival: Discharge survival / Intake survival
Mean survival for each replicate was reported as survival estimate per species
Confidence intervals (95%) and standard deviations were calculated
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within hours of collection
Raw data: were provided to verify results
Temperature effects: unknown
Mechanical effects: unknown
Quality control: QA/QC officer oversaw sorting and sample handling
Peer review: not mentioned, study was conducted for the facility

Bergum Power Station

Bergumermeer, Netherlands

1976 Study

Hadderingh, 1978

Sampling: Dates: April 27 - June 1
Samples collection frequency: approximately once per week
Times of peak abundance: coincided with abundance of larvae and juveniles
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: unclear if paired sampling
Elapsed collection time: 3 minutes
Method: conical net with 0.5 mm mesh and 0.5 m diameter
Depth: unknown
Intake location: unknown
Discharge location: in outlet before weir
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: 40 cm/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake temperature: 10.8 - 21.6
Discharge temperature: 16.7 - 24.6 °C
ΔT ranged from 2.4 - 8.0 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 6
Total number of samples collected: unknown
Total number of organisms collected: unknown at intake, 1148 at discharge
Number of organisms entrained per year: unknown
approximately 10 million organisms entrained per day in May
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: unknown
Most abundant species: smelt, perches
Stunned larvae: unknown if included in survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in floating buckets in the outlet canal for 24 hours
5 - 50% appeared to be dead in buckets floating in outlet canal
However, latent survival was not explicitly studied
Data: survival by sampling date and then averaged
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 54 - 100% for smelt
81 - 96% for perches
Initial discharge survival range: 10 - 28% for smelt
32 - 74% for perches
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals and standard deviations were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: no eggs collected
Larval survival: increased in samples later in year, may be due to larger sized
Raw data: were not provided to verify results
Temperature effects: not discussed
Mechanical effects: not discussed
Quality control: not discussed
Peer review: work done for facility, published in Applied Limnology

Bowline Point Generating Station

Hudson River, NY

1975 Study

Ecological Analysts Inc., 1976a

Sampling: Dates: June 3 - July date unknown
Samples collection frequency: 1 - 4 times per week
Times of peak abundance: sampling intended to coincide with peak densities
Time: day or night
Number of replicates: unknown
Intake and discharge sampling: unknown if paired
Elapsed collection time: 15 minutes
Method: larval collection tables
Depth: unknown
Intake location: in front of intake
Discharge location: from standpipe connected to discharge pipe of Unit 2
Water quality parameters measured: conductivity, DO, pH
DOC and POC measured: no
Intake and discharge velocity: intake: 1.5 - 2 m/sec, discharge 2- 4.6 m/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: ΔT range: 0.5 - 12.1 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 37
Total number of samples collected: 400
Total number of organisms collected: 4643
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no, more at intake
Higher percentage of larvae were collected at the discharge station in the later weeks of the collection period. Conversely, a higher percentage of larvae were collected at the intake at the beginning weeks of the collection period. This discrepancy in larval collection combined with higher survival rates later in the spawning season accounts for the bias which results in higher survival rates at the discharge station. The study acknowledges this bias and concludes that it is responsible for the higher discharge survival estimates
Most abundant species: striped bass, white perch and bay anchovy
Stunned larvae: included in initial survival proportion; most died within hours
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 81% for striped bass
56% for white perch
9% for bay anchovy
Initial discharge survival range: 74% for striped bass
68% for white perch
2% for bay anchovy
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals (95%) were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: no
Egg survival: not studied
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results
Temperature effects: too few samples collected to establish relationship
Mechanical effects: extent was not discussed
Quality control: color coded labeling, routine checks on sorting accuracy
Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1976 Study

Ecological Analysts Inc., 1977

Sampling: Dates: May 18 - July 26
Samples collection frequency: approx. 4 nights per week
Times of peak abundance: for all species except Atlantic tomcod
Time: at night
Number of replicates: stated average of 10 per sampling trip
Intake and discharge sampling: sorted simultaneously
Elapsed collection time: 15 minutes
Method: larval collection table with 4 inch diameter trash pump
Depth: unknown
Intake location: in front of Unit 1 trash racks
Discharge location: from standpipes of discharge at Units 1 or 2
Water quality parameters measured: conductivity, pH, and DO
DOC and POC measured: no
Intake and discharge velocity: intake: 0.11 - 3 m/sec, discharge: 3 - 4.6 m/sec

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: unknown
Temperature: discharge range: 29.0 - 35.9 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 39
Total number of samples collected: 688
Total number of organisms collected: 2795
Number of organisms entrained per year: unknown
Fragmented organisms: only included in count if > 50% was present
Equal number of organisms collected at intake and discharge: no, very different
Most abundant species: striped bass, white perch , atlantic tomcod, bay anchovy, herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 81 - 90% for striped bass
62% for white perch
54 - 82% for Atlantic tomcod
7 - 53% for bay anchovy
35% for herrings
Initial discharge survival range: 0 - 54% for striped bass
0 - 33% for white perch
29 - 94% for Atlantic tomcod
0 - 10% for bay anchovy
20% for herrings
Calculation of Entrainment Survival: Discharge survival / intake survival
Confidence intervals (95%) were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: decreased markedly within 12 hours of collection.
Raw data: were not provided to verify results.
Temperature effects: trend of decreasing survival when temperatures > 30 °C
Mechanical effects: unknown extent
Quality control: color coded labels, immediate checks of sorted samples, SOPs
Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1977 Study

Ecological Analysts Inc., 1978a

Sampling: Dates: March 7 - July 15
Samples collection frequency: 5 nights per week
Times of peak abundance: covered of peak densities of most targeted species
Time: at night
Number of replicates: varied between 2 and 10 per site
Intake and discharge sampling: paired
Elapsed collection time: 15 minutes
Method: larval table with pump, 2 pumps at intake; 2 tables at discharge
ambient water injection system added to reduce prolonged temp. exposure
Depth: middle to bottom at intake, at standpipes for discharge
Intake location: in front of Unit 1 trash rack
Discharge location from standpipes of either Unit 1 or 2, depending on operation
Water quality parameters measured: conductivity, pH and DO
DOC and POC measured: no
Intake and discharge velocity: intake: 0.11- 2 m/sec; discharge 3 - 4.6 m/sec

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: 2 pumps throttled or 2 pumps full
Temperature: Intake range: 3.7 - 27 °C
ΔT range: not provided
Biocide use was not noted

Survival Estimation:
Number of sampling events: 46
Total number of samples collected: 736
Total number of organisms collected: 4071
Number of organisms entrained per year: unknown
Fragmented organisms: included in count if > 50% of organism was present
Equal number of organisms collected at intake and discharge: no, very different
Most abundant species: striped bass, white perch, bay anchovy,
herrings and silversides
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 74% for striped bass
69% for white perch
0 - 16% for bay anchovy
54% for herrings
37% for silversides
Initial discharge survival range: 71 - 72% for striped bass
34% for white perch
0 - 2% for bay anchovy
23% for herrings
16% for silversides
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: survival increased with larval length
Raw data: were not provided to verify results.
Temperature effects: decreased survival > 33 °C
Mechanical effects: unknown
Quality control: color coded labels, checks of sorting efficiency
Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1978 Study

Ecological Analysts Inc., 1979b

Sampling: Dates: March 13 - October 16
Samples collection frequency: 1 - 5 times per week
Times of peak abundance: majority of samples in June and July
Time: at night
Number of replicates: varied between 1 - 10 per sampling date.
Intake and discharge sampling: mostly paired, not all sites sampled all dates
Elapsed collection time: 15 minutes
Method: pump/larval table combination; also floating larval table
Depth: at bottom for intake and unspecified for discharge
Intake location: in front of trash racks of Unit 1 or 2
Discharge location: at either Unit 1 or 2 in standpipes from discharge pipe
floating larval table used for sampling at point of discharge
Water quality parameters measured: salinity, pH, DO, conductivity
DOC and POC measured: no
Intake and discharge velocity: intake: 0.15 - 0.23 m/s

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: unknown
Temperature: unknown
Biocide use was not noted

Survival Estimation:
Number of sampling events: 40
Total number of samples collected:609
Total number of organisms collected: unknown
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: varied
Most abundant species: striped bass, bay anchovy, white perch and herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in holding jars for 96 hours
Data: was summarized and averaged over the entire sampling period.
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 48 - 49% for striped bass
39% for white perch
4% for bay anchovy
19% for herrings
Initial discharge survival range: 51 - 63% for striped bass
19% for white perch
0% for bay anchovy
23% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard error were presented
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: decreased markedly within 12 hours of collection
Survival increased with larval length
Raw data: were not provided to verify results
Temperature effects: no survival for YSL for any species at temps. > 30 °C
no survival for PYSL for any species at temps. > 33 °C
majority of samples collected at temperatures < 30 °C
Mechanical effects: recirculation of water occurs
Quality control: color coded labels, double checks, sorting efficiency checks
Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1979 Study

Ecological Analysts Inc., 1981a

Sampling: Dates: May 23 - June 27
Samples collection frequency: 3 - 5 days per week
Times of peak abundance: timed to coincide with peak densities
Time: 1400 to 2200 hours
Number of replicates: varied between 0 - 9 per sampling date, generally 7
Intake and discharge sampling: mostly paired, initiated simultaneously
Elapsed collection time: 15 minutes
Method: intake: floating larval table or rear draw sampling flume
discharge: pumpless plankton sampling flume or pumped larval table
Depth: intake: mid-depth (4.6 m)
discharge: 2 m below surface
Intake location: in front of trash racks
Discharge location: at standpipe and diffuser
Water quality parameters measured: conductivity, pH, DO
DOC and POC measured: no
Intake and discharge velocity: intake: 1.5 - 3.0 m/sec; discharge 3 - 4.6m/sec

Operating Conditions During Sampling:
Number of units in operation: varied, power generated on only 5 sampling dates
Number of pumps in operation: operated through sampling
Temperature: ΔT range: not provided
Biocide use was not noted

Survival Estimation:
Number of sampling events: 19
Total number of samples collected: 435
Total number of organisms collected:1212
Number of organisms entrained per year: estimated 1.5 million striped bass
2.7 million white perch
Fragmented organisms: included in count if 50%of organism was present
Equal number of organisms collected at intake and discharge: approx. equal
Most abundant species: white perch, bay anchovy, striped bass, herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours.
Data: was summarized and averaged over the entire sampling period.
Controls: Survival in the intake samples was considered to be the control.
Initial intake survival range: 63 - 71% for striped bass
39 - 63% for white perch
4 - 14% for bay anchovy
56 - 61% for herrings
Initial discharge survival range: 35 - 41% for striped bass
26 - 35% for white perch
0 - 4% for bay anchovy
30 - 31% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard errors were presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: determined by translucency and hatching success
Larval survival: decreased markedly within 12 hours of collection.
Raw data: were not provided to verify results.
Temperature effects: little survival at discharge temperatures > 30 °C
Mechanical effects: due to no power generation on the majority of sampling dates, results give indication of extent of mechanical induced mortality
This study included analysis of diel patterns of ichthyoplankton abundance in comparison to diel patterns of plant generation. Facility tends to operate at 85 to 95 percent of capacity in the mid-afternoon hours which results in higher ΔT's and discharge temperatures. Facility tends to operate at minimum level, 20 to 30 percent capacity, in early morning when larval abundance is high and entrainment survival samples collected. Sample collection during the hours when the facility is operating at minimum levels of percent capacity, and at times with correspondingly lower ΔT's and discharge temperatures, may add bias to the results since more organisms will be exposed to lower levels of temperature stress. The peak abundance for each species is only slightly higher than abundance throughout the day. Thus, collectively, more organisms may be exposed to higher temperatures and have higher mortality rates but are not reflected in samples collected at night.
Quality control: color coded labels, check of sorting efficiency, SOPs
Peer review: not mentioned, study was conducted for the facility

Braidwood Nuclear Station

Kankakee River, IL

1988 Study

EA Science and Technology, 1990

Sampling: Dates: June 1 - July 5
Samples collection frequency: 3 samples taken in 35 days
Times of peak abundance: peak densities of eggs and larvae were found in May
Time: varied; day and night at intake, only day at discharge
Number of replicates: varied, 8 - 14 per sampling date
Intake and discharge sampling: more discharge replicates, not always same day
Elapsed collection time: 2 minutes
Method: plankton net with 1.0 m opening, net rinsed out in bucket
Depth: unknown
Intake location: in holding pond into which river water was pumped
Discharge location: downstream of outfall in discharge canal
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: 0.4 - 0.6 ft/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: not given
Biocide use was not noted

Survival Estimation:
Number of sampling events: 3
Total number of samples collected: 62
Total number of organisms collected: 294
Samples, which were collected after peak densities, contained fewer and larger organism which may in turn have higher survival rates.
Number of organisms entrained per year: estimate 5.8 - 11.2 million eggs/larvae
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: minnows and sunfish
Stunned larvae: included in survival proportion
Dead and opaque organisms: were omitted from all calculations of survival
    Thus 67% of those dead in the intake samples and 21% of those dead in the discharge samples were omitted from the survival proportions
Latent survival: not studied
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control.
Initial intake survival range: 60% for minnows (17% including dead-opaque)
    78% for sunfish (54% including dead-opaque)
Initial discharge survival range: no minnows collected
    80% for sunfish (76% including dead-opaque)
Calculation of Entrainment Survival: Discharge survival / Intake survival
Survival proportions calculated by dividing number of live larvae by number of live plus dead-transparent larvae
Confidence intervals / standard deviations: were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: data not given
Larval survival: not studied
Raw data: were not provided to verify results.
Temperature effects: not studied
Mechanical effects: not studied
Quality control: not discussed
Peer review: not mentioned, study was conducted for the facility

Brayton Point

Mount Hope Bay, MA

1997-1998 Study

Lawler Matusky & Skelly Engineers, 1999

Sampling: Dates: April 30 - August 27, 1997 and February 26 - July 29, 1998
Samples collection frequency: weekly
Times of peak abundance: not discussed specifically
Time: varied, day or night
Number of replicates: varied between 14 and 77
Intake and discharge sampling: not paired, 2 tables located in discharge canal
Elapsed collection time: 15 minutes
Method: pump/larval table combination
Depth: mid-depth for intake, 2 - 4 m below surface at discharge
Intake location: directly in front of Unit 3 intake screens
Discharge location: middle of discharge canal or from Unit 4 discharge pipe
Water quality parameters measured: conductance and salinity periodically
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: intake range: 4.5 - 28.0 °C
discharge range: 11 - 45 °C
ΔT data not provided
Biocide use: samples collected when not in use

Survival Estimation:
Number of sampling events: 41
Total number of samples collected: 2692 in 1997; 4137 in 1998
Total number of organisms collected: 2256 in intake; 27,574 in discharge
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal no. of organisms collected at intake and discharge: 4 - 79X more in discharge
Most abundant species: bay anchovy, American sand lance
Stunned larvae: assumed stunned larvae did not survive due to increased predation risk
Dead and opaque organisms: not discussed
Latent survival: observed in holding cups in aquarium racks for 96 hours
Data: was summarized and averaged with both sampling years combined
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0% for American sand lance
4% for tautog
0% for bay anchovy
44 - 46% for windowpane flounder
32% for winter flounder
Initial discharge survival range: 0% for American sand lance
4% for tautog
0% for bay anchovy
29 - 30% for windowpane flounder
33 - 38% for winter flounder
Calculation of Entrainment Survival: discharge survival / intake survival
Standard errors were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: survival increased with larval length,
decreased markedly within 4 hours of holding in latent studies
Raw data: were provided by species and not by sample to verify results
Temperature effects: survival decrease markedly at temps > 20 °C
Mechanical effects: unknown extent
Quality control: continuous sampling plan which included reanalysis of samples
Peer review: not mentioned, study was conducted for the facility

Cayuga Generating Plant

Wabash River, IN

1979 Study

Ecological Analysts Inc., 1980a

Sampling: Dates: May 17 - 31 and June 8 - 22
Samples collection frequency: daily
Times of peak abundance: highest average densities sampled were June 8 - 10
Time: 1900 to 0300 hours
Number of replicates: varied between 0 - 6 per sampling date.
Intake and discharge sampling: simultaneous sampling, transit time = 36 mins
Elapsed collection time: 15 minutes
Method: pump / larval table collection system
Depth: intake: 2 and 5 m below surface, discharge: 3 - 4 m below surface
Intake location: in front of intake structure
Discharge location: where discharge of Units 1 and 2 enter canal
also cooling tower discharge in discharge canal
Water quality parameters measured: DO
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: varied, 2 - 4
Temperature: intake range: 17.6 - 24.3 °C
discharge range: 29.4 - 33.3 °C
ΔT ranged from 8.4 - 11.8 °C
Biocide use: occurs daily, but ceased at least 2 hours before sampling

Survival Estimation:
Number of sampling events: 24
Total number of samples collected: 80
Total number of organisms collected: 2556
Number of organisms entrained per year: unknown
Fragmented organisms: 13 - 14.6% were damaged
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: suckers, perches, carps, temperate basses
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: 48 hour observation in aerated glass jars of filtered river water
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 86 - 98% for suckers
28 - 92% for carps and minnows
50 - 86% for perches
Initial discharge survival range: 75 - 92% for suckers
12 - 74% for carps and minnows
43 - 69% for perches
Calculation of Entrainment Survival: Discharge survival/ Intake survival
Confidence intervals: were not presented; standard errors were calculated
standard error sometime as high as survival
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: latent effects were not seen until 48 hours after collection
Raw data: were provided to verify results
Temperature effects: lower survival for all species at temperatures above 30 ˚C
Mechanical effects: survival decreased when number of pumps increased
Quality control: sorting efficiency checks and color coded labels
Peer review: not mentioned, study was conducted for the facility

Connecticut Yankee Atomic Power Company

Connecticut River, CT

1970 Study

Marcy, 1971

Sampling: Dates: June 30 - July 29
Samples collection frequency: weekly
Times of peak abundance: sampling dates were estimated times of peak larvae
Time: varied throughout day to avoid biocide application
Number of replicates: sampled in triplicate, data from replicates combined
Intake and discharge sampling: samples taken successively
not all sites sampled on all dates
Elapsed collection time: 5 minutes
Method: conical nylon plankton net with 1 L plastic bucket attached to cod end
portable water table for maintaining temperature during counting
Depth: median depth at intake; surface, middle and bottom of discharge
because dead fish in canal may sink or float due to immobility or
changes in specific gravity of water, thus giving inconsistent results
Intake location: unknown
Discharge location: outfall weir and 3 location in discharge canal
Water quality parameters measured: DO
DOC and POC measured: no
Intake and discharge velocity: 1 - 2 ft/sec, may approach 8 ft/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge temperature: 28.2 - 41 °C
ΔT ranged from 6 - 12.1 °C
Biocide use: sampling avoided daily application of 13% sodium hydrochlorite

Survival Estimation:
Number of sampling events: 7
Total number of samples collected: 102
Total number of organisms collected: 2681
Number of organisms entrained per year: unknown
Fragmented organisms: majority of dead fish were mangled
Equal number of organisms collected at intake and discharge: unknown
Most abundant species: alewife and blueback herring
Stunned larvae: not discussed
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: all data for all species combined, survival calculated for each date
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 29 - 100% for all species combined
Initial discharge survival range: 0 - 7.5% for all species combined
Calculation of Entrainment Survival: number live per cubic meter in each
discharge sample/ number live per cubic meter in intake for each day
Confidence intervals and standard deviations: were not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: July 29
Egg survival: not sampled
Larval survival: no organisms were found alive at end of discharge canal at
temperatures > 30 °C
Raw data: were not provided to verify results
Temperature effects: at discharge temp. > 33.5 °C, no living organisms sampled
Mechanical effects: not discussed
Quality control: not discussed
Peer review: published in notes of Journal Fisheries Research Board of Canada

Connecticut Yankee Atomic Power Company

Connecticut River, CT

1971 - 1972 Study

Marcy, 1973

Sampling: Dates: June 2 - 24, 1971 and June 27 - July 13, 1972 (mechanical only)
Samples collection frequency: approximately once per week
Times of peak abundance: unknown
Time: afternoons and evenings
Number of replicates: three at each station although at three different depths data were combined for each station
Intake and discharge sampling: collected successively at the 5 sites
Elapsed collection time: 5 minutes
Method: conical nylon plankton net with 0.39 mm mesh and 1L plastic bucket
Depth: surface, middle, and bottom
Intake location: unknown
Discharge location: below weir and 3 points along discharge canal
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: 0.3 - 0.6 m/sec, may approach 2.4 m/sec

Operating Conditions During Sampling:
Number of units in operation: unknown in 1971, no power generation in 1972
Number of pumps in operation: unknown
Temperature: Intake temperature: 16 - 26 °C (1971); 19.9 - 28 °C (1972)
Discharge temperature: 29 - 35 °C (1971 only)
ΔT ranged from 9-13 °C (1971 only)
Biocide use: 1972 study, chemical mortality indistinguishable from mechanical

Survival Estimation:
Number of sampling events: 2 (1971) and 7 (1972)
Total number of samples collected: 30 (1971) and 246 (1972)
often 2-3 times as many samples collected at discharge
Total number of organisms collected: 1068 (1971) and 10,271 (1972)
Number of organisms entrained per year: unknown,
estimated entrainment is 1.7 - 5.8% of nonscreenable fish which pass facility
Fragmented organisms: not discussed
Equal no. of organisms collected at intake and discharge: 4X more in discharge
lower numbers collected at end of canal may be due to dead fish settling out of water column
Most abundant species: alewife and blueback herring
Stunned larvae: were included as live unless they had begun to turn opaque
Dead and opaque organisms: only opaque organisms were counted as dead
Latent survival: not studied
Data: replicate data combined; survival calculated per sampling day
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 64 - 100% for all species sampled (1971)
Initial discharge survival range: 0% for all species sampled (1971)
Calculation of Entrainment Survival: number live per cubic meter in each discharge sample/ number live per cubic meter in intake for each day
Confidence intervals and standard deviations were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none sampled
Larval survival: no survival anywhere in discharge at temperatures > 29 °C
Raw data: were not provided to verify results
Temperature effects: organisms exposed to elevated temp. for 50 - 100 min
estimated as causing 20% of mortality
most fish are dead at the end of the 1.14 mile canal
Mechanical effects: 1972 study indicated that 72 - 87% is mechanical mortality
Quality control: not discussed
Peer review: published in Journal Fisheries Research Board of Canada

Contra Costa Power Plant

San Joaquin River, CA

1976 Study

Stevens and Finlayson, 1978

Sampling: Dates: April 28 - July 10
Samples collection frequency: once per week
Times of peak abundance: unknown
Time: varied, about 25% of all samples collected at night
Number of replicates: typically 3
Intake and discharge sampling: paired at closest time and temperature
Elapsed collection time: 1 - 2 minutes
Method: 505 micron mech conical nylon plankton net with 0.58 m plastic collecting tubes on cod end; towed net on boat at 0.6 ft/sec
Depth: mid-depth
Intake location: at intake for units 6 and 7
Discharge location: at discharge for units 1 - 5 and units 6-7
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake temperature: 19 - 30 °C
Discharge temperature 19 - 38 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 6
Total number of samples collected: unknown
Total number of organisms collected: 966 (1606 at north shore control)
Number of organisms entrained per year: unknown
Fragmented organisms: enumerated in one replicate tow
higher proportion of unidentifiable fragments in discharge
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: striped bass
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: was summarized by mean larval length
Controls: survival in the intake samples was considered to be the control
additional control on north shore to determine background mortality
control site at north shore away from intake had lower mortality rates
Initial intake survival range: 33-90% for striped bass
recirculated water may be cause of some intake mortality
Initial discharge survival range: 0 - 50% for striped bass
Calculation of Entrainment Survival: paired discharge survival divided by paired intake survival
Confidence intervals and standard deviations were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: increased survival with greater larval length
Raw data: were not provided to verify results
Temperature effects: mortality increased with increase in discharge temperature
higher mortality with discharge temp. > 31 and $\Delta T > 7$ °C
linear regression showed that half died at temps >33.3 °C
0% survival at temperatures of 38 °C
Mechanical effects: stated not as much of an effects as temperature
Quality control: not discussed
Peer review: study conducted by California Fish and Game with funds provided by facility

Danskammer Point Generating Station

Hudson River, NY

1975 Study

Ecological Analysts, Inc. 1976b

Sampling: Dates: May 29 - November 18
Samples collection frequency: varied from once every 2 weeks to 4 times per week
Times of peak abundance: increased frequency during spawning
Time: varied, generally overnight
Number of replicates: varied, ranged from 1 to 12
Intake and discharge sampling: usually paired
Elapsed collection time: unknown
Method: pump/larval table
Depth: mid-depth for intake, unspecified for discharge
Intake location: in canal in front of traveling screens
Discharge location: outlet of Unit 3 to Hudson River
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: varied between 1 and 2
Temperature: Intake temperature range: 21 - 26 °C
Discharge temperature range: not provided
ΔT ranged from 0 - 10 °C
Biocide use not used during sampling; noted that chlorination will reduce survival

Survival Estimation:
Number of sampling events: 29
Total number of samples collected: 372
Total number of organisms collected: 1655
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal no. of organisms collected at intake / discharge: up to 2X more in discharge
Most abundant species: herrings, striped bass and white perch
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0 - 50% for striped bass
33 - 100% for white perch
63 - 100% for herrings
Initial discharge survival range: 0 - 39% for striped bass
38 - 80% for white perch
20 - 22% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals and standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: herring PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results
Temperature effects: significantly lower survival when ΔT > 10 °C and discharge temperature >30 °C
Mechanical effects: not discussed
Quality control: samples double checked and data entry monitored
Peer review: not mentioned, study was conducted for the facility

Fort Calhoun Nuclear Station

Missouri River, NE

1973-1977 study

Carter, 1978

Sampling: Dates: October 1973 - June 1977
Samples collection frequency: 5 - 24 times per year
Times of peak abundance: same frequency all year round
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: unknown if timing was paired
Elapsed collection time: unknown
Method: plankton net with 571 μm mesh and 0.75 m diameter
Depth: unknown
Intake location: in river near intake
Discharge location: near discharge in river immediately downstream of intake
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied, 25-97% of full power or shut down
Number of pumps in operation: unknown
Temperature: Discharge temperature: 27.0 - 36.9 °C during summer samples
ΔT ranged from 0.6 - 13.5 °C
Biocide use: unspecified number of samples collected during chlorination

Survival Estimation:
Number of sampling events: 89 (16 when facility was shut down)
Total number of samples collected: unknown
Total number of organisms collected: 24,535 macroinvertebrates
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no, varied
Most abundant species: Ephemeroptera, Hydropsychidae, Chironomidae
Stunned larvae: macroinvertebrates studied
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: was summarized and averaged over entire sampling period
Controls: Survival in the intake samples was considered to be the control
Initial intake survival range: 12 - 26% for Ephemeroptera
42 - 51% for Hydropsychidae
35 - 60% for Chironomidae
Initial discharge survival range: 18 - 32% for Ephemeroptera
47 - 56% for Hydropsychidae
43 - 66% for Chironomidae
Calculation of Entrainment Survival: Average differential mortality
Confidence intervals / standard deviations: were calculated but not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not collected
Larval survival: macroinvertebrates only were studied
Raw data: were not provided to verify results
Temperature effects: discussed but data not presented
Mechanical effects: studied during 16 dates when facility was shut down
Quality control: unknown
Peer review: not mentioned, study was conducted for the facility

Ginna Generating Station

Lake Ontario, NY

1980 Study

Ecological Analysts Inc., 1981c

Sampling: Dates: June 11 - 24 and August 8 - 21
Samples collection frequency: 5 times per week
Times of peak abundance: to coincide with peak densities of targeted species
Time: late afternoon or early evening
Number of replicates: unknown
Intake and discharge sampling: simultaneous sampling at both sites
Elapsed collection time: 15 minutes
Method: Intake: pump to floating rear-draw sampling flume
Discharge: floating rear-draw pumpless plankton sampling flume
Also used ambient water injection to reduce exposure to high temps.
Depth: unknown
Intake location: at screenhouse intake after flow through 3,100 ft intake tunnel
Discharge location: discharge canal
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge range: 18.5 - 34.4 °C
ΔT ranged from 8 - 10 °C
Biocide use: sampled 4 hours after routine injections

Survival Estimation:
Number of sampling events: 20
Total number of samples collected: 255
Total number of organisms collected: 664
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: varied
Most abundant species: alewife
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars of filtered water for 48 hours
Data: was summarized and averaged over the sampling month
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 16.3% for alewife eggs
39% for alewife larvae
58-71% for rainbow smelt
Initial discharge survival range: 62.5% for alewife eggs; 16% hatching success
0% for Alewife larvae
0% for rainbow smelt
Calculation of Entrainment Survival: Discharge survival/Intake survival
In June, only one larvae was found alive int the discharge samples
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Too few of many species were collected at the two sites (only 1 or 2 per site) to provide any reliable estimate of entrainment survival
Egg survival: determined by translucency and hatching success
Raw data: were provided to verify results
Temperature effects: none survived at any temperature
Mechanical effects: none survived at any temperature
Quality control: SOPs, color coded labels, sorting efficiency checks
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1977 Study

Ecological Analysts Inc., 1978c

Sampling: Dates: Jun 1 - July 15
Samples collection frequency: twice per week
Times of peak abundance: expected to coincide with peak densities
Time: 1800 - 0200 hours
Number of replicates: varied between 5 - 7 per sampling date.
Intake and discharge sampling:
Elapsed collection time: 15 minutes
Method: pump/larval table with ambient water injection to reduce temp. stress
Depth: unknown
Intake location: at intake of Units 2 and 3
Discharge location: discharge for Unit 3 and discharge common to all Units
Water quality parameters measured: DO, pH and conductivity
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied between 2 and 3, outage at Unit 2 from 7/4
Number of pumps in operation:6, at or near full capacity
Temperature: Intake range: 18.8 - 26.4 °C
Discharge range: 22.7 - 34.9 °C
ΔT during study not provided
Biocide use: unknown

Survival Estimation:
Number of sampling events: 7
Total number of samples collected: unknown
Total number of organisms collected: 4097
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed specifically, however, there were 115 Morone spp. organisms which could not be further identified to the species level and there were 55 organisms which were mutilated to the point of being unidentifiable to even the family level of organization. Entrainment survival may have been even lower if these mutilated samples were included in the assessment.
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: striped bass, white perch, bay anchovy and herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: in aerated holding container in ambient water bath for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0 - 11% for bay anchovy
60 - 77% striped bass
66% for white perch
36% for herrings
Initial discharge survival range: 3% for bay anchovy
29 - 45% for striped bass
15% for white perch
11% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: striped bass YSL and PYSL
white perch PYSL
bay anchovy PYSL
herring PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Raw data: were not provided to verify results
Temperature effects: no determination that temperature had a significant effect
Mechanical effects: unknown
Quality control: color coded labels and immediate checks of sorted samples
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1978 Study

Ecological Analysts Inc., 1979c

Sampling: Dates: May 1 - July 12
Samples collection frequency: 2 consecutive days per week
Times of peak abundance: coincided with spawning of targeted species
Time: 1800 - 0200 hours
Number of replicates: approximately 6 per date
Intake and discharge sampling: simultaneous
Elapsed collection time: 15 minutes
Method: pump/ larval table with ambient water injection
Depth: 1 - 3 m below surface, approximately mid-depth
Intake location: Unit 2 and 3 intake
Discharge location: Unit 2 and 3 discharge, discharge point common to all units
Water quality parameters measured: conductivity, pH and DO
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: varied between 5 - 11, near full capacity
Temperature: Intake range: 11.2 - 24.3 °C
Discharge range: 19 - 36 °C
ΔT ranged from 9 - 12 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 22
Total number of samples collected: unknown
Total number of organisms collected: 4496
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at discharge
Most abundant species: striped bass, white perch, bay anchovy and herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 26 - 48% for striped bass
15 -48% for white perch
18% for herring
2% for bay anchovy
Initial discharge survival range: 0 - 34% for striped bass
0 - 37% for white perch
0 - 8% for herring
0% for bay anchovy
Calculation of Entrainment Survival: Discharge survival/ Intake survival
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Significantly lower survival at discharge: striped bass YSL, PYSL and juveniles
white perch PYSL
herring PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none were alive in either the intake or discharge samples
Larval survival: decreased markedly within 24 hours of collection.
Raw data: were not provided to verify results
Temperature effects: at temps. > 30 °C, no striped bass or white perch survived
also 0% survived when both Unit 2 and 3 were running
Mechanical effects: not discussed
Quality control: sorting efficiency checks, color coded labeling, SOPs
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1979 Study

Ecological Analysts Inc., 1981d

Sampling: Dates: March 12 -22 and April 30 - August 14
Samples collection frequency: March: 4 times per week,
rest was 2 consecutive days per week
Times of peak abundance: coincided with spawning of targeted species
Time: 1700 to 0200
Number of replicates: unknown
Intake and discharge sampling: simultaneous sampling
Elapsed collection time: 15 minutes
Method: March sampling: two pump/larval table combination
April- August sampling: rear-draw plankton sampling flume at intake
pumpless plankton sampling flume at discharge
Depth: mid-depth for intake, 1 - 5 m below surface for discharge
Intake location: of Units 2 and 3
Discharge location: in discharge canal for Unit 3 and at end of canal
Water quality parameters measured: conductivity, pH and DO
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: one unit not operating March 20 - 26
only one continuously April - August
Number of pumps in operation: varied between 5 and 12
Temperature: Discharge range: 12.0 - 21.9 °C in March; 24 - 32.9 °C
ΔT data not provided
Biocide use was not noted

Survival Estimation:
Number of sampling events: 8 in March; 32 in April - August
Total number of samples collected: unknown
Total number of organisms collected: 478 in March; 2362 April-August
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: varied
Most abundant species: Atlantic tomcod, striped bass, white perch, herring,
bay anchovy
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars with filtered water for 96 hours
Data: sorted by discharge temperature in March; combined all April - August
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 43 - 68% for Atlantic tomcod
39 - 56% for striped bass
13 - 33% for white perch
23% for herrings
10% for bay anchovy
Initial discharge survival range: 14 - 46% for Atlantic tomcod
62 - 77% for striped bass
24 - 70% for white perch
28% for herrings
6% for bay anchovies
Calculation of Entrainment Survival: For the fish larvae samples, a difference in stress associated with the different sampling techniques at the intake and discharge was given as the reason why discharge survival was higher than intake survival for each taxa sampled. Thus, entrainment survival was not calculated.
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: determined by translucency and hatching success;
33% hatched in discharge samples; 44% in intake samples
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results.
Temperature effects: no white perch or striped bass survival at temps. > 33 °C
Mechanical effects: unknown extent
Quality control: sorting efficiency checks, color coded labels and SOPs
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1980 Study

Ecological Analysts Inc., 1982b

Sampling: Dates: April 30 - July 10
Samples collection frequency: 4 consecutive nights per week
Times of peak abundance: coincided with primary spawning of target species
Time: 1600 - 0200 hours
Number of replicates: unknown
Intake and discharge sampling: initiated simultaneously
Elapsed collection time: 15 minutes
Method: intake: rear-draw plankton sampling flume mounted on raft
discharge: pumpless plankton sampling flume mounted on raft
Depth: unknown
Intake location: Unit 3 intake
Discharge location: discharge port number 1
Water quality parameters measured: conductivity, DO, pH
DOC and POC measured: no
Intake and discharge velocity: intake: 0.3 m/sec; discharge 3 m/sec

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2, Unit 2 offline June 4-11
Number of pumps in operation: varied between 5 and 11
Temperature: intake range: 11.3 - 25.1 °C
discharge range: 23 - 31 °C
ΔT data not presented
Biocide use was not noted

Survival Estimation:
Number of sampling events: 44
Total number of samples collected: unknown
Total number of organisms collected: 2355
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at discharge
Most abundant species: striped bass, white perch, bay anchovies
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: combined by discharge temperature
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 95% for striped bass
93% for white perch
32% for bay anchovies
40% recirculation can occur so intake mortality may include organisms which were dead due to a previous passage through the facility
Initial discharge survival range: 50-81% for striped bass
0-90% for white perch
0-4% for bay anchovy
Calculation of Entrainment Survival: Discharge survival / intake survival
Confidence intervals / standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: hatching success: 82% in intake, 47% in discharge
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results
Temperature effects: little survival at discharge temps > 33 °C
Mechanical effects: unknown
Quality control: sorting efficiency checks, color coded labels and SOPs
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1985 Study

EA Science and Technology, 1986

Sampling: Dates: May 27 - June 29
Samples collection frequency: daily
Times of peak abundance: sampling did not occur during time of peak densities
Time: daytime, switched to nighttime after June 11 due to low sample sizes
Number of replicates: unknown
Intake and discharge sampling: simultaneous sampling
Elapsed collection time: 13 - 15 minutes (200 m^3)
Method: barrel sampler with 2 coaxial cylinders with 505 µm mesh
one sampler at intake; 2 at discharge
Depth: unknown
Intake location: in front of Unit 2 intake
Discharge location: in discharge canal downstream from Unit 2 discharge
Water quality parameters measured: salinity, DO, pH and conductivity
DOC and POC measured: no
Intake and discharge velocity: discharge: 2.8 - 10 ft/sec

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: unknown
Temperature: Intake range: 20.3 - 22.9 °C
Discharge range: 26.6 - 30.3 °C
ΔT range: 4.6 - 8.5 °C
Biocide use: residual chlorine not measured

Survival Estimation:
Number of sampling events: 49
Total number of samples collected: unknown
Total number of organisms collected: 457
Cited low efficiency of sampling gear as part of reason for low numbers of organisms sampled
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal no. of organisms collected at intake and discharge: 3X more at discharge
Most abundant species: bay anchovy
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 48 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 23% for bay anchovy
Initial discharge survival range: 6% for bay anchovy
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals (95%) were presented
No calculations of significance due to small sample size
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results
Temperature effects: unknown, too narrow of temperature range sampled
Mechanical effects: New dual-speed pumps installed in Unit 2 in 1984, study was conducted to determine whether extent of mechanical mortality differed from previous studies.
Quality control: SOPs, reanalysis of samples, double keypunch of all data
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1988 Study

EA Engineering Science and Technology, 1989

Sampling: Dates: June 8 - June 30
Samples collection frequency: unclear
Times of peak abundance: sampling not at peak densities for targeted species
Time: afternoon and evening hours
Number of replicates: varied, unknown number per day
Intake and discharge sampling: simultaneous with twice as many at discharge
Elapsed collection time: 15 minutes
Method: rear-draw sampling flumes, 1 at intake and 2 at discharge
Depth: unknown at intake, surface at bottom at discharge
Intake location: on raft in front of Intake 35
Discharge location: downstream from flow of Units 2 and 3
Water quality parameters measured: salinity, DO, pH
DOC and POC measured: no
Intake and discharge velocity: discharge 2.2 - 10.0 ft/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake range: 20.3 - 23.8 °C
ΔT range: not provided
Biocide use: residual chlorine not monitored

Survival Estimation:
Number of sampling events: 13
Total number of samples collected: unknown
Total number of organisms collected: 12,333
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: 10X more in discharge
Most abundant species: bay anchovy, striped bass, white perch
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 24 hours
Data: was summarized and averaged over the entire sampling period; discharge survival estimates include data from direct release studies and combined surface and bottom samples
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0 - 8% for bay anchovy
86 - 90% for striped bass
Initial discharge survival range: 0 - 2% for bay anchovy
62 - 68% for striped bass
Calculation of Entrainment Survival: discharge survival / intake survival
Standard errors were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none survived in intake and discharge samples
Larval survival: decreased markedly within hours of collection
Raw data: were not provided to verify results
Temperature effects: undetermined effect; too narrow range tested
Mechanical effects: study was conducted to determine the effect of the installation of dual speed circulating water pumps in Unit 2 in 1984 and variable speed pumps in Unit 3 in 1985; mechanical effects were determined to be main cause of mortality when discharge temperatures are < 32 °C
Quality control: SOPs, sampling stress evaluation, reanalysis of samples, double keypunch data
Peer review: not mentioned, study was conducted for the facility

Indian River Power Plant

Indian River Estuary

1975 - 1976 Study

Ecological Analysts Inc., 1978b

Sampling: Dates: July 2, 1975 - December 13, 1976
Samples collection frequency: once or twice monthly
Times of peak abundance: samples not taken frequently enough to detect
Time: mostly at night
Number of replicates: varied
Intake and discharge sampling: not paired
discharge samples not always collected
Elapsed collection time: approximately 5 minutes or until sufficient # collected
Method: 0.5 m diameter plankton sled with 505 µm net
rinsed in 10L of water of unspecified origin
Depth: unknown
Intake location: from foot bridge over intake canal
Discharge location: in discharge canal under roadway bridge
Water quality parameters measured: unknown
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake range: -0.2 - 29.2
Discharge range: 5.4 - 39° C
ΔT ranged from 5.2 - 9.0 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 27
Total number of samples collected: 25 intake and 21 discharge
Total number of organisms collected: unknown
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: unknown
Most abundant species: bay anchovy, Atlantic croaker, spot, weakfish,
Atlantic menhaden and Atlantic silversides
Stunned larvae: not discussed
Dead and opaque organisms: not discussed
Latent survival: in holding containers in ambient water baths for 96 hours
Data: sorted based on discharge temperature
Controls: survival in the intake samples was considered to be the control.
Initial intake survival range: not provided
Initial discharge survival range: not provided
Calculation of Entrainment Survival: not all were counted for most abundant species, a random sample was used instead
Confidence intervals / standard deviations: were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms: unknown
Egg survival: were alive in either the intake or discharge samples.
Larval survival: unclear trend
Raw data: in Appendix B not available to EPA
Temperature effects: all species had lower survival at discharge temps > 20 °C.
only Spot survived above 35 °C though linear regression
Mechanical effects: unknown, however dye studies performed at this facility and recirculation of discharge water has been shown to occur. The extent to which organisms are entrained repeatedly and the effect this has on the number of organisms that were shown to have died through natural causes or from sampling is not known. Thus some intake mortality may be due to the organism's previous passage through the facility.
Quality control: unknown
Peer review: not mentioned, study was conducted for the facility

Muskingum River Plant

Muskingum River, OH

Literature Review

Ecological Analysts Inc., 1979a

Sampling: no on site sampling conducted

Operating Conditions During Sampling:
no sampling conducted

Survival Estimation:

analyzed pressure regimes in circulating water system
measured discharge temperature and ΔT at the facility
determined that pressure regimes were similar to facilities with entrainment survival studies
determined that low survival occurs at ΔT > 7.8 °C which occurs for a small portion of entrainment season
reviewed documentation of survival at other steam electric stations
concluded that potential of survival at this facility was intermediate to high
Peer review: literature review prepared for facility

Northport Generating Station

Long Island Sound, NY

1980 Study

Ecological Analysts Inc., 1981c

Sampling: Dates: April 10 - 22 and July 10 - 23
Samples collection frequency: 5 nights per week
Times of peak abundance: attempted to coincide with peak abundance
Time: 1700 - 0100 hours
Number of replicates: unknown
Intake and discharge sampling: simultaneous
Elapsed collection time: 15 minutes
Method: floating rear-draw sampling flume with 505 μm mesh screens with ambient water injection system
Depth: intake: 2-8 m below surface; discharge: 1.5 m
Intake location: immediately in front of Unit 2 or 3 trash racks
Discharge location: immediately in front of Unit 2 or 3 seal well
Water quality parameters measured: DO, pH, conductivity
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge range: 15.9 - 35 °C, ave 19.9 in April and 33.6 in July
ΔT ranged from 8.6 - 15.0 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 20
Total number of samples collected: 162
Total number of organisms collected: 884 in April and 76 in July
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at discharge
Most abundant species: American sand lance, winter flounder, northern pipefish
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated jars of filtered ambient water for 48 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 66% for American sand lance
85% for winter flounder
28% for bay anchovy
Initial discharge survival range: 17% for American sand lance
35% for winter flounder
0% for bay anchovy
Calculation of Entrainment Survival: discharge survival / intake survival
Stated that survival estimate based on 4 assumptions: that the survival at the discharge is the product of the probabilities of surviving entrainment and sampling, that the survival at the intake is the probability of surviving sampling, that at the discharge there is no interaction between the two stresses, and each life stage consists of a homogenous population in which all individuals have the same probability of surviving to the next life stage
Standard errors were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within 6 hours of collection.
American sand lance significantly larger in intake sample
Raw data: were provided to verify results
Temperature effects: not studied
Mechanical effects: not studied
Quality control: SOPs, color coded labels, sorting efficiency checks
Peer review: not mentioned, study was conducted for the facility

Oyster Creek Nuclear Generating Station

Barnegat Bay, NJ

1985 Study

EA Engineering Science and Technology, 1986

Sampling: Dates: February - August
Samples collection frequency: unknown
Times of peak abundance: smaller samples collected during peak densities
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: discharge collected 2 minutes after intake
Elapsed collection time: approximately 10 minutes
Method: barrel sampler with 2 nested cylindrical tanks with 331 mm mesh
Depth: unknown
Intake location: northernmost intake groin west of recirculation tunnel
Discharge location: easternmost condenser discharge point
Water quality parameters measured: DO, salinity and pH in latent studies
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge range: 13.5 - 39.3 °C
ΔT ranged from -0.2 - 12.1 °C
Biocide use: chlorine concentration was measured, but not detected

Survival Estimation:
Number of sampling events: 20
Total number of samples collected: 13 for bay anchovy eggs, 10 for bay anchovy larvae and 5 for winter flounder
Total number of organisms collected: 60,274
Number of organisms entrained per year: 619 million to 15.4 billion
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no
Most abundant species: bay anchovy and winter flounder
Stunned larvae: included in initial survival proportion; as well as damaged
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars in water baths for 96 hours
Data: grouped by 3 day long sampling events
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 38 - 91% for bay anchovy larvae
77 - 96% for winter flounder larvae
Initial discharge survival range: 0 - 71% for bay anchovy larvae
32 - 92% for winter flounder larvae
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals / standard deviations: were not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: no
Egg survival: based on translucency and hatching success
Larval survival: decreased markedly within 3 hours of collection
Raw data: were not provided to verify results
Temperature effects: no bay anchovy larvae survived at discharge > 35 °C
Mechanical effects: 18.8% of mortality at discharge temperatures 25.9 - 27.0 °C
Quality control: unknown
Peer review: not mentioned, study was conducted for the facility

Pittsburg Power Plant

Suisun Bay, CA

1976 Study

Stevens and Finlayson, 1978

Sampling: Dates: April 28 - July 10
Samples collection frequency: once per week
Times of peak abundance: unknown
Time: varied, about 25% of all samples collected at night
Number of replicates: typically 3
Intake and discharge sampling: paired at closest time and temperature
Elapsed collection time: 1 - 2 minutes
Method: 505 micron mech conical nylon plankton net with 0.58 m plastic collecting tubes on cod end; towed net on boat at 0.6 ft/sec
Depth: mid-depth
Intake location: in river near intake
Discharge location: in river near discharge
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake temperature: 18 - 30 °C
Discharge temperature 27 - 37 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 7
Total number of samples collected: unknown
Total number of organisms collected: 462 (585 at north shore control)
Number of organisms entrained per year: unknown
Fragmented organisms: enumerated in one replicate tow
higher proportion of unidentifiable fragments in intake
43% in intake; 19% in discharge
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: striped bass
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: was summarized by mean larval length
Controls: survival in the intake samples was considered to be the control
additional controls in center of river and north shore
control site at north shore away from intake had lower mortality rates
Initial intake survival range: 49 - 93% for striped bass
Initial discharge survival range: 8 - 87% for striped bass
Calculation of Entrainment Survival: paired discharge survival divided by paired intake survival
Confidence intervals / standard deviations: were not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: increased survival with greater larval length
Raw data: were not provided to verify results
Temperature effects: mortality increased with increase in discharge temperature
higher mortality with discharge temp. > 31 and $\Delta T > 7$ °C
linear regression showed that half died at temps >33.3 °C
0% survival at temperatures of 38 °C
Mechanical effects: stated not as much of an effects as temperature;
recirculated water may be cause of some intake mortality
Quality control: not discussed
Peer review: study conducted by California Fish and Game with funds provided by facility

Port Jefferson Generating Station

Long Island Sound, NY

1978 Study

Ecological Analysts Inc., 1978d

Sampling: Dates: April 21 - 26
Samples collection frequency: 4 times in one week
Times of peak abundance: unclear if sampling coincided with peak densities
Time: 1800 - 0200 hours
Number of replicates: varied between 7 - 10 per sampling date.
Intake and discharge sampling: simultaneous collection, equal number at sites
Elapsed collection time: 15 minutes
Method: pump (2 different types) and larval table
Depth: intake: 2 m below mean low water mark
discharge: 1 m below mean low water mark
Intake location: in front of trash racks of intake of Unit 4
Discharge location: in common seal well structure for Units 3 and 4
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: 4
Temperature: Intake range: 7 - 9 °C
Discharge range: 10 - 18 °C
ΔT ranged from 2 - 11 °C
Biocide use: sampling coincided with time of no biocide use

Survival Estimation:
Number of sampling events: 5
Total number of samples collected: 94
Total number of organisms collected: 1104
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no, quite different
Most abundant species: winter flounder, sand lance, sculpin, American eel, fourbeard rockling eggs
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars in water bath for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 42 - 60% for winter flounder PYSL
11 - 67% for sand lance PYSL
33 - 84% sculpin PYSL
25 - 100% American eel juveniles
11 - 26% fourbeard rockling eggs
Initial discharge survival range:0 - 43% for winter flounder PYSL
12 - 40% for sand lance PYSL
88% for sculpin PYSL
94 - 96% for American eel juveniles
19 - 21% fourbeard rockling eggs
Calculation of Entrainment Survival: Discharge survival / intake survival
Confidence intervals / standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: winter flounder PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: classified by observation only, based on transparency
Larval survival: no information given on length or other life stages
Raw data: were provided to verify results
Temperature effects: no apparent relationship temperature and survival; low numbers collected at a narrow range of discharge temperatures
Mechanical effects: assumed cause of all mortality
Quality control: color coded labeling, checks of sorted samples, and SOPs
Peer review: not mentioned, study was conducted for the facility

PG&E Potrero Power Plant

San Francisco Bay, CA

1979 Study

Ecological Analysts Inc., 1980b

Sampling: Dates: January
Samples collection frequency: unknown
Times of peak abundance: unclear if sampling corresponded with peak densities
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: equal number but timing unknown
Elapsed collection time: 15 minutes
Method: 2 pumps and larval table with filtered ambient temperature water flow
Depth: mid-depth
Intake location: directly in front of intake skimmer wall
Discharge location: at point where discharge enters San Francisco Bay
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge range: 18 - 19.5 °C
ΔT range not presented
Biocide use: not used during sampling events

Survival Estimation:
Number of sampling events: 11
Total number of samples collected: 25
Total number of organisms collected: 1262
Number of organisms entrained per year: estimated for Units 1-3: 3 billion
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: approx. same
Most abundant species: Pacific herring
Stunned larvae: issue of stunned larvae not discussed in study
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars in water baths for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 22% for Pacific herring
Initial discharge survival range: 16% for Pacific herring
Calculation of Entrainment Survival: Discharge survival/ Intake survival
Confidence intervals / standard deviations: were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: no
Egg survival: not studied
Larval survival: Based on results of this study, an estimate of 75% entrainment survival was used for all species and life stages entrained at this facility under all conditions
Raw data: were not provided to verify results
Temperature effects: discharge temps < 30 °C over 99.5% of time
Mechanical effects: most likely cause of mortality due to low temperatures
Quality control: unknown
Peer review: not mentioned, study was conducted for the facility

Quad Cities Nuclear Station

Mississippi River, IL

1978 Study

Hazleton Environmental Science Corporation, 1978

Sampling: Dates: June 19 - 28
Samples collection frequency: varied
Times of peak abundance: unknown
Time: afternoon, evening or nighttime hours
Number of replicates: varied
Intake and discharge sampling: unknown if paired
Elapsed collection time: did not exceed 60 seconds
Method: from boat, with 0.75 m conical plankton net with 526 µm mesh and an unscreened 5 L bucket attached
Depth: mid-depth at intake, near surface at discharge
Intake location: intake forebay
Discharge location: in discharge canal common to all units;
held at discharge temp for 8.5 minutes to simulate passage through canal
then cooled to ambient temp. plus 3.5 °C before sorting
Water quality parameters measured: DO
DOC and POC measured: no
Intake and discharge velocity: exceed 1 ft/sec

Operating Conditions During Sampling: completely open cycle mode
Number of units in operation: power output 41 - 99%, Unit 1 offline on June 22
Number of pumps in operation: all 3 regardless of power load
Temperature: Intake range: 21.5 - 26.5 °C
Discharge range: 28.0 - 39.0 °C
ΔT ranged from 5.5 - 14.8 °C
Biocide use: not used during sampling

Survival Estimation:
Number of sampling events: 5
Total number of samples collected: unknown
Total number of organisms collected: 2587
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at discharge
Most abundant species: freshwater drum and minnows
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: assumed dead from natural mortality prior to collection and omitted from further analysis; 27% of all sampled
Latent survival: observed in aerated glass jars for 24 hours on June 22-23, 26-27
Data: combined by % power of station operation
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0 - 80% for all species
0 - 100% for freshwater drum
48 - 100% for minnows
Initial discharge survival range: 0 - 84% for all species
0 - 71% for freshwater drum
2 - 75% for minnows
Calculation of Entrainment Survival: Discharge survival/Intake survival
(minus dead and opaque individuals)
When discharge survival was greater than intake survival, the study indicated that entrainment survival could not be calculated, rather than assume 100 percent entrainment survival
Confidence intervals / standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: throughout study
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not presented
Larval survival: decreased with increasing power output and discharge temperature
3% survival for all species when the facility operated near full capacity (96-99 percent) and discharge temperatures exceeded 37.9 ˚C
Raw data: were provided to verify results, however replicate sample data not presented
Temperature effects: lower survival with higher discharge temperatures > 30 °C
Mechanical effects: suggest mechanical effects cause 20 - 25% of mortality
Quality control: not discussed
Peer review: not mentioned, study was conducted for the facility

Quad Cities Nuclear Station

Mississippi River, IL

1984 Study

Lawler Matusky & Skelly Engineers, 1985

Sampling: Dates: April 25 - June 27
July sampling canceled as 100% mortality was suspected
Samples collection frequency: weekly
Times of peak abundance: unknown
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: unknown if paired
Elapsed collection time: unknown
Method: from boat, with 0.75 m conical plankton net with 526 µm mesh and an unscreened 5 L bucket attached
Depth: 1.5 m for intake, surface for discharge
Intake location: intake forebay
Discharge location: in discharge canal; held at collection temperature for 8.5 min. then cooled to 3.5 °C above ambient temperature with an ice bath, in all held for over 20 minutes before sorting
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: samples collected at < 0.8 ft/sec

Operating Conditions During Sampling: operating at 40.2 to 50.7 % capacity
Number of units in operation: Unit 1 offline for refueling;
both units offline on May 9
Number of pumps in operation: all 3 on all dates except on May 9
Temperature: Intake range: 11 - 24.4 °C
Discharge range: 12 - 37 °C
ΔT ranged from 9.5 to 14.5 °C; 1 °C on May 9 when offline
Biocide use: not used during sampling

Survival Estimation:
Number of sampling events: 8
Total number of samples collected: unknown
Total number of organisms collected: 3967
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: approx. same total
Most abundant species: freshwater drum, carp and buffalo
Stunned larvae: not discussed
Dead and opaque organisms: omitted from analysis; assumed dead before collection, 2, 979 opaque individuals were collected
(75% of total, 87% of all discharge sample. range: 0 to 99% in samples)
None were found to be dead and opaque in discharge on May 9 when offline and ΔT was 1 ˚C.
Latent survival: not discussed
Data: combined by species and sampling date
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: results not presented, only number alive
10 - 81% were dead and opaque
Initial discharge survival range: results not presented, only number alive
24 - 99% were dead and opaque
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals / standard deviations: were not presented.
Significant differences were not tested due to low numbers collected
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: too little information to make any assumption of survival
Raw data: were not provided to verify results; totals collected per species not presented; actual numbers of dead and opaque not provided
Temperature effects: no sampling in July when discharge temps > 37 °C
Mechanical effects: not discussed
Quality control: 100% reanalysis quality control
Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1975 Study

Ecological Analysts, Inc., 1976c

Sampling: Dates: May 29th - November 18th
Collection frequency: varied from 4 times per week to once every 2 weeks.
Times of peak abundance: greater frequency of collection
Time: varied but generally occurred between dusk and dawn
Number of replicates: varied between 3and 14 for each date
Intake and discharge sampling: paired but timing not standardized
Elapsed collection time: not noted
Method: pump/larval table
Depth: mid-depth at both the intake and discharge
Intake location: in front of the trash rack
Discharge location: from the seal well before the end of the discharge pipe
Water quality parameters measured: none mentioned
DOC and POC measured: no
Intake and discharge velocity: not given

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: varied between 2 and 3
Temperature: ΔT ranged from 3 to 13 °C, intake and discharge T not given
Biocide use: not noted

Survival Estimation:
Number of sampling events: 41
Number of samples: 672
Number of organisms collected: 3,667
Number of organisms entrained per year: not discussed
Fragmented organisms collected: not discussed
Equal number collected from intake and discharge: differed by as much as 3.2X
Most abundant species: striped bass, white perch, alewife and blueback herring
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 96 hours.
Data: summarized and averaged over the entire sampling period
Controls: survival in intake sample; no other control
Initial intake survival range: 57 to 80% for striped bass
0 to 71% for white perch
58 to 65% for herrings
Initial discharge survival range: 62% for striped bass
29% for white perch
26% for herrings
Calculation of entrainment survival: Discharge Survival/Intake Survival
Study noted that survival cannot be calculated with insufficient data or when intake survival is very low
Confidence intervals/ standard deviations: not presented
Significant differences: tested between the intake and discharge survival
Significantly lower survival in discharge: striped bass YSL and PYSL
white perch PYSL
herring PYSL and juveniles
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none alive in either the intake or discharge samples
Larval survival: decreased markedly within 3 hours of collection
Size effects: survival by larval length was not studied
Raw data: were not provided to verify results
Temperature effects: not provided
Mechanical effects: not provided
Quality control: double check after initial sorting; monitoring of data entry
Peer review: not mentioned; study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1976 Study

Ecological Analysts Inc., 1978e

Sampling: Dates: June 14th - July 30th
Samples collection frequency: 4 nights per week
Times of peak abundance: coincided with *Morone* spp. spawning season
Time: 1700 to 0300 EST
Number of replicates: actual numbers not give, an average of 12 per night stated
Intake and discharge sampling: pairing unknown
Elapsed collection time: 15 minutes
Method: pump/ larval table combination
Depth: mid-depth for both intake and discharge
Intake location: 1 m in front of trash rack
Discharge location: in seal well near end of discharge pipe
Water quality parameters measured: no
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied between 0 and 2
Number of pumps in operation: not given
Temperature: Intake temperature range: 18.7 - 27.5 °C
Discharge temperature ranged 24 - 37 °C
ΔT ranged from 1- 10 °C
Biocide use: not noted

Survival Estimation:
Number of sampling events: 27
Total number of samples collected: unknown
Total number of organisms collected: 3,491
Number of organisms entrained per year: not given
Fragmented organisms: not discussed
Equal number of organisms collected at intake / discharge: no, up to 5.7X more
Most abundant species: herrings, white perch and striped bass
Stunned larvae: were included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 96 hours
Data: combined by discharge temperature range: 34 - 30.5 and 30.6 to 37°C
Controls: Survival in the intake samples; no other control.
Initial intake survival range: 74-100% for striped bass
53-94% for white perch
49-68% for herrings
Initial discharge survival range: 14 - 80% for striped bass
6 - 56% for white perch
5 - 29% for herrings
Calculation of Entrainment Survival: Discharge Survival/ Intake Survival
Data for many taxa or life stages collected were insufficient for analysis
Confidence intervals / standard deviations: were not presented
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: striped bass PYSL
white perch PYSL and juveniles
herring PYSL and juveniles
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: data not presented
Larval survival: decreased markedly within 3 hours of collection.
Size effects: survival by larval length was not studied
Raw data: were not provided to verify results
Temperature effects: significant decrease in survival at discharge temp > 30 °C
Mechanical effects: unknown
Quality control: double check after initial sorting; monitoring of data entry
Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1977 Study

Ecological Analysts Inc., 1978f

Sampling: Dates: March 3-17 and May 31st - July 15th
Samples collection frequency: unknown; usually 4 nights per week was stated
Times of peak abundance: coincided with spawning of targeted species
Time: 1700 to 0300 hours EST
Number of replicates: unknown; an average of 8 to 10 per night was stated
Intake and discharge sampling: unknown if samples were collected in pairs
Elapsed collection time: 15 minutes
Method: pump/larval table combination
    ambient water flow in table to reduce thermal exposure during sorting
Depth: mid-depth
Intake location: in front of trash racks
Discharge location: from seal well 244 m from end of discharge pipe
Water quality parameters measured: no
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: varied between 2 and 4
Temperature: Intake temperature: 0.5 - 5.5 °C (March); 11-27 °C (June/July)
    Discharge temperature: 7 - 17 °C (March); 24 - 36 °C (June/July)
    ΔT range: unknown
Biocide use was not noted

Survival Estimation:
Number of sampling events: unknown
Total number of samples collected: unknown
Total number of organisms collected: 6,973
Number of organisms entrained per year: unknown
Fragmented organisms: if >50% present, organism was counted
Equal number collected at intake and discharge: up to 2.3X more in discharge
Most abundant species: atlantic tomcod, herrings, striped bass, white perch
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 96 hours
Data: combined by discharge temperature range, <29.9, 30.0 - 32.9, >33 °C
Controls: Survival in the intake samples was considered to be the control
Initial intake survival range: 39% for Atlantic tomcod
    0 to 50% for striped bass
    0 to 33% for white perch
    0 to 59% for herrings
Initial discharge survival range: 16% for Atlantic tomcod
    0 to 83% for striped bass
    0 to 50% for white perch
    0 to 14% for herrings
Calculation of Entrainment Survival: Discharge Survival / Intake Survival
Confidence intervals / standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: Atlantic tomcod YSL
    striped bass PYSL
    white perch PYSL
    herring PYSL and juveniles
Survival calculated for species with fewer than 100 organisms collected: yes
    number of some taxa and life stage were too low to estimate survival reliably
Egg survival: data not presented
Larval survival: decreased markedly within 3 hours of collection.
    increased with larval length
Raw data: were not provided to verify results
Temperature effects: survival decreased at temperatures above 30 °C
    very low survival at temperatures > 33 °C (0 to 3%)
Mechanical effects: survival may increase with number of pumps operating
Quality control: color coded labels, immediate checks of sorted sample, SOP’s
Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1978 Study

Ecological Analysts Inc., 1980c

Sampling: Dates: March 13 - 23 and June 6 - July 13
Samples collection frequency: 3 - 4 nights per week
Times of peak abundance: coincided with spawning of targeted species
Time: 1700 to 0300 EDT
Number of replicates: 4 to 10 per night
Intake and discharge sampling: unknown if paired samples
Elapsed collection time: 15 minutes
Method: pump/ larval table combination with fine mesh
ambient water flow to table to minimize thermal exposure when sorting
Depth: mid-depth
Intake location: in front of trash rack
Discharge location: in seal well 244 m from end of discharge pipe
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: varied between 2 and 3
Temperature: Intake temperature: 0.2 - 5.5°C (March), 19.8 - 24.0°C (June/July)
Discharge temperature: 10 - 19°C (March), 24 - 37 °C (June/July)
ΔT range was not given
Biocide use was not noted

Survival Estimation:
Number of sampling events: 30
Total number of samples collected: 256
Total number of organisms collected: 5,308
Number of organisms entrained per year: unknown
Fragmented organisms: counted if >50% of organism was present
22% of Atlantic tomcod could not be identified to life stage due to damage
Equal number of organisms collected at intake and discharge: varied
Most abundant species: herrings, white perch, striped bass, Atlantic tomcod
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 96 hours
Data: combined by discharge temperature range <29.9, 30.0 - 32.9, >33 °C
also combined by larval length
Controls: Survival in the intake samples was considered to be the control
Initial intake survival range: 75-84% for Atlantic tomcod
8 - 100% for striped bass
0 - 93% for white perch
0 - 67% for herrings
Initial discharge survival range: 23-33% for Atlantic tomcod
0 - 50% for striped bass
0 - 100% for white perch
0 - 18% for herrings
Calculation of Entrainment Survival: Discharge survival/ Intake survival
Confidence intervals / standard deviations: were not presented
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: Atlantic tomcod YSL and PYSL
striped bass PYSL
white perch PYSL
herring PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
samples sizes of some taxa and life stages were too small to analyze survival
Egg survival: data not presented
Larval survival: decreased markedly within 3 - 6 hours of collection
increased with larval length
Raw data: consolidated data by temp. and length was provided; not by sample
Temperature effects: significant decrease in survival at temperatures > 24 °C
very little survival at temperatures > 30 °C
Mechanical effects: lower tomcod survival in discharge w/o thermal effects
Quality control: color coded labels, checks of sorted samples, SOP's
Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1980 Study

Ecological Analysts Inc., 1983

Sampling: Dates: May 26 - July 31

Samples collection frequency: usually 4 nights per week
Times of peak abundance: coincided spawning of striped bass and white perch
Time: 1600 to 0200 EDT
Number of replicates: varied between 1 and 10 per sampling date
Intake and discharge sampling: unknown if samples were paired
Elapsed collection time: 15 minutes
Method: pump/larval table or plankton sampling flume
ambient water injection system to minimize thermal exposure
Depth: unknown
Intake location: from the No. 1B circulating water pump forebay
Discharge location: from discharge seal well or submerged diffuser port
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:

Number of units in operation: varied between 1 and 2
Number of pumps in operation: varied between 3 and 4
Temperature: Intake temperature: 17.0 - 29.0 °C
Discharge temperature: 21.5 - 34.5 °C
ΔT range not given
Biocide use was not noted

Survival Estimation:

Number of sampling events: 42
Total number of samples collected: 1431
Total number of organisms collected: 4,965
Number of organisms entrained per year: not given
Fragmented organisms: counted if >50% of organism was present
7% of all organisms would not be identified to a life stage due to damage
Equal no. of organisms collected at intake/ discharge: more samples at discharge
Most abundant species: herrings, striped bass, white perch
Stunned larvae: were included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 48 hours.
Data: combined by larval length
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 33 - 100% for striped bass
0 - 75% for white perch
30 - 53% for herrings
Initial discharge survival range: 23 - 100% for striped bass
0 - 88% for white perch
0 - 31% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals / standard deviations: were not presented.
Significant differences were tested for latent survival only
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: decreased markedly within 3 - 6 hours of collection
survival increased with larval length
survival lowest for YSL and highest for juveniles
survival using flume was very low
Raw data: only consolidated data were presented, not by sample
Temperature effects: data not given
Mechanical effects: number of pumps may not affect survival
Quality control: color coded labels, SOPs
Peer review: not mentioned, study was conducted for the facility

Salem Generating Station

Delaware Bay, NJ

1984 Demonstration Study

Public Service Electric & Gas, 1984a

Sampling: Dates: 1977 - 1982
Samples collection frequency: varied, 1 to 4 times per month
Times of peak abundance: highest frequency in June and July
Time: unknown
Number of replicates: varied from 0 to 13 per sampling event
Intake and discharge sampling: usually paired with lag time
Elapsed collection time: 10 minutes
Method: larval table(1977- 1980) or low-velocity flume (1981-1982)
Depth: mid-depth for intake
Intake location: at intake bay 11A or 12B, inboard of traveling screen
Discharge location: discharge standpipe 12 or 22
Water quality parameters measured: unknown
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake temperature: unknown
Discharge temperature: unknown
ΔT range: unknown
Lab simulation studies used to test thermal mortality
Biocide use: three 30 minute periods of chlorination each day
estimated biocide use reduces survival by 6.25%

Survival Estimation:
Number of sampling events: 0 to 12 per year, 38 in all years combined
Total number of samples collected: varied per year, 640 in all years combined
Total number of organisms collected: 5,173 larvae and juvenile fish of 6 taxa
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal no. of organisms collected at intake/ discharge: unknown
Most abundant species: spot and alewife
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: tests varied with year, 12 to 96 hours in jars or aquaria
Data: combined data from all years, collected under all conditions
Controls: some fish were introduced into the larval table or low velocity flume directly; unclear if organisms passed through facility
Initial intake survival range: 90.9 % for Spot
12.5% for Herrings
Initial discharge survival range: 74.1% for Spot
7.1% for Herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Estimated survival rates from onsite and simulation studies and compared with results in the literature from other waterbodies to select “the most realistic estimates”
Confidence intervals / standard deviations: not presented
Significant differences: not tested
Survival calculated for species with fewer than 100 organisms collected: unknown
Egg survival: none collected
Larval survival: not separated from juvenile survival
Raw data: was not provided to verify results
Temperature effects: unknown
Mechanical effects: tested gear efficiency and related mortality only
Quality control: not mentioned
Peer review: not mentioned, study conducted for the facility

Chapter A8: Impingement & Entrainment by Waterbody Type

INTRODUCTION

The environmental impacts of cooling water intake structures (CWISs) are closely tied to the biological productivity of the waterbody from which cooling water is withdrawn. This chapter discusses CWIS impacts on specific waterbody types, including rivers and streams, lakes and reservoirs (excluding the Great Lakes), the Great Lakes, oceans, and estuaries. Habitats of particular biological sensitivity are highlighted within each type.

CHAPTER CONTENTS

A8-1 CWIS IMPINGEMENT AND ENTRAINMENT IMPACTS IN RIVERS AND STREAMS

Freshwater rivers and streams are free-flowing bodies of water that do no receive significant inflows of water from oceans or bays (Hynes, 1970; Allan, 1995). Current is typically highest in the center of a river and rapidly drops toward the edges and at depth because of increased friction with river banks and the bottom. Close to and at the bottom, the current can become minimal. The range of flow conditions in undammed rivers helps explain why fish with very different habitat requirements can co-exist within the same stretch of surface water (Matthews, 1998).

In general, the shoreline areas along river banks support a high diversity of aquatic life. These are areas where light penetrates to the bottom and supports the growth of rooted vegetation. Suspended solids tend to settle along shorelines where the current slows, creating shallow, weedy areas that attract aquatic life. Riparian vegetation, if present, also provides cover and shade. Such areas represent important feeding, resting, spawning, and nursery habitats for many aquatic species. In temperate regions, the number of impingeable and entrainable organisms in the littoral zone of rivers increases during the spring and early summer when most riverine fish species reproduce. This concentration of aquatic organisms along river shorelines in turn attracts wading birds and other kinds of wildlife.

Fish species such as common carp (*Cyprinus carpio*), yellow perch (*Perca flavescens*), white bass (*Morone chrysops*), freshwater drum (*Aplodinotus grunniens)*, gizzard shad (*Dorosoma cepedianum*), and alewife (*Alosa pseudoharengus*) are the main fishes harmed by CWIS located in rivers. These species occur in nearshore areas and/or have pelagic early life stages, traits that greatly increase their susceptibility to impingement and entrainment (I&E).

A8-2 CWIS IMPINGEMENT AND ENTRAINMENT IMPACTS IN LAKES AND RESERVOIRS

Lakes are inland bodies of open water located in natural depressions (Goldman and Horne, 1983). Lakes are fed by rivers, streams, springs, and/or local precipitation. The residence time of water in lakes can be weeks, months, or even years, depending on the size and volume of the lake. Water currents in lakes are small or negligible compared to rivers, and are most noticeable near lake inlets and outlets.

Larger lakes are divided into three general zones — the littoral zone (shoreline areas where light penetrates to the bottom), the limnetic zone (the surface layer where most photosynthesis takes place), and the profundal zone (relatively deeper and colder offshore area) (Goldman and Horne, 1983). Each zone differs in its biological productivity and species diversity and hence in the potential magnitude of I&E. The importance of these zones in relation to potential I&E impacts of CWIS are discussed below.

The highly productive littoral zone extends farther and deeper in clear lakes than in turbid lakes. In small, shallow lakes, the littoral zone can be quite extensive and even include the entire waterbody. As along river banks, this zone supports high primary productivity and biological diversity. It is used by a host of fish species, benthic invertebrates, and zooplankton for feeding, resting, and reproduction, and as nursery habitat. Many fish species adapted to living in the colder profundal zone also move to shallower in-shore areas to spawn, e.g., lake trout (*Salmo namycush*) and various deep water sculpin species (*Cottus* spp.).

Many fish species spend most of their early development in and around the littoral zone of lakes. These shallow waters warm up rapidly in spring and summer, offer a variety of different habitats (submerged plants, boulders, logs, etc.) in which to hide or feed, and stay well-oxygenated throughout the year. Typically, the littoral zone is a major contributor to the total primary productivity of lakes (Goldman and Horne, 1983).

The limnetic zone is the surface layer of a lake. The vast majority of light that enters the water column is absorbed in this layer. In contrast to the high biological activity observed in the nearshore littoral zone, the offshore limnetic zone supports fewer species of fish and invertebrates. However, during certain times of year, some fish and invertebrate species that spend the daylight hours hiding on the bottom rise to the surface of the limnetic zone at night to feed and reproduce. Adult fish may migrate through the limnetic zone during seasonal spawning migrations. The juvenile stages of numerous aquatic insects — such as caddisflies, stoneflies, mayflies, dragonflies, and damselflies — develop in sediments at the bottom of lakes but move through the limnetic zone to reach the surface and fly away. This activity attracts foraging fish.

The profundal zone is the deeper, colder area of a lake. Rooted plants are absent because insufficient light penetrates at these depths. For the same reason, primary productivity by phytoplankton is minimal. A well-oxygenated profundal zone can support a variety of benthic invertebrates or cold-water fish. With few exceptions, these species seek out shallower areas to spawn, either in littoral areas or in adjacent rivers and streams, where they may become susceptible to I&E at CWIS.

Most of the larger rivers in the United States have one or more dams that create artificial lakes or reservoirs. Reservoirs have some characteristics that mimic those of natural lakes, but large reservoirs differ from most lakes in that they obtain most of their water from a large river instead of from groundwater recharge or from smaller creeks and streams.

The fish species composition in reservoirs may or may not reflect the native assemblages found in the pre-dammed river. Dams create two significant changes to the local aquatic ecosystem that can alter the original species composition: (1) blockages that prevent anadromous species from migrating upstream, and (2) altered hydrologic regimes that can eliminate species that cannot readily adapt to the resulting changes in flow and habitat.

Reservoirs typically support littoral zones, limnetic zones, and profundal zones, and the same concepts outlined above for lakes apply to these bodies of water. For example, compared to the profundal zone, the littoral zone along the edges of reservoirs supports greater biological diversity and provides prime habitat for spawning, feeding, resting, and protection for numerous fish and zooplankton species. However, there are also several differences. Reservoirs often lack extensive shallow areas along their edges because their banks have been engineered or raised to contain extra water and prevent flooding. In mountainous areas, the banks of reservoirs may be quite steep and drop off precipitously with little or no littoral zone. As with lakes and rivers, however, CWIS located in shallower water have a higher probability of entraining or impinging organisms.

A8-3 CWIS IMPINGEMENT AND ENTRAINMENT IMPACTS IN THE GREAT LAKES

The Great Lakes were carved out by glaciers during the last ice age (Bailey and Smith, 1981). They contain nearly 20 percent of the earth's fresh water, or about 23,000 km^3 (5,500 cu. mi.) of water, covering a total area of 244,000 km^2 (94,000 sq. mi.). There are five Great Lakes: Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario. Although part of a single system, each lake has distinct characteristics. Lake Superior is the largest by volume, with a retention time of 191 years, followed by Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario.

Water temperatures in the Great Lakes strongly influence the physiological processes of aquatic organisms, affecting growth, reproduction, survival, and species temporal and spatial distribution. During the spring, many fish species inhabit shallow, warmer waters where temperatures are closer to their thermal optimum. As water temperatures increase, these species migrate to deeper water. For species that are near the northern limit of their range, the availability of shallow, sheltered habitats that warm early in the spring is probably essential for survival (Lane et al., 1996a). For other species, using warmer littoral areas increases the growing season and may significantly increase production.

Some 80 percent of Great Lakes fishes use the littoral zone for at least part of the year (Lane et al., 1996a). Of 139 Great Lakes fish species reviewed by Lane et al. (1996b), all but the deepwater ciscoes (*Coregonus* spp.) and deepwater sculpin (*Myxocephalus thompsoni*) use waters less than 10 m deep as nursery habitat.

A8-4 CWIS IMPINGEMENT AND ENTRAINMENT IMPACTS IN ESTUARIES

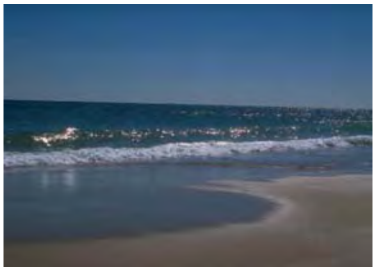
Estuaries are semi-enclosed bodies of water that have a an unimpaired natural connection with the open ocean and within which sea water is diluted with fresh water derived from land (Day et al., 1989). The dynamic interactions among freshwater and marine environments in estuaries result in a rich array of habitats used by both terrestrial and aquatic species. Because of the high biological productivity and sensitivity of estuaries, adverse environmental impacts are more likely to occur at CWIS located in estuaries than in other waterbody types.

Numerous commercially, recreationally, and ecologically important species of fish and shellfish spend part or all of their life cycle within estuaries. Marine species that spawn offshore take advantage of prevailing inshore currents to transport their eggs, larvae, or juveniles into estuaries where they hatch or mature. Inshore areas along the edges of estuaries support high rates of primary productivity and are used by numerous aquatic species for feeding and as nursery habitats. This high level of biological activity makes these shallow littoral zone habitats highly susceptible to I&E impacts from CWIS.

Estuarine species that show high rates of I&E include bay anchovy (*Anchoa mitchilli*), winter flounder (*Pleuronectes americanus*), and weakfish (*Cynoscion regalis*). During spring, summer and fall, various life stages of these and other estuarine fishes show considerable migratory activity. Adults move in from the ocean to spawn in the marine, brackish, or freshwater portions of estuaries or tributary rivers; the eggs and larvae can be planktonic and move about with prevailing currents or by using selective tidal transport; juveniles actively move upstream or downstream in search of optimal nursery habitat; and young adult anadromous fish move out of freshwater areas and into the ocean to reach sexual maturity. Because of the many complex movements of estuarine-dependent species, a CWIS located in an estuary can harm both resident and migratory species as well as related freshwater, estuarine, and marine food webs.

A8-5 CWIS IMPINGEMENT AND ENTRAINMENT IMPACTS IN OCEANS

Oceans are marine open coastal waters with salinity greater than or equal to 30 parts per thousand (Ross, 1995). CWIS in oceans are usually located over the continental shelf, a shallow shelf that slopes gently out from the coastline an average of 74 km (46 miles) to where the sea floor reaches a maximum depth of 200 m (660 ft) (Ross, 1995). The deep ocean extends beyond this region. The area over the continental shelf is known as the Neritic Province and the area over the deep ocean is the Oceanic Province (Meadows and Campbell, 1978).



Vertically, the upper, sunlit epipelagic zone over the continental shelf averages about 100 m in depth (Meadows and Campbell, 1978). This zone has pronounced light and temperature gradients that vary seasonally and influence the temporal and spatial distribution of marine organisms.

In oceans, the littoral zone encompasses the photic zone of the area over the continental shelf. As in other waterbody types, the littoral zone is where most marine organisms concentrate. The littoral zone of oceans is of particular concern in the context of section 316(b) because this biologically productive zone is also where most coastal utilities withdraw cooling water.

The morphology of the continental shelf along the U.S. coastline is quite varied (NRC, 1993). Along the Pacific coast of the United States the continental shelf is relatively narrow, ranging from 5 to 20 km (3 to 12 miles), and is cut by several steep-sided submarine canyons. As a result, the littoral zone along this coast tends to be narrow, shallow, and steep. In contrast, along most of the Atlantic coast of the United States, there is a wide, thick, and wedge-shaped shelf that extends as much as 250 km (155 miles) from shore, with the greatest widths generally opposite large rivers. Along the Gulf coast, the shelf ranges from 20 to 50 km (12 to 31 miles).

The potential for I&E at ocean facilities can be quite high if CWIS are located in the productive areas over the continental shelf where many species reproduce, or in nearshore areas that provide nursery habitat. In addition, the early life stages of many species are planktonic, and tides and currents can carry these organisms over large areas. The abundance of plankton in temperate regions is seasonal, with greater numbers in spring and summer and fewer numbers in winter. An additional concern for ocean CWIS is the presence of marine mammals and reptiles, including threatened and endangered species of sea turtles. These species are known to enter submerged offshore CWIS and can drown once inside the intake tunnel.

A8-6 SUMMARY AND CONCLUSIONS

Fish species with free-floating, early life stages are those most susceptible to CWIS impacts. Such planktonic organisms lack the swimming ability to avoid being drawn into intake flows. Species that spawn in nearshore areas, have planktonic eggs and larvae, and are small as adults experience even greater impacts because both new recruits and the spawning adults are affected (e.g., bay anchovy in estuaries and oceans). Fish species in estuaries and oceans experience the highest rates of I&E because fish spawning and nursery areas are located throughout estuaries and near coastal waters, making it difficult to avoid locating intakes in areas where fish are present.

Chapter A9: Economic Benefit Categories and Valuation

INTRODUCTION

Changes in cooling water intake structure (CWIS) design or operations resulting from the final section 316(b) rule for existing facilities are expected to reduce impingement and entrainment (I&E) losses of fish, shellfish, and other aquatic organisms and, as a result, the rulemaking is expected to increase the numbers of individuals present, increase local and regional fishery populations, and ultimately contribute to the enhanced environmental functioning of affected waterbodies (rivers, lakes, estuaries, and oceans) and associated ecosystems. The economic welfare of human populations is expected to increase as a consequence of the improvements in fisheries and associated aquatic ecosystem functioning.

CHAPTER CONTENTS

The aquatic resources affected by cooling water intake structures provide a wide range of services. Ecosystem services are the physical, chemical, and biological functions performed by natural resources and the human benefits derived from those functions, including both ecological and human use services (Daily, 1997; Daily et al., 1997). Scientific and public interest in protecting ecosystem services is increasing with the recognition that these services are vulnerable to a wide range of human activities and are difficult, if not impossible, to replace with human technologies (Meffe, 1992).

In addition to their importance in providing food and other goods of direct use to humans, the organisms lost to I&E are critical to the continued functioning of the ecosystems of which they are a part. Fish are essential for energy transfer in aquatic food webs, regulation of food web structure, nutrient cycling, maintenance of sediment processes, redistribution of bottom substrates, the regulation of carbon fluxes from water to the atmosphere, and the maintenance of aquatic biodiversity (Peterson and Lubchenco, 1997; Postel and Carpenter, 1997; Holmund and Hammer, 1999; Wilson and Carpenter, 1999). Examples of ecological and public services disrupted by I&E include:

- decreased numbers of ecological keystone, rare, or sensitive species;
- decreased numbers of popular species that are not fished, perhaps because the fishery is closed;
- decreased numbers of special status (e.g., threatened or endangered) species;
- increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E;
- disruption of ecological niches and ecological strategies used by aquatic species;
- disruption of organic carbon and nutrient transfer through the food web;
- disruption of energy transfer through the food web;
- decreased local biodiversity;
- disruption of predator-prey relationships;
- disruption of age class structures of species;
- disruption of natural succession processes;
- disruption of public uses other than fishing, such as diving, boating, and nature viewing; and
- disruption of public satisfaction with a healthy ecosystem.

Many of these services can only be maintained by the continued presence of all life stages of fish and other aquatic species in their natural habitats.

The traditional approach of EPA and other natural resource agencies to quantifying the environmental benefits of proposed regulations has focused on active use values, particularly direct use values such as recreational or commercial fishing. Nonconsumptive uses (such as the importance of fish for aquatic food webs), and passive use or non-use values (including the value of protecting a resource for its own sake), are seldom considered because they are difficult to monetize with available economic methods. However, even though economists debate methods for indirect and non-use valuation, there is general agreement that these values exist and can be important.

This chapter first identifies the types of economic benefits that are likely to be generated from improved ecosystem functioning resulting from the final section 316(b) rule for existing facilities. Then, the basic economic concepts applicable to the economic benefits, including benefit categories and benefit taxonomies associated with market and nonmarket goods and services that are likely to flow from reduced I&E, are discussed. Sections in this chapter refer to the chapter in this report that details the methods used to estimate the values of reductions in I&E. These methods are in turn applied in the regional studies described in Parts B through H of this document.

A9-1 ECONOMIC BENEFIT CATEGORIES APPLICABLE TO THE FINAL SECTION 316(B) RULE

The term "economic benefits" for our purposes refers to the dollar value associated with all the expected positive impacts of the final section 316(b) rule. The basic approach for estimating the benefits of a policy event is to evaluate changes in social welfare realized by consumers and producers. These surplus measures are standardized and widely accepted concepts within applied welfare economics, and reflect the degree of well-being derived by economic agents (e.g., people and/or firms) given different levels of goods and services, including those associated with environmental quality.[1] For the case of market goods, analysts typically use money-denominated measures of consumer and producer surplus, which provide an approximation of exact welfare effects (Freeman, 2003). For nonmarket goods, such as aquatic habitat, values must be assessed using non-market valuation methods. In such cases, valuation estimates are typically restricted to effects on individual households (or consumers), and either represent consumer surplus or analogous exact Hicksian welfare measures (e.g., compensating surplus). The choice of welfare (i.e., value) measures is often determined by the valuation context. The theory and practice of nonmarket valuation is well developed, and typically plays a pivotal role in benefit-cost analysis conducted by public and private agencies (Freeman, 2003).

Estimating economic benefits of reducing I&E at existing CWIS can be challenging. There are many steps needed to analyze the link between reductions in I&E and improvements in human welfare. The changes produced by the new regulations on fisheries and other aspects of relevant aquatic ecosystems must be determined, and then linked in a meaningful way to the associated environmental goods and services that ultimately produce increased benefits. Key challenges in environmental benefits assessment include uncertainties, data availability, and the fact that many of the goods and services beneficially affected by CWIS are not traded in the marketplace (i.e., monetary values can not be established based on observed market transactions for some of the important beneficial outcomes). In this case, several types of benefits need to be estimated using nonmarket valuation techniques. Where this cannot be done in a reliable manner, the benefits need to be described and considered qualitatively.

For the final section 316(b) rule for existing facilities, the benefits are likely to consist of several categories; some are linked to direct use of market goods and services, and others pertain to nonmarket goods and services. Figure A9-1 outlines the most prominent categories of benefit values for the final section 316(b) rule. The four quadrants are divided by two principles:

- whether the benefit can be tracked in a market (i.e., market goods and services); and
- how the benefit of a nonmarket good is received by human beneficiaries (either from direct use of the resource, from indirect use, or from non-use).

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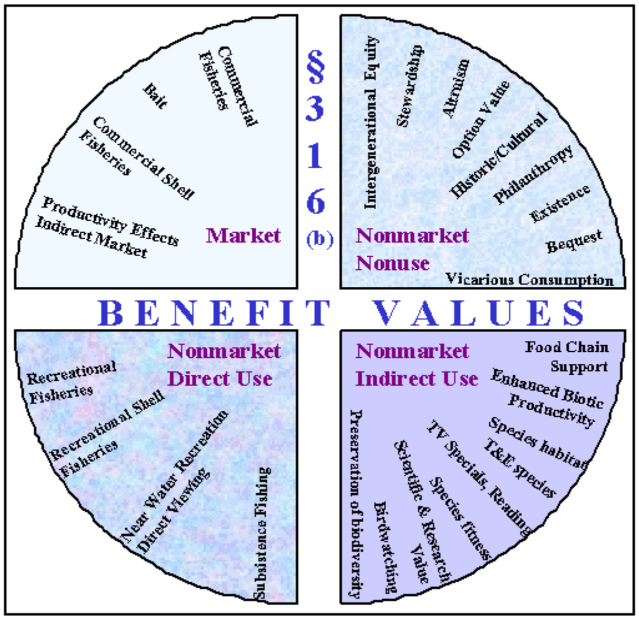
[1] Technically, consumer surplus reflects the difference between the "value" an individual places on a good or service (as reflected by the individual's "willingness-to-pay" (WTP) for that unit of the good or service) and the "cost" incurred by that individual to acquire it (as reflected by the "price" of a commodity or service, if it is provided in the marketplace). See Chapter A10 for a more detailed discussion of consumer and producer surplus.

Figure A9-1: Benefits Categories for the Final Section 316(b) Rule



The best example of market benefits for the final section 316(b) rule are commercial fisheries, where a change in fishery conditions will manifest itself in the price, quantity, and/or quality of fish harvests. These fishery changes result in changes in the marketplace, and can be evaluated based on market exchanges. A discussion of commercial benefits can be found in Chapter A10 of this document.

Direct use benefits also include the value of improved environmental goods and services used and valued by people (whether or not these services and goods are traded in markets). A typical nonmarket direct use would be recreational angling. Recreational fishing studies of sites throughout the United States have shown that anglers place high value on their fishing trips and that catch rates are one of the most important attributes contributing to the quality and, as a result, value of their trips. Higher catch rates resulting from reduced I&E of fish species targeted by recreational anglers may translate into two components of recreational angling benefits: (1) an increase in the value of existing recreational fishing trips resulting in a more enjoyable angling experience, and (2) an increase in recreational angling participation. A discussion of methodology used in valuation of recreational benefits can be found in Chapter A11.

Indirect use benefits refer to changes that contribute indirectly to an increase in welfare for users (or non-users) of the resource. An example of an indirect benefit would be when the increase in the number of forage fish enables the population of valued predator species to improve (e.g., when the size and numbers of prized recreational or commercial fish increase because their food source has been improved). In such a context, reducing I&E of forage species will indirectly result in welfare gains for recreational or commercial anglers. See Chapter A5 for a discussion on the indirect influence of forage fish.

Non-use benefits, often referred to as passive use benefits, arise when individuals value improved environmental quality apart from any past, present, or anticipated future use of the resource in question. Such passive use values have been categorized in several ways in the economic literature, typically embracing the concepts of existence, altruism, and bequest motives. Existence value is the value that individuals may hold for simply knowing that a particular good exists regardless of their present or expected use.[2] This motive applies not only to protecting endangered and threatened species (i.e., avoiding an

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[2] The term "existence value" is sometimes used interchangeably with or in place of "non-use value." In this case, where the whole of non-use benefits is represented, existence value has been described as including vicarious consumption and stewardship values. Vicarious consumption reflects the value individuals may place on the availability of a good or service for others to consume in the current time period, and stewardship includes inherent value as well as bequest value. In this case inherent value may be considered the existence value individuals hold for knowing that a good exists (described above), and bequest value is the value individuals place on preserving or ensuring the availability of a good or service for family and others in the future.

irreversible impact), but also applies (though perhaps the values held may be different) for impacts that potentially are reversible or that affect relatively abundant species and/or habitats.[3] Bequest value exists when someone gains utility through the knowledge that an amenity will be available for others (family or future generations) now and in the future (Fisher and Raucher, 1984). Altruistic values arise from interpersonal concerns (valuing the happiness that others get from enjoying the resource). Non-use values also may include the concept that some ecological services are valuable apart from any human uses or motives. Examples of these ecological services may include improved reproductive success for aquatic and terrestrial wildlife, increased diversity of aquatic and terrestrial species, and improved conditions for recovery of I&E species.

In older published studies, option value, which may exist regardless of actual future use, has been classified as either non-use value, use value, or as a third type of value, apart from both the use and non-use components of total value. Fisher and Raucher (1984) define *option price* for such an individual as “the sum of the expected value of consumer surplus from using the resource plus an *option value* or risk premium that accounts for uncertainty in demand or in supply.” Mitchell and Carson (1989) argue that on theoretical grounds this risk premium should be small for non-unique resources. It is increasingly recognized, however, that option value “cannot be a separate component of value” (Freeman, 2003; p. 249). As noted by Freeman (2003; p. 250), option value is “not mentioned in EPA’s most recent set of guidelines for economic assessment.” Accordingly, the following analysis does not assess option value as a distinct component of value.

Although different benefit categories can be developed, it makes little difference where specific types of benefits are classified as long as the classification system captures all of the types of beneficial outcomes that are expected to arise from a policy action, while at the same time avoiding any possible double counting. Some valuation approaches may capture more than one benefit category or reflect multiple types of benefits that exist in more than one category or quadrant in the diagram. For example, habitat restoration may enhance populations of recreational, commercial, and forage species alike. Thus, for the habitat-based analysis, decision makers need to be careful to account for the mix of direct and indirect uses included in the benefits estimates, including both market and nonmarket goods and services as well as non-use values.

A9-2 DIRECT USE BENEFITS

Direct use benefits are the simplest to envision. The welfare of commercial, recreational, and subsistence fishermen is improved when fish stocks increase and their catch rates rise. This increase in stocks may be induced by reduced I&E of species sought by fishermen, or through reduced I&E of forage and bait fish, which leads to increases in the number of commercial and recreational species that prey on the forage species. For subsistence fishermen, the increase in fish stocks may reduce the amount of time spent fishing for their meals or increase the number of meals they are able to catch. For recreational anglers, more fish and higher catch rates may increase the enjoyment of a fishing trip and may also increase the number of fishing trips taken. For commercial fishermen, larger fish stocks may lead to increased revenues through increases in total landings and/or increases in the catch per unit of effort (i.e., lower costs per fish caught). Increases in catch may also lead to growth in related commercial enterprises, such as commercial fish cleaning/filleting, commercial fish markets, recreational charter fishing, and fishing equipment sales.[4]

Evidence that the use value of fishery resources is considerable can be seen in the market and other observable data. For example, in 1996, over 35 million recreational anglers spent nearly $38 billion on equipment and fishing trip related expenditures (U.S. DOI, 1997), and the 1996 GDP from fishing, forestry, and agricultural services (not including farms) was about $39 billion (BEA, 1998). Americans spent an estimated 626 million days engaged in recreational fishing in 1996, an increase of 22 percent over the 1991 levels (U.S. DOI, 1997). If the average consumer surplus per angling day were only $20

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[3] Some economists consider option values to be a part of non-use values because the option value is not derived from actual current use. Alternatively, some other writers place option value in a use category, because the option value is associated with preserving opportunity for a future use of the resource. Both interpretations are supportable, but for this presentation EPA places option value in the non-use category in Figure A9-1.

[4] Increased revenues are often realized by commercial ventures whose businesses are stimulated by environmental improvements. These revenue increases do not necessarily reflect gains in national level “economic welfare” and, therefore, are not usually included in a national benefit-cost analysis. However, these positive economic impacts may be sizable and of significance to local or regional economies — and also of national importance — in times when the economy is not operating at full capacity (i.e., when the economic impacts reflect real gains and not transfers of activity across regions or sectors).

— a conservative figure relative to the values derived by economic researchers over the years (Walsh et al., 1990)[5]— then the national level of consumer surplus based on these 1996 levels of recreational angling would be approximately $12.6 billion per year (and probably is appreciably higher).

However, these baseline values do not provide a sense of how benefits change with improvements in environmental quality, such as due to reduced I&E and increased fish stocks. If the improvement resulted in a aggregate increase of 1.0 percent in recreational angling consumer surplus, it would translate into potential recreational angling benefits of approximately $100 million per year or more, based on the limited metrics in the previous paragraph.

Methodologies for estimating use values for recreational and commercial species are well developed, and some of the species affected by I&E losses have been extensively studied. As a result, estimation of associated use values is often considered to be straightforward. However, the portion of I&E losses consisting of fish that are recreationally and commercially landed represents only a very small fraction of the total age one equivalent I&E losses and, as a result, changes in direct use values resulting from the final section 316(b) rule provide an incomplete estimate of the regulation's benefits.

The following bullets discuss techniques of estimating direct use value for I&E losses of harvested fish.

❖ *Commercial fisheries*

The social benefits derived from increased landings by commercial fishermen can be valued by examining the markets through which the landed fish are sold. The first step of the analysis involves a fishery-based assessment of I&E-related changes in commercial landings (pounds of commercial species as sold dockside by commercial harvesters). The changes in landings are then valued according to market data from relevant fish markets (dollars per pound) to derive an estimate of the change in gross revenues to commercial fishermen. The final steps entail converting the I&E-related changes in gross revenues into estimates of social benefits. These social benefits consist of the sum of the producers' and consumers' surpluses that are derived as the changes in commercial landings work their way through the multi-market commercial fishery sector. Each step is described in detail in Chapter A10.

❖ *Recreational fisheries*

The benefits of recreational use cannot be tracked in the market, since much of the recreational activity associated with fisheries occurs as nonmarket events. However, a variety of nonmarket valuation methods exist for estimating use value, including both "revealed" and "stated" preference methods (Freeman, 2003). Where appropriate data are available or may be collected, revealed preference methods may represent a preferred set of methods for estimating use values. These methods use observed behavior to infer users' value for environmental goods and services. Examples of revealed preference methods include travel cost, hedonic pricing, and random utility models (RUM). Compared to non-use values, use values are often considered relatively easy to estimate, due to their relationship to observable behavior, the variety of revealed preference methods available, and public familiarity with the recreational services provided by surface waterbodies.

EPA used a random utility model (RUM) to estimate welfare gain to recreational anglers from improved recreational opportunities resulting from reduced I&E of fish species. This method has been applied frequently to value recreational fisheries and is thought to be quite reliable because it is based on people's demand for nonmarket goods and services through observable behavior.[6] The RUM approach has been applied in six of the regional studies. Chapter A11 provides greater detail on specific models used in the regional analyses.

For the Inland region, EPA used a benefit transfer approach to value recreation fishing benefits from reduced I&E. Benefits transfer is a secondary research method applied when data and other constraints limit the feasibility of doing site-specific primary research. Although primary research methods are generally considered to be superior to benefit transfer methods, benefit transfer is often a second-best (or only) alternative to original studies. Chapter H4 provides greater detail on specific values used in the benefits transfer approach.

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[5] Walsh et al. (1990) review 20 years of research and derive an average value of over $30 per day for warm water angling, and higher values for cold water and salt water angling

[6] Some researchers have argued that revealed preference methods (such as the travel cost method) suffer fundamental flaws which render them no more reliable than stated preference methods (Randall, 1994).

❖ *Avoiding double-counting of direct use benefits*

Many of the I&E-impacted fish species at CWIS sites are harvested both recreationally and commercially. To avoid double-counting the economic impacts of I&E of these species, the Agency determined the proportion of total species landings attributable to recreational and commercial fishing, and applied this proportion to the number of affected fishery catch.

❖ *Subsistence anglers*

Subsistence use of fishery resources can be an important issue in areas where socioeconomic conditions (e.g., the number of low income households) or the mix of ethnic backgrounds make such angling economically or culturally important to a component of the community. In cases of Native American use of affected fisheries, the value of an improvement can sometimes be inferred from settlements in legal cases (e.g., compensation agreements between impacted Tribes and various government or other institutions in cases of resource acquisitions or resource use restrictions). For more general populations, the value of improved subsistence fisheries may be estimated from the costs saved in acquiring alternative food sources (assuming the meals are replaced rather than foregone). This method may underestimate the value of a subsistence-fishery meal to the extent that the store-bought foods may be less preferred by some individuals than consuming a fresh-caught fish. Subsistence fishery benefits are not included in EPA’s regional analyses, although impacts on subsistence anglers may constitute an important environmental justice consideration, leading to an underestimation of the total benefits of the regulation.

A9-3 INDIRECT USE BENEFITS

Indirect use benefits refer to welfare improvements that arise for those individuals whose activities are enhanced as an indirect consequence of fishery or habitat improvements generated by the final section 316(b) rule. For example, the rule's positive impacts on local fisheries may generate an improvement in the population levels and/or diversity of fish-eating bird species. In turn, avid bird watchers might obtain greater enjoyment from their outings, as they are more likely to see a wider mix or greater numbers of birds. The increased welfare of the bird watchers is thus a legitimate but indirect consequence of the proposed rule's initial impact on fish. Impacts on other species such as birds have not been estimated for the Phase II regulation, but Chapter A4 of this document presents a qualitative discussion of the potential indirect effects of the rule on birds.

Another example of potential indirect benefits concerns forage species. A rule-induced improvement in the population of a forage fish species may not be of any direct consequence to recreational or commercial anglers. However, the increased presence of forage fish will have an indirect affect on commercial and recreational fishing values if it increases food supplies for commercial and recreational predatory species. Thus, direct improvements in forage species populations can result in a greater number (and/or greater individual size) of those fish that are targeted by recreational or commercial anglers. In such an instance, the incremental increase in recreational and commercial fishery benefits would be an indirect consequence of the proposed rule's effect on forage fish populations.

The regional case studies use two distinct estimates of trophic transfer efficiency to relate foregone forage production to foregone fisheries yield that would result from two kinds of food web pathways. The two estimates, referred to as secondary and tertiary forgone yield in this document, reflect the following:

- that portion of total forage production that has a high trophic transfer efficiency because it is directly consumed by harvested species; and
- the remaining portion of total forage production that has a low trophic transfer efficiency because it is not consumed directly by harvested species, but instead reaches harvested species indirectly after passage through other parts of the food web.

The dollar value of foregone commercial and recreational production was estimated using the same monetary values as for the direct use benefits estimates.[7] The indirectly consumed production enhancement from forage species that is not embodied in the landed recreational and commercial fish was examined in a similar manner, but values were adjusted downwards to reflect a much lower trophic efficiency transfer rate. This approach is described in greater detail in Chapter A5. A serious limitation with this approach is that I&E data collected for CWIS often overlook impacts on forage species (focusing instead on

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[7] Note that in practice values contributed by forage fish have been included as part of the valuation of increased landings of commercial and recreational species.

recreational and commercial species). Therefore, the results developed using this approach generally reflect considerable underestimates of forage species values.

A9-4 NON-USE BENEFITS

In contrast to direct use values, non-use values are often considered more difficult to estimate. Stated preference methods, or benefit transfer based on stated preference studies, are the generally accepted techniques for estimating these values. Stated preference methods rely on carefully designed surveys, which either (1) ask people to state their WTP for particular ecological improvements, such as increased protection of aquatic species or habitats with particular attributes, or (2) ask people to choose between competing hypothetical "packages" of ecological improvements and household cost. In either case, analysis of survey responses allows estimation of values.

Non-use values may be more difficult to assess than use values for several reasons. First, non-use values are not associated with easily observable behavioral trails. Second, non-use values may be held by both users and non-users of a resource, and non-users may be less familiar with particular services provided by water resources. Third, the development of a defensible stated preference survey that meets the NOAA blue ribbon panel requirements is often a time and resource intensive process. Fourth, even carefully designed surveys may be subject to certain biases associated with the hypothetical nature of survey responses (Mitchell and Carson, 1989).

EPA routinely estimates changes in use values of the affected resources as part of regulatory development. However, given EPA's regulatory schedule, developing and implementing stated preference surveys to elicit total value (i.e., non-use and use) of environmental quality changes resulting from environmental regulations is often not feasible. An extensive body of environmental economics literature demonstrates the importance of valuing all service losses, rather than just readily measured direct use losses. These studies typically reveal that the public holds significant value for service flows from natural resources well beyond those associated with direct uses (Fisher and Raucher, 1984; Brown, 1993; Boyd et al., 2001; Fischman, 2001; Heal et al., 2001; Herman et al., 2001; Ruhl and Gregg, 2001; Salzman et al., 2001; Wainger et al., 2001). Studies have documented public values for the non-use services provided by a variety of natural resources potentially affected by environmental impacts, including fish and wildlife (Stevens et al., 1991; Loomis et al., 2000); wetlands (Woodward and Wui, 2001); wilderness (Walsh et al., 1984); critical habitat for threatened and endangered species (Whitehead and Blomquist, 1991a; Hagen et al., 1992; Loomis and Ekstrand, 1997); overuse of groundwater (Feinerman and Knapp, 1983); hurricane impacts on wetlands (Farber, 1987); global climate change on forests (Layton and Brown, 1998); bacterial impacts on coastal ponds (Kaoru, 1993); oil impacts on surface water (Cohen, 1986); and toxic substance impacts on wetlands (Hanemann et al., 1991), shoreline quality (Grigalunas et al., 1988), and beaches, shorebirds, and marine mammals (Rowe et al., 1992). Brown (1993) reports that in many studies, total values exceed direct use values by greater than a factor of two.

In the case of the final section 316(b) existing facilities rule, no primary research was feasible within the budgeting, scheduling, and other constraints faced by the Agency. The Agency explored various alternatives to quantifying and monetizing non-use benefits based on secondary research. However, given the uncertainties in estimating non-use benefits with secondary estimation techniques at the national level, the Agency presented only a qualitative assessment of the non-use benefits of the environmental protections at issue in the final section 316(b) benefit cost analysis. Chapter A12 details the meta-analysis approach considered for estimating non-use benefits of the final section 316(b) regulation. Approaches to valuing I&E impacts on special status species are examined in Chapter A13. Chapter A15 discusses another way to put I&E losses into perspective: the value of habitats required to replace organisms lost to I&E.

A9-4.1 Role of Non-Use Benefits in the Final Section 316(b) Rule Benefits Analysis

Accounting for non-use values in the final section 316(b) rule benefits analysis is especially important because the portion of I&E losses consisting of organisms that have a direct human use value (i.e., those that contribute to forgone harvest) represents only a very small percentage of the organisms impinged and entrained by cooling water intake structures (CWIS). The remaining I&E losses include unharvested recreational and commercial fish and forage fish. Approximately 99.0 percent of all final section 316(b) rule Phase II estimated I&E organism losses and 98.6 percent of age-one adult equivalent losses are either forage species or the unlanded portion of recreational and commercial species. Neither forage species nor the unlanded portion of recreational and commercial species have direct uses; therefore, they do not have direct use values. Their value to the public has two sources: (1) their indirect use as both food and breeding population for fish that are harvested; and, (2) their non-use value, stemming from a sense of altruism, stewardship, bequest, or vicarious consumption, as indicated by the willingness of individuals to pay for the protection or improvement in fish numbers. To rely only on estimated use values would substantially undervalue the benefits of the final section 316(b) rule.

Table A9-1 provides detailed information on the number and percentage of organisms and age-one adult equivalent losses valued by EPA in the use commercial and recreational fishing analyses.

Table A9-1: Annual Number and Percentage of Losses Valued

Region[a]	Age-One Adult Equivalents (millions)				Forgone Harvest as % of Age 1 Eq. Lost
	Total Losses All Species[b]	Forage Losses[c]	Com./Rec. Species Losses[d]	Forgone Harvest	
California	312.9	170.6	142.3	14.9	4.8%
North Atlantic	65.7	49.7	16.0	0.7	1.0%
Mid-Atlantic	1,733.1	1,115.6	617.6	28.4	1.6%
South Atlantic	342.5	208.1	134.5	6.5	1.9%
Gulf of Mexico	191.2	53.5	137.8	8.1	4.2%
Great Lakes	319.1	300.8	18.3	0.5	0.2%
Inland	369.0	284.8	84.2	0.2	0.1%
Total	3,449.4	2,255.8	1,193.6	62.1	1.8%

[a] Regional numbers are unweighted. National totals are sample-weighted and include Hawaii.
[b] Total organisms lost to I&E expressed as age 1 equivalent fish. See Chapter A5 for details on the calculation of age 1 equivalents.
[c] Total I&E losses of fish species that are forage for species that are caught by recreational or commercial anglers.
[d] Total I&E losses of fish species that are caught by recreational or commercial anglers.

Source: U.S. EPA analysis for this report.

The organisms that remain unvalued in the analysis provide many important ecological services that do not translate into direct human use. While some ecological services of aquatic species have been studied, other ecosystems services, relationships, and interrelationships are unknown or poorly understood. To the extent that the latter are not captured in the benefits analyses, total benefits are underestimated.

Although individuals do not directly use most of the of the organisms lost by cooling water intake structures, individuals may nonetheless value these organisms. All individuals, including both commercial and recreational fishermen as well as those who do not use the resource, may have non-use values for unlanded and forage fish. Non-use values may be substantial, and may in some cases exceed use values in the aggregate.

For resource non-users, non-use values (if >0) must by definition exceed use values, which are zero if resource use is zero. Economic literature suggests that the non-use values for users of aquatic resources are significantly higher than the non-use values for non-users. This may result from additional information about water resources associated with past or expected future use, which is likely to enhance non-use value (Whitehead and Blomquist, 1991a). Other studies (e.g., Silberman et al., 1992), however, suggest that users may include their personal use values in non-use values, which could potentially result in double counting of use values. To avoid this problem, EPA used values from non-users (who have zero use values) to estimate non-use values for users *and* non-users.

A9-4.2 Overview of Explored Methods for Estimating Non-Use Benefits in the Final Section 316(b) Rule Benefits Analysis

EPA notes that results of the analyses discussed below were not used as a part of the national benefits analysis due to the unavoidable uncertainties in estimating non-use benefits at the national level.

❖ *Benefit transfer*

EPA considered the use of meta regression analysis to estimate passive or non-use benefits in the final section 316(b) rule benefits analysis These meta regressions are designed to statistically summarize the relationship between the computed benefit measures and a set of characteristics compiled from original primary study sources. The mathematical estimation of this functional relationship at study sites allows the researcher to better forecast estimates of WTP for the policy specific scenario and sites versus other types of benefit transfer. Additional advantages of the methodology employed by EPA include:

- Meta analysis utilizes varied source studies which provide increased information on the underlying components of reported benefits measures;
- Methodological differences that contribute to differences in estimated benefits across source studies can be determined and controlled with meta analysis;
- In developing benefits estimates for the policy site and scenario, the independent variable coefficients of the meta function can be adjusted to account for differences between the forecasted application and the values derived within the original studies; and
- Meta regression analysis can provide forecasted values of benefits outside the specific geographical region, site and policy specific characteristics, and scope constraints of the source study data.[8]

Much of the primary research into non-use values that is applicable to estimating benefits produced by the final section 316(b) rule implementation deals with eliciting an individual's WTP for improvements in site water quality. EPA used meta analysis of information from a number of these studies to determine the relationship between generally reported WTP values for improved water quality and those produced in studies where people were asked to value improvements in water quality that specifically affect only fish populations. This information can be used to estimate an individual's non-use WTP for an improvement in water quality that produces an increase in fish populations, a measure that the Agency believes is closely correlated with a pure WTP for increases in fish.

The meta analysis, described in Chapter A12 of this document, the meta-analysis results can used to estimate an annual willingness-to-pay estimate per non-user household (e.g., Mitchell and Carson, 1986; Carson and Mitchell, 1993). Applying this non-use value to all the households with non-use motives for the impacted waterbody (including both user and non-user households) would yield an estimate of the total non-use value.[9] EPA notes that this method for estimating non-use values may underestimate non-use values for users of aquatic resources (Whitehead and Blomquist, 1991a).

❖ *Societal revealed preference approach*

Other approaches can also provide important information to decision makers. For some specific affected fish species, non-use (or total) valuation may be deduced using restoration-based costs as a proxy for the value of the change in stocks. For example, for T&E species, the costs of restoration programs and various resource use restrictions indicate the revealed preference value of preserving the species. Where a measure of the approximate cost per preserved or restored individual fish can be deduced, and the number of individuals spared via best technology available (BTA) can be estimated, this is a viable approach. This approach is examined in the final section 316(b) rule case study of the San Francisco Bay/Delta Estuary (Chapter B.6 of this document). Improvements have been made to fish habitats by increasing stream flows, installing screening devices and fish passages, removing dams, and controlling temperatures. These changes in operations and

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[8] These meta regression forecasted values, like any other forecast, decrease in confidence or probability of correctness when used further from the range of the source data.

[9] Note that Mitchell and Carson estimate "total value," including use and non-use components. However, EPA notes that total value estimates for non-users can be interpreted as their non-use value (i.e., there is no difference between their total and non-use value). Since non-users of a resource generally have lower non-use values than users, assuming that all members of the relevant population (users and non-users) have non-use values equal to the total values of non-users is a conservative assumption.

technologies all entail significant costs, which society has shown to be willing to pay for the protection and restoration of healthy fish populations, particularly the T&E species of the Sacramento and San Joaquin Rivers. These investments provide a means to evaluate the loss imposed on society when a portion of these same fisheries are adversely impacted by I&E. Because the species involved in this restoration costing approach have no use value (due to their status as threatened or endangered), the approach yields an estimate of non-use values.

❖ *Habitat-based approach*

Another way to put I&E losses into perspective is to consider the value of the habitat required to replace organisms lost to I&E. In the absence of primary stated preference survey information, EPA believes that a restoration-based analysis can serve as a useful supplement or alternative to other benefits assessments, particularly in the context of the Clean Water Act. Restoration of aquatic species in I&E-impacted waters clearly constitutes a significant public natural resource benefit and is an important public goal, as evidenced by the Clean Water Act goals of restoring the "biological integrity" of the Nation's waters and achieving water quality for the protection and propagation of fish [33 U.S.C. § 1251(a)(2)]. It is also consistent with the wetlands protection program under Section 404 of the Clean Water Act where it is accepted that ecosystem losses that cannot be avoided are to be offset with wetlands restoration or creation to replace the functions and services (values) of the lost wetlands.

EPA recognizes the important distinction between the costs of supplying a resource or service, and the values that are derived from the active and passive uses of those resources and related services. Benefits are based on values that underlie the demand for these services, and the cost of providing such services may in some instances exceed these values, and in other instances may be less than these values. Nonetheless, available information suggests that individuals are both aware of the ecological importance of habitat restoration and value such programs.

Voluntary habitat restoration to improve the production of aquatic organisms is one indication that the public may consider habitat replacement to be worth its cost. A voluntary commitment of resources suggests economic efficiency and positive net benefits (as opposed to mandated actions that do not necessarily reveal values of those required to pay). In addition, long-standing legislation to preserve or restore aquatic habitats is a broad indication that habitat restoration is widely perceived as being worth its cost to society. Finally, a number of studies indicate a WTP for habitat restoration, and survey data could be developed to test the value of habitat restoration in the final section 316(b) rule context.

EPA believes that valuation of the amount of restoration required to offset I&E can provided important information for the final section 316(b) rule benefit-cost discussion because valuation of only direct use benefits (recreational and commercial fisheries) leaves a significant portion of I&E losses either unvalued or undervalued. Moreover, economic research indicates that many of the I&E-related benefits that are inadequately addressed through traditional benefits valuation approaches may be of considerable value. A description of how this approach can be used in the final section 316(b) rule context is presented in Chapters A15, C6, D6, and G6 of this report.

A9-5 SUMMARY OF BENEFITS CATEGORIES

Table A9-2 displays the types of benefits categories expected to be affected by the final section 316(b) rule. The table also reveals the various data needs, data sources, and estimation approaches associated with each category. Economic benefits can be broadly defined according to direct use and indirect use, and are further categorized according to whether or not they are traded in the market. As indicated in Table A9-2, “direct use” and “indirect use” benefits include both “marketed” and “nonmarketed” goods, whereas “non-use” benefits include only “nonmarketed” goods.

Table A9-2: Summary of Benefit Categories
Data Needs, Potential Data Sources, Approaches, and Analyses Completed

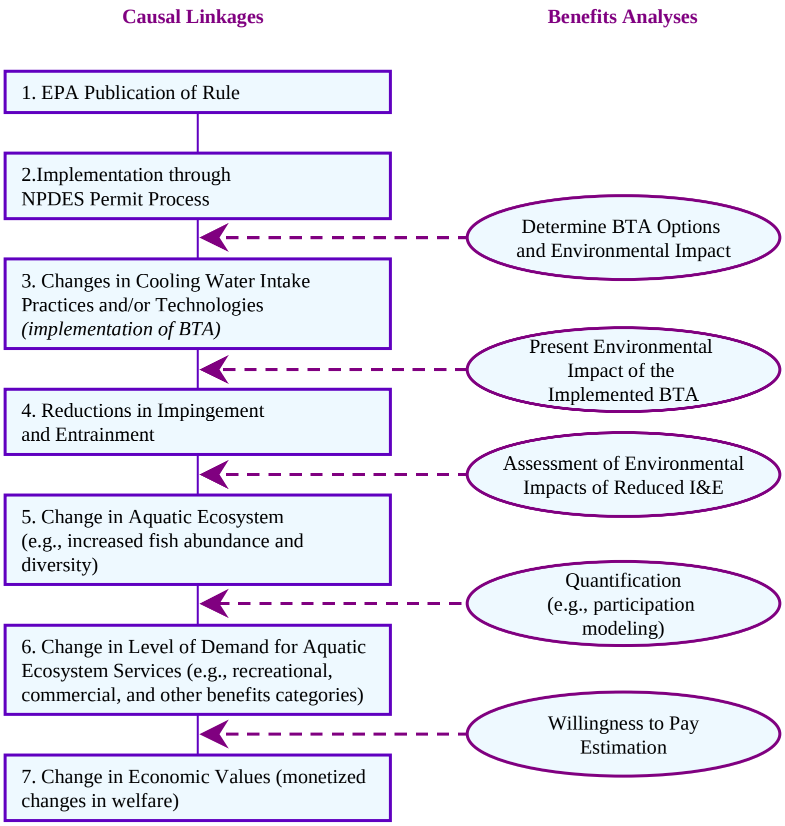
Benefits Category	Basic Data Needs	Potential Data Sources/Approaches/ Analyses Completed
Direct Use, Marketed Goods		
Increased commercial landings Fishing tournaments with entry fees and prizes	▸ Estimated change in landings of specific species ▸ Estimated change in total economic impact	▸ Market-based approach using data on landings and the value of landings data from the National Marine Fisheries Service (NMFS) ▸ Based on facility specific I&E data and ecological modeling ▸ Based on available literature
Indirect Use, Market Goods		
Increase in market values: ▸ equipment sales, rental, and repair ▸ bait and tackle sales ▸ increased consumer market choices ▸ increased choices in restaurant meals ▸ increased property values near water ▸ ecotourism (charter trips, festivals, other organized activities with fees such as riverwalks)	▸ Estimated change in landings of specific species ▸ Relationship between increased fish/shellfish landings and secondary markets ▸ Local activities and participation fees ▸ Estimated numbers of participating individuals	Not estimated for the final section 316(b) rule analysis due to data constraints
Direct Use, Nonmarket Goods		
Improved value of a recreational fishing trip: ▸ increased catch of targeted/preferred species ▸ increased incidental catch	▸ Estimated number of affected anglers ▸ Value of an improvement in catch rate	▸ Regional RUM analysis ▸ Benefit transfer (Inland region)
Increase in recreational fishing participation	▸ Estimated number of affected anglers or estimate of potential anglers ▸ Value of an angling day	Regional RUM analysis (not estimated for the California and Inland regions)
Indirect Use, Nonmarketed		
Increase in value of boating, scuba-diving, and near-water recreational experience: ▸ enjoying observing fish while boating, scuba-diving, hiking, or picnicking ▸ watching aquatic birds fish or catch aquatic invertebrates	▸ Estimated number of affected near-water recreationists, divers, and boaters ▸ Value of boating, scuba-diving, and near-water recreation experience	Not estimated for the final section 316(b) rule analysis due to data constraints
Increase in boating and near-water recreational participation	▸ Estimated number of affected boating and near-water recreationists ▸ Value of a near-water recreation experience	Not estimated for the final section 316(b) rule analysis due to data constraints
Increase in non-use values: ▸ existence (stewardship), ▸ altruism (interpersonal concerns), ▸ bequest (interpersonal and intergenerational equity) motives ▸ appreciation of the importance of ecological services apart from human uses or motives (e.g., eco-services interrelationships, reproductive success, diversity, and improved conditions for recovery).	▸ I&E loss estimates ▸ Primary research using stated preference approach (not feasible within EPA constraints) ▸ Applicable studies upon which to conduct benefit transfer	▸ Site-specific studies or national stated preference surveys ▸ Benefits transfer, including meta-analysis of applicable studies ▸ Restoration-based values of common and/or endangered species

A9-6 CAUSALITY: LINKING THE FINAL SECTION 316(B) RULE TO BENEFICIAL OUTCOMES

Understanding the anticipated economic benefits arising from changes in I&E requires understanding a series of physical and socio-economic relationships linking the installation of Best Technology Available (BTA) to changes in human behavior and values. As shown in Figure A9-2, these relationships span a broad spectrum, including institutional relationships to define BTA (from policy making to field implementation), the technical performance of BTA, the population dynamics of the aquatic ecosystems affected, and the human responses and values associated with these changes.

The first two steps in Figure A9-2 reflect the institutional aspects of implementing the final section 316(b) rule. In step 3, the anticipated applications of BTA (or a range of BTA options) must be determined for the regulated entities. This technology forms the basis for estimating the cost of compliance, and provides the basis for the initial physical impact of the rule (step 4). Hence, the analysis must predict how implementation of BTAs (as predicted in step 3) translates into changes in I&E at the regulated CWIS (step 4). These changes in I&E then serve as input for the ecosystem modeling (step 5).

Figure A9-2: Causal Linkages in the Benefits Analysis



In moving from step 4 to step 5, the selected ecosystem model (or models) are used to assess the change in the aquatic ecosystem from the pre-regulatory baseline (e.g., losses of aquatic organisms before BTA) to the post-regulatory conditions (e.g., losses after BTA implementation). The potential output from these steps includes estimates of reductions in I&E rates, and changes in the abundance and diversity of aquatic organisms of commercial, recreational, ecological, or cultural value, including T&E species.

In step 6, the analysis involves estimating how the changes in the aquatic ecosystem (estimated in step 5) translate into changes in the level of demand for goods and services. For example, the analysis needs to establish links between improved fishery abundance, potential increases in catch rates, and enhanced participation. Then, in step 7, as an example, the value of the increased enjoyment realized by recreational anglers is estimated. These last two steps are the focal points of the economic benefits portion of the analysis.

A9-7 CONCLUSIONS

The general methods described here are applied to the regional studies which are provided in Parts B through H of this document. Variations may occur to these general methodologies within distinct regional analyses to better reflect site-specific circumstances or data availability.

Chapter A10: Methods for Estimating Commercial Fishing Benefits

INTRODUCTION

Commercial fisheries can be adversely impacted by impingement and entrainment (I&E) and many other stressors. Because commercially landed fish are exchanged in markets with observable prices and quantities, it may seem as if estimating the economic value of losses due to I&E (or the economic value of the benefits of reducing I&E) would be relatively straightforward. However, many complicating conceptual and empirical issues pose significant challenges to estimating the change in economic surplus from changes in the number of commercially targeted fish.

This chapter provides an overview of these issues, and indicates how EPA is considering methods for estimating the change in commercial fisheries-related economic surplus associated with the section 316(b) regulation. This chapter includes a review of the concept of economic surplus, and describes the theory and empirical evidence on how readily observable dockside prices and quantities may relate to the economic welfare measures of producer and consumer surplus that are suitable for a benefit-cost assessment. This chapter also provides an overview of the commercial fishery sector, including an assessment of several relevant fishery stocks, trends and patterns of how the commercial fishing sector operates, and issues of commercial fisheries management and how they affect the analysis of economic welfare measures.

CHAPTER CONTENTS

A10-1 OVERVIEW OF THE COMMERCIAL FISHERY SECTOR

In estimating the effects of increased fish populations as a result of reduced I&E losses, it is important to understand who is affected. First and foremost, there are the commercial watermen, the individuals engaged in fish harvesting. These watermen typically haul their catch to established dockside wholesale markets, where they sell their catch to processors or wholesalers. Processors package or can the fish so that they can be sold as food products for people, or as pet and animal feed, or as oils and meals for various other uses. Wholesalers often resell fish to retailers (e.g., grocery stores), restaurants, or final consumers (households).

The market and welfare impacts of a change in commercial fishery harvests can be traced through a series of economic agents — individuals and businesses — that are linked through a series of "tiered markets." Through these economic relationships between the various levels of buyers and sellers, the final value of the fish product (e.g., a family dinner) creates economic signals (e.g., prices) that carry back through the various intermediate parties to the watermen who actually engage in the harvest. Additionally, beneficial changes in the commercial fishery may encourage watermen to purchase more fishing gear, fuel, and vessel repairs, which will benefit suppliers (the businesses that supply these goods and services), although such purchases from input suppliers would not typically be estimated as part of benefits.

A10-1.1 Commercial Watermen

Commercial watermen include the individuals supplying the labor and/or capital (e.g., fishing vessels) engaged in the harvesting of fish. These watermen typically haul their catch to established dockside wholesale markets, where they sell their catch to processors or wholesalers. The transactions between the watermen and these intermediate buyers provide observable market quantities and prices of dockside landings, and it is these data that serve as a starting point for estimating changes in economic surplus.

Commercial fishing is often a demanding and risky occupation. However, commercial anglers often find great satisfaction in their jobs and lifestyles. Additional detail on the economic and noneconomic aspects of commercial fishing is provided in several of the sections that follow, including a discussion of the nonmonetary benefits of commercial fishing (section A10-10).

A10-1.2 Processors, Wholesalers, and Other Middlemen

Dockside transactions typically involve buyers for whom the fish are an input to their production or economic activity. For example, processors convert raw fish into various types of final or intermediate products, which they then sell to other entities (e.g., retailers of canned or frozen fish products, or commercial or industrial entities that rely on fish oil as a production input). Wholesalers may serve as middlemen between the watermen who harvest the fish and those who will use the fish as production inputs or to retail vendors (e.g., supermarkets). Depending on the market and the type of fish, there may be numerous economic actors and layers between the commercial watermen who caught the fish and the final consumer who eats or otherwise uses the fish product.

A10-1.3 Final Consumers

After passing through perhaps several intermediate buyers and sellers, the fish (or fish products) ultimately end up with a final consumer (typically a household). This final consumption may take the form of a fish dinner prepared at home or purchased in a restaurant. Final consumption may also be in the form of food products served to household pets, or as part of a nonfood product that relies on fish parts or oils as an input to production.

A10-2 THE ROLE OF FISHING REGULATIONS AND REGULATORY PARTICIPANTS

Transactions in the fishery sector are often affected by various levels of fishery management regulations. Nearshore fishing (ocean and estuary fishing less than 3 miles from shore) and Great Lakes fishing are primarily regulated by State, Interstate, and Tribal entities. The content and relative strength of State laws affecting ocean fishing vary from state to state.

The regulated nature of many fisheries affects the manner in which the impacts and economic benefits of the section 316(b) regulation should be evaluated. For example, if the impacted fisheries were perfectly competitive with open access (i.e., no property rights or fishery regulations), then all economic rents, surplus, and profits associated with the resource would be driven to zero at the margin. However, where fisheries are regulated or in other ways depart from the neoclassical assumptions of perfectly competitive markets, there are rents and surplus that will be affected by changes in I&E. These economic considerations are addressed later in this chapter.

The primary Federal laws affecting commercial fishing in U.S. ocean territory are the Magnuson Fishery Conservation and Management Act of 1976 and the Sustainable Fisheries Act (SFA) of 1996 (the SFA amended the 1976 act and renamed it the Magnuson-Stevens Fishery Conservation and Management Act). The purpose of the 1976 act was to establish a U.S. exclusive economic zone that ranges from 3 to 200 miles offshore, and to create eight regional fishery councils to manage the living marine resources within that area. These councils comprised "commercial and recreational fishermen, marine scientists and State and Federal fisheries managers, who combine their knowledge to prepare Fishery Management Plans (FMPs) for stocks of finfish, shellfish and crustaceans. In developing these FMPs the Councils use the most recent scientific assessments of the ecosystems involved with special consideration of the requirements of marine mammals, sea turtles and other protected resources" (NMFS, 2002c). The SFA amended the law to include numerous provisions requiring science, management, and conservation action by the National Marine Fisheries Service (NMFS) (NMFS, 2002f).

The eight fishery management councils created by the 1976 act have regulatory authority within the eight regions. They receive technical and scientific support from the National Oceanic and Atmospheric Administration (NOAA), NMFS Fisheries Science Centers, which are organized into the following regions: Alaska, Northeast, Northwest, Southeast, and Southwest. Table A10-1 presents how the regions used for this analysis fit into the fishery management council regions and other fishery regions defined by NMFS.

Table A10-1: Regional Designation of Fisheries

Section 316(b) Phase II Region	States	NMFS Science Center	NMFS Marine Recreation Region	NMFS Commercial Region	Fishery Management Council (FMC)	Large Regions Reported in *Our Living Oceans* (NMFS, 1999b)
North Atlantic	Maine, New Hampshire, Massachusetts, Connecticut, Rhode Island	Northeast	North Atlantic	New England	New England	Northeast
Mid-Atlantic	New York, New Jersey, Delaware, Maryland, District of Columbia, Virginia	Northeast	Mid-Atlantic	Chesapeake Mid-Atlantic	Mid-Atlantic	Northeast
South Atlantic	North Carolina, South Carolina, Georgia, Florida (Atlantic Coast)	Southeast	South Atlantic	South Atlantic	South Atlantic (NC in Mid-Atlantic)	Southeast
Gulf of Mexico	Florida (Gulf Coast), Alabama, Mississippi, Louisiana, Texas	Southeast	Gulf of Mexico	Gulf	Gulf of Mexico	Southeast
Northern California	California, north of San Luis Obispo/Santa Barbara county border	Southwest	Northern California	Pacific Coast	Pacific	Pacific Coast
Southern California	California, south of San Luis Obispo/Santa Barbara county border	Southwest	Southern California	California	Pacific	Pacific Coast
Great Lakes	Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, New York	Northeast	na	Great Lakes	na	na

A10-3 OVERVIEW OF U.S. COMMERCIAL FISHERIES

In estimating the benefits of reducing I&E losses, it is important to understand how increased fish populations may affect stocks in different fisheries. Where stocks are thriving, a small increase in the number of individual fish affected by I&E may not be noticed, but where stocks are already depleted the marginal impact of a small increase may be much more important.

Many fisheries in the United States tend to be heavily fished. In the mid-1900s, many U.S. fisheries were over-fished, some to the point of near collapse (NMFS, 1999b, 2001a; U.S. Bureau of Labor Statistics, 2002). The situation currently is showing some improvement slowly because of recent management efforts mandated by Magnuson-Stevens Act and other regulations. However, many of the current restrictions on fishing have not been in place long enough to have a dramatic impact on fisheries.

Table A10-2 shows the utilization rate of fisheries in the United States by region. The status reported is obtained from *Our Living Oceans* (NMFS, 1999b). The regions for which fish status are reported in NMFS (1999b), and in Table A10-2, are larger than those used in the section 316(b) Phase II regional analysis. The Northeast region comprises both the North Atlantic and the Mid-Atlantic regions for the analysis; the Southeast region in the report includes the South Atlantic and Gulf of Mexico regions; and the Pacific Coast region includes the Northern California and Southern California regions as well as Oregon and Washington.

Table A10-2: Utilization of U.S. Ocean and Nearshore Fisheries by Region in 1999

***Our Living Oceans* Region**[a]	**# Fisheries with Known Status**	**# Fisheries with Unknown Status**	**# Under-Utilized**	**# Fully Utilized**	**# Over-Utilized**
Alaska	43	8	10	33	0
Northeast	55	15	4	15	36
Pacific Coast	55	11	12	37	6
Southeast	34	35	2	15	17
Western Pacific	20	7	8	9	3
Total	207	76	36	109	62
% of Total Known			17%	53%	30%

[a] The Northeast region includes the North Atlantic and Mid-Atlantic regions; the Pacific Coast region includes the Northern and Southern California regions, as well as Oregon and Washington; and the Southeast includes the South Atlantic and Gulf of Mexico regions. The Alaska and Western Pacific regions are not included in the Phase II CWIS benefit-cost analysis, but are included here for comparison.

Source: NMFS, 1999b.

Based on the NMFS definitions, a fishery is considered to be producing at a less than optimal level if its recent average yield (RAY)[1] is less than the estimated long-term potential yield (LTPY).[2] This can occur as a result of either under-utilization of the fishery or collapse of the fish stock. These data indicate that a majority, 53 percent, of the ocean and nearshore fisheries with known status, were fully utilized in 1999. Approximately 30 percent of these fisheries are identified as over-utilized. For more than a third of the fisheries, the status is unknown.

The three regions most affected by the section 316(b) Phase II regulations[3] — Northeast, Pacific Coast, and Southeast — are home to 144 fisheries, or 69 percent of the total fisheries in the United States. Of these, 83 had known status in 1999; a greater percentage of fisheries in these three regions are of “known” status relative to the status of all fisheries. A higher proportion, 40 percent, of the fisheries in the three regions of interest are over-utilized compared to 30 percent for the United States as a whole. In addition, a higher proportion are under-utilized (35 percent in the three regions, versus 17 percent in the United States). The Northeast and Southeast both have high rates of over-fishing, approximately 65 percent and 50 percent, respectively. The rate of over-fishing on the Pacific Coast is much lower, with just over 10 percent of fisheries listed as being over-utilized.

Table A10-3 shows the overall production of U.S. fisheries by region. In total, the annual RAY has been over 12 million metric tons, with Alaska and the Western Pacific providing nearly two-thirds of the catch. Because of under-utilization in some fisheries and over-fishing in others, the total RAY in the United States is only 60 percent of the estimated LTPY.

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[1] RAY is measured as “reported fishery landings averaged for the most recent 3-year period of workable data, usually 1995-1997” (NMFS, 1999b, p. 4).

[2] LTPY is “the maximum long-term average catch that can be achieved from the resource. This term is analogous to the concept of maximum sustainable yield (MSY) in fisheries science” (NMFS, 1999b, p. 5). LTPY may not be the yield that maximizes surplus rents.

[3] Of the 550 total in-scope Phase II facilities, fewer than 1 percent are located in the Alaska and Western Pacific regions: 1 is located in Alaska, 3 are in Hawaii.

Table A10-3: Productivity of U.S. Regional Fisheries in 1999 (million metric tons)

Our Living Oceans Regions[a]	Total Long-Term Potential Yield (LTPY)	Total Current Potential Yield (CPY)		Total Recent Average Yield (RAY)		
		CPY	% of LTPY	RAY	% of LTPY	% of CPY
Alaska	4.47	3.52	78.7%	2.51	56.1%	71.3%
Northeast	1.59	1.35	85.2%	0.89	55.7%	65.4%
Pacific Coast	1.04	0.85	81.9%	0.62	59.7%	72.9%
Southeast	1.50	1.15	76.7%	1.16	76.8%	100.2%
Western Pacific	3.44	3.44	100.1%	2.05	59.6%	59.6%
TOTAL	12.04	10.32	85.7%	7.22	60.0%	70.0%

[a] The Northeast region includes the North Atlantic and Mid-Atlantic regions; the Pacific Coast region includes the Northern and Southern California regions, as well as Oregon and Washington; the Southeast includes the South Atlantic and Gulf of Mexico regions. The Alaska and Western Pacific regions are not included in the Phase II CWIS benefit-cost analysis, but are included here for comparison.

Source: NMFS, 1999b.

The three regions directly affected by the Phase II regulations currently produce 2.67 million metric tons of fish, which is about 37 percent of the U.S. total. Within these regions, fisheries in the Southeast tend to be producing closest to their current and long-term potential. The RAY in the Southeast is very close to the current potential yield (CPY),[4] and is closer to the LTPY than any other region. In the Northeast region, where many fisheries are over-utilized, and in the Pacific region, where many fisheries are utilized to full capacity, the RAY is less than 60 percent of the LTPY and only about 70 percent of the CPY.

More detailed information on the status of individual species affected by I&E appears in the regional analyses presented in the Notice of Data Availability (NODA).

A10-4 PRICES, QUANTITIES, GROSS REVENUE, AND ECONOMIC SURPLUS

Dockside landings and revenues are relatively easy to observe, and readily available from NMFS. These data can be used to develop a rough estimate of the value of increased commercial catch. However, it is not always easy to interpret these data properly in estimating benefits. First, there are some empirical issues about whether the data accurately reflect the full market value of the commercial catch. Second, simply applying an average price to a change in catch does not account for a potential price response to the change in catch. Third, even if the price effect is accounted for, change in gross revenue is not necessarily the right conceptual or empirical basis for estimating benefits from reduced I&E. This section addresses these key issues.

A10-4.1 Accuracy of Price and Quantity Data

While the commercial landings data available from NMFS are the most comprehensive data available at the national and regional levels, the data may not fully capture the economic value of the commercial catch in the United States. As with any large-scale data collection effort, there are potential limitations such as database overlap and human error. Additional reasons the data may not fully capture the economic value of the commercial catch are varied and include, but are not limited to, the following:

- Fishermen often receive noncash payments for their catch. Crutchfield et al. (1982) noted that “the full amount of the payment to fishermen should include the value of boat storage, financing, food, fuel, and other non-price benefits that are often provided to fishermen by processors. These are clearly part of the overall ‘price,’ but are very difficult to measure, since they are not generally applicable to all fishermen equally and are not observed as part of dockside prices.”

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[4] CPY is measured as “the potential catch that can be taken depending on the current stock abundance and prevailing ecosystem considerations” (NMFS, 1999b, p. 4).

- Some fishermen may sell their catch illegally. There are three main reasons why illegal transactions occur:
  - To circumvent quantity restrictions (quotas) on landings allowed under fishery management rules.
  - To avoid or reduce taxes by having a reported income less than true earnings.
  - To reduce profit sharing, boat owners have been know to negotiate a lower price with the buyer and then recover part of their loss "in secret" so they do not have to share the entire profit with the crew.

- Some species are recorded inaccurately. Seafood dealers fill out the reports for commercial landings and may mislabel a species or not specifically identify the species — for example, entering "rockfish" instead of "blue rockfish." In this example the landings data for blue rockfish would under-estimate total landings, while data for "other rockfish" would be over-estimated (David Sutherland, NMFS, Fisheries Statistics and Economics Division, personal communication, November 4, 2002).

- Federal law prohibits reporting confidential data that would distinguish individual producers or otherwise cause a competitive disadvantage. These "confidential landings" are entered as "unclassified" data (e.g., finfishes, unc.) and do not distinguish individual species. Although most summarized landings are not confidential, species summary data may under-report actual landings if some of those landings have been confidential and therefore were not reported by individual species (NMFS, 2002b).

- Landings data are combined from nine databases that overlap spatially and temporally, and although they are carefully monitored for double-counting, some overlap may go unnoticed (NMFS, 2002b).

A10-4.2 The Impact of Potential Price Effects

A key issue in this analysis is whether the change in fishery conditions associated with regulatory options will be sufficiently large to generate price changes in the relevant fishery markets:

- If the estimated changes in commercial landings are so small relative to the applicable markets that no price change of consequence is anticipated (as appears to be the case in all regions included in this analysis), then the approach to estimating benefits becomes relatively simple. As will be developed later in this chapter, this is because the change in revenues becomes straightforward to estimate (i.e., the estimated change in quantity landed times the original price). Further, with no change in price, there is a fairly transparent relationship between the change in revenues and the change in economic surplus measures that are suitable for a benefits assessment (i.e., there is no change in consumer surplus, and the change in producer surplus may be equivalent to a percentage of or even equal to the change in revenues).

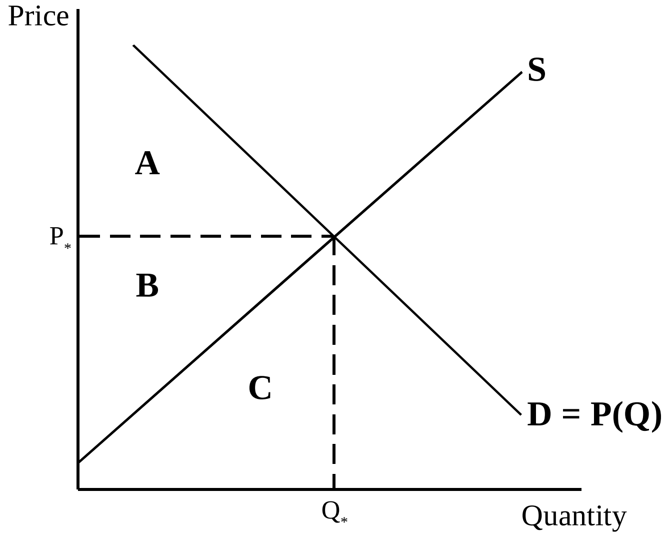
- If changes in landings are such that a price change is anticipated, then the conceptual and empirical analysis becomes more complicated. As detailed in greater depth later in this chapter, a price change makes it more difficult to estimate changes in gross revenues (in fact the change in revenues may be either positive or negative, depending on the relative elasticity of demand). Further, a change in price is anticipated to generate changes in both producer and consumer surplus, and there are numerous complex factors to be considered in assessing these changes in welfare (e.g., some of the gain in consumer surplus will reflect a transfer away from producer surplus, the overall change in producer surplus may be positive or negative, and the relationship between these measures of surplus and the estimated market revenues is much less transparent than in the case where price is reasonably constant).

As discussed later in this chapter, in all the regional analyses performed for the final rule the change in estimated harvest is small relative to the applicable market and EPA has assumed that there would be no significant change in price. The issues with estimating changes in revenues and surplus are then relatively straightforward. It may be the case in future rulemakings, however, that price changes are likely to apply in some markets. Therefore, this chapter provides additional discussion of conceptual and empirical issues that may arise if a price change scenario may be relevant in future analyses.

A10-4.3 Key Concepts Applicable to the Analysis of Revenues and Surplus

Before progressing into the details of defining and measuring surplus and revenues, or discussing further why prices may change and how one might estimate by how much, it is important to first establish some basic economic concepts relative to markets and measures of welfare. Figure A10-1 depicts a simple market for a typical economic good, with demand (labeled as line D) downward sloping to reflect what economists refer to as decreasing marginal utility, and supply (line S) upward sloping to reflect increasing marginal costs. There are numerous reasons why the market for commercial fish often differs in important ways from the typical market depicted in the figure. Commercial fisheries are considered renewable natural

Figure A10-1: Market for Typical Economic Good



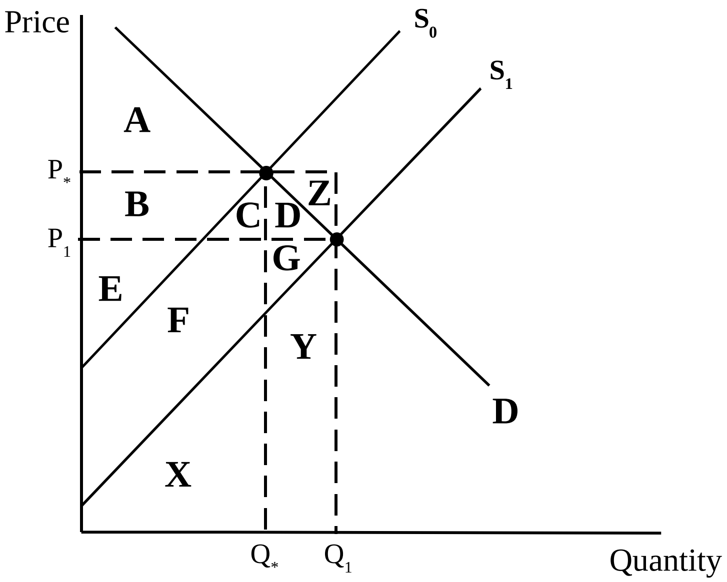
resources whereby supply is limited by ecological constraints. As a consequence, fisheries markets deviate from the traditional neoclassical view of fully competitive markets due to the impacts of open access, the socially desirable need to maximize resource rents, the corresponding need for regulations that limit catch or prevent the entry of fishermen (suppliers), and the possibility that costs may not increase in the relevant range of changes to fishery conditions. Such issues that are discussed later in the chapter. Nonetheless, to help introduce some core concepts, we begin with the standard neoclassical depiction of a market as depicted in the figure.

An equilibrium is established where supply and demand intersect, such that Q_* reflects the quantity of good exchanged and P_* reflects the market clearing price (i.e., the price at which the quantity supplied is equal to the quantity demanded). The gross revenues in this market (the sum total paid by consumers and the sum total received by sellers) are equal to P_* multiplied by Q_*, which in the figure is depicted by the rectangle made up of areas B plus C.

While the level of total (gross) revenues is of interest, it is not the same as the amount of benefit (economic welfare) that is generated by this market, which is measured by what is referred to as economic surplus (see sections A10-5.1 and A10-5.2 for further discussion of concepts related to economic surplus). Economic surplus consists of the consumer surplus generated (which is depicted by area A) plus the producer surplus generated (depicted as area B). Consumer surplus reflects the amount by which willingness-to-pay (WTP) (as reflected by the demand curve) exceeds the market-clearing price for each quantity exchanged up to Q_* (i.e., it reflects the degree by which consumers obtained the traded commodity at a price below what the good was worth to them). Likewise, producer surplus reflects the extent to which suppliers realized revenues above and beyond the marginal cost of producing some of the units (up to Q_*). Beyond Q_*, there is neither additional consumer nor producer surplus to be gained — at the margin, all the surplus has been extracted and there is no additional surplus to be gained by adding more output to the market.

Now suppose there is a change that increases the amount of a key input to production, such that the more bountiful input is now available at a lower cost to suppliers than before (e.g., when increasing the amount of locally harvestable fish makes it easier to catch a given number of fish). This could result in an outward shift in supply (a decrease in the marginal cost of producing any given quantity of the good). This is depicted in Figure A10-2, where supply shifts from S_0 to S_1. With the increased supply, a new market clearing price emerges at P_1 (which is lower than the original P_*), and the quantity exchanged increases from Q_* to Q_1.

Figure A10-2: Increased Supply in Typical Economic Market



These changes in the quantity exchanged and the market clearing price make it somewhat complex to envision how (and by how much) gross revenues and economic surplus measures may change as a consequence of the shift in supply. Using Figure A10-2 as a guide:

- Under the original supply conditions (S_0) consumer surplus had been area A, but it has now increased to A + B + C + D. Therefore, consumer surplus has increased by an amount depicted by areas B + C + D.

- Producer surplus had been area B + E before the supply shift, but becomes E + F + G after the shift in supply. Hence the change in producer surplus is depicted as areas F + G - B.
  - Note that area B is subtracted from producer surplus but added to consumer surplus — i.e., it represents a transfer of surplus from producers to consumers when supply shifts outward and prices decline.
  - Also note that consumer surplus has increased by more than the transfer of area B from producers; the additional consumer surplus (above and beyond the transfer) is depicted by the amount C + D.
  - Finally, note that the change in producer surplus might be positive or negative, depending on whether the addition of F + G outweighs the loss of B (assuming the supply curves are parallel).

- The total change in economic surplus (consumer plus producer surplus) therefore equals C + D + F + G.

- Revenues had been P_* times Q_* (areas B + C + E + F + X), but now becomes P_1 times Q_1 (areas E + F + X + G + Y). The change in revenues thus becomes (G + Y) - (B + C).
  - Note that the change in revenue can be positive or negative, depending on whether G + Y is greater than or less than B + C.
  - Also note that if one does not know by how much the price will decrease, and relies on the original price (P_*) to estimate the change in revenues, then the change in revenues would be over-estimated as P_* times (Q_1 - Q_*), which is equivalent to the areas G + Y + D + Z.
  - If the change in revenues is estimated relying on the original price level (P_*) when in fact the new price becomes P_1, then the amount by which the change in revenues will be over-estimated would be B + C + D + Z.

Even though the illustration above relies on a relatively simple depiction of a market that adheres to the basic economic assumptions and conditions of perfect competition, it reveals how complex the analysis can become if there is an anticipated change in price when supply is increased. The analysis can become even more complex when fishery-related deviations from the assumptions of open access perfect competition are considered.

A10-4.4 Estimating Changes in Price (as May Be Applicable)

One key observation from the illustration above is the importance of predicting the change in price, because relying on the baseline price can lead to potential errors. Correct estimation of the change in price of fish as a result of the regulation requires two pieces of information: the expected change in the commercial catch, and the relationship between demand for fish and the price of fish. Ideally, a demand curve would be estimated for the market for each fish species in each regional market. The level of effort required to model demand in every market is not feasible for this analysis. However, if reasonable, empirically based assumptions can be made for the price elasticity of demand for fish in each region, the change in price can be accurately estimated.

The price elasticity of demand for a good measures the percentage change in demand in response to a percentage change in price. If the price elasticity of demand for fish is assumed to be -2 over the relevant portion of the demand function, then a 1 percent *increase* in price creates a 2 percent *decrease* in the quantity demanded. Essentially, this determines the shape of the demand curve because it indicates how demand responds to a change in price. The inverse of the price elasticity of demand can be used to estimate the change in price as a result of a change in the quantity demanded. If the price elasticity of demand is assumed to be -2, the inverse is 1/-2 = -0.5. This would imply that a 1 percent *increase* in demand would correspond to a 0.5 percent *decrease* in price.

For example, in Figure A10-2, if Q_* is equal to 10,000 pounds of fish per year and reductions in I&E are expected to add 500 pounds of fish to the annual catch, Q_1 will equal 10,500 per year. This is a 5 percent increase in the quantity of fish supplied to the market. In response to the increase in supply, price will need to decrease from P_* to P_1. To clear the market, the quantity demanded would need to increase until Q_1 is also the quantity of fish demanded. If the price elasticity of demand for fish in this market is known to be approximately -2, then the inverse of the price elasticity of demand is -0.5 and, as described above, the expected change in price necessary to clear the market would be 5% x -0.5 = -2.5%. If P_* equals $1.00 per pound, then P_1 will equal $0.975 per pound, and the change in gross revenues will be (10,500 × $0.975) - (10,000 × $1.00) = $237.50. This represents a 2.375 percent increase in gross revenues for commercial fishermen in this market.

A variety of sources in the economics literature provide estimates of the price elasticity of demand for fish. In this analysis, EPA has assumed that the changes in supply of fish as a result of reduced I&E will not be large enough to create a significant change in price (see discussion below describing regional results). Therefore, assumptions about price elasticity are not necessary in this case. In future analyses if there are markets in which the estimated change in harvest is predicted to be large enough to generate a price change of consequence, EPA will revisit this issue in light of information available in the literature.

A10-5 ECONOMIC SURPLUS

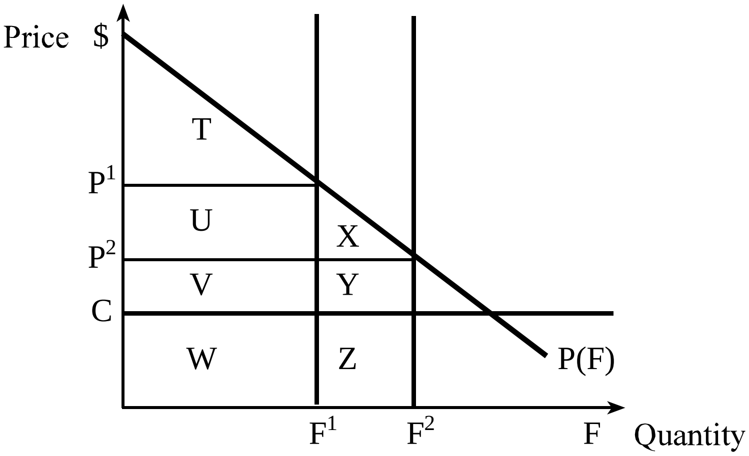
Even if the change in gross revenue is measured accurately and potential price effects (if any) are accounted for, changes in gross revenues are not generally considered to be a true measure of economic benefits. According to broadly accepted principles of microeconomics, benefits should be expressed in terms of economic surplus to consumers and producers.

A10-5.1 Consumer Surplus

To understand consumer surplus, consider the following illustration. Suppose a seafood lover goes to a fish market and pays $A for a salmon for a tasty dinner. She pays $A because that is the current market price. However, she would have been willing to pay a lot more than $A, if necessary. The maximum she would have paid for the salmon is $B. The difference between $B and $A represents an additional benefit to the consumer. When this benefit is summed across all consumers in the market, it is called consumer surplus.

Figure A10-3 shows one possible representation of a market for fish. The demand curve, P(F), shows the aggregate demand that would prevail in the market (F) at each price level (P).[5,6] The curve F^1 is the quantity of fish supplied to the market by fishermen. Equilibrium is attained a the point where P(F) equals F^1. Under these conditions, the price is P^1. In this case the total amount paid by consumers for fish is equal to $P^1 \times F^1$, which is equal to the area of the boxes U + V + W in the graph. The extra benefit to consumers, i.e., the consumer surplus, is equal to the area of the triangle T.[7]

Figure A10-3: Conceptual Model of Benefits from an Increase in Fish Catch



Source: Bishop and Holt (2003).

If the quantity of fish available to the market increases from F^1 to F^2, then the price decreases to P^2. This changes the total amount paid by consumers to $P^2 \times F^2$, which is equal to the area of the boxes V + W + Y + Z, and increases the consumer surplus to be equal to the area of the triangle T + U + X.

A10-5.2 Producer Surplus

In the example above, there is also a producer surplus that accrues to the fish seller. When the fish market sold the salmon to our consumer, it sold it for $A because that was the market price. However, it is likely that it cost less than $A to supply the salmon. If $C is the cost to supply the fish, then the market earns a profit of $A minus $C per fish. This profit is akin to the economic concept of producer surplus.[8]

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[5] Note that in the graph the quantity supplied, curves F^1 and F^2, is assumed to be constant under a given set of conditions. This assumption allows for a simplified case to be presented in the figure. An assumption of constant supply is more appropriate for a short-term analysis or for an analysis of a fishery regulated via quotas. Section A10-6 offers a discussion of the case where the supply curve is upward sloping.

[6] In this simplified illustration P(F) is really an inverse demand curve since it determines price as a function of quantity, F. The distinction is not of vital importance here.

[7] Note that Figure A10-3 is a highly simplified characterization of benefits derived from a commercial fishery, where the goal is to maximize producer surplus and consumer surplus. Figure A10-3 is drawn from Bishop and Holt (2003), who indicate that P(F) represents a general equilibrium demand function, accounting for markets downstream of harvesters, and that the welfare triangle (area T in Figure A10-3) represents consumer surplus plus post-harvest rents. F_1 is the supply of fish under a fixed, optimal quota before the Phase II rule and F_2 is the supply after the Phase II rule takes effect. A more complete interpretation of the graph in the context of renewable resources also reveals that costs for the harvester (e.g., fishing fleet) are equal to the area W (for a quota equal to F_1) and that area U + V is equal to the rents potentially captured by the harvester at F_1.

[8] Producer surplus equals economic profit minus the opportunity cost of the owner's resources invested in the fishery enterprise (see section A10-8 for additional details).

In Figure A10-3, the line C represents a simplified representation of the cost to the producer of supplying a pound of fish.[9] When the supply of fish is equal to F^1, the producers sell F^1 pounds of fish at a price of P^1. The difference between P^1 and C is the producer surplus that accrues to producers for each pound of fish.[10] Total producer surplus realized by producers is equal to $(P^1 - C) \times F^1$. In the example, this producer surplus is equal to the area of U + V. The area W is the amount that producers pay to their suppliers if the harvest equals F^1. In the example presented here, W might be the amount that the fish market paid to a fishing boat for the salmon plus the costs of operating the market.

When supply increases to F^2, the producers sell F^2 pounds of fish at a price of P^2. The total cost to produce F^2 increases from W to W + Z. The total producer surplus changes from U + V to V + Y.[11]

In this simple example, where C is assumed to be constant, the producer surplus earned by producers is equal for all units of F produced. If C increases as F increases, however, some of the producer surplus per unit will be eaten away by increased costs. In the figure, this would be seen as a decrease in the areas of V and Y and an increase in the areas of W and Z as a greater share of the revenues from the sale of the catch go to cover costs.

Table A10-3 is a graphical representation of a single market. In the real world, a fishing boat captain will sell the boat's catch to a processor, who sells processed fish to fish wholesalers, who in turn sells fish to retailers, who may sell fish directly to a consumer or to a restaurant, which will sell fish to a consumer. There will be consumer and producer surplus in each of these markets.[12] As a result, it is conceptually inaccurate to estimate the change in the quantity of fish harvested, multiply by the price per pound, and call this change in gross revenue the total benefits of the regulation.

The sections of this chapter that follow detail methods used in the final analysis of commercial fishing benefits attributable to the Phase II regulations. This involves three basic steps: estimating the increase in pounds of commercial catch under the rule, estimating the gross value of the increased catch, and estimating the increase in producer surplus as a proportion of increased gross value. If the rule were expected to have a greater impact on markets, an additional step would be estimating the increase in consumer surplus across all affected markets as a proportion of increased gross value. The appropriate methods to use depend on whether or not a price change is anticipated; hence the methods are presented according to these two possible scenarios.

A10-6 REGIONAL RESULTS: A CONTEXT OF NO ANTICIPATED CHANGE IN PRICE

As shown in Table A10-4, the proposed regulatory option is expected to result in small changes in commercial landings and gross dockside revenues for the North Atlantic and Northern California regions. The total landings and total value of landings of commercial species are estimated to increase by much less than 1 percent in most regions. The exceptions are the Mid-Atlantic and California (just over 1 percent), and the Great Lakes (about 3 percent). Nationwide, the value of total commercial harvest is expected to increase by less than 0.5 percent as a result of the rule.

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[9] In this case average cost is assumed to equal marginal cost at C and the marginal cost is assumed constant. Note that this is a simplification used here only to assist with the discussion. For example, the section 316(b) rulemaking might lead to a small decrease in cost per unit of fish caught. Also, if marginal cost were assumed to be upward sloping, the figure would more closely resemble the familiar graph of supply and demand with an upward-sloping supply curve, as depicted in Figure A10-2.

[10] Note that economists usually assume that C includes the opportunity cost of investing and working in commercial fishing. Thus, producer surplus is profit earned above and beyond normal profit. In a perfectly competitive market, when economic profit is being earned, it induces more producers to join the market until producer surplus is zero. However, many commercial fisheries are no longer allowing open access to all fishermen, thus it is realistic to assume that a level of producer surplus greater than zero is attainable in many U.S. commercial fisheries. In the case of managed fisheries, $(P^1 - C)$ can be referred to as rent.

[11] Note that the producer surplus may be smaller at quantity F^2 than at F^1, depending on whether U is bigger than Y. The relative sizes of U and Y depend on the slope of P(F). When the P(F) curve is less steep, i.e., when demand is more price elastic, Y will be larger compared to U. When the P(F) curve is steeper, i.e., when demand is more price inelastic, Y will be smaller compared to U. Changes in producer surplus may be negative with increased harvest if demand is sufficiently inelastic.

[12] As described in section A10-7 and Bishop and Holt (2003), the total consumer surplus accumulated through tiered markets can be estimated from a general equilibrium demand function (but not from a more typical single market partial equilibrium demand curve).

Table A10-4: Expected Increase in Commercial Harvest Resulting From Proposed Rule

	Average Annual Harvest 1993-2001 (million pounds)[a]	Expected Increase Attributable to Rule		Average Annual Gross Revenues 1993-2001 (million 2002$)[a]	Expected Increase Attributable to Rule	
		Million Pounds	Percent		Value (2002$)	Percent
North Atlantic	610	0.2	0.03%	595	0.2	0.03%
Mid-Atlantic	913	25.3	2.77%	350	4.6	1.32%
South Atlantic	246	3.5	1.41%	203	0.6	0.30%
Gulf of Mexico	1,742	3.6	0.21%	784	2.1	0.27%
California	556	2.4	0.43%	148	1.7	1.15%
Great Lakes	26	0.8	2.99%	18	0.5	3.07%
Inland[b]	---	---	---	---	---	---
Total[c]	4,093	35.7	0.87%	2,098	9.8	0.46%

[a] *Source: NMFS, 2003a.* Annual Commercial Landing Statistics, http://www.st.nmfs.gov/commercial/landings/annual_landings.html.

[b] Inland facilities are assumed to impact recreational fisheries only. Hawaii benefit estimates are based on estimates of benefits for all coastal facilities (i.e., North Atlantic, Mid Atlantic, South Atlantic, Gulf of Mexico, California).

[c] Total expected increases are a simple sum of estimated benefits for 540 in-scope facilities with available survey data. These estimates do not include 11 in-scope facilities for which data was unavailable or 3 in-scope facilities in Hawaii for which EPA did not estimate benefits.

While some species may experience larger increases in annual harvest and value of harvest, such modest overall changes in landings are not expected to greatly influence markets for the fish. Thus, it seems reasonable to presume that there will be no appreciable impacts on wholesale or retail fish prices. Under such a scenario of no price impacts, economic theory indicates that all changes in economic welfare will be confined to changes in producer surplus (i.e., changes in consumer and related post-harvest surplus will be zero). The benefits estimation issue then can be confined to examining producer surplus, and the core empirical and conceptual issue becomes how the change in producer surplus relates to estimates of added gross revenues, when prices remain constant.

A10-6.1 Producer Surplus as a Percentage of Gross Revenues: Assuming No Change in Prices

Given the potential for increases in producer surplus for the harvest sector (including rents to harvesters) under conditions where fish price does not change, EPA has relied on estimates derived from the literature of the percentage or fraction of gross revenue change as a proxy for changes in producer surplus. There are two relevant cases to consider: the case when fisheries are not regulated and the case when they are regulated with quotas or restrictive permits.

a. Unregulated fisheries

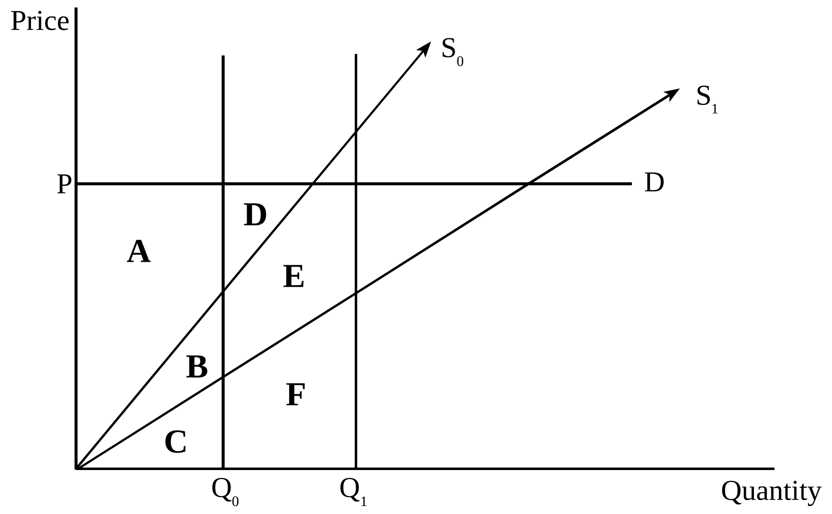
In an unregulated fishery, a reduction in I&E will lead to an increase in the stock of fish. This will decrease the marginal cost of catching more fish, creating the possibility for fishermen to earn economic rents and increasing producer surplus. According to basic microeconomic principles, in a competitive market these economic rents will attract additional fishing effort in one of two ways: either existing fishermen will exert greater effort or new fishermen will enter the market (or both). In either case, fishing effort theoretically will increase until a new equilibrium is reached where economic rents are equal to zero. In this case, there may be economic benefits to commercial fishermen in the short term, but in the long run producer surplus will be zero. Thus, in an unregulated fishery economic theory suggests that the long-run change in producer surplus will be 0 percent of the change in gross revenues.

b. Regulated fisheries

The story is different in a fishery that is regulated such that harvests are sustainable and reflect efforts to maximize resource rents. A reduction in I&E also leads to an increase in the stock of fish, which in turn leads to increases in harvest. In this case, however, there are lasting benefits to commercial fishermen.

As an example, assume that quotas are the regulatory instrument and that quotas increase in response to reduced I&E, and that the supply curve (as represented by a marginal cost curve) shifts as a result of increased stock, then we can relate change in producer surplus to change in gross revenue using Figure A10-4. Producer surplus, before the increase in stock and change in quota, is equal to area A. Producer surplus after increase in stock and change in quota is equal to area (A + B + D + E). Change in producer surplus is therefore equal to area (B + D + E).

Figure A10-4: Surplus in a Regulated Fishery



Three scenarios can be used to show how a change in revenue may over- or under-estimate change in producer surplus:

1. If B < F, then change in revenue over-estimates change in producer surplus.
2. If B = F, then change in revenue approximates change in producer surplus.
3. B > F, then change in revenue under-estimates change in producer surplus.

Note that if the first scenario prevails, then some fraction of gross revenue may be more suitable as a reliable proxy for change in producer surplus when price is assumed constant. If the marginal cost of supplying the extra fish for Q_1 is minimal or close to zero, then the second or third scenario prevails, and 100 percent or more of the change in revenue may serve as a reliable proxy for change in producer surplus.

A10-6.2 Conclusions on Surplus When No Change in Price is Anticipated

Various scenarios may arise when fishery conditions improve such that supply shifts outward, but not enough to generate any price change of consequence. In such cases, there is no anticipated change in post-harvest surplus to consumers or other post-harvest entities, because reduction in price is required to generate such surplus improvements. Hence, the change in economic welfare is limited to changes in producer surplus under these conditions.

As shown in the previous section, estimates of changes in dockside revenues become, under some scenarios, equivalent to the change in producer surplus. Hence, the change in gross revenues can be used as a proxy to estimate of the change in producer surplus for the regional analyses.[13] EPA also recognizes that under some of the possible scenarios that may arise when there is a quota-governed market, the full change in revenues (as estimated through a projected change in landings but no price change) might overstate the change in producer surplus. However, if dockside prices and/or dockside landings (quantities) are understated — as may often be the case — then the change in surplus will be understated in most scenarios by the estimated change in gross revenues.

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[13] This would be consistent with EPA's guidelines (U.S. EPA, 2000). The guidelines describe options for estimating ecological benefits for fisheries, and note that "if changes in service flows are small, current market prices can be used as a proxy for expected benefit . . . a change in the commercial fish catch might be valued using the market price for the affected species."

EPA's analysis of commercial fishery benefits relies on the premise that the change in producer surplus is only a fraction of the projected change in revenues. EPA has assumed a range of 0 percent to 40 percent of the estimated gross revenue changes as a means of estimating the change in producer surplus. The lower estimate of 0 percent represents the case of an unregulated fishery, as well as the lower bound identified in the literature. The range is based the discussion above and on a review of empirical literature (restricted to only those studies that compared producer surplus to gross revenue) that is described in greater detail in section A10-8.[14]

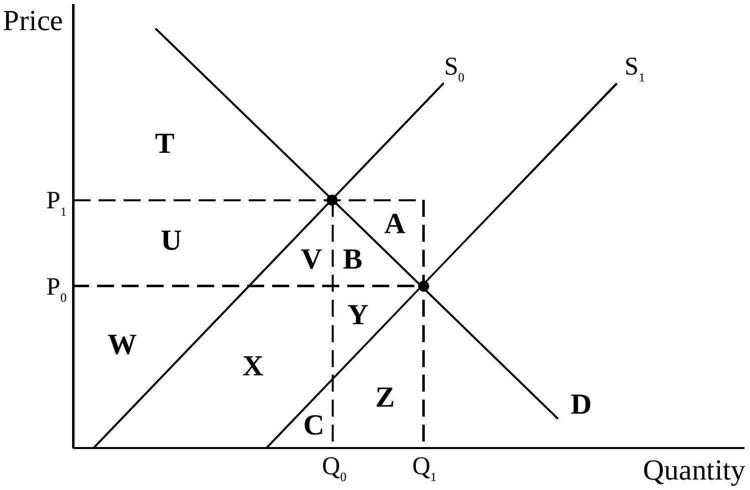
A10-7 SURPLUS ESTIMATION UNDER SCENARIOS IN WHICH PRICE MAY CHANGE

In the preceding section, the discussion was limited to cases in which no notable change in price was anticipated. These scenarios appear reasonable for very small improvements in fishery conditions, which is relevant for the regional analyses. If the estimated impacts were larger, as may be the case in other analyses, it may be inappropriate to assume that there will be no price effects in any commercial fishery markets. To ensure a complete treatment of the relevant economic theory, this section discusses the conceptual and empirical basis to estimate economic surplus (i.e., benefits) in instances where price changes are more likely to arise.

A10-7.1 Neoclassical Economic Perspective on the Market and Economic Welfare

Figure A10-5 portrays a standard, neoclassical economic depiction of a market, with demand downward sloping and supply upward sloping to reflect increasing marginal costs. There are several reasons why this neoclassical depiction may not be directly revealing or applicable to the commercial fisheries market, as discussed later in this chapter. But for the moment, Figure A10-5 provides a useful starting point for considering how the measures of economic benefit — the sum of producer and consumer surplus — might change due to a policy that shifts the supply curve outward from S_0 to S_1.

Figure A10-5: Neoclassical Model



At baseline, producer surplus is depicted by areas U + W, consumer surplus by area T, and gross revenues by areas U + V + W + X + C. With an outward shift in the supply curve to S_1, we observe:

- Producer surplus becomes W + X + Y, hence the change in producer surplus is (W + X + Y) - (U + W), which is equal to X + Y - U.

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[14] The 0 percent to 40 percent assumption represents a change from the analysis for the proposed rule, which assumed a range of 40 percent to 70 percent.

- Consumer surplus becomes T + U + V + B, hence the change in consumer surplus (which previously had been area T alone) becomes U + V + B.

- Total change in surplus (the sum of changes in consumer and producer surplus) is therefore equal to areas X + Y + V + B.

- Gross revenues become W + X + Y + Z + C, hence the change in revenues becomes (W + X + Y + Z + C) minus (U + V + W + X + C), which equals (Y + Z) - (U + V).

There are several observations to make based on the above. First, note that the area U is instrumental in the change of all three measures. Area U is a positive component of the change in consumer (post-harvest) surplus, but it is subtracted from baseline producer surplus to obtain a measure of the change in that measure of welfare. Hence, in the neoclassical market model, part of the gain in consumer surplus is, in effect, a transfer from producer surplus. Area U reflects this conceptual transfer of surplus, and any empirical effort to estimate changes in surplus needs to ensure that if area U is included in the estimate of post-harvest surplus, the producer surplus estimate should be made net of area U to ensure no double counting.[15]

Another noteworthy observation from the above neoclassical characterization is that, under some circumstances, the change in revenues may be zero or even negative (depending on how area Y + Z compares to area U + V). Likewise the change in producer surplus can be positive or negative (depending on how X + Y compares to area U); with the transfer of area U from producer to consumer surplus, there are still positive net gains in producer surplus if X + Y > U.

A10-7.2 Issues in Estimating Changes in Welfare

The discussion above regarding welfare measures — and how they change with shifts in supply within the neoclassical framework — is fairly complex, even in its simplest form. To estimate such changes in welfare as may arise from the section 316(b) regulation, the problem becomes even more complicated. Some of the empirical and conceptual complications are discussed here.

In an expedited regulatory analysis that must cover a broad range of fish species across locations and fishery markets that span the nation, EPA must rely on readily applicable generalized approaches (rather than more detailed, market-specific assessments) to estimate changes in welfare. Hence, as noted earlier in this chapter, EPA must rely on readily estimated changes in gross revenues and from there infer potential changes in post-harvest (consumer) and producer surplus. In turn, there are several issues associated with how to implement an expedited approach to accomplish this.

First, there is the issue of how to estimate the change in gross revenues. These changes in revenues are the product of the projected changes in fish harvests times observed baseline market prices. Thus, EPA can readily obtain an estimate comparable to the area Y + Z + A + B in Figure A10-5. This is the approach contemplated by the Agency for this rulemaking to handle the case in which prices change. To more suitably capture the impact of a price change, in future analyses EPA may attempt to apply an applicable estimate of price elasticity to obtain an estimate that better reflects the true measure of the change in gross revenues (i.e., areas Y + Z - U - V in Figure A10-5).

Second, there is the issue of how to infer changes in post-harvest (consumer) surplus based on changes in revenues. The approach described by Bishop and Holt (2003), described in greater detail in section A10-9, is specifically designed to examine this benefits transfer issue. Their empirical research — limited to date to some regions and fisheries (e.g., the Great Lakes) — suggests that the changes in post-harvest surplus may be approximated by the estimated change in gross revenues (where the latter is based on holding price constant at baseline levels). This method may also be revisited by EPA in future analyses.

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[15] Later in this chapter an approach developed by Bishop and Holt (2003) to estimating post-harvest surplus as depicted by areas U + V + B is described. Also, note that if the fishery in question is being conducted under open access, this means that rents to the resource are zero or very close it. Suppose furthermore that in this particular case other rents (e.g., rents to scarce fishing skills and knowledge) are also zero. Now suppose that section 316(b) regulations are imposed on power plants, causing an increase in the harvest of fish. The catch increases, but any effects in rents to the resource are dissipated by entry. The effect of the regulation is to increase consumer surplus by an amount comparable to areas U + V + B in Figure A10-5, but there is no offsetting decline in producer surplus because there was no producer surplus in the first place.

Third, there are a series of issues associated with how to estimate the change in producer surplus. Estimating the change in producer surplus under a scenario in which market forces produce a price change is a challenging exercise for a number of reasons, including:

- Many commercial fishery markets do not adhere to the usual assumptions of the neoclassical model because of regulations that establish harvest quotas and/or restrict entry through a permit system. These regulations typically are instituted to protect stocks that have been or are at risk of being over-fished. There also may be nonregulatory barriers to entry that affect this market, such as the high fixed costs and specialized knowledge and skill set required to effectively compete in some fisheries.

- Barriers to entry, regardless of the source, can have a profound impact on the economic welfare analysis. For example, the neoclassical model of open access would have rents driven to zero, but it is more likely in regulated markets (or a nonregulated market with economic barriers to entry) that there are positive rents accruing from the fishery resource (not to mention rents that accrue as well to specialized fishing skills and knowledge).[16]

- Empirical evidence regarding the magnitude of producer surplus is limited (especially for inferring a relationship with gross revenues). These data, presented later in this chapter, suggest producer surplus may be from 0 percent to 40 percent of gross revenues. However, interpreting these data properly is challenging, for a number of reasons:

    - Available empirical data pertain to average producer surplus, and EPA’s regulatory analysis must instead address changes in producer surplus at the margin.

    - The portion of producer surplus that is transferred to consumers when there is a price reduction (represented by area U in Figure A10-5) should not be double-counted if it is captured in the estimate of post-harvest surplus and also in the estimated change in producer surplus. Since area U is included in the Bishop-Holt analysis of changes in post-harvest surplus, one needs to ensure that area U is not included in (e.g., has been netted out of) the applicable estimate of the change in producer surplus.

    - The limited empirical data from the literature that estimates producer surplus and gross revenues for fisheries can be expanded to include studies with data on “normal profits.” However, these estimates of normal profits need to be adjusted downward in a logical manner to provide the more suitable producer surplus estimate. Later in this chapter some empirical evidence is provided to indicate the potential magnitude of such an adjustment.

These issues are discussed at greater length later in the chapter, but it is important to address them here because of the manner in which the departure from the neoclassical model affects how to interpret estimates of average producer surplus relative to changes expected at the margin. For example, marginal costs (MC) for commercial watermen may be minimal for a small increase in landings arising from a small increase in harvestable fish — for small increases in numbers of fish suitable for harvest in an area, small increases in harvest are likely to be realized with minimal added operating expense (i.e., MC at or near zero). This might arise where the watermen fill their quotas more easily, or exert essentially the same level of effort but come back with a few more fish. Where fishing effort and hence fishing costs would not change much, benefits (producer surplus) would equal the change in total revenue or be very close to it. For larger changes, marginal and average costs could shift down.

This has implications when interpreting the empirical literature available on producer surplus as a percentage of gross revenues. The standard neoclassical model always asserts increasing MC in the relevant range, so that producer surplus approaches zero with additional increments in landings. But for the type of situation that applies to section 316(b) — i.e., with a small change in the harvestable number of fish — and given the nature of the commercial fishery (e.g., high barriers to entry due to quotas or high fixed costs), the context is likely to reflect a situation in which costs decrease (e.g., a shift downward in MC, and perhaps MC that are at or near zero). If so, then the argument that the average estimate for producer surplus overstates the marginal value does not hold (in fact, the opposite may be true — average surplus could be less than producer surplus at the margin).

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[16] Given the highly regulated nature of many fisheries today, a wide range of producer effects is conceivable. Even where revenues decline with a reduction in price, producer surplus could increase despite the loss in revenues. This could occur if the effect on price is relatively small and the effect on costs and revenues is relatively large. The only way to know for sure is to examine producer effects in specific cases or do a benefits transfer exercise using experience in real world fisheries as a guide. Simple approaches (e.g., assuming that there is no consumer surplus because of offsetting producer effects) are not satisfactory if there are changes in prices.

A10-8 ESTIMATING PRODUCER SURPLUS

An important portion of commercial fishing benefits is the producer surplus generated by the estimated marginal increase in landings. The level of effort and data required to model supply and demand in every regional fishing market to compute producer surplus are unavailable to EPA. Various researchers, however, have developed empirical estimates that can be used to infer producer surplus for watermen based on gross revenues (landings times wholesale price). EPA reviewed the economic literature on commercial fishing to examine the available results. This body of research provides two types of data that can be used to estimate producer surplus as a percentage of gross revenues. These percentages can easily be applied to changes in gross revenues expected under the Phase II rule to estimate the changes in producer surplus expected under the Phase II rule.

The most common result reported in the literature is normal profit. A large number of studies across a variety of fisheries estimate the revenues earned and costs borne by commercial fishing operations. These results can be used to estimate normal profit. As defined here, normal profit is the standard accounting definition of profit, i.e., total revenues earned minus the costs of production (e.g., fishing equipment, fuel, boat maintenance, hired labor, bait). For example, assume a commercial fishing vessel brings in a total catch worth $100,000 in a given year. Also assume that it incurred variable material costs of $50,000 and hired labor costs of $30,000. The normal profit received by the owner would then be $20,000 ($100,000 - $50,000 - $30,000 = $20,000).

The more useful concept and result reported in the literature is producer surplus because, as described above, producer surplus is a more appropriate indicator of social welfare than is profit. Producer surplus equals normal profit minus the vessel owner's opportunity cost of participating in commercial fishing. In other words, producer surplus nets out the return to capital that the owner of a commercial fishing operation could expect to earn in another industry. Thus, producer surplus is the level of profits *above and beyond* what the owner would earn on his capital in another industry (or by investing in the stock market), and is less than or equal to normal profits. If the owner of the commercial fishing vessel in the previous example could expect to make a $1,000 return by investing his capital in another industry, then the producer surplus for this vessel owner would be $19,000 ($100,000 - $50,000 - $30,000 - $1,000 = $19,000).

While producer surplus is a preferable welfare measure, the literature review identified only four studies reporting results that can be used as direct estimates of producer surplus. Available measures of producer surplus and normal profits are reported as a percentage of gross revenue in Tables A10-5 and A10-6, respectively. Table A10-5 reports estimates of the more desirable producer surplus, and Table A10-6 reports the more common estimates of normal profits. EPA calculated these percentage values from data included in each cited study.[17] Looking at the values reported in the studies, it is clear that no single estimate of producer surplus as a percentage of gross revenue is appropriate for all regions, boat types, and species. For those studies that most closely approximate producer surplus (Table A10-5), the rough estimates of producer surplus range from 0 percent to 37 percent, with an average of approximately 23 percent. Therefore, EPA has assumed a range of 0 percent to 40 percent in the regional analyses. Note that the lower estimate of 0 percent is also consistent for the case of an unregulated fishery.

The estimates of normal profit span a wider range, with results in Table A10-6 ranging from a low of -5 percent to a high of 91.2 percent. One of the key issues for using the data on "normal profit' is whether some adjustment is reasonable to convert the ratios of normal profit to revenues into suitable estimates of the ratio of producer surplus to revenues. EPA has found limited empirical information on which to evaluate the potential adjustment factor. For example, King and Flagg (1984) provide data for California fisheries, itemizing various components of fixed and variable costs, and also providing annual revenues. Assuming that owners might be able to earn a 7 percent real rate return on all of their fixed costs that might otherwise be invested productively elsewhere, and netting these estimated returns from normal profit, the implied ratios of producer surplus to revenues are only between 0.4 percent and 2.6 percent lower than the ratios of normal profit to revenues, for the seven fishery types evaluated to date by EPA from the King and Flagg data. EPA also identified another study that contained relevant data (Larkin et al., 2000), and interpreting the data provided in similar fashion, the change in ratios is only 2.3 percent (consistent with the effect seen in King and Flagg). Because EPA identified only limited empirical evidence related to estimating an adjustment factor, the results in Table A10-6 are presented for comparative purposes only. Analysts for future rulemakings may wish to consider this issue and explore it further.

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[17] Most of the estimates in Table A10-6 are a variation of the following equation: 1 - (variable cost / gross revenue), where the variable cost includes the opportunity cost of participating in commercial fishing for the producer surplus measures.

Table A10-5: Summary of Research on Commercial Fisher Producer Surplus Measures: Producer Surplus (Studies that Report Profit Estimates that Include a Return to the Owner as Part of Costs)

Author(s)	Year	Geographic Area/Fishery	Analysis Year(s)	Type Boat(s)	Fish Species Sought	Producer Surplus % of Gross Revenue[a]	Notes on Study
Cleland and Bishop	1984	Michigan's Upper Great Lakes	1981	Varied	Most common: whitefish, lake trout, chubs	28%	Reported data used by EPA to calculate costs (including return to owner) as % of gross revenue — for 5 large Native American fishing operations
						35%	Reported data used by EPA to calculate costs (including return to owner) as % of gross revenue — for 11 moderately large Native American fishing operations
						27%	Reported data used by EPA to calculate costs (including return to owner) as % of gross revenue — for 36 small Native American fishing operations
Huppert and Squires	1987	U.S. Pacific coast	1984	Trawlers	Groundfish	37%	Reported results used by EPA to estimate: 1 - (profit + variable costs)/(total revenue) Estimates include return to owner as part of costs
Gilbert	1988	North-East North Island, New Zealand	1980s	Varied	Snapper	35%	Estimated economic surplus at dynamic maximum economic yield Estimates include return to owner as part of costs
		Hauraki Gulf, New Zealand	1980s	Varied	Red gurnard	20%	
		Firth of Thames, New Zealand	1980s	Varied	Yellow belly flounder	15%	
Norton et al.	1983	U.S. South Atlantic coast	1980	Varied	Striped bass	0%	Estimated producer surplus per pound of fish and revenue per pound of fish
		U.S. New England coast	1980	Varied	Striped bass	11%	

[a] Estimate includes returns to owners as part of costs, and thus excludes them from calculation of profit. This estimate can be considered a close proxy for producer surplus.

Table A10-6: Summary of Research on Commercial Fisher Producer Surplus Measures: Normal Profits
(Studies that DO NOT Report Profit Estimates that Include a Return to the Owner as Part of Costs)

Author(s)	Year	Geographic Area/Fishery	Year(s) of Analysis	Type Boat(s)	Fish Species Sought	Normal Profit as % of Gross Revenue[a]	Notes on Study
Brown et al.	1976	Columbia River	1960s	Varied	Salmon and steelhead	90%	Citation from other literature of percentage of gross revenue that goes to total surplus in a salmon fishery
Crutchfield et al.	1982	Tazimina River (Bristol Bay, Alaska)	1970s	Varied	Salmon	85% to 90%	Authors estimate net economic value of a change in availability of salmon in a fishery with limited access and excess capacity
King and Flagg	1984	California coast	1982	Trawlers in North CA	Groundfish	67%	Reported data by fish/boat type used by EPA to calculate 1 - (variable cost / gross revenue) Costs do not include return to owner
				Trawlers in South CA	Groundfish	89%	
				Trawlers	Shrimp	4%	
				Seiners	Tuna	45%	
King and Flagg	1984	California coast	1982	Seiners	Wetfish	22%	Reported data by fish/boat type used by EPA to calculate 1 - (variable cost / gross revenue) Costs do not include return to owner
				Gillnetters	Herring	-5%	
				Gillnetters	Other	69%	
				Small trollers	Salmon	49%	
				Large trollers	Salmon	52%	
				Crabbers	Salmon	74%	
				Albacore	Salmon	57%	
				Longliners	Varied	89%	
				Varied: using hook & line	Varied	66%	
				Varied: using pots	Black cod	91%	
				Varied	Crab-lobster, north	74%	
King and Flagg	1984	California coast	1982	Varied	Crab-lobster, south	50%	Reported data by fish/boat type used by EPA to calculate 1 - (variable cost / gross revenue) Costs do not include return to owner
				Bailboats	Varied	38%	
				Jigboats	Varied	22%	
				Diveboats	Varied	59%	
				Varied: using harpoon	Billfish	49%	

Table A10-6: Summary of Research on Commercial Fisher Producer Surplus Measures: Normal Profits (Studies that DO NOT Report Profit Estimates that Include a Return to the Owner as Part of Costs)

Author(s)	Year	Geographic Area/Fishery	Year(s) of Analysis	Type Boat(s)	Fish Species Sought	Normal Profit as % of Gross Revenue[a]	Notes on Study
Rettig and McCarl	1985	U.S. varied	Varied	Varied	Varied	50%	Authors review several studies and suggest that "variable costs may be approximately 50 percent of revenues for all commercial operators" Estimates do not include return to owner as part of costs
Usher	1987	Lake of the Woods, Ontario	1980-1982	Varied	Varied	28%	Reported results used by EPA to estimate: (net revenue) / (gross revenue) Estimate does not include return to owner as part of costs
Talhelm	1988	Great Lakes	1985	Varied	Varied	51%	Reported food fishery stats used by EPA to calculate: (gross value minus harvest costs) / (total value) Estimate does not include return to owner as part of costs
Larkin et al.	2000	U.S. Atlantic coast	1996	Longline	Varied, includes swordfish, tuna, sharks, and other	55%	Reported data used by EPA to calculate: (total net revenue) / (total gross revenue) Estimate does not include return to owner as part of costs

[a] Estimate does not include returns to owners as part of costs, and thus overstates producer surplus by that amount.

A10-9 ESTIMATING POST-HARVEST ECONOMIC SURPLUS IN TIERED MARKETS

Estimating producer surplus provides an estimate of the benefits to commercial fishermen, but significant benefits can also be expected to accrue to final consumers of fish and to commercial consumers (including processors, wholesalers, retailers, and middlemen) if the projected increase in catch is accompanied by a reduction in price. These benefits can be expected to flow through the tiered commercial fishery market (as described in section A10-1 and in Bishop and Holt, 2003).

Bishop and Holt (2003) developed an inverse demand model of six Great Lakes fisheries that they use to estimate changes in welfare as a result of changes in the level of commercial harvest. This flexible model can be used to model welfare changes under a variety of conditions in the fishery. It takes as an input the expected change in harvest and baseline gross revenues, and provides as outputs the expected change in gross revenues and change in total compensating variation (CV).

CV is the change in income that would be necessary to make consumers' total utility the same as it was before the reduction in I&E losses resulting from the Phase II rule. This is analogous to a measure of willingness to accept compensation in order to forgo the improvement. Conceptually, CV is a measure of welfare similar to consumer surplus. The key difference is that consumer surplus is calculated using the familiar demand function (or curve), which defines the quantity demanded as a function of price and income (in the simple example, Figures A10-1 and A10-2, income is assumed to be constant). CV, on the other hand, is calculated using a compensated demand function, which defines the quantity demanded as a function of price and utility. While consumer surplus and CV are generally very similar welfare measures, CV is considered to be the true measure of benefits (i.e., a more consistent indicator of utility), and consumer surplus is an approximation. The distinction between the two is a subtle point in welfare economics; the exact details are not crucial to the analysis.[18]

The key point to note is that estimates of CV from the Holt-Bishop model capture the benefits to final consumers and commercial consumers throughout the various markets in which fish are bought and resold for a given level of harvest. The model output provides a convenient way to estimate the benefits of an increase in harvest as a percentage of gross revenues, and thus a tractable way to estimate the benefits of increased catch that do not accrue to the primary producers.[19] See Holt and Bishop (2002) for further detail on the model.

For the commercial benefits estimated for the proposed rule, EPA used the results of the Holt-Bishop model, as applied to a specific Great Lakes application. These results indicated that the change in CV for the Great Lakes fisheries can be expected to be approximately 78 percent of the change in total surplus (with producer surplus equal to the remaining 22 percent). In each case study analysis at proposal, EPA applied this 22 percent estimate as a benefits transfer to all the commercial benefits estimates in the case studies developed at that time. To estimate consumer surplus from gross revenues, EPA first estimated the change in producer surplus lost at each case study facility due to I&E and then divided the producer surplus estimate by 0.22 to estimate total surplus. For example, if producer surplus was estimated to be $1,000, total surplus (producer surplus + CV) was estimated to be $1,000/0.22 = $4,545. This approach is undergoing significant revision.

Based on comments received on the commercial benefits analysis for the proposed Phase II rule, EPA worked with Dr. Bishop to re-assess the suitability of using the results from Holt and Bishop (2002) in a benefits transfer. EPA determined that the magnitude of the changes in commercial catch modeled in the Holt and Bishop paper is, in most cases, larger than the magnitude of the expected changes as a result of the Phase II regulations, and thus the benefits may be quite different. To address this issue, Bishop and Holt (2003) explore the impacts on surplus measures for more moderate changes in fishery conditions, and Bishop and Holt (2003) reports on the findings of the re-estimation of their Great Lakes model in terms that related economic surplus to levels of gross revenues.

In their recent work, Bishop and Holt (2003) observe that, as a general rule of thumb, in the fisheries they model the change in CV as a percentage of the change in gross revenues is more or less linearly related to change in catch. In other words, a 10 percent increase in catch as a result of the Phase II rule would be expected to produce an increase in CV equal to approximately a 10 percent of the change in gross revenues. As an example, if the Phase II rule increases the catch of a species by 10 percent and the gross value of the additional catch is $100,000, then the increase in CV would be $10,000.

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[18] For a more detailed discussion of the difference in consumer surplus and CV, the reader is referred to in Varian (1992, Chapters 7 and 9) or any graduate-level microeconomics text.

[19] Bishop and Holt do not estimate changes in producer surplus, and indicate such changes need to be estimated separately and then combined with post-harvest consumer surplus results.

Since no significant price changes are expected in any of the regions included in this analysis, the effective change in CV attributable to the Phase II rule is expected to be minimal. In estimating benefits, EPA has assumed the change will be $0.

A10-10 NONMONETARY BENEFITS OF COMMERCIAL FISHING

As with many activities, commercial fishing provides benefits that are not measured in the value of the catch. Fishing is hard work. It involves strenuous outdoor work, long hours, and lengthy trips to sea, often in hazardous weather conditions. Fishing is also dangerous work. "Fishing has consistently ranked as the most deadly occupation since 1992," when the Bureau of Labor Statistics (BLS) started publishing fatality rates by occupation (Drudi, 1998, p. 1). In addition, the *BLS Occupational Handbook: Fishers and Fishing Vessel Operators* (U.S. Bureau of Labor Statistics, 2002) predicts that "employment of fishers and fishing vessel operators is expected to decline through the year 2010. These occupations depend on the natural ability of fish stocks to replenish themselves through growth and reproduction, as well as on governmental regulation of fisheries. Many operations are currently at or beyond maximum sustainable yield, partially because of habitat destruction, and the number of workers who can earn an adequate income from fishing is expected to decline."

In spite of this evidence, individuals still express a desire to fish, perhaps even because of the hardships and challenges of the job. Studies on why fishermen choose to fish have determined that income is, not surprisingly, the primary reason for participating in commercial fishing. Fishermen fish to support themselves and their families, and generally earn more in fishing than they would in other occupations. There are other important factors, though, including the importance of fishing to the way of life in small, coastal towns (not unlike the importance of farming to many rural towns throughout the United States); the belief that fishing helps the U.S. economy; and identity, i.e., people opt to work in commercial fishing because it provides enjoyment and because it is an integral part of how they identify themselves psychologically and socially (Smith, 1981; Townsend, 1985; Berman et al., 1997).

Research in the economic literature indicates that some fishermen opt to remain in the fishing industry despite the ability to make higher incomes in other industries. Some economists have suggested that there exists a worker satisfaction bonus that can, at least in theory, be measured and should be included in cost-benefit analyses when making policy decisions (Anderson, 1980). One study identified in a cursory literature review of this topic also found evidence in the Alaskan fisheries that as many as 29.5 percent of all vessels across 14 fisheries from 1975 to 1980 earned net incomes that were lower than the income they could receive from selling their fishing permit. The author concluded that "this pattern of apparent losses seems to confirm much of the casual observation that is the source of speculation that non-pecuniary returns are a significant factor in commercial fishing. It is thought that these financial losses are accepted only because they are offset by non-money gains" (Karpoff, 1985).

Because the Alaskan fisheries exist under much different conditions than those in the rest of the United States, it would be a mistake to assume that nearly 30 percent of U.S. fishing vessels earn incomes less than the value of their fishing permits. However, based on the cursory review of the commercial fishing literature, there is evidence that commercial fishermen gain nonmonetary benefits from their work. Despite the existence of these nonmonetary benefits in the commercial fishing sector, there is little research that has provided defensible methods for estimating the additional nonmonetary benefits that may accrue to commercial fishermen as a result of the Phase II regulations. Thus, the omission of these nonmonetary benefits is noted here, but no estimates will be included in the benefits analyses.

A10-11 METHODS USED TO ESTIMATE COMMERCIAL FISHERY BENEFITS FROM REDUCED I&E

EPA will estimate the commercial benefits expected under the final Phase II regulations in the following steps. EPA will estimate total losses under current I&E conditions (or the total benefits of eliminating all I&E) in steps 1 through 3. Then, in step 4, EPA will apply the estimated percentage reduction in I&E to estimate the benefits expected under each regulatory option. Each step will be performed for each region in the final analysis: the North Atlantic, Mid-Atlantic, South Atlantic, Gulf of Mexico, Northern California, Southern California, Great Lakes, and the internal United States.

The steps used to estimate regional losses and benefits are as follows:

1. **Estimate losses to commercial harvest (in pounds of fish) attributable to I&E under current conditions.** EPA models these losses using the methods presented in Chapter A5 of Part A of the section 316(b) Phase II Case Study Document. Changes in these methods for the NODA and subsequent analyses are provided in the NODA (see sections on "Case Study Corrections and Clarifications" and "Impingement and Entrainment Methods"). The basic approach is to apply a linear stock to harvest assumption, such that if 10 percent of the current commercially targeted stock were harvested, then 10 percent of the commercially targeted fish lost to I&E would also have been harvested absent I&E. The percentage of fish harvested is based on data on historical fishing mortality rates.

2. **Estimate gross revenue of lost commercial catch.** The approach EPA uses to estimate the value of the commercial catch lost due to I&E relies on landings and dockside price ($/lb) as reported by NMFS for the period 1991-2001. These data are used to estimate the revenue of the lost commercial harvest under current conditions (i.e., the increase in gross revenue that would be expected if all I&E impacts were eliminated).

3. **Estimate lost economic surplus.** The conceptually suitable measure of benefits is the sum of any changes in producer and consumer surplus. The methods used for estimating the change in surplus depend on whether the physical impact on the commercial fishery market appears sufficiently small such that it is reasonable to assume there will be no appreciable price changes in the markets for the impacted fisheries.

   For the regions included in this analysis, it is reasonable to assume no change in price, which implies that the welfare change is limited to changes in producer surplus. This change in producer surplus is assumed to be equivalent to a portion of the change in gross revenues, as developed under step 2. EPA assumes a range of 0 percent to 40 percent of the gross revenue losses estimated in step 2 as a means of estimating the change in producer surplus. This is based on a review of empirical literature (restricted to only those studies that compared producer surplus to gross revenue) and is consistent with recommendations made in comments on the EPA analysis at proposal.

   EPA believes this is a conservative approach to estimating producer surplus when there is no anticipated price changes. EPA's *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2000; EPA 240-R-00-003) describe options for estimating ecological benefits for fisheries, and note that "if changes in service flows are small, current market prices can be used as a proxy for expected benefit . . . a change in the commercial fish catch might be valued using the market price for the affected species." This statement indicates that 100 percent of gross revenue change, based on current prices, may be a suitable measure of value.

4. **Estimate increase in surplus attributable to the Phase II regulations.** Once the commercial surplus losses associated with I&E under baseline conditions have been estimated according to the approaches outlined in steps 2 and 3, EPA estimates the percentage reduction in I&E at each facility under each regulatory option. This analysis is conducted for each region.

A10-12 LIMITATIONS AND UNCERTAINTIES

EPA reviewed the methods used to estimate the benefits expected to accrue to producers and consumers in commercial fish markets. Based on this review and on comments received on the benefits analysis for the proposed rule, EPA is changing some of the methods used to estimated commercial benefits. EPA believes that these changes will improve the accuracy and reduce the uncertainty of the estimates.

Some uncertainties, of course, will remain. Table A10-7 summarizes the caveats, omissions, biases, and uncertainties known to affect the estimates that will be developed for the final benefits analysis.

Table A10-7: Caveats, Omissions, Biases, and Uncertainties in the Commercial Benefits Estimates

Issue	Impact on Benefits Estimate	Comments
Change in commercial landings due to I&E	Uncertain	The economic analysis described in the chapter relies on projected changes in harvest developed using data and methods described in the NODA and elsewhere. These projected changes in harvest may be under-estimated because neither cumulative impacts of I&E over time nor interactions with other stressors are considered.
Estimates of commercial harvest losses due to I&E under current conditions not region/species specific	Uncertain	EPA estimates the impact of I&E in the case study analyses based on data provided by the facilities. The most current data available were used. However, in some cases these data are 20 years old or older. Thus, they may not reflect current conditions.
Effect of change in stocks on number of landings not considered	Uncertain	EPA assumes a linear stock to harvest relationship, that a 13 percent change in stock would have a 13 percent change in landings; this may be low or high, depending on the condition of the stocks. Region-specific fisheries regulations also will affect the validity of the linear assumption.
Effect of uncertainty in estimates of commercial landings and prices unknown	Uncertain	EPA assumes that NMFS landings data are accurate and complete. In some cases prices and/or quantities may be reported incorrectly.
Estimates of producer surplus as percentage of gross landings not region/species specific	Uncertain	EPA currently estimates that the increase in producer surplus as a result of the rule will be between 0 percent and 40 percent of the estimated change in gross revenues. The research used to develop this range is not region-specific; thus the true value may fall outside this range (higher or lower) for some regions and species.

Chapter A11: Estimating Benefits with a Random Utility Model

INTRODUCTION

This chapter describes the random utility model (RUM) and trip frequency model for recreational fishing used in the case study analyses of recreational fishing benefits from the final section 316(b) rule. The model's main assumption is that anglers will get greater satisfaction, and thus greater economic value, from sites where the catch rate is higher, all else being equal. This benefit may occur in two ways: first, an angler may get greater enjoyment from a given fishing trip when catch rates are higher, and thus get a greater value per trip; second, anglers may take more fishing trips when catch rates are higher, resulting in greater overall value for fishing in the region.

CHAPTER CONTENTS

EPA relied on two primary data sources in the case study analyses:

- the National Marine Fisheries Service (NMFS) Marine Recreational Fishing Statistics Survey (MRFSS) combined with the Add-on MRFSS Economic Survey (AMES) or combined with the Add-on MRFSS Cost Survey (NMFS 2003a, 2000, and 2003b); and
- the Michigan Recreational Anglers survey, conducted by Michigan Department of Natural Resources (MDNR, 2002).

The North Atlantic and Mid-Atlantic case studies rely on the 1994 MRFSS data; the South Atlantic and Gulf of Mexico case studies rely on the 1997 MRFSS data; and the California case study uses the 2000 MRFSS data. The Great Lakes case study relies on the 2001 MDNR Recreational Anglers survey data. The three datasets provide information on where anglers fish, what fish they catch, and their personal characteristics. When anglers choose among fishing sites they reveal information about their preferences. The case studies use information on recreational anglers' behavior to infer anglers' economic value for the quality of fishing in the case study areas.

EPA used a random utility model to investigate the impact of site characteristics on anglers' site choice for single-day trips. Key determinants of site choice include site-specific travel cost, fishing quality of the site, and additional site attributes such as presence of boat ramps and aesthetic quality of the site. EPA used the 5-year historic catch rates per hour of fishing as a measure of fishing quality in the five coastal region case studies and the Great Lakes regional case study.

The random utility models generate welfare measures resulting from changes in catch rates on a per-trip basis. To capture the effect of changes in catch rates on the number of fishing trips taken per recreational season, EPA combined a RUM model and a trip participation model. The trip participation model estimates the number of trips that an angler will take annually. The combined model is used to estimate the economic value of changes in catch rates or in fish abundance of important fish species in the case study areas.

A11-1 SITE CHOICE MODEL

The site choice model estimates how anglers value access to specific sites, and estimate per-trip economic values for changes in catch rates or fish abundance for different species. The study uses a RUM for its site choice model. The RUM assumes that the cost of travel to a recreational site may be used as a proxy for the "price" of visiting that site. The RUM is therefore a form of travel cost model, using travel costs to estimate economic values for unpriced recreational activities.

The RUM assumes that anglers maximize their utility by choosing the fishing site; mode of fishing (i.e., from shore, private or rental boat, or charter boat); and species that give the greatest level of satisfaction, compared with all available substitutes. Angler *k* chooses site *j* if the utility from that site is greater than the utility from all substitute sites:

$$u_j(k) > u_h(k) \ for \ h \neq j \ and \ h = 1,...J \qquad \text{(A11-1)}$$

where:

$u_j(k)$ = utility of visiting site *j* for angler *k*;
$u_h(k)$ = utility of visiting a substitute site *h* for angler *k*; and
J = the total number of feasible sites in the angler's choice set.

The RUM travel cost model includes the effects of substitute sites on site values. For any particular site, assuming that it is not totally unique in nature, the availability of substitutes makes the value for that site lower than it would be without available substitutes.

An angler choosing to fish on a particular day chooses a site based on site attributes. The angler weighs the attributes for various "choice set" sites against the travel costs to each site. These travel costs include both the cost of operating a vehicle and the opportunity costs of time spent traveling. The angler then weighs the value given to the site's attributes against the cost of getting to the site when making a site selection.

The RUM therefore assumes that the probability of selecting a particular site is a function of the site attributes, including catch rates, and travel costs to the site:

$$Prob\ (site_j) = f(catch\ rates,\ other\ site\ attributes,\ travel\ cost,\ travel\ time) \qquad \text{(A11-2)}$$

The RUM assumes that there is a non-random component (v_j) and a random component (ϵ_j) to each angler's utility. The random component is not observable by the researcher (Maddala, 1983; McFadden, 1981). The model therefore assumes that the utility function has a fixed component and a random component, so that:

$$u_j(k) = v_j(k) + \epsilon_j \qquad \text{(A11-3)}$$

where:

$u_j(k)$ = utility of visiting site *j* for angler *k*;
$v_j(k)$ = the observable component of utility; and
ϵ_j = the random, or unobservable component.

The conditional logit model, most often used to estimate the RUM, is based on the assumption that the random error terms ϵ_j have independently and identically distributed extreme value distributions, and are additive with the observable part of utility (McFadden, 1981; Ben-Akiva and Lerman, 1985).

The logit model therefore becomes:

$$Prob(site_j) = \frac{\exp[v_j(k)]}{\sum_j \exp[v_j(k)]} \ for \ j = 1,\ldots,J \qquad \text{(A11-4)}$$

where:

$Prob(site_j)$ = the probability that angler *k* will select site *j*;
$\exp[v_j(k)]$ = the angler's utility from visiting site *j*; and
$\Sigma_j \exp[v_j(k)]$ = the sum of the angler's utility for each site, summed over all sites in the opportunity set for a given region.

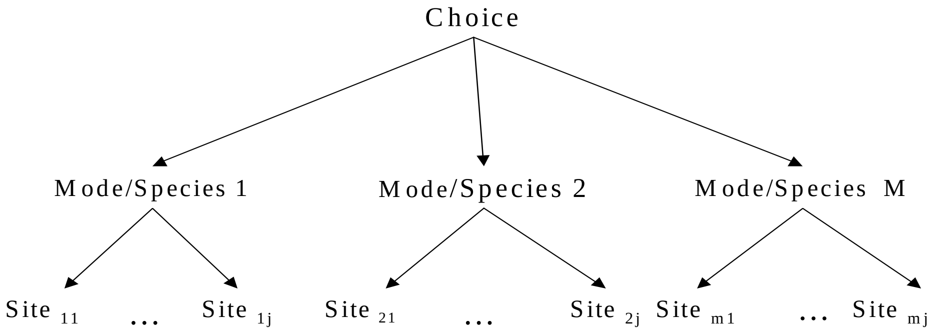
This is estimated as:

$$Prob(j) = \frac{\exp[\beta' x_j]}{\sum_j \exp[\beta' x_j]} \tag{A11-5}$$

The conditional logit model imposes the assumption that adding or deleting a site does not affect the probability ratio for choosing any two sites. This so-called independence of irrelevant alternatives (IIA) property follows from the assumption that the error terms are independent (Ben-Akiva and Lerman, 1985). Sites sharing characteristics not included in the model (e.g., saltwater vs freshwater sites) will have correlated error terms, thus violating the IIA property. In these cases a nested logit model, which groups sites with similar characteristics, is more appropriate.

The nested logit model assumes that anglers first choose the group and then a site within that group. Recreational fishing models generally assume that anglers first choose a fishing mode (e.g, fishing from a boat or from shore), and then a site. Thus, the model is structured as a tree, where anglers face a multidimensional choice, consisting of ($M \times J_m$) combinations of modes, *m*, and sites, *j*. The upper levels of the tree — in this case fishing modes — are referred to as branches, while the lower levels — individual sites — are referred to as twigs. This decision tree is illustrated in Figure A11-1.

Figure A11-1: Nested Logit RUM Model



Source: U.S. EPA analysis for this report.

The utility of each element in the angler's choice set is defined as:

$$u_{mj}(k) = V_m(k) + V_j(k) + V_{mj}(k) + \epsilon_m + \epsilon_{mj} \tag{A11-6}$$

where:

$u_{mj}(k)$ = utility of visiting site *j*, fishing by mode *m*, for angler *k*;
$V_m(k)$, $V_j(k)$, $V_{mj}(k)$ = the observable components of utility; and
ϵ_m, ϵ_{mj} = the random, or unobservable components of utility.

In the nested model, ϵ_j is assumed to equal zero, implying there is no correlation across modes, or branches (Ben-Akiva and Lerman, 1985).

The probability that an angler chooses site *j* and mode *m* is:

$$Prob\ (site_j, mode_m) = Prob\ (site_j \mid mode_m)\ x\ Prob\ (mode_m) \tag{A11-7}$$

The choice probability for each site is conditional on the choice of mode. Thus, the probability of selecting a site j is

$$Prob(site_j|mode_m) \;=\; \frac{\exp[v_{j|m}(k)]}{\sum_{j|m}\exp[v_{j|m}(k)]} \;\; j = 1,\ldots,J;\; m=1,\ldots,M \tag{A11-8}$$

where:

$Prob(site_j \mid mode_m)$ = the probability that angler k will select site j, given that the angler has selected mode m;
$\exp[v_{j\mid m}(k)]$ = the angler's utility from visiting site j for mode m;
$\Sigma_{j\mid m} \exp[v_{j\mid m}(k)$ = the sum of the angler's utility for each site available to mode m, summed over all sites in the opportunity set for a given region and mode;
J = the total number of sites available to an angler; and
M = the total number of fishing modes (e.g., shore, private boat, or charter) available to an angler.

This is estimated as:

$$Prob(j \mid m) \;=\; \frac{\exp[\beta' x_{j\mid m}]}{\exp[I_m]} \tag{A11-9}$$

where:

β = the matrix of estimated coefficients;
$x_{j|m}$ = the matrix of characteristics of each site j for fishing mode m; and
I_m = the expected maximum utility from the choice of a mode, termed the inclusive value for mode choice m.

The inclusive value is defined as:

$$I_m \;=\; \log[\, \sum_{j\mid m} \exp[\beta' x_{j\mid m}] \tag{A11-10}$$

The probability of selecting a mode is estimated as:

$$Prob(m) \;=\; \frac{\exp[\alpha' y_m \;+\; \tau_m I_m]}{\sum_m \exp[\alpha' y_m \;+\; \tau_m I_m]} \;\; for\;\; m = 1,\ldots,M \tag{A11-11}$$

where:

α = the matrix of estimated coefficients on mode characteristics;
y_m = the matrix of characteristics of each mode;
τ = the coefficient on the inclusive value; and
$\Sigma_m \exp[\alpha' y_{m\,+}\, \tau_m I_m]$ = the sum of the angler's utility for each fishing mode, summed over all modes available to an angler; and
M = the number of fishing modes, or branches, in the model.

The coefficient on the inclusive value is related to the correlation between alternatives. The condition $0<\tau<1$ is sufficient for the nested logit model to be consistent with utility maximization (McFadden, 1981). A value of τ between zero and one indicates that there is greater substitutability within, rather than across, groups of alternatives. Thus, there is greater substitutability between sites than across fishing modes. If τ is equal to one, then all modes are equally substitutable, and the model becomes identical to the standard multinomial or conditional logit model, where the IIA property holds for all alternatives.[1]

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[1] If consistency with utility maximization is required to hold globally, the coefficients on the inclusive values (i.e., dissimilarity coefficients) must lie inside the unit interval (McFadden, 1981). If consistency with utility maximization is required to hold only locally, then the dissimilarity coefficients can lie outside of the unit interval. In that case, additional tests are required to determine whether conditions for local maximum are satisfied (Kling and Herriges, 1995).

While some of the case study models used the nested logit model, the model was found to be inappropriate for other case studies. In these cases, the conditional logit model was used for site choice estimation. In all of the logit models estimated for the RUM case studies, the measurable component of utility is estimated as:

$$v_j(k) \;=\; \beta_1 tc_j(k) \;+\; \beta_2 \; tt_j(k) \;+\; \beta_3 \; X_j(k) \;+\; \textstyle\sum_s \gamma_s q_{js}(k) \qquad \text{(A11-12)}$$

where:

$v_j(k)$ = the utility realized from a conventional budget constrained utility maximization model conditional on choice *j* by angler *k*;
$tc_j(k)$ = the travel cost to site *j* for angler *k*;
$tt_j(k)$ = the travel time to site *j* for angler *k*;
$X_j(k)$ = a vector of site characteristics for site alternative *j* as perceived by angler *k*. These characteristics may include various site amenities (e.g., presence of boat ramps) and aesthetic quality of the site;
$q_{js}(k)$ = the fishing quality of site *j* for species *s*, measured in terms of catch rate or fish abundance; and
β and γ = the estimated model coefficients.

The study assumes that anglers in the estimated model consider site quality based on the catch rate for their targeted species and additional site attributes, such as the presence of boat ramps or fishing piers. Theoretically, an angler may catch any of the available species at a given site (Morey, 1999). If, however, an angler truly has a species preference, then including the catch variable for all species available at the site would inappropriately attribute utility to the angler for species not pursued (Haab et al., 2000; Hicks et al., 1999; McConnell and Strand, 1994). To avoid this problem, EPA multiplied a dummy variable for each species targeted by the catch rate, so that each angler's observation in the data set includes only the targeted species' catch rate. All other catch rates are set to zero.

A11-2 TRIP FREQUENCY MODEL

The trip frequency model estimates changes in days fished when site or individual characteristics change. The model assumes that the number of days fished in a year is a function of the travel costs, site characteristics, and characteristics of the individual anglers:

$$T \;=\; f(p,x,z) \qquad \text{(A11-13)}$$

where:

T = the number of days fished in a year;
p = a vector of travel costs;
x = a vector of site characteristics; and
z = a vector of angler characteristics.

To connect this model to the RUM, the trip frequently model is often specified as:

$$T \;=\; f(I(p,x),z) \qquad \text{(A11-14)}$$

where:

I = the inclusive value for each angler, calculated from the RUM;
p = a vector of travel costs;
x = a vector of site characteristics; and
z = a vector of angler characteristics.

The inclusive value can be interpreted as a measure of the expected utility of a set of choice alternatives (Ben-Akiva and Lerman, 1985). The participation model uses the inclusive value from the conditional logit model as a measure of the expected utility of the sites available to anglers in the study region. This is measured by:

$$I_k = \log \sum_j \exp(V_j \ (q_{js})) \qquad \text{(A11-15)}$$

where:

I_k = the inclusive value for fishing sites in the study area for angler k;
$\exp(V_j(q_{js}))$ = angler's utility from visiting site j; and
q_{js} = catch rate for species s at site j.

This study therefore estimates the trip frequency model by first estimating the site choice model (RUM), then using the model results to estimate the inclusive value I_k for each angler. Finally, the study estimates the participation model using the inclusive value and other variables to explain trip frequency. The number of days fished becomes a function of the value per trip, indicated by the inclusive value and individual angler characteristics. This model assumes that changes in site quality and travel costs do not directly influence the number of trips, but that changes in site quality will change trip values, thereby indirectly affecting the number of trips.

The study uses a Poisson regression model to estimate trip frequency. This model is one of those most commonly used for count data: discrete data where the dependent variable is a count or frequency. The Poisson regression model explicitly recognizes the non-negative integer character of the dependent variable (Winkelmann, 2000).

The Poisson regression model assumes the Poisson distribution:

$$f(y_k) = \frac{\exp(-\lambda_k)\lambda_k^{y_k}}{y_k!} \quad for \ y = 0,\ 1,\ 2, \ldots \qquad \text{(A11-16)}$$

where:

y_k = the actual number of trips taken by an individual angler in the sample;
λ = both the mean and variance of the distribution (this parameter must be positive); and
k = 1, 2,...K, the number of individuals in the sample.

If the expected value of the demand for trips in a given time period is E(Y), and:

$$E(Y) = f(I, z, \beta) \qquad \text{(A11-17)}$$

where:

I = the inclusive value;
z = a vector of angler characteristics; and
β = the vector of estimated coefficients,

then the Poisson probability distribution of demand for trips is:

$$Prob\ (Y_k = y_k) = \frac{e^{-\lambda_k}\lambda_k^{y_k}}{y_k!}, \quad y = 0,\ 1,\ 2, \ldots \qquad \text{(A11-18)}$$

where:

Y_k = the estimated number of trips taken by an individual in the sample;
y_k = the actual number of trips taken by an individual in the sample;
k = 1, 2,...K the number of individuals in the sample; and
$\lambda = f(I, z, \beta)$ = the expected number of trips for an individual in the sample, where I, z, β are variables affecting the demand for recreational trips (i.e., inclusive value and socio-economic characteristics, and β is the vector of estimated coefficients.

Generally, λ is specified as a log-linear function of the explanatory variables x_i, so that:

$$\ln \lambda_k = \beta x_k \tag{A11-19}$$

or:

$$\lambda_k = \exp(\beta x_k) \tag{A11-20}$$

This function ensures that λ_k will be positive. The parameters of the Poisson regression are estimated by maximum likelihood.

This model's primary limitation is the requirement that the mean equals the variance. The variance often exceeds the mean, resulting in overdispersion. Overdispersion may be viewed as a form of heteroskedasticity (Winkelmann, 2000). If overdispersion exists but the model is otherwise correctly specified, the Poisson estimator will still be consistent. The standard errors will be biased downward, however, leading to inflated t-statistics. When this occurs, researchers often use the negative binomial, which allows for the variance to be greater than the mean. The negative binomial distribution is derived as a compound Poisson distribution, where the Poisson distribution is the limiting form of the negative binomial distribution.

The Poisson model may be modified to derive the negative binomial model by respecifying λ_i so that:

$$\ln \lambda_k = \beta x_k + \epsilon \tag{A11-21}$$

where $\exp(\epsilon)$ has a gamma distribution with mean 1 and variance α (Greene, 1995), yielding the conditional probability distribution:[2]

$$Prob[Y = y_k | \epsilon] = \frac{\exp(-\lambda_k) \exp(\epsilon) \lambda_k^{y_k}}{y_k!} \tag{A11-22}$$

where:

$Prob[Y = y_k | \epsilon]$ = the probability that the estimated number of trips equals the actual number of trips, if ϵ has a gamma distribution with mean 1 and variance α;
y_k = 0,1,2... number of trips taken by individual k in the sample;
k = 1,2,..., k number of individuals in the sample; and
λ_k = expected number of trips for an individual in the sample.

Integrating out ϵ from equation A11-22 gives the unconditional distribution for y_k, which is used in the model's optimization:

$$Prob\ (Y = y_k) = \frac{\Gamma(\theta + y_k)}{\Gamma(\theta)\ y_k!]\ u_k^{\theta}\ (1 - u_k)^{y_k}} \tag{A11-23}$$

where:

$Prob(Y = y_k)$ = the probability that the estimated number of trips equals the actual number of trips;
y_k = 0,1,2... number of trips taken by individual k in the sample;

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[2] EPA chose this particular parameterization because it is used by the LIMDEP^{TM} software package.

$\Gamma(.)$ = gamma function;[3]
θ = $1/\alpha$, where α is an overdispersion parameter; and
u_i = $\theta/(\theta+\lambda)$.

The negative binomial model has an additional parameter, α, which is an overdispersion parameter, such that:

$$Var\ [y_k] = E\ [y_k]\ (1 + \alpha\ E\ [y_k]) \qquad \text{(A11-24)}$$

The overdispersion rate is then given by the following equation:

$$Var\ \frac{y_k}{E\ [y_k]} = 1 + \alpha\ E\ [y_k] \qquad \text{(A11-25)}$$

(Greene, 1995).

EPA used the negative binomial model to predict the seasonal number of recreation trips for each recreation activity based on the inclusive value, individual socio-economic characteristics, and the overdispersion parameter, α. If the inclusive value (i.e., the measure of the expected utility of site alternatives) has the anticipated positive sign, then increases in the inclusive value stemming from improved fishing quality at the sites in the study area will lead to an increase in the number of trips. The combined multinomial logit (MNL) model site choice and count data trip participation models allowed the Agency to account for changes in per-trip welfare values, and for increased trip participation in response to improved ambient water quality at recreation sites.

A11-3 WELFARE ESTIMATION

The case studies estimate changes in economic values when catch rates for different species change. Changes in catch rates will affect economic values in two ways. First, the value per trip will change; and second, the number of trips taken may change. The study measures the total economic value for a change in the quantity or quality of particular sites by the number of days fished per angler times the economic value per trip per angler. This value varies with the quality and number of available sites. The total value of a change in catch rate is measured as:

$$TEV = N \times X \times WTP \qquad \text{(A11-26)}$$

where:

TEV = the total economic value for a specified period of time, such as a season or year;
N = the number of participants;
X = the number of trips per participant; and
WTP = the value per angler per trip, measured by the amount of money that the angler would be willing to pay for a fishing trip.[4]

The study first estimates the value per trip using the RUM, and then estimates the number of trips per angler using the trip frequency model. The results of these models must be combined to measure the total economic value for a given change.

The value of an improvement in site quality, in this case the catch rate or fish abundance, can be measured by the compensating variation (CV) that equates the expected value of realized utility under the baseline and post-compliance conditions. If the catch rate increases from q^0 to q^1, then the CV will be measured by:

$$v_j(p_j,\ q_j^1,\ y - CV) + \epsilon_j = v_j(p_j,\ q_j^0,\ y) + \epsilon_j \qquad \text{(A11-27)}$$

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[3] Gamma function is a notation for a definite integral that appears in the equation. For detail on gamma function see Mood et al. (1974).

[4] The estimated model and resulting welfare estimates rely on the assumptions that the number of participants is fixed in the short run, and that the value per trip is independent of the number of trips.

where:

p_j = the fishing price, or travel cost, for site *j*;
q_j^1 = the quality, measured by catch rate, for site *j* under the post-compliance conditions;
q_j^0 = the quality, measured by catch rate, for site *j* under the baseline conditions; and
y = the angler's income.

To calculate *CV*, the angler's utility $(V_j\,(k))$ must be estimated as a function of price, quality, and income. The marginal utility of income cannot be estimated in the logit model because each angler's income does not change across alternatives. Price (travel cost), however, enters the indirect utility function *V(j)*, so that the model can assume the estimated coefficient on travel cost to be the negative of the marginal utility of income (Bockstael et al., 1991).

The RUM predicts only the probability of choosing a specific site. The measure of *CV* must therefore account for the researcher's uncertainty in predicting site choice. Measuring *CV* in terms of expected value yields:

$$E[v(p,\ q^1,\ y - CV)] \ = \ E[v(p,\ q^0,\ y)] \tag{A11-28}$$

where:

$v(p, q, y)$ = expected maximum utility of being able to choose among *J* sites on a given fishing trip;
p = the fishing price, or travel cost;
q^1 = sites' quality, measured by catch rate, under the post-compliance conditions;
q^0 = sites' quality, measured by catch rate, under the baseline conditions; and
y = the angler's income.

If the marginal utility of income is assumed to be constant, the compensating variation for the logit model is (Bockstael et al., 1991; Parsons et al., 1999):

$$\begin{aligned} CV_k &= (-1/\beta_1)\ \ [[\ln\textstyle\sum \exp[v_j(q^1)] \ - \ \ln\textstyle\sum \exp[v_j\ (q^0)]] \\ &= (-1/\beta_1)\ [I^1 - I^0] \end{aligned} \tag{A11-29}$$

where:

CV_k = the compensating variation for individual *k* at site *j* on a given day;
j = 1,...,J represents a set of alternative sites in the study region;
β_1 = the negative of the marginal utility of income, measured by the coefficient on travel cost;
I^0 = the baseline inclusive value; and
I^1 = the post-compliance inclusive value.

CV for the nested logit model is calculated as follows (Bockstael et al., 1991; Hicks et al., 1999):

$$\begin{aligned} CV_k &= \frac{\ln\left[\sum\limits_m \left(\sum\limits_j \exp\left(\dfrac{V_{jm}(q^1)}{(1-\tau)}\right)\right)^{(1-\tau)}\right] - \ln\left[\sum\limits_m \left(\sum\limits_j \exp\left(\dfrac{V_{jm}(q^0)}{(1-\tau)}\right)\right)^{(1-\tau)}\right]}{-\ \beta_1} \\ &= (-1/\beta_1)\ [I^1 - I^0] \end{aligned} \tag{A11-30}$$

where:

CV_k = the compensating variation for individual *k* at site *j* on a given day;
j = 1,...J represents a set of alternative sites in the study region for fishing mode *m*;
m = 1,...M represents alternative fishing modes available to an angler;
β_1 = the negative of the marginal utility of income, measured by the coefficient on travel cost;
I^0 = the baseline inclusive value; and
I^1 = the post-compliance inclusive value.

This gives the expected compensating variation for a choice occasion. To obtain the value per season, EPA multiplied the *CV* per trip by the number of trips estimated with the participation model. The two models are linked through the inclusive value, which weights the indirect utilities associated with different sites and their prices and qualities by the probabilities of choosing each site (Bockstael et al., 1991).

Parsons et al. (1999) compared several models that link site choice and trip frequency models, and find that they produce similar welfare estimates. Two methods for estimating seasonal welfare estimates are relevant to the models estimated in this case study. The first, proposed by Bockstael et al. (1987), calculates the per-trip welfare measure from the RUM, using the measure of *CV* presented above (Eq. A11-30). The authors then use the trip frequency model to predict the change in the number of trips taken under the proposed policy change. Finally, they calculate a seasonal welfare measure in one of two ways:

$$W_{low} = CV \times Pred(T^0) \tag{A11-31}$$

$$W_{high} = CV \times Pred(T^1) \tag{A11-32}$$

or

$$W = CV \times \frac{[Pred(T^0) - Pred(T^1)]}{2} \tag{A11-33}$$

where:

W_{low} = the low bound estimate of the seasonal welfare gain;
W_{high} = the upper bound estimate of the seasonal welfare gain;
CV = the compensating variation for an individual on a given day;
$Pred(T^0)$ = the predicted number of trips before the policy change; and
$Pred(T^1)$ = the predicted number of trips after the policy change.

The second method, based on Hausman et al. (1995), calculates seasonal welfare based on the trip frequency model.

EPA used the first method (Bockstael et al., 1987) to estimate lower and upper bound values for the seasonal welfare gain per individual. The Agency extrapolated the estimates of seasonal value per individual to the regional level based on estimates of the total participation level in the region. Procedures for estimating total regional participation are case study specific and discussed in the relevant chapters.

A11-4 DATA SOURCES

The data used for the regional case studies of recreational benefits are from the NMFS MRFSS in the Southeastern, Northeastern, and California regions in the U.S., and the MDNR Recreational Anglers survey database. The following sections provide a general description of each data source, sampling methods, and key variables. More detailed information on the sub-sample used in each case study can be found in the relevant case study sections.

A11-4.1 Marine Recreational Fisheries Statistics Survey

MRFSS is a long-term monitoring program that provides estimates of effort, participation, and finfish catch by recreational anglers. The MRFSS survey consists of two independent, but complementary, surveys: a random digit-dial telephone survey of households and an intercept survey of anglers at fishing access sites. Sampling is stratified by state; fishing mode (shore, private/rental boat, party/charter boat); and wave, and allocated according to fishing pressure. Fishing sites are randomly selected from an updated list of access sites.

The intercept survey distinguishes between the modes of fishing (i.e., shore, private/rental boat, party/charter boat), and is designed to elicit information about fishing trips just completed by anglers. The basic intercept survey collects information about anglers' home zip code, the length of their fishing trip, the species they were targeting on that trip, and the number of times anglers have been fishing in the past 2 and 12 months. Trained interviewers record the species and number of fish caught that are available for inspection, and weigh and measure the fish. Anglers report the number and species of each fish they caught on the trip that are not available for inspection (e.g., fish that were released alive or used for bait). The intercept survey provides the information used to estimate the historic catch rates at the case study sites for the individual species.

The random telephone survey is used to estimate the number of recreational fishing trips during a 2-month period (as opposed to annual participation) for coastal households. Households with individuals who have fished within 2 months of the phone call are asked about the mode of fishing, the gear used, and the type of waterbody where the trip took place for every trip taken within that period. NMFS estimates total catch and participation by state using the MRFSS telephone and intercept surveys, combined with U.S. Census Bureau and historical data (NMFS, 2003b). The effort estimates (i.e., number of trips) are used in the economic valuation work to expand mean trip-level recreational fishing values to aggregate, population values for recreational fishing. More details about the intercept and the random phone surveys can be found in the MRFSS Procedures Manual (NMFS, 1999a).

NMFS supplemented the routine MRFSS with socio-economic data from anglers in Southeastern and Northeastern regions.[5] The economic survey (AMES) was designed as an add-on to the MRFSS to take advantage of sampling, survey design, and quality control procedures already in place. Economic questions were added to the intercept survey, and a follow-up survey conducted over the telephone was designed to elicit additional socio-economic information from anglers who completed the add-on economic intercept survey. The AMES was implemented from Maine to Virginia in 1994 and from North Carolina to Louisiana in 1997.

The economic field intercept survey of anglers solicited data about trip duration, travel costs, distance traveled, and on-site expenditures associated with the intercepted trip. The survey was conducted by a private survey firm and administered to all marine recreational anglers aged 16 and older intercepted in the field. Data were collected according to the field sampling procedures specified in the MRFSS Procedures Manual. The economic questionnaire was administered either at the completion of the routine MRFSS questions (before inspection of fish) or after all available fish were identified and biological measurements had been obtained. As in the MRFSS, all survey participants, with the exception of beach-bank shore anglers, must have completed their fishing for the day.

Anglers were screened for willingness to participate in the telephone follow-up survey at the time of field intercept. Only those anglers agreeing to the add-on economics field survey or a telephone follow-up survey were interviewed. The telephone follow-up survey solicited additional data and information about anglers' recreational fishing avidity, attitudes, and experience.

A total of 14,868 follow-up surveys were attempted in the Northeast region in 1994, of which 8,226 (55 percent) were completed. Refusals, wrong numbers, and households that could not be reached in four calls accounted for the 45 percent non-response rate. The 1994 questionnaire targeted two distinct groups of anglers: (1) anglers who targeted — not merely caught — bluefish, striped bass, black sea bass, summer flounder, Atlantic cod, tautog, scup, or weakfish; and (2) anglers that targeted other species and happened to catch any of these 8 species. These species were chosen because they were either under management in 1994 or were expected to come under management in the near future. Approximately 10,000 AMES telephone interviews were completed in the Southeast region in 1997. The interview consisted of anglers intercepted from March 1997 through December 1997 and who agreed to be interviewed. More extensive details regarding the final results of the telephone follow-up survey are provided in Hicks et al. (1999).

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[5] Socio-economic data are not available for the California region.

The Agency used data from the 1994 and 1997 AMES to model recreational fishing behavior in the Northeastern (including North Atlantic and Mid-Atlantic) and Southeastern (including South Atlantic and Gulf of Mexico) regional case studies, respectively.

A11-4.2 Michigan Anglers Survey

The Great Lakes regional case study used data from the 2001 MDNR Recreational Anglers survey (Lockwood et al., 1999). The MDNR Fisheries Division uses roving and access site angler survey methods to collect angling effort and catch or harvest information from Inland and Great Lakes fisheries. These surveys follow a stratified design using structured sampling within strata. The collected data reflect angling characteristics for specific locations during specific calendar and daily periods. The Michigan angler surveys consist of two separate sampling components: interviews of angling trips and counts of anglers. Interviews collect information on the number of anglers in the party, length of the fishing trip, targeted species, catch or harvest by species, site information, angling mode, and zip code of angler’s home town. Typically, angling information is collected by individual angler for roving surveys, not by angling party, to avoid angler party size bias. Angler surveys provide information on both the number of fish harvested and the number of fish caught and released. However, because for caught-and-released fish, neither species type nor number are observed, the estimates of caught-and-released fish are subject to recall, prestige, and rounding errors, and species of fish are more likely to be misidentified. Angling effort is reported as estimated angler-hours or estimated angler-trips. Angler-hours reflect total hours from arrival at a given site to departure from that site for a given time period. Angler trips correspond to the number of times anglers fish at a given location for a given period of time. Part G, Chapter G4 of the Regional Studies Document provides descriptive statistics for the Michigan Angler survey.

A11-5 LIMITATIONS AND UNCERTAINTIES

Recreational survey results may suffer from recall bias, non-response bias, and bias due to sampling effects:

- Recall bias can occur when respondents are asked the number of days in which they recreate over the previous season, such as in the NDS survey. Some researchers believe that recall bias tends to lead to an overstatement of the number of recreation days, particularly for more avid participants. Avid participants tend to overstate the number of recreation days, since they count days in a "typical" week and then multiply them by the number of weeks in the recreation season. They often neglect to consider days missed due to bad weather, illness, travel, or when fulfilling "atypical" obligations. Some studies also found that the more salient the activity, the more "optimistic" the respondent tends to be in estimating the number of recreation days. Individuals also have a tendency to overstate the number of days they participate in activities that they enjoy and value. Taken together, these sources of recall bias may result in an overstatement of the actual number of recreation days.

- Non-response bias. A problem with sampling bias may arise when extrapolating sample means to population means. This could happen, for example, when avid recreation participants are more likely to respond to a survey than those who are not interested in the forms of recreation, are unable to participate, assume that the survey is not meant for them, or consider the survey not worth their time.

- Sampling effects. Recreational demand studies frequently face two types of observations that do not fit general recreation patterns: non-participants and avid participants. Non-participants are those individuals who would not participate in the recreation activity under any conditions. Assuming that an individual is a non-participant in a particular activity if he or she did not participate in that activity at any site tends to understate benefits, since some individuals may not have participated during the sampling period simply by chance, or because price/quality conditions were unfavorable during the sampling period. Avid participants can also be problematic because they claim to participate in an activity an inordinate number of times. This reported level of activity is sometimes correct, but often overstated, perhaps due to recall bias. These observations tend to be overly influential in the model and may lead to overestimation of the total number of trips.

The RUM analyses rely on the unweighted MRFSS data, not correcting for stratification. The MRFSS data is prone to avidity bias where the probability of being interviewed increases with the number of fishing trips (Thomson, 1991). EPA did not correct for avidity bias, which may result in overestimation of the predicted number of trips per season. This bias is unlikely to have a significant effect on benefit estimates, because the predicted number of trips was used only for estimating changes in fishing participation due to improved fishing opportunities. The estimated change in the number of trips was very small (see

Chapters C4, D4, E4, and F4 of this report for detail). The baseline level of participation used in the analysis was taken from NMFS. This estimate was corrected for avidity bias by NMFS.

Similarly to the MRFSS data, the Michigan Angler Survey data are prone to avidity bias where the probability of being interviewed increases with the number of fishing trips (Thomson, 1991). This may result in overestimation of the reported number of trips per season. In addition, the estimates of caught-and-released fish are subject to recall, prestige, and rounding errors, and species of fish are more likely to be misidentified. The effect of this bias on benefits estimates is, however, uncertain.

Chapter A12: Non-Use Meta-Analysis Methodology

CHAPTER CONTENTS

INTRODUCTION

Comprehensive, appropriate estimates of total resource value include both use and non-use values, such that the resulting total value estimates may be compared to total social cost. "Non-use values, like use values, have their basis in the theory of individual preferences and the measurement of welfare changes. According to theory, use values and non-use values are additive" (Freeman, 1993).[1] Therefore, use values alone may seriously understate total social values. Recent economic literature provides substantial support for the hypothesis that non-use values are greater than zero. Moreover, when small per capita non-use values are held by a substantial fraction of the population, they can be very large in the aggregate. As stated by Freeman (1993), "... there is a real possibility that ignoring non-use values could result in serious misallocation of resources."

Given that aquatic species without any direct uses account for the majority of cooling water intake structure losses, a comprehensive estimate of benefits of reduced impingement and entrainment (I&E) losses requires an estimate of non-use benefits. Stated preference methods, or benefit transfers based on stated preference studies, are the generally accepted techniques for estimating non-use values. Stated preference methods rely on surveys that assess individuals' stated willingness-to-pay (WTP) for specific ecological improvements, such as increased protection of fishery resources. Benefit transfer involves adapting research conducted for another purpose in the available literature to address the policy questions in hand (Bergstrom and De Civita, 1999). Because benefit-cost analysis of environmental regulations rarely affords sufficient time to develop original stated preference surveys specific to policy effects, benefit transfer is often the only remaining option for providing information to inform policy decisions.

Benefit transfer methods fall in three fundamental classes: 1) transfer of an unadjusted fixed value estimate generated from a single study site, 2) the use of expert judgment to aggregate or otherwise alter benefits to be transferred from a site or set of sites, and 3) estimation of a value estimator model derived from study site data, often from multiple sites (Bergstrom and De Civita, 1999). Recent studies have shown little support for the accuracy or validity of method 1, leading to increased attention to, and use of, *adjusted values* estimated by one of the remaining two approaches (Bergstrom and De Civita, 1999).

The following describes how EPA considered to apply method 3, often cited as a more appropriate means of benefit transfer, for the calculation of non-use values. Meta-analysis techniques have been increasingly explored by economists as a potential basis of policy analysis conducted by various government agencies charged with the stewardship of natural resources.

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[1] According to Freeman (1993), this additive property holds under traditional conditions related to resource levels and prices for substitute goods in the household production model.

Despite the increasing application of such methods, there are few generally accepted guidelines for meta-analyses applied to environmental policy. EPA believes that this is a promising methodology for policy valuation. However, EPA did not include the results of this approach in the benefit analysis of the final section 316(b) regulation because of limitations and uncertainties associated with estimation of non-use benefits on a national scale.

The first step in implementing an "adjusted value" benefit transfer approach for estimating non-use values of environmental regulations is a systematic analysis of the available economic studies that estimate non-use values. EPA explored available evidence concerning total benefits (including use and non-use values) applicable to the section 316(b) regulation. EPA identified 33 surface water valuation studies that used either stated preference or a combination of stated and revealed preference techniques to elicit total (including use and non-use) benefit values of aquatic habitat improvements. These studies vary in several respects, including the specific environmental change valued, the types of values estimated, the geographic region affected by environmental changes, and survey administration methods.

To examine the relative influence of study, economic and resource characteristics on WTP for aquatic habitat improvements (specifically, water quality improvements that would benefit various species groups), the Agency conducted two regression-based meta-analyses of over 78 WTP estimates for improvements to water resources, provided by the 33 original studies.[2] The estimated econometric models can be used to calculate a range of non-use values of aquatic resources that are potentially affected by I&E.

The following discussion summarizes results of EPA's analysis of surface water valuation studies and outlines the methodology for applying meta-regression results to estimating the benefits from reduced I&E attributable to the section 316(b) regulation.

A12-1 LITERATURE REVIEW PROCEDURE AND ORGANIZATION

EPA performed an in-depth search of the economic literature to identify valuation studies that estimate total WTP for quality changes that affect aquatic life habitats and/or recreational fishing and other recreational uses. EPA used a variety of sources and search methods to identify relevant literature:

- Review of EPA's research and bibliographies dealing with non-market benefits associated with water quality changes;
- Selection of surface water valuation studies from a meta-analysis conducted by Brown (1993), which includes valuation studies addressing a wide range of resources, all of which present separate estimates of non-use value;
- Systematic review of recent issues of resource economics journals (e.g., *Land Economics*, *Marine Resource Economics*, *Journal of Environmental Economics and Management*);
- Searches of online reference and abstract databases (e.g., Environmental Valuation Resource Inventory (EVRI), Benefits Use Valuation Database (BUVD), AgEcon Search);
- Visits to homepages of authors known to have published contingent valuation studies and or water quality research;
- Searches of Web sites of agricultural and resource economics departments at several colleges and universities; and
- Searches of Web sites of organizations and agencies known to publish environmental and resource economics valuation research [e.g., Resources for the Future (RFF), National Center for Environmental Economics (NCEE), Natural Resource Conservation Service (NRCS), National Bureau of Economic Research (NBER)].

From this review, EPA identified approximately 300 surface water valuation studies that are potentially relevant for this analysis, and compiled a bibliographic database to organize the literature review process. Thirty-four of these studies met the criteria identified for inclusion in the meta-analysis, which are as follows:

- **Specific amenity valued:** Selected studies were limited to those in which the environmental quality change being valued affects aquatic life and/or habitat in a waterbody that provides recreational fishing uses or other recreational activities, such as boating, swimming, or wildlife viewing;
- **U.S. studies:** Selected studies were limited to those that surveyed U.S. populations to value domestic resources; and
- **Research methods:** Selected studies were limited to those that applied research methods supported by journal literature.

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[2] Meta-analysis is "the statistical analysis of a large collection of results for individual studies for the purposes of integrating the findings" (Glass, 1976).

Based on these criteria, the Agency obtained the full text articles of the 33 studies that seemed most relevant for benefit transfer and compiled extensive information from the selected studies. The complete data set used in the meta-analysis is provided in the public record for the final rule (see DCN #6-2900), and includes the following information:

- full study citation;
- study location;
- sample data and description (e.g., size, response rate, income);
- resource characteristics (e.g., affected waterbody type, recreational uses, baseline quality);
- environmental quality change description, including geographic scale, affected species, and affected recreational uses (i.e., 50 percent increase in catch rates or water quality change from fishable to boatable);
- quantitative measure of environmental quality change (measured on quantitative scale based on the RFF water quality ladder);
- study WTP values updated to 2002 dollars; and
- WTP estimation characteristics (i.e., parametric vs. nonparametric, inclusion of protest bids and outlier bids, WTP description).

A12-2 DESCRIPTION OF STUDIES

As noted above, EPA selected 33 surface water valuation studies that allow estimation of total values from aquatic habitat improvements. These studies were conducted between 1973 and 2001, and applied standard, generally accepted valuation methods (mostly stated preference techniques) to assess WTP.[3] Studies were excluded if they did not conform to general tenets of economic theory, or if they applied methods not generally accepted in the literature.

All selected studies focus on environmental quality changes that affect surface water resources in the contiguous U.S. Beyond this general similarity, the studies vary in several respects. Differences include the specific environmental change valued, the scale of environmental improvement, the geographic region affected by environmental changes, the types of values estimated, survey administration methods, demographics of the survey sample, and statistical methods employed. The 33 studies include 17 journal articles, seven reports, four Ph.D. dissertations, three academic or staff papers, one book, and one Master’s thesis. Two studies (Whitehead et al., 1995; and Whitehead and Groothuis, 1992) had the same primary author and a total of nine individuals appear as an author on more than one study.

The 33 studies selected for the meta-analysis provided 78 observations in the final data set because multiple estimates of WTP were available from 23 studies. Some of the characteristics that allowed multiple observations to be derived from a single study include the extent of the amenity change, the respondent population type, elicitation method(s), waterbody type, number of waterbodies affected, recreational activities affected by the quality change, and species affected by the quality change. Table A12-1 lists key study and resource characteristics and indicates the number of observations derived from each study.

Surveys in 20 studies were administered by mail; seven studies collected information through personal interviews in the home, on-site, or in a centralized location; and six surveys were conducted by telephone. Survey response rates range from 25 to 90 percent, and study sample sizes range from 109 to 2,907 responses.

The two most common methods for eliciting WTP values were the dichotomous choice method, used in 12 studies, and the open-ended response used in 8 studies. Seven studies used the payment card approach, and 3 used the iterative bidding method. Two studies used multiple elicitation methods to generate a single WTP estimate.[4]

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[3] All of the selected studies used contingent valuation surveys (either discrete choice or open-ended), except for one study, which is based on a conjoint analysis survey. One study presented combined revealed and stated preference techniques in addition to contingent valuation results.

[4] The number of studies employing each elicitation technique does not sum to the total number of studies because some studies used different elicitation methods, from which multiple observations were derived.

Table A12-1: Select Characteristics of Surface Water Valuation Studies Used in Meta-Analysis[a]

Author and Year	Number of Observations	State	Waterbody Type	Affected Species	Affected Recreational Uses[b]
Aiken (1985)	1	CO	all freshwater	game fish	fishing
Anderson and Edwards (1986)	1	RI	salt pond/marshes	unspecified	fishing and swimming
Azevedo et al. (2001)	5	IA	lake	game fish	fishing and swimming
Bockstael et al. (1989)	2	MD	estuary	unspecified	swimming
Cameron and Huppert (1989)	1	CA	river/stream	game fish	game fishing
Carson et al. (1994)	2	CA	estuary	game fish; multiple categories	fishing
Clonts and Malone (1990)	3	AL	river/stream	unspecified	multiple uses
Croke et al. (1986-1987)	9	IL	river/stream	all recreational fish; none	boating and fishing; boating; other
Cronin (1982)	4	DC	river/stream	all recreational fish	fishing and swimming; boating
De Zoysa (1995)	2	OH	lake; river and lake	multiple categories	multiple uses
Desvousges et al. (1983)	2	PA	river/stream	unspecified	boating
Hayes et al. (1992)	2	RI	estuary	shellfish; none	fishing; swimming
Herriges et al. (1996)	2	IA	lake	all recreational fish	boating and fishing
Huang et al. (1997)	2	NC	estuary	multiple categories	fishing
Kaoru (1993)	1	MA	salt pond/marshes	shellfish	fishing
Lant and Roberts (1990)	3	IA/IL	river/stream	game fish; all recreational fish	boating, fishing, and swimming; boating and fishing
Loomis (1996)	1	WA	river/stream	game fish	fishing
Lyke (1993)	2	WI	lake	game fish	fishing
Magat et al. (2000)	2	CO/NC	all freshwater	all aquatic species	fishing; fishing and swimming
Matthews et al. (1999)	2	MN	river/stream	all aquatic species	boating and fishing
Mitchell and Carson (1981)	1	National	all freshwater	all aquatic species	fishing
Olsen et al. (1991)	3	Pacific NW (ID, MT, OR, WA)	river/stream	game fish	fishing
Roberts and Leitch (1997)	1	MN/SD	lake	multiple categories	multiple uses
Rowe et al. (1985)	1	CO	river/stream	game fish	boating, fishing, and swimming
Sanders et al. (1990)	4	CO	river/stream	unspecified	swimming
Schulze et al. (1995)	2	MT	river and lake	multiple categories	boating, fishing, and swimming
Stumborg et al. (2001)	2	WI	lake	multiple categories	multiple uses
Sutherland and Walsh (1985)	1	MT	river and lake	unspecified	swimming

Table A12-1: Select Characteristics of Surface Water Valuation Studies Used in Meta-Analysis[a]

Author and Year	Number of Observations	State	Waterbody Type	Affected Species	Affected Recreational Uses[b]
Welle (1986)	6	MN	all freshwater	multiple categories; game fish	game fishing and wildlife viewing; game fishing
Wey (1990)	2	RI	salt pond/marshes	shellfish	other
Whitehead and Groothuis (1992)	3	NC	river/stream	all recreational fish	multiple uses
Whitehead et al. (1995)	2	NC	estuary	multiple categories	boating, fishing, and swimming
Whittington et al. (1994)	1	TX	estuary	all aquatic species	multiple uses

[a] Where multiple observations are available from a given study, waterbody type, affected species, and/or affected recreational uses may take on different values for different observations from that study. In such cases where characteristics vary within a single study, these different characteristics are listed. For example, “boating, fishing, and swimming; boating and fishing,” represents a study where one or more observations from a given study dealt with quality changes that affected boating, fishing, and swimming, and at least one other observation from the same study dealt with boating and fishing.

[b] “Multiple uses” signifies that the water quality change would affect a wide variety of uses. For most of the studies with this designation, the uses were unspecified.

Source: U.S. EPA analysis for this report.

The Agency's review of the relevant economic literature showed that available surface water valuation studies focus primarily on water quality changes. Only 5 of the 33 studies specified environmental quality change in terms of increased fish abundance or harvest. In addition, 2 studies valued changes in the number of acres of shellfish beds. However, most of the reviewed studies (22) focusing on water quality improvements indicated these improvements would affect recreational fishing among other uses, and 24 studies specifically indicated that water quality improvements would affect fish abundance or diversity.

From these 33 studies, the Agency compiled a data set for the meta-analysis of WTP values. EPA specified two regression models based on these data to estimate a range of household non-use benefits. These two models include a model based on a semi-log functional form and a model based on a log-log specification. Section A12-3 focuses on the semi-log model; the alternative log-log specification is presented in section A12-4. Based on the peer-review results (see DCN 6-2500), the semi-log specification can be used in the main analysis of policy alternatives; the log-log specification can be used in a sensitivity analysis.

A12-3 SEMI-LOG META-ANALYSIS REGRESSION MODEL

EPA estimated a semi-log model based on 78 WTP estimates for improvements in water resources, derived from 33 original studies. These meta-data, the model specification, model results, and interpretation of results, are described in sections A12-3.1 through A12-3.3.

In a frequently cited work, Glass (1976) characterizes meta-analysis as "the statistical analysis of a large collection of results for individual studies for the purposes of integrating the findings. It provides a rigorous alternative to the casual, narrative discussion of research studies which is commonly used to make some sense of the rapidly expanding research literature" (p. 3; cited in Poe et al. (2001), p. 138). Meta-analysis is being increasingly explored as a potential means to estimate resource values in cases where original targeted research is impractical, or as a means to reveal systematic components of WTP (e.g., Poe et al., 2001; Bateman and Jones, 2003; Santos, 1998; Rosenberger and Loomis, 2000a; Smith and Osborne, 1996; Woodward and Wui, 2001). While the literature urges caution in the use and interpretation of benefit transfers for direct policy application (e.g., Poe et al., 2001; Desvousges et al., 1998), such methods are "widely used in the United States by government agencies to facilitate benefit-cost analysis of public policies and projects affecting natural resources" (Bergstrom and De Civita, 1999). Transfers based on meta-analysis are likewise common in both the United States and Canada (Bergstrom and De Civita, 1999).

Depending on the suitability of available data, a meta-analysis can provide a superior alternative to the calculation and use of a simple arithmetic mean WTP over the available observations, as it allows estimation of the systematic influence of study, economic, and natural resource attributes on WTP. The primary advantage of a regression-based (statistical) approach is that it accounts for differences among study characteristics that may contribute to changes in WTP, to the extent permitted by available data. An additional advantage is that meta-analysis can reveal systematic factors influencing WTP, allowing assessments of whether, for example, WTP estimates are (on average) sensitive to scope (Smith and Osborne, 1996).

A12-3.1 Meta-Data for Semi-Log Model

Meta-analysis is largely an empirical, data-driven process, but one in which variable and model selection is guided by theory. Given a reliance on information available from the underlying studies that comprise the meta-data, meta-analysis models most often represent a middle ground between model specifications that would be most theoretically appropriate and those specifications that are possible given available data. Poe et al. (2001), Bateman and Jones (2003), Rosenberger and Loomis (2000a), Smith and Osborne (1996), Dalhuisen et al. (2003), and others provide insight into the mechanics of specifying and estimating meta-equations in resource economics applications.

Past meta-analyses have incorporated a range of different statistical methods, with none universally accepted as superior (e.g., Poole and Greenland, 1999; Bateman and Jones, 2003; Poe et al., 2001; Santos, 1998). Nonetheless, the model is estimated following standard methods illustrated in the most recent literature. For example, there is significant consensus that models must somehow address (or at a minimum, test for) potential correlation among observations provided by like authors or studies and the related potential for heteroskedasticity (Bateman and Jones, 2003; Rosenberger and Loomis, 2000b). EPA followed recent work of Bateman and Jones (2003) in applying a multilevel model specification to the meta-data, to address potential correlation among observations gathered from single studies. Also following prior work (e.g., Poe et al., 2001; Smith and Osborne, 1996) EPA applied the Huber-White robust variance estimation. As described by Smith and Osborne

(1996, p. 293), "this approach treats each study as the equivalent of a sample cluster with the potential for heteroskedasticity…across clusters." Weighted models are avoided following the arguments of Bateman and Jones (2003). For comparison, models were also estimated using ordinary least squares (OLS) with robust variance estimation, weighted least squares (WLS) with robust variance estimation, and multilevel models with standard (non-robust) variance estimation. None of these models outperformed the illustrated model in terms of overall model significance and fit, and statistical significance of individual coefficients (see section A12-3.2 for further details concerning the specification of the semi-log model).

To guide development of the semi-log model and variable specifications, EPA relied upon a set of general principles. These principles are designed to help prevent excessive data manipulations and other factors that may lead to misleading model results. The general principles include, all else being equal:

- Fewer and simpler data transformations are preferred to more extensive ones;
- In the absence of overriding theoretical considerations, continuous variables are generally preferred to discrete variables derived from underlying continuous distributions;
- Models should attempt to capture elements of scope and scale of resource changes;
- Models should distinguish WTP associated with different types of resources and resource uses, particularly where relevant to the policy question at hand; and
- Where possible, exogenous constraints should be avoided in favor of "letting the data speak for themselves."

The dependent variable in the meta-analysis is the natural logarithm of estimated household WTP for water quality improvements in aquatic habitat, as reported in each original study. For this analysis, original study values were adjusted to 2002$ based on the relative change in Consumer Price Index (CPI) from the study year to 2002. Total WTP over the sample ranged from $7.26 to $376.61, with a mean value of $110.70. As expected, WTP for non-users had a lower mean value of $86.60, with a range from $27.74 to $242.34.[5]

All right-hand-side variables are linear, resulting in a standard semi-log functional form. This functional form has advantages because of 1) its fit to the data, 2) the intuitive results provided by the functional form, and 3) the common use of this functional form in the meta-analysis literature (e.g., Smith and Osborne, 1996; Santos, 1998). While linear forms are also common in this literature (Bateman and Jones, 2003; Poe et al., 2001; Rosenberger and Loomis, 2000a,b), specifications requiring more intensive data transformations (e.g., Box-Cox, log-log) are less common.

As noted in the preceding section, the meta-data include independent variables characterizing specifics of the resource(s) valued such as the baseline resource conditions; the extent of resource improvements and whether they occur in estuarine or freshwater; the geographic region and scale of resource improvements (e.g., the number of waterbodies); elicitation and survey methods; characteristics of surveyed populations (e.g., users, non-users); and other specifics of each study. For ease of exposition, these variables are categorized into those characterizing 1) study and methodology, 2) surveyed populations, 3) geographic region and scale, and 4) resource improvements. Attributes included within each category are summarized below.

Study and methodology variables characterize such features as:

- The year in which a study was conducted;
- The payment vehicle and elicitation format (e.g., discrete choice versus open-ended, voluntary versus non-voluntary, interview versus mail versus phone);
- WTP estimation methods and conventions (e.g., approaches to protest and outlier bids, use of parametric versus nonparametric statistical methods, estimation of mean or median WTP, the use of annual or lump-sum payments);
- Reported survey response rates; and
- Whether the original survey represented water quality changes using the Resources for the Future water quality ladder.

Surveyed populations variables characterize such features as:

- The average income of respondents; and
- Whether the survey specifically targeted non-users.

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[5] EPA notes that only 10 of the 33 studies provided WTP values for non-users.

Geographic region and scale variables characterize such features as:

- The number of waterbodies affected by the policy; and
- The geographic area of the country in which the study was conducted.

Resource improvement variables characterize such features as:

- The extent of water quality change affecting different species groups;
- Baseline water quality;
- Those studies for which changes in uses other than fishing are specifically noted in the survey;
- Those studies identifying large increases in fish populations (i.e., greater than 50 percent); and
- Those studies in which the resource improvements are described (within the associated survey) as affecting uses that are not directly affected by improvements in fishery resources (e.g., outing and swimming).

Although the interpretation and calculation of most independent variables requires little explanation, a few variables require additional detail. These include the variables characterizing surface water quality and its measurement. Many (23) observations in the meta-data characterize quality changes using variants of the RFF water quality ladder (e.g., Mitchell and Carson, 1989). This scale is linked to specific pollutant levels which, in turn, are linked to presence of aquatic species and recreational uses. However, some observations provide water quality measures using other, primarily descriptive, means that differ from the RFF water quality ladder.

To allow consistent comparisons of water quality change using a single scale, EPA mapped all water quality measures to the original water quality scale (or ladder) developed and tested by RFF. Water quality ladder values were therefore developed for those studies that did not originally use the RFF ladder. This scale was chosen for two reasons. First, a large number of the original studies in the meta-data included RFF ladder measures as "native" components of the original surveys. Hence, for these studies, no additional transformations were required. Second, it was decided that the use of an existing, well-tested and accepted water quality index was in general superior to the development of a unique scale for this study.

While not all studies in the meta-data included the RFF ladder as a native survey component, in most cases the descriptions of water quality (present in the studies that did not apply the water quality ladder) rendered mapping of water quality measures to the RFF ladder straightforward. In cases where baseline and improved (or declined) water quality was not defined by suitability for recreational activities (e.g., boating, fishing, swimming) or corresponding qualitative measures (e.g., poor, fair, good), EPA used descriptive information available from studies (e.g., amount/indication of the presence of specific pollutants, historical decline of the quality of the resource) to approximate the baseline level of water quality and the magnitude of the change.[6] For studies that valued discrete changes in the size of species populations, EPA characterized the baseline quality based on the current presence and prevalence of the species at hand, and assumed population increases to correspond to modest increases in water quality in order to be conservative.[7] To account for the uncertainty involved in mapping those studies that are not based on the RFF water quality ladder, EPA introduced the binary variable *wq_ladder*, which indicates those studies in which water quality ladder measurements were an original component of the survey instrument.

Variables incorporated in the final model are listed and described in Table A12-2.

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[6] For example, a study by Huang et al. (1997) described current water quality as degraded from 1981 levels in terms of reduced fish catches (60 percent) and reduced number of open shellfish beds (25 percent). However, because the water resource was still supporting recreational fishery, the baseline water quality was set to "fishable" on the water quality ladder.

[7] For example, a study by Lyke (1993) describes the baseline conditions as follows: (1) "there are no naturally reproducing lake trout in Lake Michigan; all lake trout found there are from hatcheries." 2) "Lake Superior stocks of self-reproducing lake trout were much reduced, but not wiped out, and both natural and hatchery-raised lake trout are found there." These baseline conditions correspond to the "game-fishable" level on the water quality ladder. The study estimates WTP for restoring natural populations of lake trout to the Wisconsin Great Lakes. Therefore, the expected change that will occur within the "game-fishable" category is likely to be small.

Table A12-2: Variables and Descriptive Statistics for the Semi-Log Regression Model

Variable	Description	Units and Measurement	Mean (Std. Dev.)
ln_WTP	Natural log of WTP for specified resource improvements.	Natural log of dollars (Range: 1.98 to 5.93)	4.45 (0.78)
year_indx	Year in which the study was conducted, converted to an index by subtracting 1,970.	Year index (Range: 3 to 31)	18.51 (6.54)
discrete_ch	Binary (dummy) variable indicating that WTP was estimated using a discrete choice survey instrument.	Binary (Range: 0 or 1)	0.32 (0.47)
voluntary	Binary (dummy) variable indicating that WTP was estimated using a payment vehicle described as voluntary as opposed to, for example, property taxes.	Binary (Range: 0 or 1)	0.08 (0.27)
interview	Binary (dummy) variable indicating that the survey conducted through in-person interviews (default value for this dummy is a phone survey).	Binary (Range: 0 or 1)	0.19 (0.40)
mail	Binary (dummy) variable indicating that the survey was conducted through mail (default value for this dummy is a phone survey).	Binary (Range: 0 or 1)	0.54 (0.50)
lump_sum	Binary (dummy) variable indicating that payments were to occur on something other than an annual basis over a long period of time, such as property taxes. For example, some studies specified that payments would occur over a five-year period.	Binary (Range: 0 or 1)	0.18 (0.39)
nonparam	Binary (dummy) variable indicating that WTP was estimated using nonparametric methods.	Binary (Range: 0 or 1)	0.47 (0.50)
wq_change	Change in mean water quality, specified on the RFF water quality ladder (Mitchell and Carson, 1989). Defined as the difference between baseline and post-compliance quality. Where the original study (survey) did not use the RFF water quality ladder, EPA mapped water quality descriptions to analogous levels on the RFF ladder to derive water quality change (see text). Note that this variable was only included in the final model as part of an interaction term (*WQ_fish*, *WQ_shell*, *WQ_many*, *WQ_non*).	Water quality ladder units (Range: 0.5 to 5.75)	2.45 (1.06)
wq_ladder	Binary (dummy) variable indicating that the original survey reported resource changes using a standard RFF water quality ladder.	Binary (Range: 0 or 1)	0.29 (0.46)
protest_bids	Binary (dummy) variable indicating that protest bids were excluded when estimating WTP.	Binary (Range: 0 or 1)	0.47 (0.50)
outlier_bids	Binary (dummy) variable indicating that outlier bids were excluded when estimating WTP.	Binary (Range: 0 or 1)	0.23 (0.42)
median_WTP	Binary (dummy) variable indicating that the study reported median, not mean, WTP.	Binary (Range: 0 or 1)	0.06 (0.25)
hi_response	Binary (dummy) variable indicating that the survey response rate exceeds 74 percent (i.e., 75 percent or above).	Binary (Range: 0 or 1)	0.32 (0.47)
income	Mean income of survey respondents, either as reported by the original survey or calculated by EPA based on U.S. Census Bureau averages for the original surveyed region.	Dollars (Range: 30,396 to 137,693)	47,189.37 (13,010.15)
nonusers	Binary (dummy) variable indicating that the survey is implemented over a population of non-users (default category for this dummy is a survey of any population that includes users).	Binary (Range: 0 or 1)	0.19 (0.40)
single_river[a]	Binary (dummy) variable indicating that resource change explicitly takes place over a single river (default is a change in an estuary).	Binary (Range: 0 or 1)	0.21 (0.41)
single_lake [b]	Binary (dummy) variable indicating that resource change explicitly takes place over a single lake (default is a change in an estuary).	Binary (Range: 0 or 1)	0.13 (0.34)
multiple_river	Binary (dummy) variable indicating that resource change explicitly takes place over multiple rivers (default is a change in an estuary).	Binary (Range: 0 or 1)	0.09 (0.29)

Table A12-2: Variables and Descriptive Statistics for the Semi-Log Regression Model

Variable	Description	Units and Measurement	Mean (Std. Dev.)
salt_pond	Binary (dummy) variable indicating that resource change explicitly takes place over multiple salt ponds (default is a change in an estuary).	Binary (Range: 0 or 1)	0.05 (0.22)
num_riv_pond	Number of rivers or salt ponds affected by policy; if unspecified *num_riv_pond* = 0. (In the present data, only studies addressing rivers and lakes specified >1 number of waterbodies. All others specified either 1 waterbody, or the number was unspecified.)	Number of specified rivers or ponds (Range: 0 to 15)	1.41 (3.63)
regional_fresh	Binary (dummy) variable indicating that resource change explicitly takes place in a fresh waterbody (default is a change in a salt waterbody or an estuary).	Binary (Range: 0 or 1)	0.37 (0.49)
southeast	Binary (dummy) variable indicating that survey was conducted in the USDA southeast region (default is northeast region).	Binary (Range: 0 or 1)	0.13 (0.34)
pacif_mount	Binary (dummy) variable indicating that survey was conducted in the USDA pacific/mountain region.	Binary (Range: 0 or 1)	0.21 (0.41)
plains	Binary (dummy) variable indicating that survey was conducted in the USDA northern or southern plains region.	Binary (Range: 0 or 1)	0.03 (0.16)
mult_reg	Binary (dummy) variable indicating that survey included respondents from more than one of the section 316(b) regions.	Binary (Range: 0 or 1)	0.04 (0.19)
WQ_fish	Interaction variable: *wq_change* multiplied by a binary (dummy) variable identifying studies in which water quality improvements are stated to benefit only fin fish species.[c] Default is zero (i.e., water quality change did not affect fish).	Water quality ladder units (Range: 0.5 to 5.75)	1.13 (1.54)
WQ_shell	Interaction variable: *wq_change* multiplied by a binary (dummy) variable identifying studies in which water quality improvements are stated to benefit only shellfish.[c] Default is zero (i.e., water quality change did not affect shellfish).	Water quality ladder units (Range: 0.5 to 4.0)	0.13 (0.65)
WQ_many	Interaction variable: *wq_change* multiplied by a binary (dummy) variable identifying studies in which water quality improvements are stated to benefit multiple species types (including fish, shellfish, and birds).[c] Default is zero (i.e., water quality change did not affect multiple species).	Water quality ladder units (Range: 0.5 to 4.0)	0.65 (1.21)
WQ_non	Interaction variable: *wq_change* multiplied by a binary (dummy) variable identifying studies in which species benefitting from water quality improvements remain unspecified.[c] Default is zero (i.e., water quality change affected specified species).	Water quality ladder units (Range: 0.5 to 2.5)	0.53 (0.94)
nonfish_uses	Binary (dummy) variable identifying studies in which changes in uses other than fishing are specifically noted in the survey.	Binary (Range: 0 or 1)	0.76 (0.43)
fishplus	Binary (dummy) variable identifying studies in which a fish population or harvest change of 50 percent or greater is reported in the survey.	Binary (Range: 0 or 1)	0.13 (0.34)
baseline	Baseline water quality, specified on the RFF water quality ladder.	Water quality ladder units (Range: 0 to 7)	4.66 (2.49)

[a] Examples of rivers and streams considered in the studies include the Columbia, Potomac, Elwha, Eagle, and Tar-Pamlico rivers.
[b] Includes one study that focused on a segment of the Lake Erie shoreline.
[c] The variable *wq_change* is defined earlier in this table as the difference between baseline and post-compliance quality, specified on the RFF water quality ladder (Mitchell and Carson, 1989).

Source: U.S. EPA analysis for this report.

A12-3.2 Semi-Log Model and Results

a. Semi-log model

As noted above, EPA estimated the meta-analysis regression using a multilevel, random-effects specification. This model follows the general approach of Bateman and Jones (2003). Multilevel (or hierarchical) models may be estimated as either random-effects or random-coefficients models, and are described in detail elsewhere (Goldstein, 1995; Singer, 1998). The fundamental distinction between these and classical linear models is the two-part modeling of the equation error to account for hierarchical data. Here, the meta-data are comprised of multiple observations per study, and there is a corresponding possibility of correlated errors among observations that share a common study or author.

The common approach to modeling such potential correlation is to divide the residual variance of estimates into two parts, a random error that is independently and identically distributed across all studies and for each observation, and a random effect that represents systematic variation related to each study. The model is estimated as a two-level hierarchy, with level one corresponding to non-use value estimates (individual observations), and level two corresponding to individual studies. The random-effect may be interpreted as a deviation from the mean equation intercept associated with individual studies (Bateman and Jones, 2003). The model is estimated using a maximum likelihood estimator (MLE), assuming that random effects are distributed multivariate normal. Following Bateman and Jones (2003), observations are unweighted. Covariances are obtained using the Huber-White covariance estimator (Smith and Osborne, 1996). Random-effects models such as the multilevel model applied here are becoming increasingly standard in resource economics applications, and are estimable using a variety of readily available software packages.

❖ *A note on functional form*

The dependent variable in the semi-log model is the natural log of WTP for surface water quality improvement, as shown by Table A12-2. The combination of this dependent variable with linear independent variables results in a common semi-log functional form. This functional form was chosen based on a combination of theoretical and empirical factors. Of particular importance was the performance of the semi-log model with regard to 1) data fit, 2) intuitive nature of results, and 3) history in the meta-analysis literature (e.g., Smith and Osborne, 1996; Santos, 1998).

The semi-log model was chosen over the linear model based on the ability of the semi-log form to capture curvature in the valuation function and its improved fit to the data. It also allows independent variables to influence WTP (after transformation from its natural log) in a multiplicative rather than additive manner.

The choice between log-log and semi-log functional forms is somewhat less straightforward. An appropriately specified log-log model has the theoretical advantage of requiring WTP to be zero when quality change is also equal to zero. The semi-log model does not impose this exogenous restriction. However, in the present context, it is questionable whether this restriction is justified by the meta-data. Average WTP in the data is approximately $111, with WTP values in the lowest 95th percentile of approximately $21. There are no zero WTP values in the data, and no studies for which water quality change approaches zero. Hence, the extreme low-end of any model specification forecasts beyond the range of available data. The ability of a model specification to restrict the WTP equation at a point beyond the reach of the available data may be of questionable empirical value — particularly given that threshold effects or nonconvexities may influence WTP at extremely low levels of quality change.

Given the questions about *a priori* restrictions on the functional form, final decisions regarding functional forms were made based on a combination of general principles and empirical performance. Based on these criteria, the semi-log model seems to outperform the log-log model. First, EPA used the Box-Cox method to see wether the data suggest linear independent variables or log dependent variables.[8] The Box-Cox test rejected the log specification. Moreover, the overall significance level of many variables is better in the semi-log model, including key variables characterizing such features as baseline water quality, water quality change, and the number of waterbodies affected by a policy.

From an empirical standpoint, another benefit of the semi-log specification is that it provides intuitive forecasts of WTP for marginal (small) quality changes at the low end of the data. For example, using the final semi-log specification, the difference in WTP between a 1 percent and 3 percent improvement in water quality (a barely perceptible difference for most

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[8] EPA estimated the Box-Cox exponent (*Lambda*) for the independent variables only. In addition, the Box-Cox transformation was only tested for continuous variables (i.e., dummy variables were not transformed, following standard practice). The Box-Cox test strongly rejects the log-log specification (*Lambda*= 0); it also strongly rejects the multiplicative inverse specification of independent variables (*Lambda*= -1). However, it fails to reject the semi-log specification, or linear specification of independent variables (*Lambda*=1).

respondents) is fairly small: far less than $1 in most model specifications. In contrast, log-log models tend to forecast fairly large relative changes in WTP for very small changes in water quality improvements.

❖ *A note on model specification*

Following standard econometric practice, the final model is specified based on guidance from theory and prior literature. For example, Arrow et al. (1993) make a fundamental distinction between discrete choice and open-ended payment mechanisms (where open ended include iterative bidding, payment cards, etc.). Hence, this is the distinction made in the final model (i.e., including the variable *discrete_ch*). Similarly, other "survey methodology" variables in the model were chosen based on theoretical considerations and prior findings in the literature (e.g., voluntary vs. mandatory payment vehicles, parametric vs. non-parametric, treatment of protest and outlier bids, use of mean versus median WTP).

Few variables were excluded solely because of lack of statistical significance. Individual variables were only excluded if they could not be shown to be statistically significant in any version of the model (restricted or unrestricted), and there was no overriding rationale for retaining the variable in the model. For example, variables distinguishing different *types* of discrete choice instruments (e.g., conjoint vs. dichotomous choice) added no significant explanatory power to the model (p=0.44).

Another example of excluded variables involves a set of variables identifying waterbody uses. While the model includes a key variable (*nonfish_uses*) distinguishing studies in which non-fishing uses were emphasized, the model excludes variables characterizing *specific* uses of included waterbodies. These variables are suppressed for a variety of reasons. First, substantial variability of types and magnitudes of uses present in the 78 different observations prevented a simple characterization of specific uses in a reasonable number of variables. Attempts to approximate such effects using information available in the original published studies produced unsatisfactory results — the associated variables were insignificant as a group in all model variants (tested as a group in the final model, χ^2=9.04 with df=8, such that p=0.31). Moreover, the primary purpose of the model is to assess non-use values for habitat improvements (affecting fish) in "average" waterbodies supporting a variety of uses.

It is important to note that although empirical considerations certainly play a role in model development, certain variables were retained in the model for theoretical reasons, even if significance levels were low. Such specification of meta-analysis models using a combination of theoretical guidance and empirical considerations is standard in modeling efforts.

b. Semi-log model results

Table A12-3 presents results of the semi-log model.

Table A12-3: Estimated Multilevel Model Results for the Semi-Log Model: WTP for Aquatic Habitat Improvements

Variable	Parameter Estimate	Standard Error	t Value	Prob > |t|
intercept	6.0158	0.6163	9.7600	<.0001
year_indx	-0.1072	0.0187	-5.7400	<.0001
discrete_ch	0.3956	0.3728	1.0600	0.2961
voluntary	-1.6330	0.2441	-6.6900	<.0001
interview	1.3252	0.2330	5.6900	<.0001
mail	0.5666	0.1774	3.1900	0.0030
lump_sum	0.5954	0.2526	2.3600	0.0243
nonparam	-0.4472	0.2228	-2.0100	0.0527
wq_ladder	-0.3799	0.2069	-1.8400	0.0751
protest_bids	0.9537	0.1580	6.0400	<.0001
outlier_bids	-0.8764	0.1212	-7.2300	<.0001
median_WTP	0.2206	0.1625	1.3600	0.1836
hi_response	-0.8094	0.1223	-6.6200	<.0001
income	0.0000	0.0000	0.1100	0.9128
nonusers	-0.5017	0.1189	-4.2200	0.0002
single_river	-0.3378	0.2189	-1.5400	0.1321
single_lake	0.3193	0.2723	1.1700	0.2492
multiple_river	-1.6050	0.3020	-5.3200	<.0001
salt_pond	0.7574	0.3650	2.0800	0.0456
num_rivers_ponds	0.0791	0.0094	8.4100	<.0001
regional_fresh	-0.0073	0.1664	-0.0400	0.9655
southeast	1.1482	0.2175	5.2800	<.0001
pacif_mount	-0.3125	0.1329	-2.3500	0.0246
plains	-0.8153	0.3173	-2.5700	0.0147
mult_reg	0.5951	0.2548	2.3400	0.0256
WQ_fish	0.2055	0.0861	2.3900	0.0227
WQ_shell	0.2561	0.0999	2.5600	0.0149
WQ_many	0.2332	0.1107	2.1100	0.0426
WQ_non	0.4695	0.2117	2.2200	0.0334
nonfish_uses	-0.1412	0.1841	-0.7700	0.4484
fishplus	0.8052	0.1951	4.1300	0.0002
baseline	-0.1265	0.0425	-2.9800	0.0053
Error Term (σ^2)	0.1151			
-2 Log Likelihood	65.6			
Covariance Factors:				
Study Level (σ_u)	6.19×10^{-18}			
Residual (σ_e)	0.1357			

Source: U.S. EPA analysis for this report.

A12-3.3 Interpretation of Semi-Log Regression Analysis Results

Regression results reveal strong systematic elements influencing WTP. The analysis finds both statistically significant and intuitive patterns that influence WTP for water quality improvements in aquatic habitats. In general, the statistical fit of the equation is quite good; there is a strong systematic element of WTP variation that allows forecasting of WTP based on site and study characteristics. The model as a whole is statistically significant at $p<0.0001$. The adjusted R-square is 0.77. Of the 31 independent variables in the restricted model (not including the intercept), 24 are statistically significant at the 10 percent level, with most statistically significant at the 1 percent level. Signs of significant parameter estimates generally correspond with intuition, where prior expectations exist. As shown in Table A12-3, the random effect is statistically insignificant (i.e., study level covariance factors are essentially zero). Considering these factors, the statistical fit of the semi-log model compares quite favorably to prior meta-analyses present in the literature.

a. Resource improvement effects

Seven variables characterize resource improvements; all are of the expected sign. The variables *WQ_fish*, *WQ_shell*, *WQ_many*, and *WQ_non* indicate the effects of water quality improvements associated with gains in fish, shellfish, multiple species, and unspecified habitat, respectively (see Tables A12-2 and A12-3). (One of the key advantages of the model is that it distinguishes among marginal water quality gains that influence these different types of aquatic species.) All signs are as expected. All four associated coefficients are positive and statistically significant ($p<0.05$ or better), indicating that higher WTP is associated with larger gains in water quality. This is an important result, and indicates that WTP is sensitive to the scope of water quality improvements. Moreover, the model reveals that water quality changes affecting different types of habitat (e.g., fish only, shellfish only, unspecified, or multiple species) may have substantially divergent WTP values. Given the focus of the section 316(b) rule on fish only, the ability of the model to distinguish habitat quality improvements targeted solely at fish is an important element of the model.

Another important and theoretically intuitive finding is that WTP for water quality improvements declines as baseline water quality increases. The variable *baseline* represents the baseline water quality from which water quality change would occur. The associated parameter estimate is significant ($p<0.01$) and has the expected negative sign, revealing diminishing returns to scale for water quality improvements. This finding suggests that the model is not only sensitive to scope at a broad level (i.e., larger water quality improvements generate larger WTP), but also is able to distinguish more subtle, if no less important, scope effects (WTP for marginal water quality improvements declines as baseline water quality improves).

Finally, the variable *fishplus* identifies those studies for which the associated survey identified particularly large gains in fish populations or harvest rates (>50 percent). The positive and statistically significant result ($p<0.01$) indicates that large gains in fish populations or harvests are associated with statistically significant increases in total WTP.

b. Geographic region and scale effects

Ten binary variables characterize geographic region and scale; seven are statistically significant at $p<0.10$. The default category from which these variables allow systematic variations in WTP is an estuarine waterbody in the northeast U.S.[9] Compared to this baseline, WTP associated with rivers is lower (*single_river* and *multiple_river* both have negative and significant values). *Single_lake* and *regional_fresh* both have positive values, but neither is significant. WTP for water quality gains in salt ponds (*salt_pond*) is higher than for estuaries ($p<0.05$). This is not surprising since water quality gains in salt ponds correspond to an increase in the number of acres of shellfish beds.

Of particular importance for the general validity of empirical findings, the model results further suggest that WTP is sensitive to the *number of waterbodies* under consideration. Of the waterbody categories distinguished above, both rivers and salt ponds allowed variation in numbers of affected waterbodies explicitly described by the survey. This variation is captured by the variable *num_riv_pond* (see Table A12-2).[10] The associated parameter estimate is statistically significant ($p<0.01$) and indicates that WTP increases with the number of waterbodies considered. This result, combined with the statistical

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[9] The Northeast region, as defined in Feather et al. (1999), encompasses all of the states in the National Marine Fisheries Service (NMFS) Marine Recreational Fisheries Statistics Survey (MRFSS) North Atlantic region. The Northeast region also corresponds most closely to the MRFSS Mid-Atlantic region, as well as those states bordering the Great Lakes, which comprise the Great Lakes region used in this analysis.

[10] Technically, this variable is the sum of two interaction variables: 1) an interaction between *multiple_river* and the number of waterbodies noted in the survey (0 if unspecified), and 2) an interaction between *salt_pond* and the number of waterbodies noted in the survey (0 if unspecified).

significance of the water quality change variables noted above, suggests that WTP values (in this case for water quality improvements) are strongly sensitive to scope, both in terms of the number of waterbodies considered and the magnitude of water quality change.

Finally, the regional indicator variables *southeast*, *pacif_mount*, *plains*, and *mult_reg* are statistically significant at p<0.05, suggesting that there are significant differences among WTP estimates from surveys in different geographical regions of the U.S. This suggests that socio-economic and cultural factors that vary by region (but that could not be included in this model), such as education level or occupation, may affect WTP. In some cases, however, the large magnitude of these regional effects suggests that spurious or otherwise unexplained effects (e.g., the effect of specific researchers who appear more than once in the data) may drive their overall magnitude. For example, the size of the positive parameter estimate associated with WTP in the southeast U.S. leads in many cases to relatively large increases in WTP for southeast policies — a finding that defies simple intuitive explanation. Hence, EPA believes that particular, spurious, or unexplained aspects of studies from this region may have caused the associated parameter estimate to have a larger-than-expected influence on WTP.

c. Surveyed populations effects

Only two variables, *nonusers* and *income*, are used to characterize surveyed populations. In particular, the *nonusers* variable is of substantial policy relevance. The negative and strongly significant (p<.0001) parameter estimate indicates that surveys of non-users only, who by definition only have non-use values for the resource improvements in question (cf. Freeman, 2003, p. 142), generate lower WTP values than surveys that include users, who may have both use and non-use values. Based on this statistically significant result, EPA is able to use the model to estimate non-use values, interpreted as the mean WTP values estimated by surveys of non-users only (see section A12-5). Such methods, however, may underestimate non-use values of the general population, if the non-use values of users exceed those of non-users (Whitehead and Blomquist, 1991b).

The *income* parameter estimate is positive, as expected, but is not statistically significant.

d. Study and methodology effects

A variety of study and methodology effects can be shown to influence WTP for water quality improvements. While not surprising, this does indicate that the methodological approach influences WTP, as argued by Arrow et al. (1993). Of 12 variables characterizing study and methodological effects, 10 are statistically significant at p<0.10. Among these is the year in which a study was conducted (*year_indx*, a continuous variable), with later studies associated with lower WTP. This is the expected result, as the focus of survey design over time has often been on the reduction of survey biases that would otherwise result in an overstatement of WTP (Arrow et al., 1993).

Model results reveal that voluntary (*voluntary*=1) payment vehicles (i.e., surveys that describe hypothetical payments as voluntary) are associated with reduced WTP estimates. This result counters common intuition and empirical findings that voluntary payment vehicles are associated with overstatements of true WTP (Carson et al., 2000). The reason for this counter-intuitive finding is unknown, but may be a feature of the small number of studies that applied voluntary mechanisms. Reduced WTP estimates are also associated with studies applying nonparametric methods to WTP estimation (*nonparam*). Survey elicitation method does not have a strong effect in this model; studies using discrete choice formats have higher WTP values, but this difference is not statistically significant.

Smaller WTP estimates are associated with studies that eliminate or trim outlier bids when estimating WTP (*outlier_bids*=1; p<0.01). However, increased WTP estimates are associated with studies that seek to eliminate protest bids (*protest_bids*=1; p<0.01). While one might assume that elimination of protest bids would reduce WTP, this is based on a perhaps mistaken presumption that only high protest bids are excluded. In many cases WTP estimates may also exclude protest "zeros," or zero bids. As a result, there is no *a priori* necessary expected sign for this effect. Studies that report median WTP (*median_WTP*) have higher WTP values, but this effect is not statistically significant. Nonetheless, this variable is retained for theoretical reasons.

Studies with high response rates (*hi_response*=1; p<0.01) are associated with lower WTP estimates — an expected result. In addition, lower WTP is associated with the use of the RFF water quality ladder in the original survey (*wq_ladder*=1; p<0.10). As is the case with a variety of study design variables, there is no *necessary* expectation with respect to the direction of this effect. Nonetheless, this finding might suggest the capacity of such scales to clarify the specific magnitude and implications of water quality change, and hence (perhaps) reduce methodological misspecification or symbolic biases that might act to systematically inflate estimated WTP.

Survey format variables also have an effect on WTP, as might be expected. *Interview* and *mail* both have positive and statistically significant coefficients ($p<0.01$), compared to the default of telephone surveys. It may be possible that the interview survey format results in larger WTP values either because the respondents are better able to understand the valuation scenario, or because respondents may feel pressure from interviewers to bias their WTP estimates upward. There is no *a priori* explanation for the difference between mail surveys and phone surveys. Finally, as expected, studies that ask respondents to report an annual payment (as opposed to a *lump_sum* payment) have lower WTP estimates ($p<0.05$).

e. Model limitations

The validity and reliability of benefit transfer — including that based on meta-analysis — depends on a variety of factors. While benefit transfer can provide valid measures of use and non-use benefits, tests of its performance have provided mixed results (e.g., Desvousges et al., 1998; Vandenberg et al., 2001; Smith et al., 2002). Nonetheless, benefit transfers are increasingly applied as a core component of benefit cost analyses conducted by EPA and other government agencies (Bergstrom and De Civita, 1999; Griffiths, *undated*). Moreover, Smith et al. (2002, p. 134) argue that “nearly all benefit cost analyses rely on benefit transfers, whether they acknowledge it or not.” Given the increasing [or as Smith et al. (2002) might argue, universal] use of benefit transfers, an increasing focus is on the empirical properties of applied transfer methods and models.

Although the statistical performance of the model is quite good, EPA notes several limitations of the model. These limitations stem largely from information available from the original studies, as well as degrees of freedom and statistical significance. An important factor in any benefit transfer is the ability of the study site or estimated valuation equation to approximate the resource and context under which benefit estimates are desired. As is common, the meta-analysis model presented here provides a close but not perfect match to the context in which values are desired. Specifically, the model estimates WTP for marginal improvements to aquatic habitat that directly benefit fish populations. The specification of the model distinguishes improvements that benefit only fish populations from those that benefit other aquatic or non-aquatic species (as stated in the original surveys whose WTP estimates are incorporated in the meta-analysis). The model also distinguishes effects related to surveys emphasizing non-fishing uses of affected waterbodies. However, the original studies in the meta-analysis do not (in general) value individual fish. Hence, additional assumptions are required to estimate non-use values; these are discussed in section A12-5.

Additional limitations relate to the paucity of demographic variables available for inclusion in the model. The only demographic variable incorporated in the analysis (*income*) was not statistically significant. Moreover, other demographic variables are unavailable. EPA recognizes that the model is statistically significant and allows estimation of WTP from study and site characteristics. However, strictly speaking, model findings are relative to the specific case studies considered, and must be viewed within the context of 78-observation data set, with all the appropriate caveats. Although this represents a fairly standard-to-large sample-size for a meta-analysis in this context, it is relatively small relative to other statistical applications in resource and environmental economics. Model results are also subject to choices regarding functional form and statistical approach, although many of the primary model effects are robust to reasonable changes in functional form and/or statistical methods. The rationale for the specific functional form chosen here (the semi-log form) is detailed above.

Finally, the relatively large (positive) magnitude of the parameter estimate for the southeastern U.S. regional dummy variable (*southeast*) leads EPA to question the appropriate interpretation of this effect. While it is theoretically possible that WTP for water quality changes is substantially higher in the southeast, the magnitude of the effect suggested by the model seems unlikely from an intuitive perspective. As suggested above, it is possible that spurious, unexplained factors influence the magnitude of this parameter in the present model. However, assessments of preliminary model runs suggest that this effect is relatively robust given the present data and selection of variables available. Nonetheless, EPA recommends that the magnitude of the predicted shift in WTP associated with the southeast region should be viewed with caution.

Based on the results presented in Table A12-3, EPA estimated WTP for water resource changes as a function of resource, regional, and study design attributes (see section A12-5). This, in general, provides a superior alternative to the calculation and use of a simple arithmetic mean over the 78 observations, as it allows WTP to be adjusted to account for the characteristics of the transfer site. The ability of the model to appropriately adjust WTP is suggested by the many systematic (statistically significant) patterns revealed by the meta-analysis regression model. Nonetheless, the use (and interpretation) of such WTP estimates for benefit transfer is subject to the constraints and concerns expressed elsewhere in the literature (e.g., Vandenberg et al., 2001; Desvousges et al., 1998; Poe et al., 2001).

A12-4 LOG-LOG META-ANALYSIS REGRESSION MODEL

The following sections present the results for the alternative log-log meta-analysis regression model. Section A12-4.1 presents the data and variable specifications used to estimate the log-log model; section A12-4.2 presents the results of the log-log model; and section A12-4.3 discusses and interprets the findings of the log-log model.

A12-4.1 Meta-Data for Log-Log Model (Alternative Specification)

The dependent variable in the log-log meta-analysis is the natural log of estimated WTP (2002$) for water quality improvements as reported in each original study. Right-hand-side continuous and categorical variables relate to study and methodology, population, spatial, and water quality characteristics.

Study and methodology variables characterize such features as:

- The year in which the study was conducted. For this model, a binary variable that identifies those studies conducted in 1990 or before was employed. A continuous variable for the study year would be problematic for the log-log form. EPA selected 1990 for the break in light of the increased attention to stated preference methods following the Exxon Valdez disaster.
- Whether a discrete choice model was used.
- The survey mode of administration (telephone surveys are the default category).
- Whether the payment vehicle was voluntary.
- Whether WTP was expressed in terms of something other than an annual payment, such as a lump sum or a series of installments.
- Whether the WTP was estimated using a parametric model.
- Whether protest or outlier bids were discarded before WTP was estimated.

Surveyed population variables characterize such features as:

- Mean income of respondents.
- Whether the sample or sub-sample consisted of users, non-users, or a general population that included both. These appear in the model as interactions with the water quality change variable.
- Whether the sample included non-local respondents, such as might occur using an intercept survey.

Spatial variables characterize such features as:

- The waterbody type and scale. The default category reflects large saltwater bodies.
- Region of the country. The Northeast is the default region.
- Whether the aquatic resource is known primary as a Superfund site on the National Priority List. This variable is intended to single out and control for one particular study (Schulze et al., 1995).

Water quality variables characterize such features as:

- Whether the change scenario focused on wildlife, on fish specifically, or on a broader set of attributes (that may have included recreational opportunities or aesthetic qualities). Those that are more general compose the default category.
- The desired level of water quality. This performs a function analogous to incorporating the baseline water quality level into the model but avoid issues associated with taking the natural log of 0.
- The extent of water quality change.

Eighty-two observations from 33 studies were used to estimate the model. Variables incorporated in the final model are listed and described in Table A12-4.

Table A12-4: Meta-Analysis Variables and Descriptive Statistics for the Log-Log Model

Variable	Description	Units and Measurement	Mean (Std. Dev.)
ln_wtp	Natural log of WTP for specified resource improvements.	Natural log of dollars	4.55 (0.80)
year1990	Binary (dummy) variable indicating that the year of the study was 1990 or earlier.	Binary	0.66
discrete_ch	Binary (dummy) variable indicating that WTP was estimated using a discrete choice survey instrument.	Binary	0.33
interview	Binary (dummy) variable indicating that the survey used an interview mode of administration.	Binary	0.24
mail	Binary (dummy) variable indicating that the survey used an mail-in mode of administration.	Binary	0.54
voluntary	Binary (dummy) variable indicating that WTP was estimated using a payment vehicle described as voluntary.	Binary	0.16
lump_sum	Binary (dummy) variable indicating that payment was to occur on something other than an annual basis.	Binary	0.20
nonparam	Binary (dummy) variable indicating that WTP was estimated using nonparametric methods.	Binary	0.46
protest_bids	Binary (dummy) variable indicating that protest bids were excluded when estimating WTP.	Binary	0.44
outlier_bids	Binary (dummy) variable indicating that outlier bids were excluded when estimating WTP.	Binary	0.24
ln_income	Natural log of the mean income of survey respondents.	Natural log of thousands of dollars	3.82 (0.20)
nonusers	Binary (dummy) variable indicating that the WTP estimate is based upon a sample of non-users.	Binary	0.17
users	Binary (dummy) variable indicating that the WTP estimate is based upon a sample of users.	Binary	0.26
genpop	Binary (dummy) variable indicating that the WTP estimate is based upon a sample of a general population consisting of both users and non-users.	Binary	0.57
nonlocal	Binary (dummy) variable indicating that the WTP estimate is based upon a sample not limited to locals.	Binary	0.46
small_rivers	Binary (dummy) variable indicating that the water quality change affects river resources of a small region, e.g., the Potomac River in DC.	Binary	0.18
large_rivers	Binary (dummy) variable indicating that the water quality change affects river resources of a large region, e.g., the Columbia River Basin.	Binary	0.21
small_lakes	Binary (dummy) variable indicating that the water quality change affects lake resources of a small region, e.g., Clear Lake, IO.	Binary	0.12
large_lakes	Binary (dummy) variable indicating that the water quality change affects lake resources of a large region, e.g., Lake Michigan.	Binary	0.05
small_fresh	Binary (dummy) variable indicating that the water quality change affects fresh water resources — either unspecified or a combination of types — of a small region.	Binary	0.09
large_fresh	Binary (dummy) variable indicating that the water quality change affects fresh water resources — either unspecified or a combination of types — of a large region, e.g., lake and streams of northeastern MN.	Binary	0.11
natl_fresh	Binary (dummy) variable indicating that the water quality change affects fresh water resources nationwide.	Binary	0.06
small_salt	Binary (dummy) variable indicating that the water quality change affects saltwater resources in a limited area.	Binary	0.07

Table A12-4: Meta-Analysis Variables and Descriptive Statistics for the Log-Log Model

Variable	Description	Units and Measurement	Mean (Std. Dev.)
great_lakes	Binary (dummy) variable indicating that survey was conducted in the Great Lakes region.	Binary	0.37
pacif_mount	Binary (dummy) variable indicating that survey was conducted in the Pacific/mountain region.	Binary	0.18
plains	Binary (dummy) variable indicating that survey was conducted in the Plains region.	Binary	0.09
southeast	Binary (dummy) variable indicating that survey was conducted in the Southeast region.	Binary	013
multi_reg	Binary (dummy) variable indicating that survey was conducted in multiple regions.	Binary	0.09
npl	Binary (dummy) variable indicating that the aquatic resource is known primarily as a Superfund site.	Binary	0.02
wildlife	Binary (dummy) variable indicating that the changes valued relate expressly to wildlife populations.	Binary	0.05
fish_only	Binary (dummy) variable indicating that the changes valued relate expressly to fish populations.	Binary	0.15
ln_hiwq	Natural log of desired water quality level expressed on a 0-100 scale.	Natural log of desired water quality level	4.30 (0.35)
ln_chwq	Natural log of water quality change expressed on a 0-100 scale.	Natural log of water quality change	3.77 (0.38)

Source: U.S. EPA analysis, for this report.

A12-4.2 Log-Log Model and Results

a. Log-log model

In light of the absence of a standard approach to developing parametric models to synthesize valuation summary results, there is good reason to explore and report on an alternative to the semi-log model that makes different, though plausible, assumptions for a few critical aspects of the meta-analysis. Although the two models share many features (e.g., their consideration of random effects), the alternative model developed by EPA departs from the former in three significant ways:

❖ *Functional form*

The first significant difference between the two models is that the alternative model takes a log-log form, i.e., the natural log of both the dependent variable and all covariates are taken. This functional form makes sense on three counts. First, study features and resource characteristics likely affect WTP in a multiplicative, rather than additive, fashion. With the log-log form, this is how explanatory variables affect the underlying (un-logged) dependent variable. Second, this functional form has the desirable feature of associating a WTP of $0 with any scenario in which no water quality change has occurred. Third, by forcing the curve through the origin, the model increases sensitivity of the WTP estimates to the magnitude of the water quality change, i.e., scope.

❖ *Water quality change index*

The second difference between the two models is that the alternative model uses a different approach to mapping the somewhat disparate scenarios valued by respondents in the original studies onto a water quality metric. For the alternative model, EPA first established what the upper and lower bounds of water quality were for each study, i.e., how the researcher explicitly or implicitly defined the level at which the waterbody was “dead” or totally impaired and that at which it was considered pristine. These points of reference were used to define the endpoints on a scale of 0 to 100. With the endpoints established, the Agency mapped the baseline water quality levels and the magnitude of the water quality change onto this new ratio scale.

The way that EPA mapped water quality changes onto the meta model's index depended on how they were characterized in the original studies:

- For water quality changes specified by a study as movements along a generic ordinal scale (e.g., poor, fair, good, excellent), the original levels were positioned at uniform intervals across the new index (e.g., 0, 33, 67, 100) and changes calculated as the difference between the two relevant values.
- For water quality changes that refer to levels at which particular recreation types are possible (e.g., non-boatable, boatable, fishable, swimmable), the original levels were placed on the index at the same relative position in which they would be found on the "RFF water quality ladder" (e.g., 0, 2.5, 5, 7), which some studies handed to respondents during interviews.
- For water quality changes expressed in terms of species' populations (e.g., 25 percent increase in trout populations), the baseline value on the index was selected according to whatever narrative or quantitative information was provided in the original survey or study, and considering that 0 would equate to extirpation of the species and 100 to historic, peak population levels. The change upon which a valuation scenario was based was then applied to this baseline index value. For example, a 25 percent increase in a trout population described as currently being in fair condition would be translated into a 25 percent shift in the index from 33 to 42.

❖ *Focusing on non-use value for changes in fish populations*

The third difference between the two models is that the alternative model includes the sample type dummies as interactions with *ln_chwq*, allowing the relationship between WTP and water quality change to vary according to the degree to which use values are reflected in WTP responses. While consideration was given to further interacting *ln_chwq* with the species focus dummies, the lack of observations in some of the cross-categories effectively precluded it.

The log-log meta model facilitates policy simulations. For example, estimating the WTP for the non-use value of the section 316(b) rule effects would require a focus both on a water quality change that affects solely fish and on non-use values. Use of the model for this purpose is straightforward, essentially involving assigning a value of 1 to both *fish_only* and *nonusers*, the latter of which is interacted with the appropriate water quality change measured on the index as well as its ln_chwq parameter.

b. Log-log model results

Table A12-5 presents results of the log-log model.

Table A12-5: Estimated Multilevel Model Results for the Log-Log Model: WTP for Aquatic Habitat Improvements

Variable	Parameter Estimate	Robust Std. Error	t Statistic	Prob>|t
intercept	6.64	1.57	4.23	0.00
year1990	0.89	0.21	4.19	0.00
discrete_ch	0.69	0.25	2.72	0.01
interview	0.50	0.16	3.07	0.00
mail	0.11	0.26	0.41	0.68
voluntary	0.55	0.21	2.71	0.01
lump_sum	0.82	0.27	3.00	0.00
nonparam	-0.38	0.18	-2.10	0.04
protest_bids	1.00	0.15	6.88	0.00
outlier_bids	-0.23	0.10	-2.27	0.03
ln_inc	-1.32	0.31	-4.29	0.00
nonlocal	-0.63	0.29	-2.20	0.03
small_river	-1.78	0.61	-2.94	0.01
large_river	-0.37	0.33	-1.13	0.27
small_lake	0.13	0.25	0.53	0.60

Table A12-5: Estimated Multilevel Model Results for the Log-Log Model: WTP for Aquatic Habitat Improvements

Variable	Parameter Estimate	Robust Std. Error	t Statistic	Prob>|t
large_lake	1.56	0.46	3.40	0.00
small_fresh	0.27	0.16	1.68	0.10
large_fresh	0.78	0.31	2.50	0.02
natl_fresh	0.99	0.42	2.34	0.02
small_salt	2.79	0.33	8.39	0.00
great_lakes	-0.50	0.56	-0.90	0.38
pacif_mount	-1.28	0.28	-4.52	0.00
plains	-0.38	0.23	-1.70	0.10
southeast	-3.01	0.68	-4.44	0.00
multi_reg	-0.50	0.22	-2.28	0.03
npl	-1.09	0.22	-4.93	0.00
wildlife	-0.32	0.25	-1.26	0.22
fish_only	-0.48	0.23	-2.04	0.05
ln_hiwq	-0.07	0.33	-0.22	0.83
*ln_chwq*nonusers*	0.66	0.31	2.12	0.04
*ln_chwq*users*	0.82	0.31	2.63	0.01
*ln_chwq*genpop*	0.70	0.28	2.48	0.02
-2 Restricted Log Likelihood	118.0			
Covariance Factors				
Study Level (σ_u)	0.12			
Residual (σ_e)	0.21			
χ^2 for significance of random-effects	0.00			

Source: U.S. EPA analysis, for this report.

A12-4.3 Interpretation of Log-Log Regression Analysis Results

The log-log model finds both statistically significant and economically reasonable patterns influencing WTP for water quality improvements. The statistical fit of the equation is good; there is a strong systematic element of WTP variation which allows forecasting of WTP based on site and study characteristics. The model as a whole is statistically significant at better than $p<0.0001$.

While author-level random-effects are not statistically significant (2 of 0), 25 of the 31 fixed-effects (disregarding the intercept) in the model are significant at $p<0.1$. Nearly all of the signs of the significant parameter estimates correspond with prior expectations.

a. Resource improvement effects

EPA included two dummy variables in the log-log model, *wildlife* and *fish_only*, that measured the species that were affected by the water quality change. The negative signs on these parameter estimates support the expectation that respondents provide a lower WTP for water quality improvements described solely in terms of changes in species populations. Further, a description that is limited to effects on fish relates to a lower WTP than one depicting effects on other wildlife as well, e.g., fish-eating birds.

The model included several water quality variables. The positive and statistically significant ($p<0.05$) estimates for the three *ln_chwq* interaction terms support the hypothesis that higher WTP values are associated with larger water quality changes. Moreover, the relative sizes of the estimates provide support to prior expectations in that the non-user value is smallest and the user value largest. The statistically insignificant estimate for *ln_hiwq* suggests that the level of water quality has little effect on the WTP for the change in water quality, i.e., there may not be a big difference in the respondent's mind between an improvement that raises water quality from a poor to a mediocre state and one that raises it to a mediocre to an excellent state as long as the changes are thought to be of the same magnitude.

b. Geographic region and scale effects

Most of waterbody scale and type dummies have parameter estimates that are statistically significant at $p<0.1$. For the most part, the estimates for the "large" dummies are larger than the "small" ones, which would be expected. Surprisingly, the estimates for *small_lake* and *large_lake* are both significant and relate to each other in the opposite manner. This may be due to that these two categories may differ in kind more than degree, as Great Lakes studies exert a strong influence in the latter. The negative and statistically significant ($p<0.01$) estimate for *npl* indicates that waterbodies that are recognized Superfund sites may be considered by respondents to be qualitatively different, and of lesser value, than other waterbodies.

Although there are no prior expectations for the regional dummies, all estimates are significant at $p<0.1$. The results suggest that the default region, the North Atlantic, has higher WTP values than elsewhere, whereas the Inland region has the lowest.

c. Surveyed population effects

The negative and statistically significant ($p<0.01$) estimate for *ln_inc* indicates that lower incomes are associated with relatively higher WTP estimates. This does not correspond well with the commonly held notion of environmental quality as luxury good. However, since *ln_inc* is the only variable in the model that relates to respondent socioeconomic characteristics, it is possible that it is picking up the influence of omitted factors, such as demographics (e.g., retirees may appreciate aquatic resources more) or locale (e.g., rural respondents may as well).

The negative and statistically significant ($p<0.05$) estimate for *nonlocal* supports the hypothesis that respondents who live further from a resource do not value it as highly.

d. Study and methodology effects

There are no strong theoretical expectations about the sign or magnitude of several of the study and methodology variables. The results from the log-log model show positive and statistically significant ($p<0.01$) parameter estimates for *discrete_ch*, *interview*, *voluntary*, and *lump_sum*. These results indicate that the discrete choice study type, the interview solicitation method, the voluntary payment mechanism, and the lump sum payment type are all associated with higher WTP values.

The signs of the remaining variables generally correspond with prior expectations. The statistically significant estimates for *nonparam* (negative, $p<0.05$), *protest_bids* (positive, $p<0.01$), and *outlier_bids* (negative, $p<0.05$) indicate that studies that use a parametric model, exclude protest bids, or include outlier bids have relatively higher WTP values. The positive and statistically significant ($p<0.01$) estimate for *year1990* supports the hypothesis that earlier surveying and modeling approaches may have biased WTP estimates upward.

A12-5 APPLICATION OF THE META-ANALYSIS RESULTS TO THE ANALYSIS OF NON-USE BENEFITS OF THE SECTION 316(B) RULE

The results of the meta-analysis in conjunction with information specific to the affected aquatic resources and the populations that will benefit from reduced I&E impacts can be used to estimate the non-use value of the section 316(b) regulation. This analysis involves the following steps:

- Estimating annual non-use value of the affected fishery resources per household for completely eliminating baseline I&E losses, and for reducing I&E losses from the baseline to post-compliance levels;
- Estimating the population of households holding non-use value for the affected resources; and
- Estimating the total non-use value to the affected populations for completely eliminating baseline I&E losses, and for reducing I&E losses from the baseline to post-compliance levels.

A12-5.1 Estimating Non-Use Values per Household

Region-specific non-use WTP values for aquatic habitat improvements can be estimated for two population classes: (1) all households in the vicinity of the waterbodies affected by I&E, and (2) recreational anglers who may visit the affected waterbody. Separate household values can be estimated using the semi-log and log-log regression equations specified in sections A12-3.2 and A12-4.2, respectively. To estimate the non-use values of baseline I&E losses and reduced I&E impacts, values should be assigned to independent variables to reflect resource characteristics, area demographics, and other factors. These values are then multiplied by the estimated regression coefficients to predict the average non-use WTP for aquatic habitat improvements for a household with specific characteristics (e.g., non-user household in the North Atlantic region).

Two variables are of particular importance to the valuation of benefits of the final section 316(b) rule: *baseline* and *WQ_fish*. For example, it can be assumed that all waterbodies affected by cooling water intakes meet water quality standards (*baseline*=7.0 or swimmable conditions). In reality, some waterbodies may not meet water quality standards. EPA notes that this assumption leads to more conservative estimates of non-use values for aquatic habitat improvements, because higher baseline quality leads to lower WTP for environmental improvements. If feasible, site specific values should be used for the *baseline* variable.

The *WQ_fish* variable, the effect of aquatic habitat quality change on fish, is a key policy variable. The value assignments of the *WQ_fish* variable should be based on the expected change in recreational fishing quality at the affected sites, which is measured by the expected change in recreational catch rate. For example, the estimated changes in recreational catch rates from eliminating baseline I&E losses range from 2.5 percent to 25.9 percent, with a mean value of 12.9 percent. The estimated changes in recreational catch rates under the final option range from 1.2 percent to 12.6 percent, with a mean value of 6.3 percent.

Using the equation specified in the preceding section and the values of independent variables described above, one can derive region-specific WTP values for all households in the vicinity of the waterbodies affected by I&E losses.

A12-5.2 Estimating the Affected Populations

Two non-use benefit population categories should be considered in this analysis: 1) households in the counties abutting the affected waterbodies, and 2) recreational anglers residing outside of the abutting counties but who visit recreational fishing sites in each study region. Households in the counties abutting the affected waterbodies can be further restricted to include only households in counties where some part of the county is within 10 miles of a power plant subject to the Phase II section 316(b) rule.[11] The sum of the two affected household categories for a given study region, assuming one user household per recreational angler, represents the total population of households affected by I&E impacts at section 316(b) facilities.[12] The following data sources can be used to obtain information on the number of anglers visiting recreational fishing sites in a given region:

- Coastal region — National Marine Fisheries Statistics Survey (NMFS, 1997-2001); and
- Great Lakes region — 2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation (U.S. Fish and Wildlife Service, 2001).

U.S. Census Bureau data can be used to estimate the number of households residing in the counties abutting the affected waterbodies (U.S. Census Bureau, 2002).

EPA notes that resource users typically hold higher non-use values than the non-use values held by non-users for the same resource, and therefore the application of total *non-user* value, which is used in this analysis to approximate total *non-use* value, may underestimate the total non-use value of aquatic habitat improvements. In addition, the two population categories considered in the non-use benefits analysis do not represent all the households that may hold values for these natural resources (e.g., households in coastal states outside of the counties abutting the affected waterbodies). Furthermore, most of the studies on which the meta-analysis was based analyzed sample populations from larger geographic areas than the area considered

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[11] This 10 mile criterion is a conservative assumption that excludes households in counties that abut large, affected waterbodies, but that are distant from section 316(b) facilities.

[12] The relevant population in this analysis is the number of households because WTP for environmental improvements are estimated on per-household basis.

here. For these reasons, the resulting non-use estimates are likely to represent a lower-bound estimate of the value of reduced baseline I&E losses.

A12-5.3 Estimating the Total Non-Use Value to the Affected Populations

Total regional non-use value can be calculated by multiplying the region-specific non-use value per household from each regression model by the corresponding estimate of the total number of affected households in each region.

A12-6 LIMITATION AND UNCERTAINTIES

A number of issues are common to all benefit transfers. Benefit transfer involves adapting research conducted for another purpose in the available literature to address the policy questions at hand. Because benefits analysis of environmental regulations rarely affords enough time to develop original stated preference surveys that are specific to the policy effects, benefit transfer is often the only option to inform a policy decision. Specific issues associated with the estimated regression model and the underlying studies are discussed in discussed in section A12-3.3e. Additional limitations and uncertainties associated with implementation of the meta-analysis approach are addressed below.

A12-6.1 Sensitivity Analysis of Semi-Log Model Based on Krinsky and Robb (1986) Approach

The semi-log model presented above can be used to predict WTP for each of the studies in the database; however, estimates derived from regression models are subject to some degree of error and uncertainty. To better characterize the uncertainty or error bounds around predicted WTP, EPA recommends using the procedure described by Krinsky and Robb in their 1986 *Review of Economics and Statistics* paper "On Approximating the Statistical Property of Elasticities." The procedure involves sampling the variance-covariance matrix of the estimated coefficients, which is standard output from the statistical package used to estimate the meta model. WTP values are then calculated for each drawing from the variance covariance matrix and an empirical distribution of WTP values is constructed. By varying the number of drawings, it is possible to generate an empirical distribution with a desired degree of accuracy (Krinsky and Robb, 1986). The lower or upper bound of WTP values is then identified based on the 10th and 90th percentile of WTP values from the empirical distribution. These bounds may help decision-makers understand the uncertainty associated with the benefit results.

A12-6.2 Sensitivity Analysis of Variable Assignments for Independent Regressors

In addition to developing the WTP values and bounds based on best estimates of values for independent variables, EPA recommends performing a sensitivity analysis to show how these values could change based on more site-specific or geographic-specific conditions and alternative assumptions regarding desirable study characteristics.

A12-6.3 Affected Population

As noted above, the two population categories considered in the non-use benefits analysis do not represent all the households that may hold values for these natural resources (e.g., households in coastal states outside of the counties abutting the affected waterbodies). The resulting non-use estimates therefore are likely to represent a lower-bound valuation of reduction in baseline I&E losses. However, EPA notes that some resource valuation studies have found that respondents in the typical contingent market situation may overstate their WTP compared to their likely behavior in a real world situation. EPA recommends conducting a sensitivity analysis to assess the effect of hypothetical bias on the estimated non-use values. For example, one can assume that only 50 percent of the households residing in the vicinity of the affected waterbodies would actually pay for aquatic habitat improvements resulting from reduced I&E.

Chapter A13: Threatened & Endangered Species Analysis Methods

INTRODUCTION

Threatened and endangered (T&E) and other special status species can be adversely affected in several ways by cooling water intake structures (CWISs). T&E species can suffer direct harm from impingement and entrainment (I&E), they can suffer indirect impacts if I&E at CWISs adversely affects another species upon which the T&E species relies within the aquatic ecosystem (e.g., as a food source), or they can suffer impacts if the CWIS disrupts their critical habitat.[1] The loss of individuals of listed species from CWISs is particularly important because, by definition, these species are already rare and at risk of irreversible decline because of other stressors.

This chapter provides information relevant to an analysis of listed species in the context of the section 316(b) regulation; defines species considered as threatened, endangered, or of special concern; gives a brief overview of the potential for I&E-related adverse impacts on T&E species; and describes methods available for considering the economic value of such impacts.

CHAPTER CONTENTS

A13-1 LISTED SPECIES BACKGROUND

The Federal government and individual States develop and maintain lists of species that are considered endangered, threatened, or of special concern. The Federal trustees for endangered or threatened species are the Department of the Interior's U.S. Fish and Wildlife Service (U.S. FWS) and the Department of Commerce's National Marine Fisheries Service (NMFS). Both departments are also are referred to herein as the Services. The U.S. FWS is responsible for terrestrial and freshwater species (including plants) and migratory birds, whereas the NMFS deals with marine species and anadromous fish (U.S. Fish and Wildlife Service, 1996a). At the State level, the departments, agencies, or commissions with jurisdiction over T&E species include Fish and Game; Natural Resources; Fish and Wildlife Conservation; Fish, Wildlife and Parks; Game and Parks; Environmental Conservation; Conservation and Natural Resources; Parks and Wildlife; the States' Natural Heritage Programs, and several others.

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[1] To simplify the discussion, in this chapter EPA uses the terms "T&E species" and "special status species" interchangeably to mean all species that are specifically listed as threatened or endangered, plus any other species that has been given a special status designation at the State or Federal level.

A13-1.1 Listed Species Definitions

a. Threatened and endangered and species

A species is listed as “endangered” when it is *likely to become extinct* within the foreseeable future throughout all or part of its range if no immediate action is taken to protect it. A species is listed as “threatened” if it is *likely to become endangered* within the foreseeable future throughout all or most of its range if no action is taken to protect it. Species are selected for listing based on petitions, surveys by the Services or other agencies, and other substantiated reports or field studies. The 1973 Endangered Species Act (ESA) outlines detailed procedures used by the Services to list a species, including listing criteria, public comment periods, hearings, notifications, time limits for final action, and other related issues (U.S. Fish and Wildlife Service, 1996a).

A species is considered to be endangered or threatened if one or more of the following listing criteria apply (U.S. FWS, 1996a):

- the species’ habitat or range is currently undergoing or is jeopardized by destruction, modification, or curtailment;
- the species is overused for commercial, recreational, scientific, or educational purposes;
- the species’ existence is vulnerable because of predation or disease;
- current regulatory mechanisms do not provide adequate protection; or
- the continued existence of a species is affected by other natural or man-made factors.

b. Species of concern

States and the Federal government have also included species of “special concern” to their lists. These species have been selected because they are (1) rare or endemic, (2) in the process of being listed, (3) considered for listing in the future, (4) found in isolated and fragmented habitats, or (5) considered a unique or irreplaceable State resource.

A13-1.2 Main Factors in Listing of Aquatic Species

Numerous physical and biological stressors have resulted in the listing of aquatic species. The major factors include habitat destruction or modification, displacement of populations by exotic species, dam building and impoundments, increased siltation and turbidity in the water column, sedimentation, various point and non-point sources of pollution, poaching, and accidental catching. Some stresses, such as increased contaminant loads or turbidity, can be alleviated by water quality programs such as the National Pollutant Discharge Elimination System (NPDES) or the current EPA efforts to develop Total Maximum Daily Loads (TMDLs). Other factors, such as dam building or habitat modifications for flood control purposes, are relatively permanent and therefore more difficult to mitigate. In addition to these major factors, negative effects of CWISs on some listed species have been documented.

Congress amended the ESA in 1982 and established a legal mechanism authorizing the Services to issue permits to non-Federal entities — including individuals, private businesses, corporations, local governments, State governments, and tribal governments — who engage in the “incidental take” of Federally-protected wildlife species (plants are not explicitly covered by this program). Incidental take is defined as take that is “incidental to, and not the purpose of, the carrying out of an otherwise lawful activity under local, State or Federal law.” Examples of lawful activities that may result in the incidental take of T&E species include developing private or State-owned land containing habitats used by Federally-protected species, or the withdrawal of cooling water that may impinge or entrain Federally-protected aquatic species present in surface waters.

An integral part of the incidental take permit process is development of a Habitat Conservation Plan (HCP). An HCP provides a counterbalance to an incidental take by proposing measures to minimize or mitigate the impact and ensuring the long-term commitment of the non-Federal entity to species conservation. HCPs often include conservation measures that benefit not only the target T&E species, but also proposed and candidate species, and other rare and sensitive species that are present within the plan area (U.S. Fish and Wildlife Service and National Marine Fisheries Service, 2000). The ESA stipulates the major points that must be addressed in an HCP, including the following (U.S. Fish and Wildlife Service and National Marine Fisheries Service, 2000):

- defining the potential impacts associated with the proposed taking of a Federally-listed species;

- describing the measures that the applicant will take to monitor, minimize, and mitigate these impacts, including funding sources;[2]

- analyzing alternative actions that could be taken by the applicant and reasons why those actions cannot be adopted; and

- describing additional measures that the Services may require as necessary or appropriate.

HCP permits can be issued by the Services' regional directors if:

- the taking will be incidental to an otherwise lawful activity;
- any impacts will be minimized or fully mitigated;
- the permittee provides adequate funding to fully implement the permit;
- the incidental taking will not reduce the chances of survival or recovery of the T&E species; and
- any other required measures are met.

The Services have published a detailed description of the incidental take permit process and the habitat conservation planning process (U.S. Fish and Wildlife Service and National Marine Fisheries Service, 2000). The Federal incidental take permit program has only limited application within the context of the section 316(b) regulation because many T&E species (fish in particular) are listed mainly by States, not by the Services, and hence fall outside of the jurisdiction of this program.

A13-2 FRAMEWORK FOR IDENTIFYING LISTED SPECIES POTENTIALLY AT RISK OF I&E

Evaluating benefits to listed species from the proposed section 316(b) regulation requires data on the number of listed organisms impinged and entrained and an estimate of how much the I&E of listed species will be reduced as a result of the regulation. Estimating I&E for candidate and listed species presents significant challenges due to the following:

- Most facilities operating CWISs do not monitor for I&E on a regular basis;

- T&E populations are generally restricted and fragmented so that their I&E may be sporadic and not easy to detect by conventional monitoring activities; and

- Entrained eggs and larvae are often impossible to identify to the species level, making it difficult to know the true number of losses of a species of concern.

Some facilities have knowledge about the extent of their impact on T&E species. These facilities require incidental take permits and must develop HCPs (e.g., the Pittsburg and Contra Costa facilities in California, see Part E of this document). Where specific knowledge of I&E rates does not exist, risks to T&E species must be estimated from other information. The remainder of this section discusses EPA's methodology of estimating the numbers of listed species potentially at risk of I&E. The framework involves four main steps (see Figure A13-1).

- Step 1 identifies all State- or Federally-listed species for the States that border the CWIS source waterbody.

- Step 2 determines if a listed species from Step 1 is present in the vicinity of the CWIS. If a species distribution overlaps with the CWIS, the analysis proceeds to Step 3.

- Step 3 uses information on habitat preferences and site-specific intake structure characteristics to better define the degree of vulnerability of the listed species to the CWIS.

- Step 4, if necessary, further refines the potential for I&E based on the life history characteristics of the listed species.

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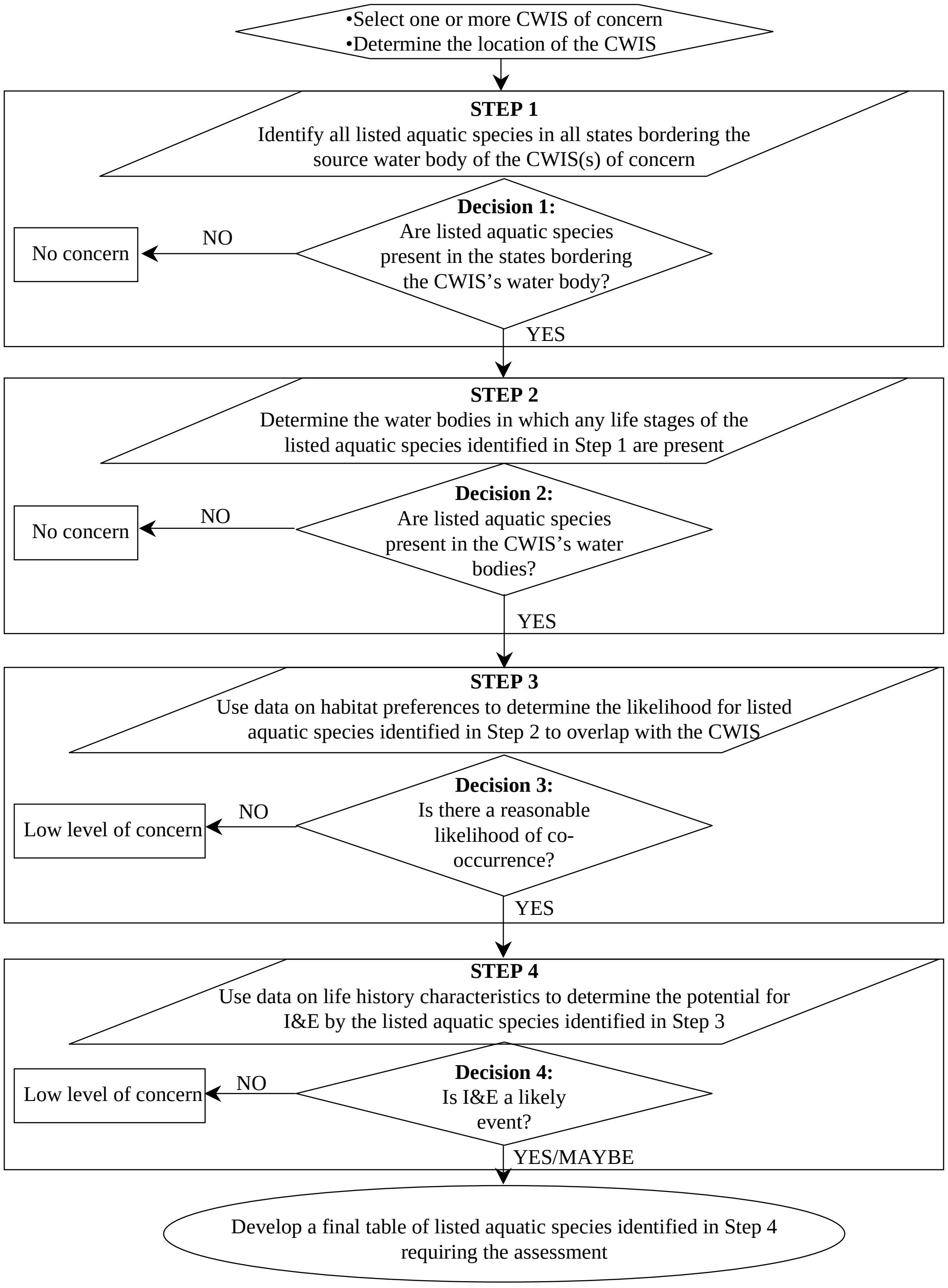
[2] Mitigation can include preserving critical habitats, restoring degraded former habitat, creating new habitats, modifying land use practices to protect habitats, and establishing buffer areas around existing habitats.

Figure A13-1: Flowchart for Identifying T&E Aquatic Species with a Reasonable Potential for I&E by CWISs



The result of this four-step analysis is a table of listed species that are likely to experience I&E by a CWIS of concern based on their geographic distribution, habitat preferences, and life history characteristics.

A13-2.1 Step 1: Compile a Comprehensive Table of Potentially-Affected Listed Species

The first step in determining the potential for I&E by a CWIS is to identify all State and Federally-listed aquatic species in the area of interest. Aquatic species may include fish; gastropods (such as snails, clams, or mussels); crustaceans (such as shrimp, crayfish, isopods, or amphipods); amphibians (such as salamanders, toads, or frogs); reptiles (such as turtles, alligators, or water snakes); and mammals (such as seals or sea lions). The U.S. FWS maintains a web site (http://endangered.fws.gov/endspp.html) on all Federally-listed species organized by State or taxonomic group. Because the Federal list represents only a small subset of the species listed by individual States, however, the analyst also needs to obtain State lists to develop a comprehensive table of aquatic species potentially affected by the CWISs of concern.[3] Individual State agencies, universities, or local organizations maintain web sites with data on State-listed species. A preliminary search in support of this chapter showed that various agencies have responsibilities for maintaining species lists in different States. The departments, agencies, or commissions with jurisdiction of T&E species include Fish and Game; Natural Resources; Fish and Wildlife Conservation; Fish, Wildlife and Parks; Game and Parks; Environmental Conservation; Conservation and Natural Resources; Parks and Wildlife; and several others. The States' Natural Heritage Programs can also be contacted to request listing information, species-specific data on geographic distributions, and other valuable data. Appendix A1 provides a recent compilation of aquatic T&E species by The Nature Conservancy (TNC). Information on Natural Heritage Programs in the U.S. can be obtained from The Natural Heritage Network at http://www.heritage.tnc.org. A thorough search of these and other relevant sources should be performed to get the data required to identify target species.

If a CWIS of concern is located on a waterbody confined to one State, then only Federally-listed aquatic species found in that State and the aquatic species listed by the State itself need to be considered in the analysis. An example would be the Tampa Bay Estuary, which is entirely contained within the State of Florida. The search should expand if the CWIS is located on a waterbody that covers more than one State, which may be the case for large lakes, rivers, and estuaries. For example, the watersheds abutting the U.S. side of Lake Erie cover parts of New York, Pennsylvania, Ohio, and Michigan. The Delaware River Basin covers parts of Delaware, Pennsylvania, New Jersey, and New York. At a minimum, a table of potentially affected T&E species should include species listed by the State in which the CWIS is located, together with any Federally-listed aquatic species in all the States covered by the watershed. A more rigorous approach at this initial stage might be to include all State-listed aquatic species from every State covered by the waterbody of concern, even if the likelihood is small that a listed species moves beyond the boundaries of the CWIS's State.

The product of this initial step is a table of all the aquatic species listed by the U.S. FWS and the State(s) of interest. The information should be organized by species category — such as fish, amphibians, aquatic invertebrates, aquatic reptiles, and/or aquatic mammals. The information should also include:

- the common and scientific name of each listed species;
- the agency listing the species (State or U.S. FWS, or both); and
- the legal status of the species (threatened, endangered, or of special concern).

The analyst can assume that the CWIS does not have a direct impact on listed species only if no aquatic species are listed as threatened, endangered, or of special concern in the target State(s). The analyst must also determine if there is an indirect impact through the food chain. If not, then no further analysis is required for that CWIS.

A13-2.2 Step 2: Determine the Geographic Distribution of Listed Species

In the second step, the analyst determines if the listed species identified in Step 1 are present in the same waterbody as the CWIS of concern. This step represents a simple pass-fail decision: a species is retained if the distribution of one or more of its life stages coincides with the waterbody of interest; it is removed if it does not (see also Figure A13-1).

The analyst can obtain the information required for this step from several sources. Local agencies may have developed "species accounts" for certain Federally-listed species. Recovery plans may also be available for some of the Federally-listed species. These and other sources may provide information on species ranges, population levels, reproductive strategies, developmental characteristics, habitat requirements, reasons for current status, and/or management and protection needs. When compiling this information, the analyst should look not only at the distribution of adults but also of juveniles,

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[3] As discussed earlier, both T&E species and species of special concern should be included.

particularly if the species is known to migrate between different locations over its life. This step is particularly important for anadromous fish species, but may also apply to other species that have seasonal or life cycle-dependent migrations (for example, adult frogs may live on land but spawn in rivers).

Most listed aquatic species are listed by individual States rather than on a Federal level. Data on the Federally-listed species are therefore unlikely to suffice for the analysis. States typically post their species list on the Internet. A few States have also developed short species accounts with information on distribution, life history characteristics, habitat requirements, and other useful details. Distribution or range data may consist of specific locations of sightings or catches (for example, particular river miles), general distributions within individual watersheds, or more generic and qualitative descriptions. Some States have also published hardcopy reports with species-specific information that may not be available on the Internet. Finally, the Natural Heritage Programs in numerous States have also developed species-specific data (see Appendix A1). All these materials should be obtained and reviewed during the data gathering process.

Distributional information for some of the T&E species may not be available. The analyst may need to consult secondary sources, such as species atlases (for example, see fish species distributions in the U.S.; or Smith, 1985, for fish distributions in New York State), field guides, published papers, or textbooks. Distributional data may be missing altogether for some of the more obscure species. The lack of such data should not by itself result in the removal an T&E species at this point in the selection process. The analyst should instead look at habitat requirements (Step 3) or life history characteristics (Step 4) before the species is no longer considered of concern to the CWIS under consideration.

The majority of species will be eliminated at this stage because most of the listed aquatic species, with some notable exceptions, tend to have rather fragmented and limited distributions due to extensive habitat loss or narrow habitat requirements. Step 2 produces a table of listed species whose geographic distributions generally overlap with the location of the CWIS.

A13-2.3 Step 3: Compare Habitat Preferences of Listed Species to the CWIS

Step 3 identifies listed species that could be affected by the CWIS of concern through a comparison of their habitat preferences and the location of the CWIS. The potential for I&E exists, and hence the listed species is retained, if the habitat preferences of one or more life stages match the location of the CWIS of concern. If the habitat preferences of no life stages of the listed species match the location of the CWIS, then the species can be removed from further consideration.
The analyst needs to obtain a general description of the location of the CWIS of concern in terms of (1) where the CWIS is found within the waterbody (e.g., inshore versus off-shore; deep versus shallow; etc.) and (2) the kinds of habitats associated with this general location. Such information may be available from site-specific field observations, permit applications by the facilities, natural resources maps, or other related sources.

a. Location

The presence of a listed species in the waterbody from which a CWIS withdraws water does not necessarily mean that the species will be impinged or entrained by the intake structure. Two additional variables need to be considered: the habitat preferences of the listed species and the characteristics of the CWIS (location, design, and capacity). The following example highlights the relationship between these two variables:

An endangered darter species is present in a river with a CWIS of concern. All life stages of this species are confined to swift-running, shallow (i.e., less than one foot deep) riffle zones, whereas the CWIS of concern is located many miles downstream in deep areas of the river that are unsuitable darter habitat. The likelihood of impact on the darter by the CWIS is minimal even though both are present within the same waterbody.

b. Other habitat information

Detailed information on the habitat requirements of the target species is also needed. This information should focus on *any* of the life stages, including eggs, larvae, juveniles, and adults, because habitat requirements often vary by life stage. For example, adults of a listed fish species may inhabit deeper waters of large lakes and produce pelagic eggs, but juveniles may be found only in nearshore nursery areas. It would be insufficient to consider only the habitat requirements of adults of this species, particularly if a CWIS of concern was located nearshore.

The U.S. FWS T&E species web page, the web pages of individual States or other organizations, or general reference materials can provide data on the habitat preferences of the listed species. Such information may be qualitative, anecdotal, or missing altogether for obscure T&E species. Not all States have developed accounts for their listed species. T&E species web sites of neighboring States may offer additional information if the target species has a regional distribution and is listed throughout its range. The information base can also be augmented by looking at a closely-related species. The substitute species must share the same general habitat preferences as the target species for the comparison to be valid. The analyst should consult appropriate reference materials to ensure a proper match.

c. Assess whether the overlap between habitat requirements and CWIS location exists

The information on habitat preferences for the listed species is compared to location-specific data on the CWIS of concern. The decision step is a simple pass-fail test: a species is retained if the habitat requirements of one or more of its life stages is likely to coincide with the CWIS of concern; otherwise it is removed. The logic supporting this decision is that I&E is unlikely if all the habitat requirements of the target T&E species do not overlap with the habitat in which the CWIS of concern is located.

The exact habitat cutoff point for eliminating a species outright cannot be defined up front; it will depend not only on the target T&E species but also on site-specific factors tied to the CWIS of concern. Several aquatic habitats, however, can be dismissed out of hand because they are not suitable to support CWISs. These habitats include springs, caves, temporary pools, very small ponds and lakes, and shallow headwater streams and creeks. Target T&E species that spend their entire life cycle in these habitats are unlikely to encounter CWISs and can be removed from further consideration. Habitats that have enough volume to support CWISs, namely large rivers and lakes, large estuaries, and inshore marine areas, are likely to require more analysis.

A13-2.4 Step 4: Use Life History Characteristics to Refine Estimate of I&E Potential or Monitor for Actual I&E of the Listed Species

From this point on, the assessment can go in two different directions (see Figure A13-1): (1) the target species is added to the final table because the data indicate potential for I&E, or because more data are needed to refine the assessment; or (2) the species is excluded from the list because there is a low level of concern.

The data may not be as clear-cut for smaller or less mobile species. The overlap between habitat requirements and the location of a CWIS of concern may not suffice to justify adding a target species to the final table without first considering life history information. The decision to proceed beyond Step 3 will vary on a case-by-case basis: it will depend on the target species, access to additional biological information, and the CWIS of concern. The analyst should focus on finding information that will support the decision to add or eliminate a target species. Additional data may not exist for some of the more obscure listed species. Given the protected status of T&E species, however, EPA recommends using a conservative approach to ensure that species are not accidentally omitted when in fact they should be added to the final table. The species should be retained if doubts persist after Step 3: it can still be removed during more site-specific assessments.

Listed clams in big Midwestern rivers are an example of species which may require further assessment in Step 4. Certain clam species would likely pass Step 2 because their distribution overlaps with the locations of CWISs of concern on major rivers. These clam species may also pass Step 3 if their presence coincided with the general location of one or more CWIS of concern. Yet, it is unclear if they should be added to the final table: a closer look at the clams' life history is required to determine the potential for I&E.

The risk of I&E of adult clams is low because they are sedentary, benthic filter feeders or are firmly attached to the substrate. The risk may increase, however, during the reproductive season. During the reproductive season, males release their sperm into the water column. The sperm are carried downstream by the water current and are captured by feeding female clams. The sperm fertilize the female's eggs, which develop inside her body until they hatch. The larvae are released into the water column and must quickly find and attach themselves to a specific fish host to complete their development.[4] Larval clams die if they fail to find a host. After a period of days to weeks, the larval clams detach themselves from their hosts, drop to the bottom, and bury into the sediment or attach to a solid substrate where they remain for the rest of their lives. The only reasonable chance for clam I&E occurs when a fish host with larval life stages attached to it becomes impinged or entrained by a CWIS of concern. Adding a clam species to the final table would depend on whether or not the following occurs:

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[4] Larvae of freshwater clams typically require a very specific fish species to complete their development. Scientists do not always know which fish hosts are required by the T&E river clams.

- The host fish is known to science.
- The host fish is present in the stretch of river containing the CWIS.
- The habitat characteristics of the host fish match the general location of the CWIS of concern. These decisions can be made only on a case-by-case and species-by-species basis.

The information on life history characteristics for the target T&E species should be carefully reviewed to determine the potential for I&E. Several variables may raise concerns, including migratory behavior, pelagic eggs or larvae, foraging activity, and so on. This information is evaluated in comparison to the location of the CWIS of concern. The decision point in this step is a simple pass-fail test: a species is retained if one or more of its life history characteristics enhances the potential for contact with the CWIS of concern; it is removed if all of its life characteristics are unlikely to result in vulnerability to the CWIS of concern.

A13-3 IDENTIFICATION OF SPECIES OF CONCERN AT CASE STUDY SITES

The following sections illustrate the use of this procedure for identifying vulnerable special status species. The example is for fish species of the Delaware Estuary, the site of one of EPA's benefits case studies (see Part B of this document).

A13-3.1 The Delaware Estuary Transition Zone

a. Step 1: Identify all State- or Federally-listed species for the States that border the waterbody on which the CWIS is located

Table A13-1 summarizes information compiled by EPA for fish species in the Delaware Estuary.

Table A13-1: Fish Species Listed as Threatened, Endangered, or of Special Concern (Federal plus PA, NJ, DE, and NY)

Common Name (*Latin Name*)	**Federally-Listed Species**			**State-Listed Species**											
				Pennsylvania			**New Jersey**			**Delaware**			**New York**		
	E	**T**	**O**[a]	**E**	**T**	**O**[b]	**E**	**T**	**O**[b]	**E**	**T**	**O**[b]	**E**	**T**	**O**[b]
Burbot (*Lota lota*)					X										
Chub, Gravel (*Erimystax x-punctata*)				X										X	
Chub, Silver (*Macrhybopsis storeiana*)													X		
Chub, Streamline (*Erymystax dissimilis)*															X
Chubsucker, Lake (*Erimyzon sucetta)*														X	
Darter, Bluebreast (*Etheostoma Camurum*)					X								X		
Darter, Channel (*Percina copelandi*)					X										
Darter, Eastern Sand (*Ammocrypta pellucida*)					X									X	
Darter, Gilt (*Percina evides*)					X								X		
Darter, Longhead (*Percina macrocephala*)				X										X	
Darter, Spotted (*Etheostoma maculatum*)				X										X	
Darter, Swamp (*Etheostoma fusiforme*)														X	
Darter, Tippecanoe (*Etheostoma tippecanoe*)				X											
Lamprey, Mountain Brook (*Ichthyomyzon greeleyi*)					X										X
Lamprey, Northern Brook (*Ichthyomyzon fossor*)				X											
Lamprey, Ohio (*Ichthyomyzon bdellium*)					X										
Madtom, Mountain (*Noturus eleutherus*)					X										
Madtom, Northern *(notutus stigmotus)*					X										
Mooneye *(Hiodon tergisus*)														X	

Table A13-1: Fish Species Listed as Threatened, Endangered, or of Special Concern (Federal plus PA, NJ, DE, and NY) (cont.)

Common Name (*Latin Name*)	Federally-Listed Species			State-Listed Species											
				Pennsylvania			New Jersey			Delaware			New York		
	E	T	O[a]	E	T	O[b]	E	T	O[b]	E	T	O[b]	E	T	O[b]
Redhorse, Black *(Moxostoma duquesnei)*															X
Sculpin, Deepwater *(Myoxocephalus thompsoni)*													X		
Sculpin, Spoonhead *(Cottus ricei)*													X		
Shiner, Ironcolor *(Notropis chalybaeus)*															X
Shiner, Pugnose *(Notropis anogenus)*													X		
Shiner, Redfin *(Lythrurus umbratilis)*															X
Sturgeon, Atlantic (*Acipenser oxyrhynchus*)					X										
Sturgeon, Lake (*Acipenser fulvescens*)				X										X	
Sturgeon, Shortnose (*Acipenser brevirostrum*)	X			X			X			X			X		
Sucker, Longnose (*Catostomus catostomus*)				X											
Sunfish, Banded *(Enneacanthus obesus)*														X	
Sunfish, Longear *(lepomis megalotis)*														X	
Sunfish, Mud *(Acantharchus pomotis)*														X	
Whitefish, Round *(Prosopium cylindraceum)*													X		
TOTAL	**1**	**0**	**0**	**8**	**10**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**8**	**11**	**5**

[a] Other Federally-listed species may include species of special interest or concern, monitored species, candidate species, etc.
[b] Other State-listed species may include rare species, species of special interest, species of concern, candidate species, etc.

Sources: New Jersey Division of Fish and Wildlife (2002); Pennsylvania Department of Conservation and Natural Resources (2002); State of New York, Department of Environmental Conservation (2001); U.S. Fish and Wildlife Service (date unknown).

b. Step 2: Determine if a species listed in Step 1 is present in the area of the CWIS

After identifying species of concern in the source waterbody, the next step is to determine if any of these species are present in the vicinity of the CWIS. This step involves consulting local biologists as well as literature sources such as species atlases, field guides, and scientific publications. Table A13-2 summarizes the results of EPA's analysis of the distribution of species of concern in the Delaware River Basin. Results indicate two there are two fish species potentially vulnerable to CWIS in the Delaware Estuary transition zone, Atlantic sturgeon and shortnose sturgeon (highlighted in bold in the table).

Table A13-2: Distribution of Listed Species Identified in Step 1

Species Name	Current Distribution	Found in Delaware River Basin?
Burbot	PA: Lake Erie and headwaters of Allegheny River	NO
Chub, gravel	NY: medium and large-sized streams in the Allegheny basin PA: Allegheny River and French Creek	NY: NO PA: NO
Chub, silver	NY: Lake Erie	NO
Chub, Streamline	NY: Allegheny River drainage	NO
Chubsucker, Lake	NY: the Lake Erie drainage basin and embayments along the southern shore of Lake Ontario	NO
Darter, bluebreast	NY: upper reaches of the Allegheny River drainage basin PA: upper Allegheny River and two of its tributaries, namely Little Brokenstraw Creek and French Creek	NY: NO PA: NO
Darter, channel	PA: Lake Erie and large tributaries, and the upper part of the Allegheny River	NO

Table A13-2: Distribution of Listed Species Identified in Step 1 (cont.)

Species Name	Current Distribution	Found in Delaware River Basin?
Darter, eastern sand	NY: Lake Erie, the Metawee and Poultney Rivers near Lake Champlain, the Saint Regis and Salmon Rivers near Quebec, and the Grasse River PA: Lake Erie and Allegheny basin	NY: NO PA: NO
Darter, gilt	NY: found only in the Allegheny River PA: Upper Allegheny River	NY: NO PA: NO
Darter, longhead	NY: Allegheny River and a few of its large tributaries; French Creek PA: Scattered sites in the Allegheny River and French Creek headwaters	NY: NO PA: NO
Darter, spotted	NY: French Creek PA: upper Allegheny River and French Creek	NY: NO PA: NO
Darter, swamp	NY: eastern two-thirds of Long Island	NY: NO
Darter, tippecanoe	PA: upper Allegheny River and French Creek	PA: NO
Lamprey, mountain brook	NY: French Creek and Allegheny River tributaries PA: moderate to large streams of the upper Allegheny River system	NY: NO PA: NO
Lamprey, northern brook	PA: Conneaut Creek in Crawford County in north west PA	NO
Lamprey, Ohio	PA: moderate to large streams of the upper Allegheny River system	NO
Madtom, mountain	PA: French Creek in Mercer and Erie Counties in north west PA	NO
Madtom, northern	PA: French Creek	NO
Mooneye	NY: Lake Champlain, Black Lake, Oswegatchie River, Lake Erie, Saint Lawrence River, and the mouth of Cattaraugus Creek	NO
Redhorse, black	NY: Lake Ontario (likely extirpated) and Lake Erie drainage basins, and the Allegheny River	NO
Sculpin, deepwater	NY: Lakes Erie and Ontario	NO
Sculpin, spoonhead	NY: historically found in Lakes Erie and Ontario but believed to be extirpated	NO
Shiner, ironcolor	NY: Basher Kill and Hackensack River	NO
Shiner, pugnose	NY: Sodus Bay and Saint Lawrence River	NO
Shiner, redfin	NY: drainages of Lakes Erie and Ontario in western NY	NO
Sturgeon, Atlantic	PA: Delaware Estuary	**YES**
Sturgeon, Lake	NY: Saint Lawrence River, Niagara River, Oswegatchie River, Grasse River, Lakes Ontario & Erie, Lake Champlain, Cayuga Lake, Seneca & Cayuga canals PA: Lake Erie	NY: NO PA: NO
Sturgeon, shortnose	DE: Tidal Delaware River NJ: Tidal Delaware River NY: Lower portion of the Hudson River PA: Tidal Delaware River	**DE, NJ, PA: YES** NY: NO
Sucker, longnose	PA: Youghiogheny River headwater streams in south west PA	NO
Sunfish, landed	NY: Passaic River drainage and in eastern Long Island in the Peconic River drainage	NO
Sunfish, longear	NY: Tonawanda Creek	NO
Sunfish, mud	NY: Hackensack River	NO
Whitefish, round	NY: scattered lakes throughout the State	NO

Sources: New Jersey Division of Fish and Wildlife (2002); Pennsylvania Department of Conservation and Natural Resources (2002); Smith (1985); State of New York, Department of Environmental Conservation (2001).

c. Step 3: Use information on habitat preferences and intake location to better define the degree of overlap between listed species and the CWIS

Step 3 involves determining the habitat preferences and life history requirements of species identified in Step 2. In Step 2 EPA determined that two fish species of concern are potentially vulnerable to CWIS in the Delaware Estuary transition zone, Atlantic sturgeon and shortnose sturgeon. The habitat preferences and life histories of these species are summarized in Table A13-3.

Table A13-3: Habitat Preferences and Life Histories of Listed Species Identified in Step 2

Species Name	Current Distribution	Habitat Preferences	Potential of Overlap w/ CWIS?	Life History	Potential for I&E?	Life Stages Susceptible to I&E?
Sturgeon, atlantic	Delaware estuary	Estuarine and riverine bottom habitats of large river systems	YES	Adults stay in the ocean but move into estuaries and large rivers to spawn in deep water (> 10m deep); eggs sink and stick to the bottom; juveniles make seasonal migrations between shallower areas (summer) and deeper areas (winter) of their birth rivers; juveniles move to the ocean at age 4-5 to mature	YES	Larvae and juveniles
Sturgeon, shortnose	Tidal Delaware River (mostly in the upper and transitional estuary)	Estuarine and riverine bottom habitats of large river systems	YES	Adults stay in nearshore marine habitats but move in estuaries and large rivers to spawn; eggs sink and stick to the bottom; juveniles make seasonal migrations between shallower areas (summer) and deeper areas (winter) of their birth rivers; juveniles move out to the ocean at age 4-5 to mature	YES	Larvae and juveniles

d. Step 4: Use of monitoring or life history characteristics to refine estimate of I&E

In some cases I&E or waterbody monitoring data may be available to estimate CWIS impacts on T&E species. However, in many cases, it will be necessary to estimate relative risk based on waterbody monitoring of the species distribution relative to CWIS and life history and facility characteristics that influence a species vulnerability to I&E.

For the Delaware Estuary example discussed here, there are only limited data available for shortnose sturgeon (Masnik and Wilson, 1980) and Atlantic sturgeon (Shirey et al., 1997) from monitoring in the vicinity of transition zone CWIS. In the case of shortnose sturgeon, 1980 monitoring results indicate that the species is not vulnerable to transition zone CWIS. However, because the data are over 20 years old, further information is needed to confirm that the potential for I&E of shortnose sturgeon remains low. An analysis of life history information indicates that spawning takes many miles upstream of transition zone CWIS, and therefore the risk of entrainment of eggs and larvae is minimal (Masnik and Wilson, 1980). Impingement is also unlikely because salinity and feeding conditions in the transition zone are unfavorable for impingeable-sized juveniles and adults (Masnik and Wilson, 1980).

In the case of Atlantic sturgeon, monitoring in the transition zone indicates that young Atlantic sturgeon occur in the vicinity of the Hope Creek and Salem facilities in the summer months. Data also suggest that Atlantic sturgeon move back downstream in fall, although use of the lower estuary (Delaware Bay) remains unknown (Shirey et al., 1997). This information suggests that Atlantic sturgeon are potentially at risk to transition zone CWIS and indicates the need for I&E monitoring to confirm the degree of harm.

A13-4 BENEFIT CATEGORIES APPLICABLE FOR IMPACTS ON T&E SPECIES

Once a T&E species has been identified as vulnerable to a CWIS, special considerations are necessary to fully capture the benefits of reducing I&E of the species. The benefits case study presented in Part E of this document illustrates some of the challenges in assigning economic value to T&E species and presents a valuation approach that may prove useful in other cases.

Estimating the economic benefits of helping to preserve T&E and other special status species, such as by reducing I&E impacts, is difficult due to a lack of knowledge of the ecological role of different T&E species and a relative paucity of economic studies focusing on the benefits of T&E preservation. Most of the wildlife economic literature focuses on recreational use benefits that may be irrelevant for valuation of T&E species because T&E species (e.g., the delta smelt in California) are not often targeted by recreational or commercial fishermen. The numbers of special status species that are recreationally or commercially fished (e.g., shortnose sturgeon in the Delaware Estuary) have been so depleted that any use estimates associated with angling participation or landings data for recent years (or decades) would not be indicative of the species' potential value for direct use if and when the population recovers. Nevertheless, there are some T&E species for which consumptive use-related benefits could be significant once the numbers of individuals are restored to levels that enable resumption of relevant uses.

Based on their potential uses, T&E species can be divided into three broad categories:

- *T&E species with high potential for consumptive uses.* The components of total value of such species are likely to include consumptive, non-consumptive, and indirect use values, as well as existence and option values. Pacific salmon, a highly prized game species, is a good example of such species. In addition to having a high consumptive use value, this species is likely to have a high non-consumptive use value. People who never go fishing may still watch salmon runs. The user value may actually dominate the total economic value of enhancing a T&E fish population for species like salmon. For example, Olsen et al. (1991) found that users contribute 65 percent to the total regional WTP value ($171 million in 1989$) for doubling the Columbia River salmon and steelhead runs. Nonusers with zero probability of participation in the sport fishery contribute 25 percent. Nonusers with some probability of future participation contribute the remaining ten percent.

- *T&E species that do not have consumptive uses, but are likely to have relatively large non-consumptive and indirect use values.* The total value of such species would include non-consumptive use and indirect values, and existence and option values. Loggerhead sea turtles can represent such species. The non-consumptive use of loggerhead sea turtles may include photography or observation of nesting or swimming reptiles. For example, a study by Whitehead and Blomquist (1992) reports that the average subjective probability that North Carolina residents will visit the North Carolina coast for non-consumptive use recreation is 0.498. Policies that protect loggerhead sea turtles may therefore enhance individual welfare for a large group of participants in turtle viewing and photography.

- *T&E species whose total value is a pure non-use value*. Some prominent T&E species with minimal or no use values may have high non-use values. The bald eagle and the gray whale are examples of such species. Conversely, many T&E species with little or no use value are not well known or of significant public interest and therefore their non-use values may be difficult to elicit.. Most obscure T&E species, which may have ecological, biological diversity and other non-use values, are likely to fall into this category.

Non-use motives are often the principal source of benefits estimates for T&E species because many T&E species fall into the "obscure species" group. As described in greater detail in Chapter A9, motives often associated with non-use values held for T&E species include bequest (i.e., inter-generational equity) and existence (i.e., preservation and stewardship) values. These non-use values are not necessarily limited to T&E species, but I&E-related adverse impacts to these unique species would be locally or globally irreversible, leading to extinction being a relevant concern. Irreversible adverse impacts on unique resources are not a necessary condition for the presence of significant non-use values, but these attributes (e.g., uniqueness; irreversibility; and regional, national, or international significance) would generally be expected to generate relatively high non-use values (Carson et al., 1999; Harpman et al., 1993).

A13-5 METHODS AVAILABLE FOR ESTIMATING THE ECONOMIC VALUE ASSOCIATED WITH I&E OF T&E SPECIES

Estimating the value of increased protection of T&E species from reducing I&E impacts requires the following steps:

- Estimating I&E impacts on T&E species; and
- Attaching an economic value to changes in T&E status from reducing I&E impacts on species of concern (e.g., increasing species population, preventing species extinction, etc.).

A13-5.1 Estimating I&E Impacts on T&E Species

Several cases of I&E of Federally-protected species by CWIS are documented, including the delta smelt in the Sacramento-San Joaquin River delta, sea turtles in the Delaware Estuary and elsewhere (NMFS, 2001b), and shortnose sturgeon eggs and larvae in the Hudson River (New York State Department of Environmental Conservation, 2000). Mortality rates vary by species and life stage: it is estimated to range from two to seven percent for impinged sea turtles (NMFS, 2001b), but mortality can be expected to be much higher for entrained eggs and larvae of the shortnose sturgeon and other special status fish species. The estimated yearly take of delta smelt by CWISs in the Sacramento-San Joaquin River Delta led to the development of a Habitat Conservation Plan as part of an incidental take permit application (Southern Energy Delta LLC, 2000).

A13-5.2 Economic Valuation Methods

Valuing impacts on special status species requires using nonmarket valuation methods to assign likely values to losses of these individuals. The fact that many of these species typically are not commercially or recreationally harvested (once they are listed) means no market value can be placed on their consumption. Benefits estimates are therefore often confined to non-use values for special status species. The total economic value of preserving species with potentially high use values (i.e., T&E salmon runs) should include both use and non-use values. Economic tools allowing estimates of both use and non-use values (e.g., stated preferences methods) may be suitable for calculating the benefits of preserving T&E species. The relevant methods are briefly summarized below.

It is necessary to note that the benefits of preserving T&E species estimated to date reflect a human-centered view; benefit cost analysis may not be appropriate when T&E species are involved because extinction is irreversible.

a. Stated preference methods

As described in Chapter A9, the only available way to directly estimate non-use values for special status species is through applying stated preference methods, such as the contingent valuation method (CVM). This method relies on statements of intended or hypothetical behavior elicited though surveys to value species. CVM has sometimes been criticized, especially in applications dating back a decade or more, because the analyst cannot verify whether the stated values are realistic and absent of various potential biases. CVM and other stated preference techniques (including conjoint analysis) have evolved and improved in recent years, however, and empirical evidence shows that the method can yield reliable (and perhaps even conservative) results where stated preference results are compared to those from revealed preference estimates (e.g., angling participation as observable behavior) (Carson et al., 1996).

Regardless of the debates over whether or not stated preference methods such as the CVM can generate reliable estimates of non-use values, EPA cannot apply this approach to the section 316(b) rulemaking because the time and cost associated with conducting the necessary primary research is well beyond the budget and schedule available to the Agency. Such research also requires that the survey questionnaire and sampling design be reviewed and approved by OMB to comply with the Paperwork Reduction Act. The cost, time requirements, and administrative burdens associated with implementing a valuation survey in accordance with Paperwork Reduction Act create significant additional barriers to the potential for EPA implementing such relevant and useful research.

b. Benefits transfer approach

Using a benefit transfer approach may be a viable option in some cases. By definition, benefits transfer involves extrapolating the benefits findings estimated from one analytic situation to another situation(s). The initial analytic situation is defined in terms of an environmental resource (e.g., T&E species), the policy variable(s) (e.g., changes in species status or population), and the benefitting populations being investigated. Only in ideal circumstances do the environmental resource and policy variables of the original study very closely match those of the analytic situation to which a policy or regulatory analyst may wish to extrapolate study results. Despite discrepancies, this approach may provide useful insights into benefits to society from reducing stress on T&E species.

The current approach to benefit transfers most often focuses on the meta analysis of point estimates of the Hicksian or Marshalian surplus reported from original studies. If, for example, the number of candidate studies is small and the variation of characteristics among the studies is substantial, then meta analysis is not feasible. This is likely to be the case when T&E species are involved, requiring a more careful consideration of analytic situations in the original and policy studies. If only one or a few studies are available, an analyst evaluates their transferability based on technical criteria developed by Desvouges (1992).

The analyst first identifies T&E species affected by I&E and the type of environmental change resulting from reducing I&E impacts on T&E species, and then selects from a pool of available studies the appropriate WTP values for protecting those species. EPA illustrated the value to society of protecting T&E species by conducting a review of the contingent valuation (CV) literature that estimates WTP to protect those species. This review focused on those studies valuing those aquatic species that may be at risk of I&E by CWISs. EPA also identified studies that provide WTP estimates for fish-eating species, i.e., the bald eagle, peregrine falcon, and the whooping crane. These species may also be at risk because they rely to some degree on aquatic organisms as a food source. EPA used select studies identified in a meta-analysis that Loomis and White (1996) conducted as a literature base. Loomis and White included all rare or endangered species in their analysis, but EPA limited its own literature review to those studies that valued threatened or endangered aquatic species, or birds that consume aquatic species. Table A13-4 lists the 14 relevant CV studies that EPA identified and provides corresponding WTP estimates and selected study characteristics. WTP estimates represent either one-time payments, annual payments, or an annual payment in a 5-year program. The table indicates which of these payment types each WTP estimate represents, along with the corresponding value, inflated to 2002$, are presented in the table. EPA also converted lump-sum payments and 5-year program annual payments into annualized values in order to aid in the comparison of values from all studies.[5]

The identified valuation studies vary in terms of the species valued and the specific environmental change valued. Thirteen of these studies represent a total of 16 different species. In addition, one study (Walsh et al., 1985) estimates WTP for a group of 26 species. Most of these studies value prominent species well known by the public, such as salmon. The studies valued one of the following general types of environmental changes:

- avoidance of species loss/extinction;
- species recovery/gain;
- acceleration of the recovery process;
- improvement of an area of a species' habitat; and
- increases in species population.

In order to compare consistent measures of WTP, EPA chose to use values that represent either annual or annualized WTP, which represent conservative estimates of consumer surplus. The value of preserving or improving populations of T&E species reported in T&E valuation studies has a wide range. Mean annual (or annualized) household WTP estimates of obscure aquatic species range from $7.52 (2002$) for the striped shiner (Boyle & Bishop, 1987) to $8.32 for the silvery minnow (Berrens et al., 1996). It is not likely that use values associated with these species are significant.

WTP for prominent fish species range from the relatively low estimate of $2.29 (Stevens et al., 1991), to $8.74 (Stevens et al., 1991); both values are mean non-user WTP for Atlantic salmon, and are annualized. Total user values would likely be much higher for Atlantic salmon, as this species is commonly targeted by recreational anglers. WTP estimates for fish-eating species (i.e., whooping crane, bald eagle, and peregrine falcon), which all have high non-use values (i.e., existence value), range from $4.39 (Carson et al., 1994) to $62.15 (Bowker and Stoll, 1988). It is important to note that the above WTP ranges are derived from studies that used various valuation scenarios and valued different types of environmental changes, and therefore should be viewed as approximate values as opposed to finite ranges.

It may be possible to develop individual WTP ranges for a given species or species group based on the estimated changes in T&E status (e.g., species gain or recovery) from reducing I&E impacts and the applicable WTP values from existing studies. Once individual's WTP for protecting T&E species or increasing their population is developed the next step is the estimation of total benefits from reducing I&E of the special status species. The analyst should apply the estimated WTP value to the relevant population groups to estimate the total value of improving protection of T&E species. The affected population may include both potential users and non-users, depending on species type. The relevant population may also include area residents, regional population, or, in exceptional cases (e.g., bald eagle), the U.S. population. The total value of improved protection of T&E species (e.g., preventing extinction or doubling the population size) should be then adjusted to reflect the percentage of cumulative environmental stress attributable to I&E.

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[5] For each study that presents annual payments in a 5-year program, EPA calculated the present value of those payments using a 3 percent discount rate, and annualized present day value over 25 years using the same discount factor. EPA considered lump sum payments to represent present value, and thus merely annualized these payments using the same assumptions.

Table A13-4: WTP ($2002) for Improving T&E Species Populations[a]

Species Type	Reference	Publication Date	Survey Date	Species	Environ-mental Change	Size of Change	Value Type[b]	Mean WTP ($2002)	Annual or Annualized Mean WTP ($2002)[c]	CVM Method	Survey Region	Sample Size	Response Rate	Payment Vehicle
Aquatic	Berrens et al.	1996	1995	Silvery minnow	Maintain in-stream flow to protect species		5	$33.05	$8.32	DC	NM households	698	45%	Trust fund
	Boyle and Bishop	1987	1984	Striped shiner	Avoid loss	100%	A	$7.52	$7.52	DC	WI households	365	73%	Foundation
	Carson et al.	1994	1994	Kelp Bass White Croaker Bald Eagle Peregrine falcon	Speed recovery from 50 to 5 years		L	$78.73	$4.39	DC	CA households	2810	73%	One-time tax
	Cummings et al.	1994	1994	Squawfish	Avoid loss	100%	A	$10.48	$10.48	OE	NM	921	42%	Increase State taxes
	Duffield and Patterson	1992	1992	Arctic grayling	Improve 1 of 3 rivers		L	$21.62	$1.21	PC	US visitors	157	27%	Trust fund
				Cutthroat Trout			L	$16.21	$0.90	PC	US visitors	170	77%	Trust fund
	Kotchen and Reiling	2000	1997	Shortnose Sturgeon	Recovery to self-sustaining population		L	$29.85	$1.66	DC	Maine residents (random)	635	63%	One-time tax
	Loomis and Larson	1994	1991	Gray Whale	Gain	50%	A	$21.35	$21.35	OE	CA households	890	54%	Protection fund
					Gain	100%	A	$23.94	$23.94	OE	CA households	890	54%	Protection fund
					Gain	50%	A	$32.99	$32.99	OE	CA visitors	1003	72%	Protection fund

Table A13-4: WTP ($2002) for Improving T&E Species Populations (cont.)[a]

Species Type	Reference	Publication Date	Survey Date	Species	Environmental Change	Size of Change	Value Type[b]	Mean WTP ($2002)	Annual or Annualized Mean WTP ($2002)[c]	CVM Method	Survey Region	Sample Size	Response Rate	Payment Vehicle
Aquatic (cont.)	Loomis and Larson (cont.)	1994	1991	Gray Whale	Gain	100%	A	$39.23	$39.23	OE	CA visitors	1003	72%	Protection fund
	Olsen et al.	1991	1989	Pacific Salmon and Steelhead	Gain (existence value)	100%	A	$38.96	$38.96	OE	Pac. NW household	695	72%	Electric bill
					Gain (user value)	100%	A	$110.06	$110.06	OE	Pac. NW anglers	482	72%	Electric bill
	Stevens et al.	1991	1989	Atlantic salmon	Avoid loss	100%	5	$9.08	$2.29	DC	MA households	169	30%	Trust fund
				Atlantic salmon	Avoid loss	100%	5	$10.08	$2.54	OE	MA households	169	30%	Trust fund
	Stevens et al.	1994	1993	Atlantic salmon	Gain	50%	5	$24.19	$6.09	DCOE	College students	76	93%	Contribution
				Atlantic salmon	Gain	90%	5	$34.73	$8.74	DCOE	College students	76	93%	Contribution
	Walsh et al.	1985	1985	26 species in CO	Avoid loss	-100%	A	$72.21	$72.21	OE	CO households	198	99%	Taxes
	Whitehead	1992	1991	Sea turtle	Avoid loss	100%	L	$16.17	$0.90	DC	NC households	207	35%	Preservation fund

Table A13-4: WTP ($2002) for Improving T&E Species Populations (cont.)[a]

Species Type	Reference	Publication Date	Survey Date	Species	Environ-mental Change	Size of Change	Value Type[b]	Mean WTP ($2002)	Annual or Annualized Mean WTP ($2002)[c]	CVM Method	Survey Region	Sample Size	Response Rate	Payment Vehicle
Fish-eating birds	Bowker and Stoll	1988	1983	Whooping crane	Avoid loss	100%	A	$39.61	$39.61	DC	TX and US visitors	316	36%	Foundation
				Whooping crane	Avoid loss	100%	A	$62.15	$62.15	DC	TX and US visitors	254	67%	Foundation
	Boyle and Bishop	1987	1984	Bald eagle	Avoid loss	100%	A	$19.17	$19.17	DC	WI households	365	73%	Foundation
	Carson et al.	1994	1994	Bald eagle Peregrine Falcon Kelp bass White Croaker	Speed recovery from 50 to 5 years		L	$78.73	$4.39	DC	CA households	2810	73%	One-time tax
	Stevens et al.	1991	1989	Bald eagle	Avoid loss	100%	A	$41.01	$41.01	DCOE	NE households	339	37%	Trust fund
				Bald eagle	Avoid loss	100%	A	$28.89	$28.89	DCOE	NE households	339	37%	Trust fund
	Swanson	1993	1991	Bald eagle	Increase in populations	300%	L	$317.01	$17.67	DC	WA visitors	747	57%	Membership fund
				Bald eagle	Increase in populations	300%	L	$222.05	$12.38	OE	WA visitors	747	57%	Membership fund

[a] Exhibit adapted from Loomis and White (1996), and includes only those studies that valued aquatic species or fish-eating birds.

[b] Indicates type/ length of WTP payment reported in study: 5 = annual payment in 5-year program; LS = lump sum, or one-time; payment, A = annual payment.

[c] Lump-sum values are annualized over 25 years using a 3 percent discount rate; values that are annual payments in 5-year programs were converted into present value before annualizing over 25 years at a 3 percent discount rate; annual payments are presented as in the original study, in 2002$. Values that already represent annual values are unadjusted.

Sources: Exhibit adapted from Loomis and White, 1996; CPI: U.S. Bureau of Labor Statistics, Division of Consumer Prices and Price Indexes, 2003.

c. Cost of T&E species restoration

EPA explored an approach based on the premise that under specific circumstances it is possible to infer how much value society places on a program or activity by observing how much society is willing to forego (in out-of-pocket expenses and opportunity costs) to implement the program. For example, the costs borne by society to implement programs that preserve and restore special status species can, under select conditions, be interpreted as a measure of how much society values the outcomes it anticipates receiving. This is analogous to the broadly accepted revealed preference method of inferring values for private goods and services based on observed individ‘ual behavior.

In the case of observed individual behavior, when a person willingly bears a cost (pays a price) to receive a good or service, then it is deduced that the person's value for that acquired good or service must be at least as great as the price paid. That is, based on the presumption that individual behavior reflects the economic rationality of seeking to maximize utility (well-being), the person's observed willingness-to-pay must exceed the price paid, otherwise they would not have purchased that unit of the commodity. The approach described in this section uses the same premise, but applies it to societal choices rather than to a single individual's choices.

A critical issue with the approach is determining when it is likely that a specific public sector activity (or other form of collective action) does indeed reflect a "societal choice." EPA recognizes clearly that not every policy enacted by a public sector entity can rightfully be interpreted as an indication of social choice. Hence, the costs imposed in such instances may not in any way reveal social values. For example, some regulatory actions may have social costs that outweigh the social benefits, but may be implemented anyway because of legal requirements or other considerations. In such a case, asserting that the costs imposed reflect a lower bound estimate of the "value" of the action would not be accurate (the values may be less than the imposed costs). Alternatively, there are some regulatory programs for which the benefits greatly exceed costs, and in such instances using costs as a reflection of value would greatly understate social benefits.

There are some public policy actions that can be suitably interpreted as expressions of societal preferences and values. In these instances, the incurred costs may be viewed as an indication of social values. The criteria to help identify when such situations arise include whether the actions taken are voluntary, or whether the actions reflect an open and broadly inclusive policy-making process that enables and encourages active participation by a broad spectrum of stakeholders. This is especially relevant where (1) plans and actions are developed in an inclusive, consensus-building manner; (2) implementation steps are pursued in an adaptive management framework that enables continuous feedback and refinement; or (3) the actions are ultimately supported by some positive indication of broad community support, such as voter approval of a referendum. In such instances, the policy choices made are the product of a broad-based, collective decision-making process, and such programs should be viewed as an expression of societal preferences. When programs or activities stem from such open collective processes, the actions (and costs incurred) reflect the revealed preference of society.

EPA's method values T&E species in a two step process. First, estimates of costs incurred and anticipated from voluntary or other suitable collective actions taken to maintain and or increase the populations of T&E species (e.g., restoration of critical spawning or nursery habitat) are combined with estimates of the value of any foregone opportunities (i.e., opportunity costs, where direct costs are not involved) from additional actions required to achieve the T&E population objectives (e.g., maintaining instream flows for a species instead of providing water for agricultural diversions). This resulting total social cost provides a cumulative estimate of society's valuation of the preservation and enhancement of the T&E species affected by the actions. Categories of actions that would be addressed in this step could include private and public expenditures on habitat restoration/population enhancement programs, funds that have been allocated for such actions through legislative appropriations or public referenda (even if not yet expended), or resources allocated through a formal project evaluation and selection process designed to allocate limited resources such as those used by numerous State and Federal resource management agencies.

Second, the numbers of the T&E organisms that are expected to benefit from the identified actions, as measured by the increased production or avoided losses of individuals, are estimated to place the valuation estimates in context. If dollar per organism results are required for a valuation analysis, as is the case in this rulemaking, the estimates from the first step can be divided by the increased production (avoided loss) estimate from the second step to provide such results.

The economic foundations for using this approach to value T&E species are firmly established through the widespread recognition and acceptance of revealed preference data as a source of nonmarket information that is acceptable for the valuation of resources. In EPA's approach, valuation estimates rely on the costs of actions or the value of foregone opportunities that are *voluntarily* undertaken or that have been approved through extensive public input and review (and developed in a consensus-oriented approach). With these sources of data, the method avoids the well-established problems associated with using "costs" as a measure of "value" — a problem that can arise when the cost is realized involuntarily (e.g., avoided cost-based measures of value). Specifically, because of the available evidence of the public's acceptance and willingness to incur the opportunity costs associated with the actions that are selected for evaluation, the fundamental criteria for defining the value of any resource are satisfied.

One issue that arises with the use of the method is that it is not clear that the resulting values can be distinctly categorized as direct use or non-use values because the underlying actions benefitting the T&E species could reflect an expressed mix of non-use values (e.g., preservation and existence) and discounted future use values (e.g., the actions are seen as an "investment" that could return the species to levels at which direct use would be permitted). As result, it is believed that results provide an approximation of the total use value for the T&E species in question.

A13-6 ISSUES IN THE APPLICATION OF THE T&E VALUATION APPROACHES

Several technical and conceptual issues are associated with valuing I&E impacts on T&E species:

- issues associated with estimating I&E contribution to the cumulative impact from several stressors; and
- issues associated with implementing an economic valuation approach.

A13-6.1 Issues in Estimating Environmental Impacts from I&E on Special Status Fish

Difficulties in estimating the number of individuals or size of the population of special status fish present in a given location are often very difficult for numerous reasons, including the following:

- The act of monitoring a T&E species is problematic in and of itself because monitoring generally results in some harm to the species, so researchers and Federal agencies are reluctant to do it.

- Monitoring programs typically focus only on harvested species.

- The number of individuals may be so low that they rarely or never show up in monitoring programs for other species.

- A lack of complete knowledge of the life cycles of special status fish species contributes to an inability to accurately estimate population sizes for some species.

Deriving population estimates from existing monitoring programs often means extrapolating sampling catches to the population as a whole. The variance in estimates is likely to be very high. Several assumptions must be met when extrapolating sample catches to population estimates:

- Fish are completely recruited and vulnerable to the gear (i.e., are large enough to be retained by the mesh and do not preferentially occupy habitats not sampled) or selectivity of the gear by size is known.

- Sampling fixed locations for species approximates random sampling, which approximates a stratified random sampling scheme.

- Species are uniformly distributed through the water column.

- Volume filtered by trawls can be accurately estimated.

- Volumes of water can be estimated for each embayment in the habitat range for the species.

a. Issues in using a benefits transfer approach

The following issues may arise in developing a benefit transfer approach:

- *Some studies estimated WTP for multiple species.* Values established by Carson et al. (1994), Olsen et al. (1991), and Walsh et al. (1985) are for groups of T&E species, and therefore transferring values from these studies to particular species may not be feasible.

- The type of *environmental change* valued in the study may not provide a good match to the changes resulting from reducing I&E impacts. As noted above, previous T&E valuation studies addressed one of the following qualitative changes in T&E status:

  - avoidance of species loss/extinction
  - species recovery/gain
  - acceleration of the recovery process
  - improvement of an area of a species' habitat
  - increases in species population.

  The environmental change resulting from reduced I&E effects on T&E species may not match the scenarios considered in the original studies.

- The *size of the environmental change* that the hypothetical scenario defines is also vital for developing WTP estimates. Several studies describe programs that avoid the loss of a species. This outcome may be considered a 100 percent improvement with respect to the alternative, extinction, but the restoration of a species or the increase in population may be specified at any level (e.g., 50 percent, 300 percent). Swanson (1993) estimated a 300 percent *increase* in bald eagle populations and Boyle and Bishop (1987) estimated WTP to avoid the possibility of bald eagle *extinction* in Wisconsin (cited in Loomis and White, 1996). Although avoiding extinction may be considered a 100 percent improvement, this environmental change is not comparable to the 300 percent increase in existing populations; preventing regional extinction is quite different than realizing a nominal increase in species population (in which the alternative is not necessarily species loss).

- Although a considerable amount of CV literature has valued T&E species, such research is largely limited to species with high consumptive use or non-use values. They either have high recreational or commercial value, or are popularly valued as significant species for various reasons (e.g., national symbol, aesthetics). Many T&E species that are likely to be affected by I&E (either Federal or State-listed) are obscure, and WTP for their preservation has not been estimated.

b. Cost of restoration approach

- "Restoration" programs need not be relied on exclusively to infer societal revealed WTP to preserve special status species. In many instances, other programs or restrictions are used in lieu of (or in conjunction with) restoration programs, and the costs associated with the nonrestoration components also reveal a WTP. For example, efforts to preserve fish species in the San Francisco Estuary also include water use restrictions that reduce the amount of fresh water diverted from the upstream portion of the Sacramento River to highly valued water uses in the central and southern parts of California. The foregone use values of these waters in agricultural and municipal applications are an important component of the cost society bears to protect and preserve special status fish species.

- Costs directed at a special status species must be isolated from program elements intended to address other species or problems. For example, in a multifaceted restoration or use restriction program, the percentage of costs used mainly to target restoration of special status species as opposed to other ecosystem benefits needs to be estimated.

- Estimates must be developed of the change in species abundance associated with the program. A habitat restoration program may set population targets for restoration of special status species, but might not target a specific population size. Often targets are set to abundance levels that existed before a significant decline in populations.

Chapter A14: Discounting Benefits

INTRODUCTION

CHAPTER CONTENTS

Discounting refers to the economic conversion of future benefits and costs to their present values, accounting for the fact that individuals tend to value future outcomes less than comparable near-term outcomes. Discounting is important when benefits and costs occur in different years, and enables a comparison of benefits to costs across time periods.

For the section 316(b) Phase II rule, the need to discount arises from two sources. First, there will be a delay between the time the rule is enacted and the time facilities attain compliance and begin to reduce impingement and entrainment (I&E) impacts. Second, some fish saved today will require one or more years to grow to a size at which anglers will harvest them. The discounting methods EPA has applied to address both of these issues are discussed in the following sections.

A14-1 DISCOUNTING TO ACCOUNT FOR THE TIME IT TAKES TO ENACT NEW TECHNOLOGIES

Under the section 316(b) Phase II rule, facilities will not achieve compliance immediately. Facilities will face costs once the rule takes effect, but it will take time to make the required changes. EPA has assumed that it will take one year from the start of the rule for facilities to reach compliance. Thus all recreational, commercial, and non-use benefits are discounted one year using two discount rates. A real discount rate of 3 percent is applied as a reasonable estimate of the social rate of time preference. Results assuming a real discount rate of 7 percent are also reported as an alternative, in accordance with OMB guidance to reflect the estimated opportunity cost of capital.

A14-2 DISCOUNTING TO ACCOUNT FOR THE TIME IT TAKES FISH SPARED I&E TO GROW TO HARVESTABLE AGE

The issue of time lags between implementation of best technology available (BTA) and resulting increased fishery yields stems from the fact that one or more years may pass between the time an organism is spared impingement or entrainment (I&E) and the time of its ultimate harvest. For example, a larval fish spared entrainment (in effect, at age 0) may be caught by a recreational angler at age 3, meaning that a 3-year time lag arises between the incurred cost of BTA and the realization of the estimated recreational benefit. Likewise, if a 1 year old fish is spared impingement and is then harvested by a commercial waterman at age 2, there is a 1-year lag between the incurred BTA cost and the subsequent commercial fishery benefit. In this analysis, EPA applied discounting by species groups in each regional study, as described below.

A14-2.1 Discounting Recreational and Commercial Fishing Benefits

To discount recreational and commercial fishing benefits, EPA collected species specific information on ages of fish at harvest to estimate the average time required for an age-1 equivalent fish to reach a harvestable age. EPA then discounted these results using two discount rates: a real rate of 3 percent is applied as a reasonable estimate of the social rate of time preference, and a real rate of 7 percent is also used.

The key factor in the analysis is the range of ages at which different types of fish are typically landed by commercial or recreational anglers. These results are species specific; they account for the life history of each species (i.e., the percent harvested in each year class, and weight attained in each year). For each species, EPA's model uses fishery data that indicate what percentage of the impacted fish will survive to a given age. Then, for each cohort of fish that survives to a given age (for each species), EPA applies a suitable fishery mortality estimate that indicates how many of that cohort will be harvested. The detailed methods are presented in Chapter A5.

As an example of how the discounting works, assume for a given fish species, X, killed in a larval stage (i.e., at age 0), that 3 percent of the surviving fish typically are landed at age 1, and 15 percent at age 2. Thus, 3 percent of the surviving fish of species X would have their landed values discounted over a 1 year period for entrainment (since once spared mortality from entrainment, it takes 1 year until they are landed and the benefit is "realized"). Also, 15 percent of the fish in this entrainment example for species X would have their associated landed values discounted for 2 years. Then, the present values are summed across the cohort of base year entrainment survivors for species X to give the present value of the stream of commercial (or recreational) landings associated with implementing BTA in the base year. In this example, with a 3 percent discount rate, if 1,000 fish are saved today at age 0, then an estimated 3 percent, or 30, would be caught next year. If the benefit for each fish is $1 today, the total benefit would be $30 now, while the discounted benefit 1 year in the future would be $29.10. Similarly, an estimated 15 percent, or 150 fish, would be caught in year 2, which at $1 per fish would have benefits of $150, but when discounted would have benefits of $141.10. The total benefit of saved fish that are eventually harvested is $180 with no discounting, which equals $170.20 when discounted at 3 percent. Thus, the discounted benefits in this example are equal to 0.95 the undiscounted benefits ($170.20/$180.00).

The discounted values vary depending on the life history of each fish species affected. Fish that tend to be harvested at young ages will have relatively short time lags between implementation of BTA and the subsequent timing of changes in landings. In contrast, long-lived fish that tend to be caught at relatively older ages will tend to have longer time lags (and, hence, they will have larger impacts from discounting and lower present values).

The discounted results also vary between commercial and recreational landings, because the former is based on weight of landings whereas the latter is based on number of fish landed. Results also vary between I&E, because impacts from the former are reflected as adult fish with age distributions that vary by species whereas entrainment impacts are predominantly on eggs and larvae (age 0).

To calculate the discounted impacts, EPA compiled data on the time stream of landed fish (and associated fish mass) and applied alternative discount rates (3 percent and 7 percent) to calculate the present value stream of landings from a given year's I&E impacts. An illustrative summary is provided in Tables A14-1 (3 percent discount rate) and A14-2 (7 percent discount rate) for three generalized classes of fish ranging from relatively long-lived fish (e.g., striped bass, pollack) to short-lived species that tend to be harvested by or at age 1 (e.g., pink shrimp).

In brief, at a 3 percent discount rate, the present value benefits will be at about 90 percent to 95 percent of the undiscounted estimate (i.e., between 5 percent to 10 percent less than stated at proposal) for most of the fish with mid-range life/harvest histories (e.g., walleye). For longer-lived species, the present values will tend to be lower (e.g., 80 percent to 91 percent), and for shorter-lived species, the present values will tend to be higher (with discounted values between 96 percent and 100 percent of undiscounted results).

EPA recognizes that addressing species groups rather than individual species means that potentially important species-specific differences cannot be accounted for. However, the lack of life history data, fishing mortality rates, and other information necessary to calculate foregone yield and other endpoints of interest at the regional and national level rather than at the facility specific level makes it necessary to group species in this way.

The results of these discounting methods were applied in the commercial and recreational benefits analyses for each region. The discount factors used by species are reported in the I&E chapter for each region (B2, C2, etc.).

Table A14-1
Examples of Discounted Losses as a Percentage of Undiscounted Losses
3% Rate of Discount

Species Group	Entrainment		Impingement	
	Commercial	Recreation	Commercial	Recreation
Low (long-lived species, e.g., pollack, striped bass)	0.83	0.88	0.86	0.91
Midrange (walleye, crappie)	0.90	0.93	0.92	0.95
High (short-lived species, e.g., silverside, pink shrimp)	0.96	0.97	1.0	1.0

Table A14-2
Examples of Discounted Losses as a Percentage of Undiscounted Losses
7% Rate of Discount

Species Group	Entrainment		Impingement	
	Commercial	Recreation	Commercial	Recreation
Low (long-lived species, e.g., pollack, striped bass)	0.66	0.75	0.71	0.80
Midrange (walleye, crappie)	0.78	0.84	0.83	0.90
High (short-lived species, e.g., silverside, pink shrimp)	0.93	0.93	1.0	1.0

A14-2.2 Discounting Non-use Benefits

EPA assumes that non-use benefits from reductions in I&E would begin to accrue to the affected populations after technology installation is completed because non-use benefits are not associated with fish size or weight. Therefore, baseline non-use values are not discounted in analyses of non-use benefits.

Chapter A15: Habitat Based Methodology for Estimating Non-Use Values

INTRODUCTION

Aquatic species without any direct uses account for the majority of losses at cooling water intake structures (CWIS). Therefore, non-use value is an important component of value to consider.

This chapter describes a methodology for estimating non-use values for lost aquatic organisms using a benefit transfer of habitat values. EPA explored this approach to estimating non-use values for three case study regions: the North Atlantic, Mid-Atlantic, and Great Lakes regions. However, because of limitations and uncertainties regarding the application of this methodology to the national level discussed in section A15-4, EPA elected not to include benefits based on this approach in the benefit-cost analysis of the final section 316(b) rule.

One way to consider impingement and entrainment (I&E) losses is to value the habitat necessary to replace the lost organisms. The value of fish habitat can provide an indirect basis for valuing the fish that are supported by the habitat. For example, existing wetland valuation studies found that members of the general public are aware of the fish production services provided by eelgrass (submerged aquatic vegetation, SAV) and wetlands, and that they express support for steps that include increasing SAV and wetland areas to restore reduced fish and shellfish populations (Opaluch et al., 1995, 1998; Mazzotta, 1996).

CHAPTER CONTENTS

The method described here first estimates the quantity of different habitats required to replace fish and shellfish lost to I&E, and then assesses respondents' values for these habitats. These data are then combined to yield an estimate of household values for improvements in fish and shellfish habitat, which provides an indirect estimate of the benefits of reducing or eliminating I&E.

This benefit transfer approach involves four general steps:

1. Estimate the amount of restored habitat needed to produce organisms at a level necessary to offset I&E losses for the subset of species for which potential production information is available.

2. Develop willingness-to-pay (WTP) values for fish production services of habitat ecosystems.

3. Estimate the total value of baseline I&E losses by multiplying the WTP values for fish and shellfish services of restored habitat by the number of acres of each habitat type needed to offset I&E losses.

4. Estimate the total benefits of the final section 316(b) rule, in terms of the value of decreased I&E losses, by multiplying the WTP values for fish and shellfish services of restored habitat by the number of acres of each habitat type needed to offset decreased I&E losses.

The rest of this chapter outlines the methodology.

A15-1 ESTIMATING THE AMOUNT OF HABITAT NEEDED TO OFFSET LOSSES FOR SPECIFIC SPECIES

The first step in the analysis involves calculating the area of habitat needed to offset I&E losses for the subset of species for which restoration of these habitats was identified by local experts as the preferred restoration alternative, and for which production information is available (i.e., the habitat that will produce the equivalent quantity of fish impinged and entrained at CWIS). Habitats that support fish and shellfish include seagrasses, tidal wetlands, coral reefs, and estuarine soft-bottom sediments. The analysis may also consider man-made habitat enhancements, such as artificial reefs or fish passageways. The most suitable habitat restoration option was selected for each affected species. For a detailed description of this method, see Chapter F5 of the Brayton Point Case Study report presented at the time of proposal in the final section 316(b) Phase II Case Study Document (DCN 4-0003; U.S. EPA, 2002a).

Using a typical restoration scaling rule, the estimates of the acres of required SAV and wetlands restoration reflect the acreage needed for the species requiring the maximum quantity of habitat restoration to offset its I&E losses. For any given species, the number of acres of restored habitat needed to offset I&E losses is determined by dividing the species average annual age 1 equivalent I&E loss by its estimated abundance per acre in that habitat.[1]

While the acreage needed for the species requiring the maximum amount of habitat may overstate the acreage necessary for other species, local experts using abundance data on additional species that were identified as benefitting from tidal wetland restoration were unavailable to determine the acreage necessary to replace these other species. Because of this uncertainty in developing precise acreage estimates involving the large variation in species and required habitats on a national scale, EPA elected not to present benefits based on this method in the final rule analysis.[2]

A15-2 DEVELOPMENT OF WTP VALUES FOR FISH PRODUCTION SERVICES OF HABITAT

EPA's local case study analyses focused on wetlands and eelgrass habitats, as these are the habitats for which data were available. Therefore, the following sections provide examples of the available data and how it would be used in the application of this approach.

EPA points out that it has not attempted to transfer values per acre of habitat to directly value specific species and numbers of fish affected by I&E. Rather, the approach that EPA used is to 1) estimate the number of acres of habitat required to produced fish equivalent to those lost due to I&E; and 2) evaluate citizens' WTP for this *habitat*, not for the fish produced by the habitat. This method is consistent with the preferred methods that NOAA suggests be used for natural resource damage assessment (NRDA) under the Oil Pollution Act (OPA). NOAA's NRDA regulations focus on restoration of injured resources, rather than monetary compensation for damages. In the case of lost interim values pending restoration, additional habitat may be provided, in lieu of money compensation. NOAA refers to this as "compensatory restoration" (DARP, 1997, pp. 2-7 - 2-8).

EPA calculated the amount of "service-to-service" compensatory restoration — in the form of restored acres of wetlands and eelgrass — required to offset losses, and then evaluated WTP for restoring these acres. Whereas NOAA would recommend actually restoring such acreage to provide compensation to the public, EPA is not suggesting that the restoration actually be carried out (thus requiring industry to pay the *costs* of restoring these acres). EPA is instead looking at the *benefits*, in the form of fish, that would be provided by these restored acres.

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[1] Note that specific restoration locations were not identified for this analysis. As noted above, the restoration concept is used for developing useful information regarding people's WTP for fish production services of restored habitat.

[2] While this is the primary source of uncertainty, additional sources of uncertainty are discussed in section A15-4.

For each habitat type, EPA used available fish sampling data for the habitats of interest to determine the number of acres required to offset I&E losses. The sources of these data are noted in the individual case study chapters. To estimate public values for fish and shellfish habitat for the North Atlantic and Mid-Atlantic case studies, EPA considered using values from a study of public values for wetlands and eelgrass in the Peconic Estuary, located on the East End of Long Island, New York (Johnston et al., 2001a, 2001b; Opaluch et al., 1995, 1998; Mazzotta, 1996). To estimate public values for habitat for the Great Lakes region, EPA considered using values from a study of the Maumee River Basin, located in the northwestern corner of Ohio near Lake Erie (de Zoysa, 1995). For all three case studies, EPA used additional information from a stated preference study from Narragansett Bay, Rhode Island (Johnston et al., 2002) to estimate the portion of habitat value attributable to fish habitat services of wetlands. These studies are described in detail in the following sections.

A15-2.1 Description of the Peconic Estuary Study

EPA selected the Peconic Estuary study for two reasons:

1. The study elicited the public's total WTP values for coastal wetlands and eelgrass, using the contingent choice method. Wetland and eelgrass habitats are essential for supporting fish and shellfish species. These habitats were frequently identified by an expert panel as the preferred habitats for restoration in order to increase production of species with I&E losses. The survey described eelgrass to respondents as "fish and shellfish habitat" but did not specifically describe wetlands' services.

2. Both eelgrass and wetlands located in the Peconic Estuary support aquatic species that are found in the North and Mid-Atlantic regions and that are likely to be affected by I&E (e.g., bay anchovy, Atlantic silverside, scup, summer flounder, winter flounder, windowpane flounder, weakfish, tautog, bay scallops, and hard clams).[3,4] The Peconic Estuary study thus provides values for eelgrass and wetlands that may be representative of habitat needed to produce many of the species affected by I&E in the North Atlantic and Mid-Atlantic regions.

The Peconic study used an original contingent choice survey to estimate the relative preferences of residents and second homeowners in the study area for preserving and restoring key natural and environmental resources.[5] The study area is the East End of Long Island, New York, which includes the five towns surrounding the Peconic Estuary: Southold, Riverhead, Southampton, East Hampton, and Shelter Island. The primary goal of the survey was to learn about the public's preferences, priorities, and values for the environmental and natural resources of the Peconic Estuary that might be affected by preservation and restoration actions.

The contingent choice survey format asks respondents to choose between bundles of public commodities, which differ across their physical, environmental, aesthetic, and/or monetary dimensions. For example, respondents might compare two environmental policy proposals, each with a different impact on coastal resources and a different monetary cost. By analyzing the choices that respondents make among a variety of potential policies (i.e., their preferences), it is possible to estimate respondents' relative values for environmental commodities (or policy results), and their willingness to trade off elements of policy packages (Cameron, 1988; Hanemann, 1984).

The extensive process to develop the survey over a six-month period, from February to August 1995, included individual interviews, focus groups, and pretests of preliminary versions of the survey. Based on concerns expressed by participants in focus groups, and natural resources identified as important by the Technical Advisory Committee, the survey addressed five natural resources: (1) farmland, (2) undeveloped land, (3) wetlands, (4) shell fishing areas, and (5) eelgrass. The survey objective was to determine respondents' values for improvements in natural resources above a specified baseline level. The baseline is that level that would exist in the year 2020 if no action occurred to preserve or restore the resource. The baseline

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[3] Further detail on fish abundance in SAV in the North Atlantic and Mid-Atlantic regions can be found in Wyda et al. (2002), "The response of fishes to submerged aquatic vegetation complexity in two ecoregions of the Mid-Atlantic Bight: Buzzards Bay and Chesapeake Bay."

[4] See Peconic Estuary Program CCMP, Chapter 4, www.savethepeconicbays.org/ccmp (Peconic Estuary Program, 2001) for details.

[5] The values presented here understate total benefits because they do not include values for visitors to the Peconic region, values for other individuals outside the region who may value the resources of this region, producer surplus values to commercial users of the resources, and values to users of the resources in other regions who may benefit from species that are migratory.

was determined in consultation with the Technical Advisory Committee, based on historical declines and the judgment of experts, for each resource.

In the contingent choice questions, each resource was included at three different levels: the projected level for 2020 (the "no new action," or baseline, scenario), and two levels associated with hypothetical programs that would preserve or restore the resource. Eelgrass was presented at the current level of 9,000 acres; the baseline or "no action" level of 8,000 acres; and a high level, with restoration, of 11,000 acres. Wetlands were presented at the current level of 16,000 acres; the baseline or "no action" level of 12,000 acres; and a high level, with restoration, of 17,500 acres.

Each survey question asked respondents to compare the "No New Action" baseline levels of two of the resources to two hypothetical programs to protect or restore these resources.[6] Respondents were asked to select their preferred option, given the program costs. Figure A15-1 shows an example question. A total of 60 different questions were developed, using Addelman's fractional factorial design, to produce orthogonal arrays of attributes (Addelman 1962a, 1962b).[7] Each booklet contained five contingent choice questions.

Respondents completed a total of 968 surveys and answered 4,307 contingent choice questions. The distribution of surveys in various locations within the study area ensured response collection from a wide cross-section of the public.[8] The data were analyzed using a conditional logit model. Based on standard economic consumer theory, the analysis assumed that respondents choose the option that maximizes utility received from attributes of the option, subject to their budget constraint. In this study, the options are described in terms of a set of natural resources and the cost of the option. Based on the model coefficients, relative values for the different resources and dollar values for protecting an additional acre of each resource can be calculated as described by Hanemann (1984). The estimated values are marginal values, or WTP, for an additional acre of each resource.

The study found that the survey sample population was better educated and had higher incomes than the area population. Thus, the estimated values were adjusted to be representative of the general population of the East End in terms of education and income. These adjustments were made to the model coefficients prior to estimating welfare values. The study used separate adjustments for those who live in the area year-round (about 2/3 of the sample) and those who are seasonal area residents.

The original study presented estimates of several statistical models. For the analysis presented below, EPA used the most conservative model, in terms of estimated values, to calculate the per household WTP values per acre of eelgrass and wetlands. This model includes alternative-specific constants, which capture differences between taking action and choosing the "no action" alternative, as well as any unexplained differences between programs A and B.

Table A15-1 presents the Peconic model valuation results for eelgrass and wetlands. To separate users' values from non-users' values for purposes of this analysis, EPA re-estimated the Peconic model with separate coefficients for users and non-users of fishery resources. The Agency defined users as those who stated that they either fish or shellfish. These individuals have both non-use and indirect use values from the fish habitat services of eelgrass and wetlands. EPA estimated non-use values for those who do not fish or shellfish.[9] For eelgrass, the value for non-users is 77.7 percent of the total value for users, and 82.4 percent of the total value estimated for both users and non-users; while for wetlands, the value for non-users is 94.4 percent of the total value for users, and 95.8 percent of the total value for both users and non-users.

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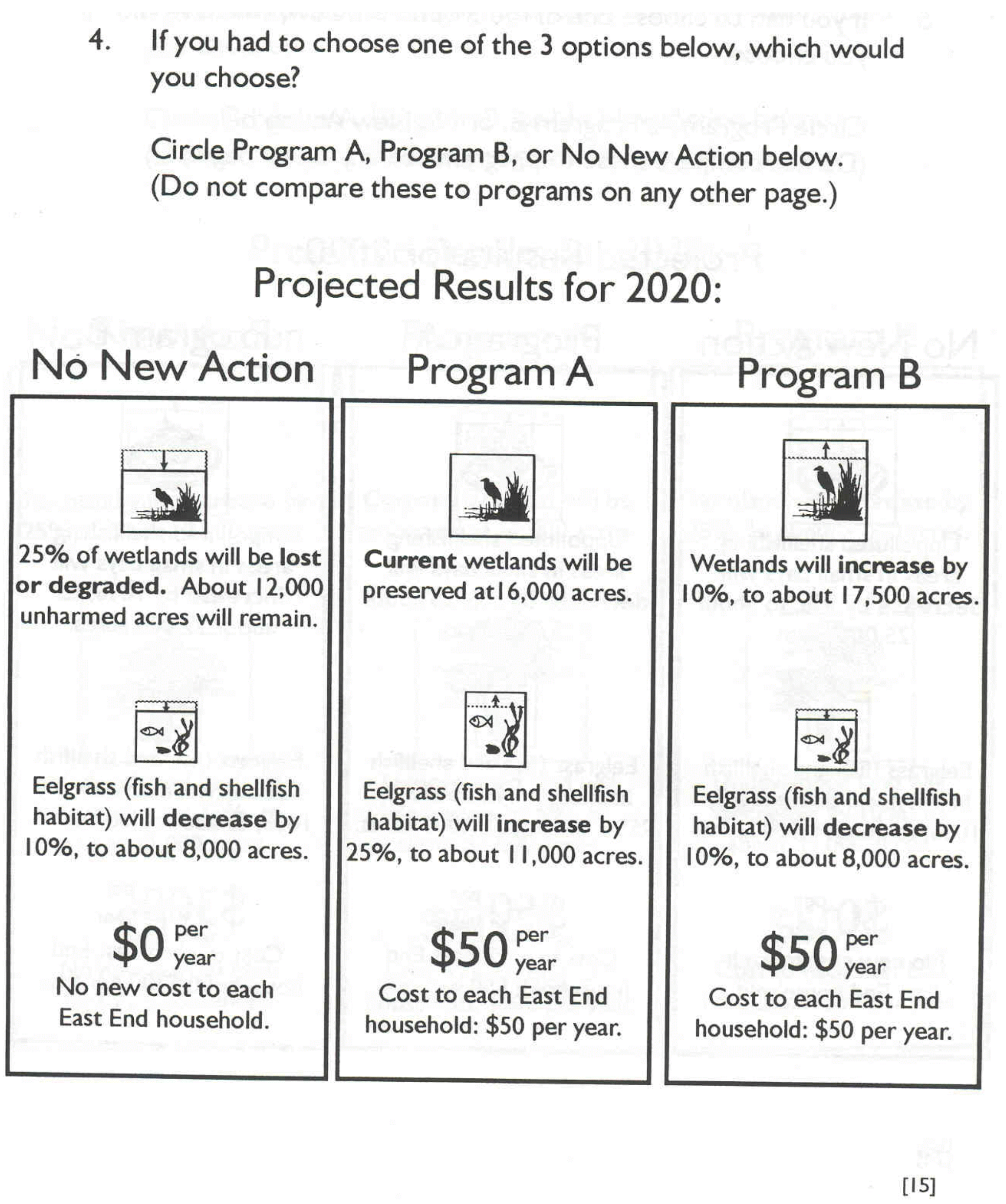
[6] In order to avoid choice questions that are excessively complex, each question included only two of the five resources, plus the cost to each household. The survey instructions led respondents to assume that the three resources not included in each question would not be affected by the program being evaluated, and would thus be at the baseline levels.

[7] The orthogonal design selected did not allow for estimation of interactions among the resources. Such a design would have required a much larger sample size, which was not possible given the project budget limitations.

[8] In order to obtain a wide cross-section of the public, surveys were conducted at over 37 locations around the East End. Four hundred fifty-one surveys were collected at various grocery stores and shopping areas; 248 at public libraries and post offices; 82 surveys at beaches; and 187 at other locations, including the Department of Motor Vehicles, the ferry from New London to Long Island, an aquarium, and a vineyard.

[9] Note that this is not strictly true for wetlands, because other services exist that allow for use values such as birdwatching. The value of wetlands is adjusted to reflect fish production services only in the section on wetlands in section A15-2.4.

Figure A15-1: Example Survey Question from the Peconic Survey



4. If you had to choose one of the 3 options below, which would you choose?

Circle Program A, Program B, or No New Action below.
(Do not compare these to programs on any other page.)

Projected Results for 2020:

No New Action	Program A	Program B
25% of wetlands will be **lost or degraded.** About 12,000 unharmed acres will remain.	**Current** wetlands will be preserved at 16,000 acres.	Wetlands will **increase** by 10%, to about 17,500 acres.
Eelgrass (fish and shellfish habitat) will **decrease** by 10%, to about 8,000 acres.	Eelgrass (fish and shellfish habitat) will **increase** by 25%, to about 11,000 acres.	Eelgrass (fish and shellfish habitat) will **decrease** by 10%, to about 8,000 acres.
$0 per year No new cost to each East End household.	$50 per year Cost to each East End household: $50 per year.	$50 per year Cost to each East End household: $50 per year.

[15]

Table A15-1: Estimated WTP Values from the Peconic Study (2002$)[10]

	Wetlands[a]		Eelgrass (SAV)	
	$/HH/Acre/Year[b]	Non-Use Value %	$/HH/Acre/Year[b]	Non-Use Value %
All residents	$0.056	95.80%	$0.063	82.40%
Users	$0.057	94.40%	$0.067	77.70%
Non-users[c]	$0.054	100.0%	$0.052	100.0%

[a] Note that wetlands values presented here are WTP for all wetland services, not just fish habitat services. The adjustment for fish habitat values appears below.

[b] Values shown are WTP per household per *additional* (i.e., marginal) acre per year.

[c] Non-users are defined as respondents who neither fish nor shellfish.

The Peconic survey described eelgrass specifically as fish and shellfish habitat. EPA is not aware of other direct uses of eelgrass. Based on focus groups during survey development and pretesting, the Peconic authors concluded that participants were aware of eelgrass and its importance for fish and shellfish production. Thus, EPA assigned all of the estimated WTP for SAV restoration to fish and shellfish production services. Based on these same focus groups and pretests, the authors also concluded that individuals were aware of and valued a number of functions of wetlands, including fish and other wildlife habitat, storm buffering, and aesthetics. Because coastal wetlands provide several services (e.g., habitat, water quality, storm buffering, and aesthetics), EPA assigned only a portion of the estimated WTP for wetlands restoration to fish habitat services.

The survey data available from the Peconic study, however, provide no direct means to estimate the share of total wetland value from fish habitat services alone. Wetland values presented in Table A15-1 reflect all ecological services provided by the wetlands, not just fish habitat services. EPA therefore used a stated preference study from Narragansett Bay, Rhode Island, to adjust wetland values. This study was designed to assess tradeoffs among different services of restored salt water wetlands (Johnston et al., 2002). The results from this study allow estimation of the share of salt water wetland restoration values associated with various services, including fish habitat services. EPA estimated the value of salt water wetlands associated with fish habitat services alone by multiplying this share by the total values in Table A15-1.

A15-2.2 Description of the Maumee River Basin Study

EPA selected the Maumee River Basin study for two reasons:

1. Wetlands located in the Maumee River Basin support aquatic species that are found in Lake Erie and that are likely to be affected by I&E (e.g., yellow perch, gizzard shad, various species of shiner, white bass, carp, sunfish, and fresh water drum). The Maumee River Basin study thus provides values for wetlands that may be representative of habitat needed to produce many of the species affected by I&E in the Great Lakes.

2. The study solicited the public's total WTP for wetlands, a necessary input for EPA's habitat-based analysis.

The Maumee River Basin study used an original contingent valuation mail survey to estimate WTP for residents in the study area for protecting groundwater quality, improving surface water quality, and protecting and restoring wetlands.[11] The study area included 15 counties in northwestern Ohio in the Maumee River Basin area. Residents from those counties were divided into two groups: residents in zip codes with primarily rural populations, and residents in zip codes with primarily urban populations. The study also included residents from Columbus and Cleveland who did not live in the Maumee River Basin but who might visit. The primary goal of the survey was to analyze the welfare effects of different farm management strategies in the Maumee River Basin area.

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[10] EPA made dollar value adjustments using the Consumer Price Index for all urban consumers for the first half of 2002.

[11] The values presented here understate total benefits because they do not include values for all visitors to the Maumee River Basin region, values for all other individuals outside of the region who may value the resources of this region, producer surplus values to commercial users of the resources, and values to users of the resources in other regions who may benefit from species that are migratory.

The study used the contingent valuation method. There were seven versions of the survey questionnaire, each of which described a different resource conservation program involving groundwater, surface water, wetlands, or some combination thereof. The wetlands program description indicated that the proposed program would restore and protect 3,000 acres of wetlands from a baseline of 10,000 existing acres that are declining. The program description also pointed out that those wetlands provide habitat for water fowl, other birds, and endangered species; provide nursery habitat for fish; and play a role in water purification. Respondents were then presented with a referendum style question that asked if they would be willing to pay a certain price for the program. This question was followed by an open-ended solicitation of maximum WTP for the program. WTP amounts were for a one-time payment.

Out of 1,050 questionnaires mailed to randomly selected households in the study area, 118 were undeliverable, and 476 were returned. Of those returned, 10 were judged incomplete, making the overall response rate 50 percent. The data were analyzed using a probit model based on a log-normal distribution for responses to the WTP question. The model estimates median and lower bound mean WTP for each of the programs.

Although the study includes socioeconomic variables in the model, it does not attempt to account for differences between the survey respondents and the target population. Respondents had a mean household income of $49,537 (2002$); 47 percent were male; and 32 percent had a college degree.

The original study presented WTP value estimates under several different sets of assumptions. For the analysis presented below, EPA used the most conservative estimate to calculate the per household WTP values per acre of wetlands. This model assumed that protest responses meant a no vote, and estimated WTP as a lower bound mean. Also, to be conservative, EPA included WTP values only from the residents of the Maumee River Basin and excluded WTP values from Columbus and Cleveland respondents.

Table A15-2 presents the valuation results for wetlands for rural and urban Maumee respondents. Since the study provided total household WTP for an increase of 3,000 acres of wetlands, EPA divided WTP per household by 3,000 to calculate WTP per marginal acre of wetland per household.

Table A15-2: Estimated WTP Values for Wetlands from the Maumee River Basin Study (2002$)[12, a]

Population	$/HH/Acre/Year[b]
Rural Maumee residents	$0.0254
Urban Maumee residents	$0.0248
All Maumee residents[c]	$0.0249

[a] Note that wetlands values presented here are WTP for all wetland services, not just fish habitat services. The adjustment for fish habitat values appears below.

[b] Values shown are WTP per household per *additional* (i.e, marginal) acre per year.

[c] EPA calculated the value for all Maumee residents by taking a population weighted average of the rural and urban WTP estimates.

The Maumee River Basin survey described wetlands as providing a number of ecological services. Because the survey data from the Maumee River Basin do not provide the information needed to estimate the share of total wetland value from fish habitat services alone, EPA used a stated preference study from Narragansett Bay, Rhode Island, to adjust wetland values. This study was designed to assess tradeoffs among different services of restored salt water wetlands (Johnston et al., 2002). The results from this study allow estimation of the share of salt water wetland restoration values associated with various services, including fish habitat services. Although the Maumee River Basin study evaluated fresh water wetlands, the services provided by both types of wetlands are similar (fish nursery habitat, water purification, bird habitat). Because of these similarities, EPA believes that the Narragansett Bay study can be applied to the values from the Maumee River Basin. EPA estimated the value of salt water wetlands associated with fish habitat services alone by multiplying this share by the total values in Table A15-2.

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[12] EPA made dollar value adjustments using the Consumer Price Index for all urban consumers.

A15-2.3 Description of the Narragansett Bay Wetland Restoration Study

The survey instrument, *Rhode Island Salt Marsh Restoration: 2001 Survey of Rhode Island Residents*, was designed to assess tradeoffs among attributes of salt marsh restoration plans. Survey development required more than 16 months and involved extensive background research, interviews with experts in salt marsh ecology and restoration, and over 16 focus groups with more than 100 Rhode Island residents. Numerous pretests, including verbal protocol analysis (Schkade and Payne, 1994), ensured that the survey language and format would be easily understood by respondents, and that respondents would have a common understanding of survey scenarios (cf. Johnston et al., 1995).

Focus groups and pretests led to an in-person survey approach that combined a printed survey booklet with an eight-minute introductory video. This video introduced respondents to information about salt marshes and salt marsh restoration; reminded respondents of tradeoffs involved in salt marsh restoration; reminded respondents of their budget constraint and the implications of choosing to direct funds to restoration programs; emphasized the importance of respondents' choices; and provided basic survey instructions.

Johnston et al. (2002) chose attributes distinguishing restoration plans based on background research, expert interviews, and focus groups. The authors tailored these attributes to reflect primary salt marsh services in the northeast U.S. that would be influenced by restoration activities, and characterized each wetland by the size of the marsh, together with effects of restoration, on (1) habitat for birds, (2) habitat for fish, (3) habitat for shellfish, (4) potential to control mosquito nuisance, (5) recreational access, and (6) household cost.[13] Based on the results of focus groups and expert interviews, habitat and mosquito control services were presented from a standardized, statewide perspective. For example, improvements to fish habitat were characterized as "ecological improvements to RI fish populations…[resulting from a particular restoration project]…as judged by wetlands experts, compared to all other potential salt marsh restoration projects in Rhode Island."

Following the general approach of Johnston et al. (1999), the conjoint (or multi-attribute choice) survey presented respondents with four sets of discrete choices, each involving two alternative, multi-attribute restoration plans. The authors used fractional factorial design to construct a range of survey questions with an orthogonal array of attribute levels, resulting in 80 contingent choice questions divided among 20 unique booklets. Attributes distinguishing plans were selected based on background research, expert interviews, and focus groups. All attributes were free to vary over their full range for both restoration plans presented in each question, with no imposed ordering of attribute levels between the two plans. Based on these attributes, respondents chose one of the two plans, or chose "Neither Plan."

The survey was conducted from September through December 2001. Respondents were intercepted in person at Rhode Island Department of Motor Vehicle offices, public libraries, and other survey sites. Interviewers did not tell respondents that the survey concerned salt marsh restoration. Rather, interviewers asked respondents to participate in an important survey regarding "environmental issues in Rhode Island," to reduce the potential for topic-related nonresponse. In total, interviewers collected 661 completed surveys, providing complete and usable responses to 2,341 individual contingent choice questions (89 percent of the potential 2,644).

Table A15-3 presents variables incorporated in the analysis of salt marsh restoration choices. These variables include (1) a dummy variable identifying the "neither" option, (2) quadratic interactions between this dummy and certain demographic characteristics, and (3) variables for the restored salt marsh attributes. Mean values for salt marsh attributes (Table A15-3) indicate the mean values of these attributes over all completed surveys included in the analysis. The last column in the table calculates these mean values with "neither plan" data rows excluded. (As noted above, each wetland restoration choice included the option of choosing neither plan. In the multinomial logit data, these options are presented as a "plan" with zeros for all wetland attributes.)

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[13] Additional, non-habitat services that may be provided by salt water wetlands include, among others, nutrient transformation, storm buffering, and coastal erosion control. Interviews with experts on salt water wetland functions in New England (and Rhode Island in particular) indicated, however, that wetland restoration would provide negligible impacts on these non-habitat functions in the majority of cases. They based this assessment on the small size of most New England coastal wetlands, and on the fact that restoration may not always increase substantially the ability of a wetland to provide such functions as storm buffering or erosion control. Based on this advice, the survey focused mainly on wetland habitat functions.

Table A15-3: Definitions and Summary Statistics for Model Variables for Narragansett Bay Wetland Restoration Study

Variable Name	Description	Whole Sample Mean (Std. Dev.)	Mean, Excluding "Neither Plan" Scenarios[a]
Neither	Neither=1 identifies "neither plan" options.	0.3333 (0.4714)	0.0000
Environ	Dummy variable identifying respondents with membership in environmental organizations.	0.1900 (0.3923)	0.1900
Taxgrp	Dummy variable identifying respondents with membership in taxpayer associations.	0.0233 (0.1510)	0.0233
Loincome	Dummy variable identifying respondents with household income less than $35,000/year.	0.2450 (0.4301)	0.2450
Hiedu	Dummy variable identifying respondents with greater than a four-year college degree.	0.1817 (0.3856)	0.1817
Birds	Ecological improvement to statewide bird populations resulting from specified salt marsh restoration plan, compared to all other potential salt marsh restoration plans in Rhode Island (0-10 scale).	2.7608 (2.6072)	4.1413
Fish	Ecological improvement to statewide fish populations resulting from specified salt marsh restoration plan, compared to all other potential salt marsh restoration plans in Rhode Island (0-10 scale).	2.9075 (2.6530)	4.3613
Shellfish	Ecological improvement to statewide shellfish populations resulting from specified salt marsh restoration plan, compared to all other potential salt marsh restoration plans in Rhode Island (0-10 scale).	2.9070 (2.6518)	4.3619
Mosquito	Increased ability to control statewide mosquito nuisance resulting from specified salt marsh restoration plan, compared to all other potential salt marsh restoration plans in Rhode Island (0-10 scale).	2.9077 (2.6506)	4.3617
Size	Size of restored salt marsh (minimum 3 acres; maximum 12 acres).	4.8890 (4.3965)	7.3335
Pro-access	Dummy variable indicating that respondent feels that access to salt marshes should be "somewhat limited" or "unlimited."	0.8367 (0.3697)	0.8367
Con-access	Dummy variable indicating that respondent feels that access to salt marshes should be "severely limited" or "prohibited."	0.2266 (0.4187)	0.1633
Platform	Dummy variable indicating that restoration provides "viewing platforms" but no "trails."	0.2215 (0.4153)	0.3400
Both	Dummy variable indicating that restoration provides both "viewing platforms" and "trails."	0.2215 (0.4153)	0.3323
Cost	Annual cost of restoration plan in increased taxes (minimum $0; maximum $200).	63.1694 (70.7816)	94.7542

[a] Each wetland restoration choice included the option of choosing neither plan. In the multinomial logit data, this option is presented as a "plan" with zeros for all wetland attributes. The last column in the table calculates means with the "neither plan" zeros excluded.

The signs of parameter estimates correspond with prior expectations derived from focus groups, where prior expectations exist (Table A15-4). Respondents favor plans that restore larger salt marshes; improve bird, fish, and shellfish habitat; control mosquitoes; provide public access; and result in lower costs to the household. Comparing preferences for habitat improvements and mosquito control (all measured on a 10-point scale), respondents placed the greatest weight on mosquito control, followed by habitat improvements for shellfish, fish, and birds, respectively. The likelihood of rejecting restoration outright (i.e., choosing neither plan) was smaller for members of environmental organizations, and larger for members of taxpayers organizations, lower income individuals, and more highly educated individuals (Johnston et al., 2002). Changes in education and income do not influence the marginal utility of fish and shellfish habitat, or that of other wetland attributes.

Table A15-4: Conditional Logit Results for Narragansett Bay Wetland Restoration Study

	Parameter Estimate	Std. Error	z	P>|z|
Neither	1.1568	0.1934	5.98	0.0001
Neither x Environ	-1.1820	0.2232	-5.30	0.0001
Neither x Tax	0.8676	0.3651	2.38	0.0170
Neither x Loincome	0.3104	0.1437	2.16	0.0310
Neither x Hiedu	0.4147	0.1686	2.46	0.0140
Birds	0.1191	0.0153	7.78	0.0001
Fish	**0.1465**	**0.0157**	**9.36**	**0.0001**
Shellfish	**0.1587**	**0.0162**	**9.78**	**0.0001**
Mosquito	0.1611	0.0162	9.95	0.0001
Size	0.0510	0.0098	5.22	0.0001
Pro-access x Platform	0.1678	0.0826	2.03	0.0420
Pro-access x Both	0.4310	0.0844	5.11	0.0001
Cost	-0.0072	0.0005	-14.23	0.0001
-2LnL χ^2	1157.56	Prob>χ^2	0.0001	

A15-2.4 Estimating the Portion of Wetlands Value Associated with Fish Habitat

Results of the conjoint analysis (i.e., the public survey results) presented by Johnston et al. (2002) allow policy makers to rank restoration projects based on their estimated influence on residents' welfare. These results also allow assessment of residents' willingness to trade off elements of wetland restoration plans, or WTP for particular wetland attributes. Finally, for any specified restoration plan, provided that incremental gains or losses in wetland services are known, it allows the calculation of the *proportion* of the total gain in social value attributable to a particular service (e.g., fish habitat).

To estimate the proportion of value associated with fish habitat, in a representative, conservative scenario, EPA began with the average wetland restoration scenario considered by the Rhode Island survey sample. The mean values of wetland attributes presented to survey respondents provide the most representative set of results from which value proportions may be estimated, and forecast the value proportions that would result from an average survey respondent confronted with an average wetland restoration scenario, as characterized by the Rhode Island Salt Marsh Restoration Survey data. Excluding all "Neither Plan" scenarios, which offered zero restoration, Table A15-3 summarizes the mean values for services considered by the Rhode Island sample.

Although mean values are used for most attributes (i.e., wetland attributes or services considered by survey respondents in choice scenarios), changes in certain attributes are set to zero to correspond more closely with the policy scenario and with the Peconic study (because the purpose of this analysis is to assess the proportion of the Peconic wetland values that may reasonably be attributed to fish habitat services). For example, because the Peconic study survey did not specify or discuss the provision of viewing platforms or trails at preserved wetlands, EPA assumed that survey respondents to the Peconic study did not consider such unusual provisions when making survey choices. Accordingly, in calculating value proportions in this analysis using the Rhode Island data, EPA assumed that viewing platforms and trails are not provided.

EPA also assumed that any wetland created or restored to provide fish habitat will likely not provide a great degree of additional mosquito control, because a large proportion of existing salt marshes have already been modified to minimize mosquito production.[14] For this reason, modern marsh restoration typically does not provide a significant increase in mosquito control. Rather, it often replaces older, more detrimental (to marsh function and habitat) forms of mosquito control

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[14] The mosquito control variable was included in the survey in response to the strong concern of Rhode Island residents over the impact of restoration on mosquitoes and related illnesses for which mosquitoes are the primary vector. Wetlands experts indicated, however, that salt marsh restoration had limited impact on mosquito populations in most cases.

with Open Marsh Water Management (OMWM), in which open water and natural fish predation is used to control mosquito nuisance (Kennish, 2002). OMWM has not been an "unqualified success" at eliminating the mosquito nuisance (New York Conservationist, 1997). Accordingly, for many salt marshes, the positive net effect of restoration on mosquito nuisance, if any, is often minimal. To generate the most conservative estimates, however, and in recognition of the fact that some salt marsh restoration projects may provide significant mosquito control, EPA also estimated value proportions assuming that significant additional mosquito control is provided. For all other wetland attributes included in the Rhode Island survey, EPA used the mean values shown in the final column of Table A15-3.

Estimation of value proportions is based on the estimated utility function $v(\cdot)$, which specifies the utility provided by a wetland restoration plan as a function of the attributes or services provided by that plan (Johnston et al., 2002). That is, following the standard random utility model of Hanemann (1984), the underlying model specifies respondents' choices using the conditional logit specification, in which the probability (P_i) of choosing any wetland restoration plan *i* (plan A, plan B, or neither plan) over the two remaining options (*j* or *k*) is given by:

$$P_i = \frac{\exp[v_i(\cdot)]}{\exp[v_i(\cdot)] + \exp[v_j(\cdot)] + \exp[v_k(\cdot)]} \qquad \text{(A15-1)}$$

where $v(\cdot)$ represents the relative benefits or utility resulting from each restoration option, including the "neither plan" option. The function $v(\cdot)$ is typically estimated as a simple function of program attributes (in this case wetland restoration); in practice linear, functional forms are often used (Johnston et al., 2002).

From the assumptions and model noted above, the attribute definitions given in Table A15-3, and the model results of Table A15-4, the estimated utility function used to calculate value proportions is specified as:

$$v(\cdot) = 0.1191(birds) + 0.1465(fish) + 0.1587(shellfish) + 0.1611(mosquito) + 0.0510(size) \qquad \text{(A15-2)}$$

If mosquito control is *not* provided, then *mosquito*=0. Given this linear specification, the proportion of wetland restoration value provided by the gain in fish habitat services is given by:

$$\frac{v(\cdot)_{fish} - v(\cdot)_{fish\,=\,0}}{v(\cdot)_{fish}} \qquad \text{(A15-3)}$$

where $v(\cdot)_{fish}$ represents the value of $v(\cdot)$ with the gain in fish habitat services set to its mean value (as described above), and $v(\cdot)_{fish=0}$ represents the value of the function with the gain in fish habitat services set to zero.

Table A15-5 shows the resulting value proportions, in which EPA calculated the proportion of wetland restoration value associated with different wetland services based on mean values of wetland attributes presented to survey respondents, as discussed above. Analogous methods were used to assess value proportions associated with shellfish and other habitat services; Table A15-5 shows these results for comparison. The table also illustrates the results of a sensitivity analysis in which EPA calculated analogous value proportions for wetland habitat services, but allowed wetland size to vary. Wetland size was allowed to vary from its minimum value in the Rhode Island survey data (3 acres) to its maximum value (12 acres), while holding habitat service changes constant. EPA chose these size values to be representative of unrestored salt water wetlands currently existing in Narragansett Bay, which are typically quite small (i.e., less than five acres). The three estimates of acreage are therefore likely closer to the "average" Rhode Island wetland than estimates based on larger acreages. [In actual wetlands, changes in restored acres are typically correlated with larger gains in habitat services (Johnston et al., 2002). To illustrate even more conservative estimates, however, Table A15-5 contains cases in which restored wetland size increases from the mean, without any resultant increase in habitat services.]

Table A15-5: Proportions of Restored Wetland Value Associated with Various Service Categories[a]

Restoration Scenario	Percentage of Value Associated with Service				
	Fish Habitat	Bird Habitat	Shellfish Habitat	Mosquito Control	Other[b]
1a: No additional mosquito control; mean values for all other attributes	**0.2906**	0.2244	0.3149	0.0000	0.1701
1b: No additional mosquito control; mean values for habitat gains; size=3 acres	**0.3231**	0.2494	0.3501	0.0000	0.0774
1c: No additional mosquito control; mean values for habitat gains; size=12 acres	**0.2622**	0.2024	0.2841	0.0000	0.2512
2a: Mosquito control at mean value; mean values for all other attributes	**0.2202**	0.1700	0.2386	0.2422	0.1289
2b: Mosquito control at mean value; mean values for habitat gains; size=3 acres	**0.2384**	0.1840	0.2583	0.2622	0.0571
2c: Mosquito control at mean value; mean values for habitat gains; size=12 acres	**0.2035**	0.1571	0.2205	0.2238	0.1950
3a: Mean over all scenarios	**0.2564**	0.1979	0.2778	0.1214	0.1466

[a] Results assume that restoration does not provide viewing platforms or hiking trails.
[b] Other services may include, among others, nutrient transformation, storm buffering, and coastal erosion control.

a. Results: Proportion of wetland restoration value attributable to fish habitat services

As shown by Table A15-5, the proportion of value associated with fish habitat ranges from 0.2035 to 0.3231, with a mean value over all scenarios of 0.2564. Scenario 1a is perhaps the most representative scenario for estimating value proportions for two reasons: (1) restored wetlands are not expected to provide additional mosquito control, and (2) other wetland attributes are set to their mean values. Its results are somewhat higher than those of scenario 3a, which represents the mean value over all scenarios presented. EPA therefore, to be conservative, used the proportion calculated in scenario 3a (0.2564) as an estimate of the proportion of total wetland restoration value attributable to gains in fish habitat services, given representative, mean values for other wetland services.

Although these numbers are not directly comparable to other results found in the literature, they appear to be reasonable and conservative compared to similar proportions generated for freshwater habitats. For example, Schulze et al. (1995) estimate that between 32.98 percent and 33.44 percent of WTP for resource cleanup in the Clark Fork River Basin was associated with “aquatic resources and riparian habitat” (p. 5-13).

EPA also considered directly the parametric results of Table A15-4 for further support of the soundness of the proposed value proportions. Estimates presented in Table A15-4 indicate that the parametric weights are similar among the dominant wetland services in Narragansett Bay (i.e., bird habitat services, fish habitat services, shellfish habitat services, and mosquito control). In other words, the parameter estimates are very similar among these four variables. This correspondence suggests that restoration providing similar scale improvements for each of these services should produce a roughly equivalent increment to utility. Given the four habitat services considered in the survey (including mosquito control), each service provides roughly one-fourth (or 25 percent) of the total marginal utility associated with the combination of habitat improvements and mosquito control. For wetlands that do not provide substantial access provisions (e.g., boardwalks) and that are of moderate or small size, it would be highly improbable for the proportion of value associated with fish habitat to fall significantly below the 25.64 percent approximation estimated here.

A15-3 ESTIMATING THE VALUE OF HABITAT NEEDED TO OFFSET I&E LOSSES

A15-3.1 Determining the Affected Population

Evaluating the total value per acre of wetlands and SAV for the coastal population of each region requires a definition of the geographical extent of the affected population. The Peconic study defined the affected population as the total number of households in the towns bordering the Peconic Estuary. Similarly, the affected population can be defined as households residing in the counties that abut the waterbodies affected by CWIS. These households are likely to value gains of fish in the affected water body, due to their close proximity to the affected resource.

Households in counties that do not directly abut affected water bodies will also likely value the water body's resources. Analysis of data from the Rhode Island Salt Marsh Restoration Survey (Johnston et al., 2002) reveals that values ascribed to even relatively small-scale salt marsh restoration actions (i.e., 3-12 acres) were stated by respondents from various parts of the state. Thus, it is reasonable to assume in the context of the final section 316(b) analysis that residents within a similar distance from the affected water body as residents in the Johnston et al. (2002) study would have positive values for improving fish habitat. The Agency calculated the average distance from the Narragansett Bay's study locations to the farthest edges of Rhode Island, which totaled 32.43 miles.

EPA also reviewed additional studies to identify the effect of distance on WTP for public goods with large non-use values.

1. A study by Pate and Loomis (1997) found that respondents outside the political jurisdiction in which a study site is located were also willing to ascribe stated preference values to the amenity being studied. The study was designed to determine the effect of distance on WTP for public goods with large non-use values. Specifically, the study evaluated environmental programs designed to improve wetlands habitat and wildlife in the San Joaquin Valley. It compared WTP values for households residing in the San Joaquin Valley, California, to values for California households outside the Valley, and to households in Washington State, Oregon, and Nevada. The study found that WTP values for California residents outside the Valley were 97.7 percent of the WTP of the Valley residents, and WTP values for Oregon residents were approximately 27 percent of the WTP of the Valley residents. (The distances to these locations outside the Valley exceed the 32.43 mile radius used in the analysis for Mount Hope Bay.)

2. An NRDA study conducted by Schulze et al. (1995) examined the effect of distance on household WTP to clean up the Clark Fork River Basin in Montana, which had been polluted by hazardous waste from mining activities.[15] The study surveyed Montana residents and asked their WTP for partial and complete cleanup of the site, which would result in improvements to surface water, groundwater, soil, vegetation, and wildlife. More specifically, the partial cleanup program, for example, would improve water quality, but trout populations would remain below normal, and about one-fourth of the habitat lost for wildlife species would be restored. The authors examined the effect of distance on WTP by grouping respondents based on the distance between their residences and the resource site. Respondents residing between 101 and 200 miles from the Clark Fork River Basin were willing to pay 49.7 percent of what those respondents residing within 100 miles were willing to pay. The group of respondents residing more than 500 miles driving distance from the Clark Fork River Basin were willing to pay 18.5 percent of what those respondents within 100 miles were willing to pay.

A15-3.2 Estimating Aggregate Values

The final steps in the analysis are:

1. Multiply the value per acre per household by the total number of households affected.

2. Multiply the estimated number of acres of habitat needed to offset a subset of the I&E losses developed for specific species by the estimated per acre values of SAV and wetlands, to evaluate the benefits of I&E reduction. Another way of presenting these results is to calculate the implied per household WTP for households residing in the two different definitions of the study area.

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[15] Schulze et al. prepared this NRDA for the State of Montana Natural Resource Damage Litigation Program.

A15-4 LIMITATIONS AND UNCERTAINTIES

A number of issues are common to all benefit transfers. Benefit transfer involves adapting research conducted for another purpose in the available literature to address the policy questions at hand. Because benefits analysis of environmental regulations rarely affords enough time to develop original stated preference surveys that are specific to the policy effects, benefit transfer is often the only option to inform a policy decision. The following sections discuss specific issues associated with this benefit transfer approach.

A15-4.1 Estimating the Extent of the Affected Population

The extent of the affected population can have a large effect on total values for I&E losses. EPA considered two estimates of the affected human population. EPA believes that both of these estimates are conservative, and that it is likely, based on studies cited in the text above, that people living outside of these areas also would benefit from reduced I&E.
This may contribute to an under estimation of non-use benefits.

A15-4.2 All Species and Losses are Not Compensated

As discussed above, there is uncertainty associated with estimating the number and type of habitat needed to compensate for all I&E losses for each large scale region. As a result, some species may be overcompensated, while others are under compensated, or not included at all. In addition, habitat restoration may provide additional benefits, beyond increases in populations of species affected by I&E.

A15-4.3 Use of Abundance Estimates to Estimate Production from SAV and Tidal Wetland Habitats

Ideally, there would be quantified species-specific estimates for the expected increase in age-1 production of fish species for various habitats that could be used in conjunction with the recommendations from a local expert panel identifying preferred categories of habitat restoration actions to pursue in order to scale the acreage estimates of required habitat restoration. Unfortunately, such production estimates were unavailable. Lacking this production information, this analysis assumes that the age-1 equivalent estimates of abundance of fish in SAV and tidal wetland habitats provides an accurate estimate of the age-1 equivalent production of fish that would be realized, on a per-acre basis, if additional acres of these habitats were to be restored. This assumption implies that when restored acres have reached their full potential, they will produce additional age-1 fish in the same mix of species and at the quantities observed in sampling of existing undisturbed habitats. While the relationship between measured abundance of a species in a given habitat is complex and unique for each species, this assumption was necessary given the limited amount of quantitative data on fish species habitat production that is currently available.

A15-4.4 Application of the Approach to Large Geographic Regions

Application of this method on a regional or national scale can be problematic because of both diversity of habitats and species, and diversity of public values across regions. For example, different habitats might be the limiting factor for a single species in different locations, and different species may be important in different locations. Similarly, people may value habitats and their services differently in diverse areas of the country. Therefore, application of this method to all regions to obtain national estimates might require additional regional studies to use for benefit transfer. The studies used by EPA in its exploratory analysis were deemed most appropriate for the North Atlantic and Mid-Atlantic regions, and the Great Lakes region, as the original studies were conducted in these regions and population demographics for the original study areas were found to be quite similar to population demographics for the policy areas.

Application of the Johnston et al. (2002) study to estimate the portion of wetlands value that is attributed to fish habitat might lead to an overestimation or an underestimation of WTP for fish habitat services of wetlands, when applied to other regions. Because the Johnston et al. study was conducted in Rhode Island, it is most appropriately transferred within southern New England and nearby areas of New York state, where both coastal populations (i.e., tastes) and coastal wetland conditions (i.e., ecology) are quite similar. Thus, EPA believes that the application of the Johnston et al. study, and therefore the value estimates, are most appropriate and accurate in southern New England.

Appendix A1

This appendix contains information compiled by The Nature Conservancy on threatened, endangered, and special status species in 30 States (NatureServe, 2002). States included are AZ, CA, NM, ID, WY, ND, SD, NE, KS, MI, IN, KY, VA, NC, AR, LA, MS, AL, FL, WV, MD, DE, NJ, CT, RI, NH, IA, OK, IL, and PA. Table A1-1 lists the status of species and their location by hydrologic unit code (HUC). Table A1-2 provides definitions of abbreviations used for global status listings in Table A1-1. Table A1-3 provides definitions of the abbreviations used for federal status.

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	01080205
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	01080205
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	01100003
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	01100004
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	01100005
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	01100007
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02040105
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02040201
AFCQC02680	Freshwater Fishes	*Etheostoma Sellare*	Maryland Darter	GH	LE	02050306
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02050306
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	02050306
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02060001
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	02060001
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02060002
AFCQC02680	Freshwater Fishes	*Etheostoma Sellare*	Maryland Darter	GH	LE	02060003
AFCQC04240	Freshwater Fishes	*Percina Rex*	Roanoke Logperch	G1G2	LE	03010101
AFCQC04240	Freshwater Fishes	*Percina Rex*	Roanoke Logperch	G1G2	LE	03010103
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03010107
AFCQC04240	Freshwater Fishes	*Percina Rex*	Roanoke Logperch	G1G2	LE	03010201
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03010203
AFCQC04240	Freshwater Fishes	*Percina Rex*	Roanoke Logperch	G1G2	LE	03010204
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03010205
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03020105
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03020204
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03030001
AFCJB28660	Freshwater Fishes	*Notropis Mekistocholas*	Cape Fear Shiner	G1	LE	03030002
AFCJB28660	Freshwater Fishes	*Notropis Mekistocholas*	Cape Fear Shiner	G1	LE	03030003
AFCJB28660	Freshwater Fishes	*Notropis Mekistocholas*	Cape Fear Shiner	G1	LE	03030004

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03030005
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03030005
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03040201
AFCND02020	Freshwater Fishes	*Menidia Extensa*	Waccamaw Silverside	G1	LT	03040206
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03080103
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	03080103
AFCAA01042	Freshwater Fishes	*Acipenser Oxyrinchus Oxyrinchus*	Atlantic Sturgeon	G3T3	C	03080103
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03080201
AFCNG01020	Marine Fishes	*Rivulus Marmoratus*	Mangrove Rivulus	G3	(PS:C)	03080202
AFCAA01042	Freshwater Fishes	*Acipenser Oxyrinchus Oxyrinchus*	Atlantic Sturgeon	G3T3	C	03080202
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03080203
AFCNG01020	Marine Fishes	*Rivulus Marmoratus*	Mangrove Rivulus	G3	(PS:C)	03080203
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03090202
AFCNG01020	Marine Fishes	*Rivulus Marmoratus*	Mangrove Rivulus	G3	(PS:C)	03090202
AFCND02030	Marine Fishes	*Menidia Conchorum*	Key Silverside	G3Q	C	03090203
AFCNG01020	Marine Fishes	*Rivulus Marmoratus*	Mangrove Rivulus	G3	(PS:C)	03090203
AFCNG01020	Marine Fishes	*Rivulus Marmoratus*	Mangrove Rivulus	G3	(PS:C)	03090204
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03100101
AFCPB09010	Freshwater Fishes	*Microphis Brachyurus*	Opossum Pipefish	G4G5	(PS:C)	03100206
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03100207
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03110101
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03110205
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03120003
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03130011
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03140101
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03140102
AFCQC02520	Freshwater Fishes	*Etheostoma Okaloosae*	Okaloosa Darter	G1	LE	03140102
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03140103
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03140104
AFCNB04090	Marine Fishes	*Fundulus Jenkinsi*	Saltmarsh Topminnow	G2	C	03140105
AFCNB04090	Marine Fishes	*Fundulus Jenkinsi*	Saltmarsh Topminnow	G2	C	03140107
AFCNB04090	Marine Fishes	*Fundulus Jenkinsi*	Saltmarsh Topminnow	G2	C	03140305
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03140305
AFCAA02030	Freshwater Fishes	*Scaphirhynchus Suttkusi*	Alabama Sturgeon	G1	LE	03160103
AFCQC04360	Freshwater Fishes	*Percina Aurora*	Pearl Darter	G1	C	03170001
AFCQC04360	Freshwater Fishes	*Percina Aurora*	Pearl Darter	G1	C	03170004
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03170004
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03170006

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03170007
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03170008
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03170009
AFCNB04090	Marine Fishes	*Fundulus Jenkinsi*	Saltmarsh Topminnow	G2	C	03170009
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	03180001
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03180002
AFCQC04360	Freshwater Fishes	*Percina Aurora*	Pearl Darter	G1	C	03180002
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	03180002
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03180003
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	03180003
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	03180004
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03180004
AFCQC04360	Freshwater Fishes	*Percina Aurora*	Pearl Darter	G1	C	03180004
AFCQC04360	Freshwater Fishes	*Percina Aurora*	Pearl Darter	G1	C	03180005
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	03180005
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	03180005
AFCJB31010	Freshwater Fishes	*Phoxinus Cumberlandensis*	Blackside Dace	G2	LT	05130101
AFCJB31010	Freshwater Fishes	*Phoxinus Cumberlandensis*	Blackside Dace	G2	LT	05130101
AFCJB31010	Freshwater Fishes	*Phoxinus Cumberlandensis*	Blackside Dace	G2	LT	05130102
AFCJB31010	Freshwater Fishes	*Phoxinus Cumberlandensis*	Blackside Dace	G2	LT	05130103
AFCJB28A90	Freshwater Fishes	*Notropis Albizonatus*	Palezone Shiner	G2	LE	05130104
AFCQC02X30	Freshwater Fishes	*Etheostoma Percnurum*	Duskytail Darter	G1	LE	05130104
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	05140101
AFCKA02060	Freshwater Fishes	*Noturus Flavipinnis*	Yellowfin Madtom	G1	(LT,XN)	06010101
AFCJB50010	Freshwater Fishes	*Erimystax Cahni*	Slender Chub	G1	LT	06010101
AFCJB15080	Freshwater Fishes	*Hybopsis Monacha*	Spotfin Chub	G2	LT	06010101
AFCJB15080	Freshwater Fishes	*Hybopsis Monacha*	Spotfin Chub	G2	LT	06010102
AFCJB15080	Freshwater Fishes	*Hybopsis Monacha*	Spotfin Chub	G2	LT	06010105
AFCJB15080	Freshwater Fishes	*Hybopsis Monacha*	Spotfin Chub	G2	LT	06010202
AFCJB15080	Freshwater Fishes	*Hybopsis Monacha*	Spotfin Chub	G2	LT	06010203
AFCJB50010	Freshwater Fishes	*Erimystax Cahni*	Slender Chub	G1	LT	06010205
AFCQC02X30	Freshwater Fishes	*Etheostoma Percnurum*	Duskytail Darter	G1	LE	06010205
AFCKA02060	Freshwater Fishes	*Noturus Flavipinnis*	Yellowfin Madtom	G1	(LT,XN)	06010205
AFCJB50010	Freshwater Fishes	*Erimystax Cahni*	Slender Chub	G1	LT	06010206
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	06040006
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08010100
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	08010100
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08010100

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCFA01020	Freshwater Fishes	*Alosa Alabamae*	Alabama Shad	G3	C	08010100
AFCQC02B00	Freshwater Fishes	*Etheostoma Chienense*	Relict Darter	G1	LE	08010201
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08020100
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08020203
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08030100
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08030207
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08060100
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	08060100
AFCQC02630	Freshwater Fishes	*Etheostoma Rubrum*	Bayou Darter	G1	LT	08060203
AFCQC02630	Freshwater Fishes	*Etheostoma Rubrum*	Bayou Darter	G1	LT	08060302
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08070100
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	08070205
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08080101
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08090100
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	08090201
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	08090202
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	08090203
AFCAA01041	Freshwater Fishes	*Acipenser Oxyrinchus Desotoi*	Gulf Sturgeon	G3T2	LT	08090203
AFCHA07011	Freshwater Fishes	*Thymallus Arcticus Pop 2*	Arctic Grayling - Upper Missouri River Fluvial	G5T2Q	C	10020007
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10060005
AFCHA07011	Freshwater Fishes	*Thymallus Arcticus Pop 2*	Arctic Grayling - Upper Missouri River Fluvial	G5T2Q	C	10070001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10080007
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10080010
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10090202
AFCJB3705B	Freshwater Fishes	*Rhinichthys Osculus Thermalis*	Kendall Warm Springs Dace	G5T1	LE	10090202
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10090207
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10100004
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10100004
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110101
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10110101
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110201
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110202
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110203
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110204
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10110205
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10110205
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10120109

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10120110
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10120111
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10120112
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10130102
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10130102
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10130102
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10130105
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10130202
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10140101
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10140101
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10140103
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10140201
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10140202
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10140203
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10140204
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10150007
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10160004
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10160006
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10160011
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10160011
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10170101
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10170101
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10170101
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10170101
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10170102
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10170103
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10170202
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10170203
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10180002
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10200101
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10200202
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10200202
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10200203
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10210006
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10210009
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10220002
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10220003
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10230001

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10230001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10230001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10230006
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10230006
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10230006
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10230006
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10240001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10240001
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10240001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10240005
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10240005
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10240005
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10240011
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10240011
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10240011
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10250004
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10250016
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10250017
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10260001
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10260008
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10260008
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270101
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10270102
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270102
AFCJB53030	Freshwater Fishes	*Macrhybopsis Meeki*	Sicklefin Chub	G3	C	10270104
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10270104
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270104
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270202
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270205
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10270206
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	10290101
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11010001
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030004
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030009
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030010
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11030010
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11030013
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030013

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030014
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030015
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11030015
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11030016
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11030016
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	11030017
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11040006
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040006
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11040007
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040007
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11040008
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040008
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11060002
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11060002
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11060003
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11060003
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11060005
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	11070201
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070201
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	11070202
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070203
AFCJB28960	Freshwater Fishes	*Notropis Topeka*	Topeka Shiner	G2	LE	11070203
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070204
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070205
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11070207
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070207
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11070208
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11070209
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11110103
AFCQC02170	Freshwater Fishes	*Etheostoma Cragini*	Arkansas Darter	G3	C	11110103
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11110202
AFCQC04210	Freshwater Fishes	*Percina Pantherina*	Leopard Darter	G1	LT	11140108
AFCQC04210	Freshwater Fishes	*Percina Pantherina*	Leopard Darter	G1	LT	11140109
AFCJB16070	Freshwater Fishes	*Hybognathus Amarus*	Rio Grande Silvery Minnow	G1G2	LE	13020201
AFCJB16070	Freshwater Fishes	*Hybognathus Amarus*	Rio Grande Silvery Minnow	G1G2	LE	13020203
AFCJB13110	Freshwater Fishes	*Gila Nigrescens*	Chihuahua Chub	G1	LT	13030202
AFCHA02101	Freshwater Fishes	*Oncorhynchus Gilae Gilae*	Gila Trout	G3T1	LE	13030202
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	13060003

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCJB28891	Freshwater Fishes	*Notropis Simus Pecosensis*	Pecos Bluntnose Shiner	G2T2	LT	13060003
AFCNC02070	Freshwater Fishes	*Gambusia Nobilis*	Pecos Gambusia	G2	LE	13060003
AFCNC02070	Freshwater Fishes	*Gambusia Nobilis*	Pecos Gambusia	G2	LE	13060005
AFCNC02070	Freshwater Fishes	*Gambusia Nobilis*	Pecos Gambusia	G2	LE	13060007
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	13060007
AFCJB28891	Freshwater Fishes	*Notropis Simus Pecosensis*	Pecos Bluntnose Shiner	G2T2	LT	13060007
AFCNC02070	Freshwater Fishes	*Gambusia Nobilis*	Pecos Gambusia	G2	LE	13060008
AFCJB28891	Freshwater Fishes	*Notropis Simus Pecosensis*	Pecos Bluntnose Shiner	G2T2	LT	13060011
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	13060011
AFCNC02070	Freshwater Fishes	*Gambusia Nobilis*	Pecos Gambusia	G2	LE	13060011
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	14040106
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	14040106
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	14040107
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	14070006
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	14070006
AFCJB35020	Freshwater Fishes	*Ptychocheilus Lucius*	Colorado Pikeminnow	G1	(LE,XN)	14080101
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	15010001
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	15010002
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	15010003
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15010005
AFCJB33010	Freshwater Fishes	*Plagopterus Argentissimus*	Woundfin	G1	(LE,XN)	15010010
AFCJB13170	Freshwater Fishes	*Gila Seminuda*	Virgin River Chub	G1	(PS:LE)	15010010
AFCJB20040	Freshwater Fishes	*Lepidomeda Vittata*	Little Colorado Spinedace	G1G2	LT	15020001
AFCJB20040	Freshwater Fishes	*Lepidomeda Vittata*	Little Colorado Spinedace	G1G2	LT	15020002
AFCJB20040	Freshwater Fishes	*Lepidomeda Vittata*	Little Colorado Spinedace	G1G2	LT	15020005
AFCJB20040	Freshwater Fishes	*Lepidomeda Vittata*	Little Colorado Spinedace	G1G2	LT	15020008
AFCJB20040	Freshwater Fishes	*Lepidomeda Vittata*	Little Colorado Spinedace	G1G2	LT	15020010
AFCJB13080	Freshwater Fishes	*Gila Cypha*	Humpback Chub	G1	LE	15020016
AFCJB13100	Freshwater Fishes	*Gila Elegans*	Bonytail	G1	LE	15030101
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15030101
AFCJB13100	Freshwater Fishes	*Gila Elegans*	Bonytail	G1	LE	15030104
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15030104
AFCJB35020	Freshwater Fishes	*Ptychocheilus Lucius*	Colorado Pikeminnow	G1	(LE,XN)	15030107
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15030203
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15030204
AFCJB13100	Freshwater Fishes	*Gila Elegans*	Bonytail	G1	LE	15030204
AFCHA02101	Freshwater Fishes	*Oncorhynchus Gilae Gilae*	Gila Trout	G3T1	LE	15040001
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15040001

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15040001
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15040002
AFCHA02101	Freshwater Fishes	*Oncorhynchus Gilae Gilae*	Gila Trout	G3T1	LE	15040002
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15040002
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15040004
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15040004
AFCHA02101	Freshwater Fishes	*Oncorhynchus Gilae Gilae*	Gila Trout	G3T1	LE	15040004
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15040004
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15040005
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15040005
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15040005
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15040005
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15040005
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15040006
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15040007
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15050100
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15050100
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15050202
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15050203
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15050203
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15050203
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15050301
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15050301
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15050302
AFCJB37140	Freshwater Fishes	*Rhinichthys Cobitis*	Loach Minnow	G2	LT	15060101
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15060103
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15060105
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15060106
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15060106
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15060201
AFCJB22010	Freshwater Fishes	*Meda Fulgida*	Spikedace	G2	LT	15060202
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15060202
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15060202
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	15060203
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15060203

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15070102
AFCJB13160	Freshwater Fishes	*Gila Intermedia*	Gila Chub	G2	C	15070102
AFCNB02061	Freshwater Fishes	*Cyprinodon Macularius Macularius*	Desert Pupfish	G1T1	(LE)	15070103
AFCJB13100	Freshwater Fishes	*Gila Elegans*	Bonytail	G1	LE	15070103
AFCNB02062	Freshwater Fishes	*Cyprinodon Macularius Eremus*	Quitobaquito Desert Pupfish	G1T1	(LE)	15080102
AFCJB13090	Freshwater Fishes	*Gila Ditaenia*	Sonora Chub	G2	LT	15080201
AFCJB13140	Freshwater Fishes	*Gila Purpurea*	Yaqui Chub	G1	LE	15080301
AFCJB13140	Freshwater Fishes	*Gila Purpurea*	Yaqui Chub	G1	LE	15080302
AFCJB49080	Freshwater Fishes	*Cyprinella Formosa*	Beautiful Shiner	G2	LT	15080302
AFCHA02089	Freshwater Fishes	*Oncorhynchus Clarki Seleniris*	Paiute Cutthroat Trout	G4T1T2	LT	16060010
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010101
AFCAA01051	Freshwater Fishes	*Acipenser Transmontanus Pop 1*	White Sturgeon - Kootenai River	G4T1Q	LE	17010104
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010104
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010105
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010213
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010214
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010215
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010216
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010301
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010303
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17010304
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17040212
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17040217
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17050101
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050102
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17050103
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050111
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050112
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050113

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050120
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050121
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050122
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050124
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17050201
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17050201
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon or King Salmon	G5	(PS)	17060101
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060101
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060101
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060101
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060103
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060103
AFCHA02042	Freshwater Fishes	*Oncorhynchus Nerka Pop 1*	Sockeye Salmon - Snake River	G5T1Q	LE	17060103
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060103
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060103
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060108
AFCHA02042	Freshwater Fishes	*Oncorhynchus Nerka Pop 1*	Sockeye Salmon - Snake River	G5T1Q	LE	17060201
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060201
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060201
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060201
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060201
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060202
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060202
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060202
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060203
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060203
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060203
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060203
AFCHA02042	Freshwater Fishes	*Oncorhynchus Nerka Pop 1*	Sockeye Salmon - Snake River	G5T1Q	LE	17060203
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060204

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060204
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060204
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060205
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060205
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060205
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060206
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060206
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060206
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060207
AFCHA02042	Freshwater Fishes	*Oncorhynchus Nerka Pop 1*	Sockeye Salmon - Snake River	G5T1Q	LE	17060207
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060207
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060207
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060207
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060208
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060208
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060208
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060209
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060209
AFCAA01050	Freshwater Fishes	*Acipenser Transmontanus*	White Sturgeon	G4	(PS)	17060209
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060209
AFCHA02042	Freshwater Fishes	*Oncorhynchus Nerka Pop 1*	Sockeye Salmon - Snake River	G5T1Q	LE	17060209
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060210
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060210
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060210
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060301
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060301
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060301

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060302
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060302
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060302
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060303
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060303
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060303
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060304
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060304
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060305
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060305
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060305
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060306
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060306
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060306
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060307
AFCHA05020	Freshwater Fishes	*Salvelinus Confluentus*	Bull Trout	G3	(PS)	17060308
AFCHA02050	Freshwater Fishes	*Oncorhynchus Tshawytscha*	Chinook Salmon Or King Salmon	G5	(PS)	17060308
AFCHA0209M	Freshwater Fishes	*Oncorhynchus Mykiss Pop 13*	Steelhead - Snake River Basin	G5T2T3Q	LT	17060308
AFCJB1303M	Freshwater Fishes	*Gila Bicolor Vaccaceps*	Cowhead Lake Tui Chub	G4T1	PE	17120007
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18010101
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18010102
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18010108
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18010111
AFCJC03010	Freshwater Fishes	*Chasmistes Brevirostris*	Shortnose Sucker	G1	LE	18010204
AFCJC12010	Freshwater Fishes	*Deltistes Luxatus*	Lost River Sucker	G1	LE	18010204
AFCJC12010	Freshwater Fishes	*Deltistes Luxatus*	Lost River Sucker	G1	LE	18010206
AFCJC03010	Freshwater Fishes	*Chasmistes Brevirostris*	Shortnose Sucker	G1	LE	18010206
AFCJC02140	Freshwater Fishes	*Catostomus Microps*	Modoc Sucker	G1	LE	18020002

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCHA0205B	Freshwater Fishes	*Oncorhynchus Tshawytscha Pop 7*	Chinook Salmon - Sacramento River Winter Run	G5T1Q	LE	18020101
AFCHA0205B	Freshwater Fishes	*Oncorhynchus Tshawytscha Pop 7*	Chinook Salmon - Sacramento River Winter Run	G5T1Q	LE	18020102
AFCHA0205B	Freshwater Fishes	*Oncorhynchus Tshawytscha Pop 7*	Chinook Salmon - Sacramento River Winter Run	G5T1Q	LE	18020103
AFCJB34020	Freshwater Fishes	*Pogonichthys Macrolepidotus*	Splittail	G2	LT	18020104
AFCJB34020	Freshwater Fishes	*Pogonichthys Macrolepidotus*	Splittail	G2	LT	18020106
AFCJB34020	Freshwater Fishes	*Pogonichthys Macrolepidotus*	Splittail	G2	LT	18020109
AFCHA0205B	Freshwater Fishes	*Oncorhynchus Tshawytscha Pop 7*	Chinook Salmon - Sacramento River Winter Run	G5T1Q	LE	18020112
AFCHA0209B	Freshwater Fishes	*Oncorhynchus Mykiss Whitei*	Little Kern Golden Trout	G5T2Q	LT	18030001
AFCHA0209B	Freshwater Fishes	*Oncorhynchus Mykiss Whitei*	Little Kern Golden Trout	G5T2Q	LT	18030006
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18050005
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18050006
AFCHA0209J	Freshwater Fishes	*Oncorhynchus Mykiss Pop 10*	Steelhead - Southern California	G5T1T2Q	LE	18050006
AFCHA0209J	Freshwater Fishes	*Oncorhynchus Mykiss Pop 10*	Steelhead - Southern California	G5T1T2Q	LE	18060001
AFCHA0209J	Freshwater Fishes	*Oncorhynchus Mykiss Pop 10*	Steelhead - Southern California	G5T1T2Q	LE	18060001
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060001
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060001
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060006
AFCHA0209J	Freshwater Fishes	*Oncorhynchus Mykiss Pop 10*	Steelhead - Southern California	G5T1T2Q	LE	18060006
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060008
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060009
AFCPA03011	Freshwater Fishes	*Gasterosteus Aculeatus Williamsoni*	Unarmored Threespine Stickleback	G5T1	LE	18060010
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060011
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18060013
AFCPA03011	Freshwater Fishes	*Gasterosteus Aculeatus Williamsoni*	Unarmored Threespine Stickleback	G5T1	LE	18060013
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18070101
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18070102
AFCJC02190	Freshwater Fishes	*Catostomus Santaanae*	Santa Ana Sucker	G1	LT	18070102
AFCJC02190	Freshwater Fishes	*Catostomus Santaanae*	Santa Ana Sucker	G1	LT	18070203
AFCQN04010	Freshwater Fishes	*Eucyclogobius Newberryi*	Tidewater Goby	G3	LE,PDL	18070301

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCNB02090	Freshwater Fishes	*Cyprinodon Radiosus*	Owens River Pupfish	G1	LE	18090102
AFCJB1303J	Freshwater Fishes	*Gila Bicolor Snyderi*	Owens Tui Chub	G4T1	LE	18090102
AFCHA02089	Freshwater Fishes	*Oncorhynchus Clarki Seleniris*	Paiute Cutthroat Trout	G4T1T2	LT	18090102
AFCNB02090	Freshwater Fishes	*Cyprinodon Radiosus*	Owens River Pupfish	G1	LE	18090103
AFCJB1303J	Freshwater Fishes	*Gila Bicolor Snyderi*	Owens Tui Chub	G4T1	LE	18090103
AFCJB1303H	Freshwater Fishes	*Gila Bicolor Mohavensis*	Mohave Tui Chub	G4T1	LE	18090207
AFCJB1303H	Freshwater Fishes	*Gila Bicolor Mohavensis*	Mohave Tui Chub	G4T1	LE	18090208
AFCPA03011	Freshwater Fishes	*Gasterosteus Aculeatus Williamsoni*	Unarmored Threespine Stickleback	G5T1	LE	18100200
AFCNB02060	Freshwater Fishes	*Cyprinodon Macularius*	Desert Pupfish	G1	LE	18100200
AFCJC11010	Freshwater Fishes	*Xyrauchen Texanus*	Razorback Sucker	G1	LE	18100200
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	07110000
AFCAA02010	Freshwater Fishes	*Scaphirhynchus Albus*	Pallid Sturgeon	G1G2	LE	10000000
AFCJB53020	Freshwater Fishes	*Macrhybopsis Gelida*	Sturgeon Chub	G2	C	10000000
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040001
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040006
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11040008
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11050001
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11050002
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11050003
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11060004
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11060006
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11070105
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11070206
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11070206
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11070207
AFCLA01010	Freshwater Fishes	*Amblyopsis Rosae*	Ozark Cavefish	G2G3	LT	11070209
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11090201
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11090202
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11090203
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11090204
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100101
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100102
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100103
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100104
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100201
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100203
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100301
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100302

Table A1-1: Listing Status and Hydrologic Unit Code (HUC) for Threatened and Endangered Species in 30 States Compiled by The Nature Conservancy (cont.)

ABI Identifier	Informal Taxon	Scientific Name	Common Name	Global Status	Federal Status	HUC Code
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11100303
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11110101
AFCKA02200	Freshwater Fishes	*Noturus Placidus*	Neosho Madtom	G2	LT	11110103
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11110104
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11130210
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11130304
AFCJB28490	Freshwater Fishes	*Notropis Girardi*	Arkansas River Shiner	G2	LT	11140107
AFCQC04210	Freshwater Fishes	*Percina Pantherina*	Leopard Darter	G1	LT	11140107
AFCQC04210	Freshwater Fishes	*Percina Pantherina*	Leopard Darter	G1	LT	11140108
AFCAA01010	Freshwater Fishes	*Acipenser Brevirostrum*	Shortnose Sturgeon	G3	LE	02040202
AFCAA01040	Freshwater Fishes	*Acipenser Oxyrinchus*	Atlantic Sturgeon	G3	(LT,C)	02040201

Source: NatureServe, 2002.

Table A1-2: Definitions of Abbreviations for Global Status

Abbreviation	Global Status
GX	Presumed Extinct (species) — Believed to be extinct throughout its range. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.
GH	Possibly Extinct (species) — Known from only historical occurrences, but may nevertheless still be extant; further searching needed.
G1	Critically Imperiled — Critically imperiled globally because of extreme rarity or because of some factor(s)making it especially vulnerable to extinction. Typically 5 or fewer occurrences or very few remaining individuals (<1,000) or acres (<2,000) or linear miles (<10).
G2	Imperiled — Imperiled globally because of rarity or because of some factor(s) making it very vulnerable to extinction or elimination. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000) or acres (2,000 to 10,000) or linear miles (10 to 50).
G3	Vulnerable — Vulnerable globally either because very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction or elimination. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
G4	Apparently Secure — Uncommon but not rare (although it may be rare in parts of its range, particularly on the periphery), and usually widespread. Apparently not vulnerable in most of its range, but possibly cause for long-term concern. Typically more than 100 occurrences and more than 10,000 individuals.
G5	Secure — Common, widespread, and abundant (although it may be rare in parts of its range, particularly on the periphery). Not vulnerable in most of its range. Typically with considerably more than 100 occurrences and more than 10,000 individuals.
G#G#	Range Rank — A numeric range rank (e.g., G2G3) is used to indicate uncertainty about the exact status of a taxon. Ranges cannot skip more than one rank (e.g., GU should be used rather than G1G4).
GU	Unrankable — Currently unrankable due to lack of information or due to substantially conflicting information about status or trends. NOTE: Whenever possible, the most likely rank is assigned and the question mark qualifier is added (e.g., G2?) to express uncertainty, or a range rank (e.g., G2G3) is used to delineate the limits (range) of uncertainty.
G?	Unranked — Global rank not yet assessed.
HYB	Hybrid — (species elements only) Element not ranked because it represents an interspecific hybrid and not a species. (Note, however, that hybrid-derived species are ranked as species, not as hybrids.)
?	Inexact Numeric Rank — Denotes inexact numeric rank
Q	Questionable taxonomy that may reduce conservation priority. Distinctiveness of this entity as a taxon at the current level is questionable; resolution of this uncertainty may result in change from a species to a subspecies or hybrid, or inclusion of this taxon in another taxon, with the resulting taxon having a lower-priority (numerically higher) conservation status rank.
C	Captive or Cultivated Only — Taxon at present is extant only in captivity or cultivation, or as a reintroduced population not yet established.
T_	Infraspecific Taxon (trinomial) — The status of infraspecific taxa (subspecies or varieties) are indicated by a “T-rank” following the species’ global rank. Rules for assigning T ranks follow the same principles outlined above. For example, the global rank of a critically imperiled subspecies of an otherwise widespread and common species would be G5T1. A T subrank cannot imply the subspecies or variety is more abundant than the species (e.g., a G1T2 subrank should not occur). A vertebrate animal population (e.g., listed under the U.S. Endangered Species Act or assigned candidate status) may be tracked as an infraspecific taxon and given a T rank; in such cases a Q is used after the T rank to denote the taxon’s informal taxonomic status.

Table A1-3: Definitions of Abbreviations for Federal Status Listing

Abbreviation	Federal Status
LE	Listed endangered
LT	Listed threatened
PE	Proposed endangered
PT	Proposed threatened
C	Candidate
PDL	Proposed for delisting
E(S/A) or T(S/A)	Listed endangered or threatened because of similarity of appearance
XE	Essential experimental population
XN	Experimental nonessential population
Combination values	The taxon has one status currently, but a more recent proposal has been made to change that status with no final action yet published. For example, LE-PDL indicates that the species is currently listed as endangered, but has been proposed for delisting.
Values in parentheses	The taxon itself is not named in the Federal Register as having federal status; however, it does have federal status as a result of its taxonomic relationship to a named entity. For example, if a species is federally listed with endangered status, then by default, all of its recognized subspecies also have endangered status. The subspecies in this example would have the value “(LE)” under U.S. Federal Status. Likewise, if all of a species’ infraspecific taxa (worldwide) have the same federal status, then that status appears in the record for the “full” species as well. In this case, if the taxon at the species level is not mentioned in the Federal Register, the status appears in parentheses in that record.
Combination values in parentheses	The taxon itself is not named in the Federal Register as having official federal status; however, all of its infraspecific taxa (worldwide) do have official status. The statuses shown in parentheses indicate the statuses that apply to infraspecific taxa or populations within this taxon.
(PS)	Indicates “partial status” - status in only a portion of the species’ range. Typically indicated in a “full” species record where an infraspecific taxon or population has federal status, but the entire species does not.
Null value	Usually indicates that the taxon does not have any federal status. However, because of potential lag time between publication in the Federal Register and entry in the NHCD, some taxa may have a status that does not yet appear.

Part B

California

Chapter B1: Background

INTRODUCTION

This chapter presents an overview of the Phase II facilities in the California study region and summarizes their key operating, economic, technical, and compliance characteristics. For further discussion of operating and economic characteristics of Phase II facilities, refer to Chapter A3 of the *Economic and Benefits Analysis for the Final Section 316(b) Phase II Existing Facilities Rule*; for further discussion of the technical and compliance characteristics of Phase II facilities, refer to the *Technical Development Document for the Final Section 316(b) Phase II Existing Facilities Rule* (U.S. EPA, 2004a,b).

CHAPTER CONTENTS

B1-1 OVERVIEW

The California Regional Study includes 20 facilities that are in scope for the final Phase II regulation. Of these 20 facilities, 8 are located in Northern California and 12 are located in Southern California. Eight of the 20 facilities withdraw cooling water from an estuary or tidal river while 12 withdraw water from the Pacific Ocean. Figure B1-1 presents a map of the 20 in-scope Phase II facilities located in the California Regional Study area.

Figure B1-1: In-Scope Phase II Facilities in the California Regional Study

Source: U.S. EPA analysis for this report.

B1-2 OPERATING AND ECONOMIC CHARACTERISTICS

Most of the 20 California Regional Study facilities (16) are oil/gas facilities; two are nuclear facilities; one is a combined-cycle facility; and one uses another type of steam-electric prime mover. In 2001, these 20 facilities accounted for 21 gigawatts of generating capacity, 93,000 gigawatt hours of generation, and $6.1 billion in revenues.

The operating and economic characteristics of the California Regional Study facilities are summarized in Table B1-1. Section B1-4 provides further information on each facility [including facility subregion, North American Electric Reliability Council (NERC) region, plant type, capacity, 2001 generation, and whether impingement and entrainment estimates were developed for the facility].

Table B1-1: Operating and Economic Characteristics of Phase II Facilities

Waterbody Type	Number of Facilities by Plant Type[a]					Total Capacity (MW)[b]	Total Generation (MWh)[b]	Electric Revenue (millions)
	Combined Cycle	Nuclear	Oil/Gas Steam	Other Steam	Total			
Northern California								
Estuary/Tidal River	-	-	6	-	6	6,294	27,936,568	$1,089
Ocean	-	1	1	-	2	2,403	18,755,346	$1,408
Subtotal	-	*1*	*7*	-	*8*	*8,697*	*46,691,914*	*$2,497*
Southern California								
Estuary/Tidal River	-	-	2	-	2	1,736	6,004,221	$256
Ocean	1	1	7	1	10	10,518	39,981,138	$3,299
Subtotal	*1*	*1*	*9*	*1*	*12*	*12,254*	*45,985,359*	*$3,555*
TOTAL	**1**	**2**	**16**	**1**	**20**	**20,951**	**92,677,273**	**$6,052**

[a] Based on largest steam-electric capacity at facilities.
[b] MW is an abbreviation for megawatt; MWh is an abbreviation for megawatt hour.

Sources: Plant type (IPM Analysis, U.S. EPA, 2002; Form EIA-860, U.S. DOE, 2001a); capacity (Form EIA-860, U.S. DOE, 2001a); generation (Form EIA-906, U.S. DOE, 2001c); revenue (Form EIA-861, U.S. DOE, 2001b; Form EIA-906, U.S. DOE, 2001c).

B1-3 TECHNICAL AND COMPLIANCE CHARACTERISTICS

Nineteen of the 20 California Regional Study facilities employ a once-through cooling system and one facility employs a combination system in the baseline. The 19 facilities with once-through cooling systems incur a combined pre-tax compliance cost of $30.7 million. Table B1-2 summarizes the flow, compliance responses, and compliance costs for these 20 facilities.

Table B1-2: Technical and Compliance Characteristics of Phase II Facilities

	Cooling Water System (CWS) Type[a]		
	Once-Through	**Combination**	**All**
Design Flow (MGD)	**17,136**	**691**	**17,827**
Number of Facilities by Compliance Response			
Fish H&R	5	1	6
Fine Mesh Traveling Screens w/Fish H&R	2	-	2
Passive Fine Mesh Screens	4	-	4
Fish Barrier Net/Gunderboom	3	-	3
Velocity Cap	1	-	1
None	4	-	4
Total	**19**	**1**	**20**
Compliance Cost (2002$, millions)	**$30.7**	**w[b]**	**w[b]**

[a] Combination CWSs are costed as if they were once-through CWSs.

[b] Data withheld because of confidentiality reasons.

Source: U.S. EPA analysis for this report.

B1-4 PHASE II FACILITIES IN THE CALIFORNIA REGIONAL STUDY

Table B1-3 presents economic and operating characteristics of the California Regional Study facilities.

Table B1-3: Phase II Facilities in the California Regional Study

EIA Code	Plant Name	Plant Subregion	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
Northern California							
Estuary/Tidal River							
228	Contra Costa	CN	WSCC	O/G Steam	690	3,295,794	Y
247	Hunters Point	CN	WSCC	O/G Steam	427	436,130	Y
259	Morro Bay	CN	WSCC	O/G Steam	1,056	4,197,701	Y
260	Moss Landing	CN	WSCC	O/G Steam	1,624	8,349,240	Y
271	Pittsburg	CN	WSCC	O/G Steam	2,080	10,388,204	Y
273	Potrero	CN	WSCC	O/G Steam	417	1,269,499	Y
Ocean							
246	Humboldt Bay	CN	WSCC	O/G Steam	102	677,633	Y
6099	Diablo Canyon	CN	WSCC	Nuclear	2,300	18,077,713	Y
Southern California							
Estuary/Tidal River							
302	Encina	CS	WSCC	O/G Steam	1,007	4,043,079	Y
310	South Bay	CS	WSCC	O/G Steam	729	1,961,142	N
Ocean							
330	El Segundo	CS	WSCC	O/G Steam	996	2,909,876	Y
335	Huntington Beach	CS	WSCC	O/G Steam	563	1,305,859	Y
341	Long Beach	CS	WSCC	Other Steam	587	866,159	N
345	Mandalay	CS	WSCC	O/G Steam	574	2,066,920	Y
350	Ormond Beach	CS	WSCC	O/G Steam	1,500	6,008,123	Y
356	Redondo Beach	CS	WSCC	O/G Steam	1,321	5,631,001	Y
360	San Onofre	CS	WSCC	Nuclear	2,254	15,141,807	Y
399	Harbor	CS	WSCC	Combined Cycle	293	889,857	Y
400	Haynes	CS	WSCC	O/G Steam	1,606	3,315,253	Y
404	Scattergood	CS	WSCC	O/G Steam	823	1,846,283	Y

Source: U.S. EPA analysis for this report.

Chapter B2: Evaluation of Impingement and Entrainment in California

CHAPTER CONTENTS

BACKGROUND: CALIFORNIA MARINE FISHERIES

The oceanic transition zone off Point Conception creates a natural ecological separation between northern and southern California (Leet et al., 2001). North of Point Conception, coastal waters are cold and oceanic conditions are harsh, whereas to the south waters are warmer and conditions are moderate. As a result, the fish species composition differs between the two regions. Surface and bottom temperatures along the continental shelf off northern California support polar and cold-temperate species such as chinook salmon, coho salmon, striped bass, rock gunnels, and lanternfish (Leet et al., 2001). In Southern California, warm waters from the south join with the cold California current to provide habitat for a wide variety of seasonal subtropical visitors like yellowtail, white seabass, Pacific bonito, and California barracuda, all found in close association with the abundant strands of giant kelp (Pacific Fishery Management Council, 2003b). Major resident species such as kelp bass, sheephead, halfmoon and olive rockfish sustain year-round nearshore fisheries (Leet et al., 2001).

California fisheries are managed by the Pacific Fishery Management Council (PFMC), which governs commercial and recreational fisheries in Federal waters from 3 to 200 nautical miles off the coasts of Washington, Oregon, and California (Pacific Fishery Management Council, 2003a). The National Marine Fisheries Service (NMFS) Northwest Fisheries Science Center provides scientific and technical support for management, conservation, and fisheries development for Northern California. The NMFS Southwest Fisheries Science Center provides support for Southern California.

There are 83 species of groundfish included under PFMC's Groundfish Fishery Management Plan, including nearly 50 species of rockfish (*Sebastes* spp.) (Table 3 in NMFS, 2002a). The midwater trawl fishery for Pacific whiting (*Merluccius productus*) dominates the commercial fishery, accounting for 78 percent of Pacific Coast landings (NMFS, 1999b). Important deepwater trawl fisheries also exist for sablefish, Dover sole, and thornyheads. During the 1990s a major fishery developed for nearshore species, including rockfishes, cabezon, and sheephead (Leet et al., 2001). Rockfishes are important for both commercial and recreational fisheries (NMFS, 1999b). In 1994, a limited entry program was implemented for the groundfish fishery because of concerns about overfishing (NMFS, 1999b). Most major West Coast groundfishes are now fully harvested, and catches have recently been controlled by quotas and trip limits (Pacific Fishery Management Council, 2003c).

Pacific Coast pelagic species managed by the PFMC include Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), Pacific sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), and California market squid (*Loligo opalescens*) (NMFS, 2002a). These species typically fluctuate widely in abundance, and currently most stocks are low relative to historical levels (NMFS, 1999b). Pacific mackerel and Pacific sardine are not overfished, but the stock size of the other species governed by the Coastal Pelagic FMP is unknown (Table 3 in NMFS, 2002a). Because of increases in abundance in recent years, Pacific mackerel now accounts for over half of recent landings of Pacific Coast pelagic species (NMFS, 1999b). At times, Pacific sardine has been the most abundant fish species in the California current. When the population is large, it is abundant from the tip of Baja California to southeastern Alaska (Pacific Fishery Management Council, 2003b).

Five species of anadromous Pacific salmon support coastal and freshwater commercial and recreational fisheries along the Pacific Coast, including chinook (*Oncorhynchus tshawytscha)*, coho (*O. kisutch*), sockeye (*O. nerka*), pink (*O. gorbuscha*), and chum (*O. keta*) salmon (NMFS, 1999b). The Sacramento River is a major producer of chinook salmon in California. Since 1991, NMFS has listed 20 Evolutionary Significant Units (ESUs)[1] of Pacific Coast salmon and steelhead trout (*O. mykiss*) under the Federal Endangered Species Act (ESA) (NMFS, 1999c). In NMFS's Northern California region, listed species include steelhead, coho salmon, and chinook salmon of the central California Coast and steelhead and chinook salmon of California's Central Valley.

Ocean fisheries for chinook and coho salmon are managed by the PFMC under the Pacific Coast Salmon FMP. In Puget Sound and the Columbia River, chinook and coho fisheries are managed by the States and Tribal fishery agencies. Declines in chinook and coho salmon along the coast have led to reductions and closures of ocean fisheries in recent years (NMFS, 1999b).

The Pacific Salmon FMP contains no fishery management objectives for sockeye, chum, even-year pink, and steelhead stocks because fishery impacts are considered inconsequential (Table 3 in NMFS, 2002a). Pink, chum, and sockeye salmon are managed jointly by the Pacific Salmon Commission, Washington State, and Tribal agencies (NMFS, 1999b).

Pacific Coast shellfish resources are important both commercially and recreationally (NMFS, 1999b). Shrimps, crabs, abalones, and clams command high prices and contribute substantially to the value of Pacific Coast fisheries, even though landings are small.

B2-1 FISHERY SPECIES IMPINGED AND ENTRAINED

Available impingement and entrainment (I&E) data indicate that 20 of the 248 distinct species that are impinged and entrained by California facilities are harvested species subject to FMPs developed by the PFMC. Table B2-1 summarizes information on the stock status of these species. Note that stock status is known for only 4 of these species. Most of the species listed are rockfish species. Northern anchovy falls under the Coastal Pelagic FMP, and the other species in the table are included in the Groundfish FMP. Although under the jurisdiction of the PFMC, there are no fishery management objectives for Central Valley chinook salmon and Central California Coast coho salmon because of their ESA listing (NMFS, 2002a). There are also no fishery management goals for steelhead because fishery impacts are considered inconsequential (NMFS, 2002a).

Table B2-1: Summary of Stock Status of Harvested Species in California that are Impinged and Entrained and are Included in Federal FMPs

Stock (Species in bold are major stocks, with annual landings over 200,000 pounds)	Overfishing? (Is fishing mortality above threshold?)	Overfished? (Is stock size below threshold?)	Approaching Overfished Condition?
Aurora rockfish	Unknown	Unknown	Unknown
Black rockfish	No	No	No
Black-and-yellow rockfish	Unknown	Unknown	Unknown
Blue rockfish	Unknown	Unknown	Unknown
Bocaccio	No	Yes	N/A
Cabezon	Unknown	Unknown	Unknown
California scorpionfish	Unknown	Unknown	Unknown
Central California Coast coho salmon[a]	N/A	N/A	N/A

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[1] An Evolutionarily Significant Unit (ESU) is a term introduced by NMFS in 1991 to refer to the Endangered Species Act (ESA) interpretation of "distinct population segment." A stock must satisfy two criteria to be considered an ESU: (1) "it must be substantially reproductively isolated from other conspecific population units," and (2) "it must represent an important component in the evolutionary legacy of the species."

Table B2-1: Summary of Stock Status of Harvested Species in California that are Impinged and Entrained and are Included in Federal FMPs

Stock (Species in bold are major stocks, with annual landings over 200,000 pounds)	Overfishing? (Is fishing mortality above threshold?)	Overfished? (Is stock size below threshold?)	Approaching Overfished Condition?
Central Valley chinook salmon[a]	N/A	N/A	N/A
Chilipepper rockfish	No	No	No
Copper rockfish	Unknown	Unknown	Unknown
Gopher rockfish	Unknown	Unknown	Unknown
Grass rockfish	Unknown	Unknown	Unknown
Kelp rockfish	Unknown	Unknown	Unknown
Northern anchovy-central subpopulation		Undefined	Unknown
Olive rockfish	Unknown	Unknown	Unknown
Shortbelly rockfish	No	No	No
Starry flounder	Unknown	Unknown	Unknown
Steelhead[b]	N/A	N/A	N/A
Yellowtail rockfish	No	No	No

[a] There are no fishery management goals for Central Valley chinook salmon and Central California Coast coho salmon because of their ESA listing (NMFS, 2002a).

[b] There are no fishery management goals for steelhead because fishery impacts are considered inconsequential (NMFS, 2002a).

Source: Table 4 in NMFS (2002a).

B2-2 I&E SPECIES AND SPECIES GROUPS EVALUATED

Table B2-2 provides a list of species in the California region that are impinged and entrained at cooling water intake structures in scope of the section 316(b) Phase II rule that were evaluated in EPA's analysis of regional I&E. Life histories of the species with the highest losses are summarized in the following section. The life history data used in EPA's analysis and associated data sources are provided in Appendix B1 of this report.

Table B2-2: Species Evaluated by EPA that are Subject to I&E in California

Species Group	Species	Recreational	Commercial	Forage	Special Status[a]
Anchovies	Deepbody anchovy		X		
	Northern anchovy		X		
	Slough anchovy		X		
Blennies	Bay blenny			X	
	Combtooth blennies			X	
	Mussel blenny			X	
	Orangethroat pikeblenny			X	
	Rockpool blenny			X	
	Tube blenny			X	
Cabezon	Cabezon	X	X		
California halibut	California halibut	X	X		
California scorpionfish	California scorpionfish	X	X		

Table B2-2: Species Evaluated by EPA that are Subject to I&E in California

Species Group	Species	Recreational	Commercial	Forage	Special Status[a]
	Spotted scorpionfish	X	X		
Chinook salmon	Chinook salmon				X (FT, ST, FE, SE, FCT)
Commercial sea basses	Giant sea bass		X		
Commercial shrimp	Alaskan bay shrimp		X		
	Franciscan bay shrimp		X		
	Ghost shrimp		X		
	Smooth bay shrimp		X		
	Black-tailed shrimp		X		
Delta smelt	Delta smelt				X (FT, ST)
Drums croakers	Black croaker	X	X		
	California corbina	X	X		
	Queenfish	X	X		
	Spotfin croaker	X	X		
	White croaker	X	X		
	White sea bass	X	X		
	Yellowfin croaker	X	X		
Dungeness crab	Dungeness crab		X		
Flounders	Bigmouth sole	X	X		
	CO sole	X	X		
	Curlfin sole	X	X		
	Diamond turbot	X	X		
	Dover sole	X	X		
	English sole	X	X		
	Fantail sole	X	X		
	Hornyhead turbot	X	X		
	Longfin sanddab	X	X		
	Pacific sand sole	X	X		
	Pacific sanddab	X	X		
	Petrale sole	X	X		
	Rock sole	X	X		
	Slender sole	X	X		
	Speckled sanddab	X	X		
	Spotted turbot	X	X		
	Starry flounder	X	X		
Forage shrimp	Anemone shrimp			X	
	Blue mud shrimp			X	
	Broken back shrimp			X	
	California green shrimp			X	
	Dock shrimp			X	

Table B2-2: Species Evaluated by EPA that are Subject to I&E in California

Species Group	Species	Recreational	Commercial	Forage	Special Status[a]
	Mysids			X	
	Opossum shrimp			X	
	Oriental shrimp			X	
	Pistol shrimp			X	
	Sidestriped shrimp			X	
	Skeleton shrimp			X	
	Stout bodied shrimp			X	
	Striped shrimp			X	
	Tidepool shrimp			X	
	Twistclaw pistol shrimp			X	
Gobies	Arrow goby			X	
	Bay goby			X	
	Blackeyed goby			X	
	Blind goby			X	
	Chameleon goby			X	
	Cheekspot goby			X	
	Long jaw mudsucker			X	
	Shadow goby			X	
	Yellowfin goby			X	
Herrings	Middling thread herring			X	
	Pacific herring			X	
	Pacific sardine			X	
	Round herring			X	
	Threadfin shad			X	
Longfin smelt	Longfin smelt				X (SOC)
Other commercial species	Basketweave cusk-eel		X		
	California moray		X		
	Catalina conger		X		
	Leopard shark		X		
	Monkeyface prickleback		X		
	Moray eel		X		
	Pacific hagfish		X		
	Pacific hake		X		
	Pricklebreast poacher		X		
	Rock prickleback		X		
	Spotted cusk-eel		X		
	Yellow snake-eel		X		
Other forage species	Barcheek pipefish			X	
	Bay pipefish			X	
	Bigscale goatfish			X	

Table B2-2: Species Evaluated by EPA that are Subject to I&E in California

Species Group	Species	Recreational	Commercial	Forage	Special Status[a]
	Black bullhead			X	
	Blacksmith			X	
	Blue lanternfish			X	
	Broadfin lampfish			X	
	Bullseye puffer			X	
	California clingfish			X	
	California flyingfish			X	
	California killifish			X	
	California lizardfish			X	
	California needlefish			X	
	California tonguefish			X	
	Combfish			X	
	Cortez angelfish			X	
	Crevice kelpfish			X	
	Finescale triggerfish			X	
	Flathead mullet			X	
	Fringehead			X	
	Garibaldi			X	
	Giant kelpfish			X	
	Hatchet fish			X	
	High cockscomb			X	
	Island kelpfish			X	
	Kelp gunnel			X	
	Kelp pipefish			X	
	Kelpfish			X	
	Lampfish			X	
	Lanternfish			X	
	Longfin lanternfish			X	
	Longspine combfish			X	
	Medusafish			X	
	Mexican lampfish			X	
	Northern clingfish			X	
	Northern lampfish			X	
	Northern spearnose poacher			X	
	Ocean sunfish			X	
	Ocean whitefish			X	
	Onespot fringehead			X	
	Pacific butterfish			X	
	Pacific cornetfish			X	
	Pacific cutlassfish			X	

Table B2-2: Species Evaluated by EPA that are Subject to I&E in California

Species Group	Species	Recreational	Commercial	Forage	Special Status[a]
	Pacific lamprey			X	
	Pacific sand lance			X	
	Penpoint gunnel			X	
	Pipefish species			X	
	Plainfin midshipman			X	
	Popeye smelt			X	
	Pygmy poacher			X	
	Ratfish			X	
	Red brotula			X	
	Reef finspot			X	
	Ribbonfish			X	
	Rockweed gunnel			X	
	Ronquil			X	
	Saddleback gunnel			X	
	Salema			X	
	Sarcastic fringehead			X	
	Sargo			X	
	Scarlet kelpfish			X	
	Sea porcupine			X	
	Sharksucker			X	
	Shovelnose guitarfish			X	
	Slimy snailfish			X	
	Smalleye squaretail			X	
	Snubnose pipefish			X	
	Southern poacher			X	
	Southern spearnose poacher			X	
	Specklefin midshipman			X	
	Spotted kelpfish			X	
	Spotted ratfish			X	
	Squid			X	
	Striped kelpfish			X	
	Thornback			X	
	Threespine stickleback			X	
	Tubesnout			X	
	Zebra perch			X	
Other recreational species	Angel shark	X			
	Bat ray	X			
	Big skate	X			
	Black skate	X			
	Broadnose sevengill shark	X			

Table B2-2: Species Evaluated by EPA that are Subject to I&E in California

Species Group	Species	Recreational	Commercial	Forage	Special Status[a]
	Brown smoothhound	X			
	California butterfly ray	X			
	Chub mackerel	X			
	Diamond stingray	X			
	Gray smoothhound	X			
	Halfmoon	X			
	Horn shark	X			
	Kelp greenling	X			
	Mexican scad	X			
	Monterey spanish mackerel	X			
	Opaleye	X			
	Pacific angel shark	X			
	Pacific bonito	X			
	Pacific bumper	X			
	Pacific electric ray	X			
	Pacific mackerel	X			
	Pacific moonfish	X			
	Pacific pompano	X			
	Painted greenling	X			
	Rock wrasse	X			
	Round stingray	X			
	Senorita	X			
	Sevengill shark	X			
	Soupfin shark	X			
	Striped mullet	X			
	Swellshark	X			
	Thornback ray	X			
	California sheephead	X			
	Jack mackerel	X			
	Lingcod	X			
	Pacific barracuda	X			
	Piked dogfish	X			
	Spiny dogfish	X			
Other commercial crabs	Anthonys rock crab		X		
	Black clawed crab		X		
	Brown rock crab		X		
	Common rock crab		X		
	Cryptic kelp crab		X		
	Dwarf crab		X		
	Elbow crab		X		

Table B2-2: Species Evaluated by EPA that are Subject to I&E in California

Species Group	Species	Recreational	Commercial	Forage	Special Status[a]
	European green crab		X		
	Graceful kelp crab		X		
	Hairy rock crab		X		
	Kelp crab		X		
	Lined shore crab		X		
	Lumpy crab		X		
	Majid crab		X		
	Masking crab		X		
	Mole crab		X		
	Moss crab		X		
	Mud/Stone crab		X		
	Northern kelp crab		X		
	Pacific sand crab		X		
	Pea crab		X		
	Pebble crab		X		
	Porcelain crab		X		
	Porcelain crabs		X		
	Purple shore crab		X		
	Red crab		X		
	Red rock crab		X		
	Sharp nosed crab		X		
	Shore crab		X		
	Slender crab		X		
	Slender rock crab		X		
	Southern kelp crab		X		
	Spider crab		X		
	Striped shore crab		X		
	Thickclaw porcelain crab		X		
	Xantus swimming crab		X		
	Yellow crab		X		
	Yellow shore crab		X		
Rec sea basses	Barred sand bass	X			
	Broomtail grouper	X			
	Kelp bass	X			
	Spotted sand bass	X			
Rockfishes	Aurora rockfish	X	X		
	Black and yellow rockfish	X	X		
	Black rockfish	X	X		
	Blue rockfish	X	X		
	Bocaccio	X	X		

Table B2-2: Species Evaluated by EPA that are Subject to I&E in California

Species Group	Species	Recreational	Commercial	Forage	Special Status[a]
	Brown rockfish	X	X		
	Calico rockfish	X	X		
	Chilipepper	X	X		
	Copper rockfish	X	X		
	Flag rockfish	X	X		
	Grass rockfish	X	X		
	Kelp rockfish	X	X		
	Olive rockfish	X	X		
	Shortbelly rockfish	X	X		
	Treefish	X	X		
	Vermilion rockfish	X	X		
	Yellowtail rockfish	X	X		
Sacramento splittail	Sacramento splittail				X (FT)
Salmon	Coho salmon	X			
Sculpins	Bonehead sculpin	X	X		
	Brown Irish lord	X	X		
	Buffalo sculpin	X	X		
	Coralline sculpin	X	X		
	Fluffy sculpin	X	X		
	Manacled sculpin	X	X		
	Pacific staghorn sculpin	X	X		
	Prickly sculpin	X	X		
	Rosy sculpin	X	X		
	Roughcheek sculpin	X	X		
	Roughneck sculpin	X	X		
	Smoothhead sculpin	X	X		
	Snubnose sculpin	X	X		
	Staghorn sculpin	X	X		
	Tidepool sculpin	X	X		
	Woolly sculpin	X	X		
Silversides	California grunion			X	
	Jacksmelt			X	
	Topsmelt			X	
Smelts	Night smelt	X	X		
	Surf smelt	X	X		
Steelhead	Steelhead				X (FT)
Striped bass	Striped bass	X			
Surfperches	Barred surfperch	X	X		
	Black surfperch	X	X		
	Calico surfperch	X	X		

Table B2-2: Species Evaluated by EPA that are Subject to I&E in California

Species Group	Species	Recreational	Commercial	Forage	Special Status[a]
	Dwarf surfperch	X	X		
	Island surfperch	X	X		
	Kelp surfperch	X	X		
	Pile surfperch	X	X		
	Pink seaperch	X	X		
	Rainbow surfperch	X	X		
	Rubberlip surfperch	X	X		
	Shiner surfperch	X	X		
	Silver surfperch	X	X		
	Spotfin surfperch	X	X		
	Striped seaperch	X	X		
	Walleye surfperch	X	X		
	White surfperch	X	X		

[a] FT = Federally listed as threatened.
ST = State listed as threatened.
FE = Federally listed as endangered.
SE = State listed as endangered.
FCT = Federal candidate for listing as threatened.
SOC = Species of concern.

B2-3 LIFE HISTORIES OF PRIMARY SPECIES IMPINGED AND ENTRAINED IN CALIFORNIA

Chinook salmon (*Oncorhynchus tshawytscha*)

Chinook salmon are anadromous members of the salmon and trout family (Salmonidae) (Moyle, 1976; Emmett et al., 1991; Boydstun et al., 1992). The San Francisco Bay-Delta is an important nursery area and migration route for chinook salmon (Kennish, 2000). Eggs, alevins (larvae), and young juveniles (fry and parr) use freshwater streams and rivers upstream of the delta, and juveniles migrate through the delta and use it as a nursery area (Emmett et al., 1991). Juveniles eventually migrate downstream to the Pacific Ocean as they transform into smolts, the ocean-dwelling stage. Chinook salmon spend from 1-8 years in the ocean before returning to their natal stream to spawn.

Four races of chinook salmon use the Sacramento-San Joaquin River system (Moyle, 1976; Yoshiyama et al., 2000). These include the fall run, late fall run, winter run, and spring run chinook salmon. In the Sacramento River, the winter run spawns from April to July, and the other runs spawn from July to December (Moyle, 1976). Spawning once occurred into the upper reaches of both the Sacramento and San Joaquin rivers, but dams have limited spawning to the lower reaches of these rivers and their tributaries (Moyle, 1976; Yoshiyama et al., 2000). The Central Valley late fall run was recently evaluated as a part of a proposed listing of the fall run under the Federal Endangered Species Act (ESA). Although it was decided that the combined Central Valley fall/late-fall run currently does not qualify for formal protection, both runs remain under consideration as candidate species (Yoshiyama et al., 2000). The Sacramento River winter run is listed as endangered under both the State and Federal ESA. The Central Valley spring run is listed as threatened under both statutes.

The four Central Valley runs of chinook salmon are vulnerable to I&E at the Pittsburg and Contra Costa power plants. Adults have been observed near the plants in October, and larvae (alevins) have been collected from inshore, shallow areas of Suisun Bay in January and February (Wang, 1986). Parr have been observed throughout the estuary in spring, with peak migration occurring in May and June (Wang, 1986).

CHINOOK SALMON
(Oncorhynchus tshawytscha)

Family: Salmonidae (salmon and trout).

Common names: Blackmouth, king salmon, quinnat salmon, spring, tyee.[a]

Similar species: Steelhead.

Geographic range: Arctic and Pacific from Point Hope, Alaska to Ventura River, California.[a]

Habitat: Oceans, streams and lakes.[a] Prefers gravel substrates for spawning.[b]

Lifespan: Can live up to 9 years.[a]

Fecundity: 2,000 to 14,000 eggs.[b]

Food sources:
- In streams, food is mainly terrestrial insects and small crustaceans.[a]
- In oceans, chinook salmon consume fish, crustaceans, and other invertebrates.[a]

Prey for:
- Striped bass, American shad, sculpins, Sacramento squawfish, sea gulls, mergansers, kingfishers.[a,b]

Life stage information:

***Eggs:* demersal**
- Eggs range from 6.0 to 8.5 mm (0.24 to 0.33 in).[b]
- Deposited and buried in gravel, and are bright orange-red in color.[b]

***Larvae:* demersal for 2-3 weeks, then free-swimming.[b]**
- Approximately 20 mm (0.79 in) at hatching.

Juveniles:
- Found in shallow and open waters of the Sacramento - San Joaquin Estuary.[b]
- Remain in freshwater for 1-2 years.[b]
- Drift feeders.[b]

***Adults*:**
- Return to natal streams from the sea for spawning.[a]
- Reach up to 147 cm (58 in).[a]

[a] Froese and Pauly, 2001.
[b] Wang, 1986.
Fish graphic from NEFSC, 2001.

Delta smelt (*Hypomesus transpacificus*)

The delta smelt is a pelagic member of the smelt family (Osmeridae). It is a small, short-lived species that is found only in the bay-delta estuary, in areas with low salinities (Moyle, 1976; Moyle et al., 1992; U.S. Fish and Wildlife Service, 1996b). It is the only smelt species endemic to California and the only true native estuarine species found in the delta (Moyle et al., 1992).

The spawning period of delta smelt is relatively long, and adults may spawn from December to May, although most spawning occurs in February and March (Moyle, 1976). Before spawning in the fall, delta smelt congregate in upper Suisun Bay and the lower reaches of the delta (Moyle, 1976). Spawning takes place in freshwater along river margins and adjoining dead-end sloughs of the western delta. Fecundity is low, ranging from only 1,247 to 2,590 eggs per female (Moyle, 1976). Adults apparently die shortly after spawning, at the end of their 1-year life span (Moyle et al., 1992).

Eggs are demersal and adhesive, sticking to aquatic plants and gravel, and are therefore unlikely to be drawn into cooling water intakes, although the larvae are vulnerable (Bruce Herbold, EPA Region 9, personal communication, September 1, 2000). After hatching, the buoyant larvae are carried downstream to the entrapment zone, the highly productive areas where freshwater and salt water mix. This zone is located in Suisun Bay in years of high freshwater inflow. Juveniles move downstream to San Pablo Bay and Carquinez Strait before turning back to Suisun Bay for spawning.

The delta smelt was once one of the most common fish species in the bay-delta estuary, but the species has declined nearly 90 percent over the last 20 years. A number of physical and biological factors have contributed to declines in recent years, including increased water exports, competition and predation from the accidentally introduced inland silverside (*Menidia beryllina*), drought conditions in the late 1980s and early 1990s, and changes in food availability (CDWR, 1994; U.S. Fish and Wildlife Service, 1996b). Another major factor is the seasonal location of the entrapment zone. The location of the entrapment zone is a function of the timing and magnitude of delta outflow. There is a significant positive relationship between delta smelt abundance and the number of days that the entrapment zone is located within Suisun Bay from February through June (Moyle et al., 1992). Habitat and prey availability for delta smelt are greater when the entrapment zone is in this area because Suisun Bay is broad and shallow, and therefore light penetrates most of its waters, promoting algal growth (U.S.

Fish and Wildlife Service, 1996b). Algal growth under these conditions provides an abundant food supply for zooplankton, which in turn provide food for plankton-eating fish like delta smelt.

Altered flow patterns caused primarily by agricultural water diversions during spawning also appear to contribute to delta smelt population losses by increasing the likelihood of entrainment of spawning adults and newly hatched larvae in diversion pumps (Moyle et al., 1992). In dry years, delta smelt are concentrated in upstream areas, whereas in wet years overall habitat conditions are more favorable and delta smelt are more widely distributed. When favorable conditions result in wider distribution, more delta smelt are affected by water diversion pumps (CDWR, 1994). The California Department of Water Resources (CDWR) estimated that entrainment losses of delta smelt at delta diversions reached 1.2 million in 1992 (CDWR, 1994).

Losses of delta smelt related to other water uses equal or exceed those at government water project pumps (CDWR, 1994). For example, because of their schooling behavior and preference for the region around Suisun Bay, delta smelt are highly vulnerable to the intakes of the Pittsburg and Contra Costa power plants. Monitoring of this species has not been required of the power plants, and the only estimates of I&E are based on incidental collection in striped bass monitoring samples in the late 1970's (Ecological Analysts, 1981b, 1981e). Nonetheless, the data indicate that in the late 1970's delta smelt were one of the most common fish species in the vicinity of the plants and experienced I&E in the millions each year.

Delta smelt is currently listed as a threatened species by both the USFWS and California. Historically, the delta smelt occurred from Suisun Bay upstream to the city of Sacramento on the Sacramento River and upstream to Mossdale on the San Joaquin River (Moyle et al., 1992). The size of the current population is uncertain, but in the early 1990's the population was estimated to be about 280,000 (Southern Energy Delta, LLC, 2000). Even at this population size, the delta smelt is considered highly vulnerable to environmental stressors because of its 1-year life cycle and low fecundity. Low fecundity and a short life span mean that even as few as 2 successive years of low reproductive success could decimate the population (Moyle, 1976).

DELTA SMELT
(Hypomesus transpacificus)

Family: Osmeridae (smelt).

Common names: none.

Similar species: Longfin smelt.

Geographic range: Sacramento - San Joaquin Delta.[a]

Habitat: Deadend sloughs, inshore areas of the delta and lower reaches of the Sacramento and San Joaquin rivers.[b]

Lifespan: Only live for one year.[c]

Fecundity: Fecundity is low, ranging from only 1,247 to 2,590 eggs per female.[d] Delta smelt die shortly after spawning.[c]

Food sources:
- Juveniles eat planktonic crustaceans, small insect larvae, and mysid shrimp.[b]

Prey for:

Life stage information:

***Eggs:* demersal**
- Eggs are adhesive and stick to aquatic plants and gravel.[e]
- Approximately 1mm (0.04 in) in diameter.[b]

***Larvae:* pelagic**
- Larvae are approximately 5.5 to 6.0 mm (0.22 to 0.24 in) at hatching.[b]
- Found near surface of water column.[b]

***Juveniles:* pelagic**
- Juveniles are concentrated in the Suisun Bay and the delta and in the lower reaches of the Sacramento and San Joaquin rivers.[b]

***Adults*:**
- Reach 12 cm (4.7 in).[a]

[a] Froese and Pauly, 2001.
[b] Wang, 1986.
[c] Moyle et al., 1992.
[d] Moyle, 1976.
[e] Bruce Herbold, EPA Region 9, personal communication, September 1, 2000.
Fish graphic from California Department of Fish and Game, 2002b.

Green sturgeon (*Acipenser medirostris*)

The green sturgeon is a member of the sturgeon family Acipenseridae (Emmett et al., 1991; Southern Energy Delta, LLC, 2000). It is an anadromous species that is closely related to the white sturgeon (*A. transmontanus*), though it shows a greater preference for marine waters, spending little time in freshwater. It is not abundant in any Pacific Coast estuary, and therefore life history characteristics are poorly known (Emmett et al., 1991). Along the North America coast it is found from Mexico north to the Bering Sea (Southern Energy Delta, LLC, 2000).

Although not abundant in the bay-delta, in the Columbia River green sturgeon is caught commercially with the white sturgeon, but it is considered inferior eating and therefore less valuable (Emmett et al., 1991). Green sturgeon is also incidentally captured in the white sturgeon recreational fishery.

Females mature at 15 to 20 years of age (Southern Energy Delta, LLC, 2000). Spawning occurs in California in spring and early summer in deep, fast water in the lower reaches of the Sacramento and Klamath Rivers (Emmett et al., 1991; Southern Energy Delta, LLC, 2000). The green sturgeon is a broadcast spawner, with fecundity ranging from 60,000 to 140,000 eggs per female (Emmett et al., 1991). Juveniles are found in freshwater areas of the San Joaquin Delta in summer (Emmett et al., 1991). By age 2, juveniles move to the ocean. Adults move back into estuaries in spring and early summer to feed and spawn. Adults can reach up to 2.1 m (6.9 ft) in length and live up to 60 years (Emmett et al., 1991).

Green sturgeon are found near the Pittsburg and Contra Costa power plants as adults migrating to freshwater rivers to spawn in spring and as juveniles moving to the ocean (Southern Energy Delta, LLC, 2000). Green sturgeon has been identified as a species of concern in this area (Southern Energy Delta, LLC, 2000).

GREEN STURGEON
(Acipenser medirostris)

Family: Acipenseridae (sturgeon).

Common names: none.

Similar species: White sturgeon.

Geographic range: North America from the Aleutian Islands and the Gulf of Alaska to Ensenada, Mexico.[a]

Habitat: Spawn in freshwater rivers, found in estuaries in spring, and in oceans.[b,c]

Lifespan: Live up to 60 years.[c]

Fecundity: Females mature at 15 to 20 years.[b] Females produce 60,000 to 140,000 eggs.[c]

Food sources:
- Juveniles consume amphopods and mysid shrimp.[d]

Prey for:

Life stage information:

Eggs:
- Little known, difficult to differentiate from white sturgeon.[d]

Larvae:
- Little known, difficult to differentiate from white sturgeon.[d]

Juveniles:
- Found in freshwater areas of the San Joaquin Delta in summer.[c]

***Adults*: anadromous**
- Prefer marine environments.[c]

[a] Froese and Pauly, 2001.
[b] Southern Energy Delta, LLC, 2000.
[c] Emmett et al., 1991.
[d] Wang, 1986.
Fish graphic from California Department of Fish and Game, 2002a.

Longfin smelt (*Spirinchus thaleichthys*)

Longfin smelt is a member of the smelt family (Osmeridae) (Moyle, 1976). Longfin smelt is a native planktivore with a reproductive biology that is similar to delta smelt (Moyle, 1976; Wang, 1986; Herbold and Moyle, 1989; Emmett et al., 1991). It is an anadromous species that is abundant in many Pacific Coast estuaries from Monterey Bay, California, as far north as Prince William Sound, Alaska (Emmett et al., 1991). Longfin smelt have been sold seasonally in bay-delta fish markets (Wang, 1986). They also provide food for numerous predatory fishes, birds, and marine mammals (Emmett et al., 1991).

Adult longfin smelt are found in conditions ranging from seawater to freshwater during their upstream spawning migrations (Moyle, 1976; Wang, 1986; Herbold and Moyle, 1989; Emmett et al., 1991). Adults also show vertical migrations within the water column, concentrating in bottom waters during the day and surface waters at night. Spawning occurs in winter and spring in rivers (Kennish, 2000).

In California, longfin smelt are concentrated around San Pablo Bay, but the population also shows distinct seasonal movements (Moyle, 1976). Early summer is spent in San Francisco and San Pablo bays. In August, longfin smelt move into Suisun Bay, and in winter they congregate for spawning in upper Suisun Bay and the lower delta. In April and May, large schools of juveniles move back downstream, and concentrate in the Carquinez Strait, San Pablo Bay, and San Francisco Bay throughout spring and summer.

Most longfin smelt reach maturity at age 2 (Moyle, 1976; Wang, 1986; Herbold and Moyle, 1989; Emmett et al., 1991). Spawning takes place in freshwater at night from December to June, and is known to occur near both the Pittsburg and Contra Costa plants (Wang, 1986). The majority of adults die after spawning, but some females apparently live to spawn a second time (Moyle, 1976). The average female produces 18,000 to 24,000 eggs (Emmett et al., 1991). Eggs are demersal and adhesive and are deposited singly over rocks and submerged vegetation. Larvae are pelagic, and are found in surface waters from the Carquinez Strait to the lower reaches of the Sacramento and San Joaquin rivers. Schools of larvae often also include delta smelt (Wang, 1986), and it can be difficult to distinguish the two species in I&E samples. Juveniles range from 22 to 88 mm (0.9 to 3.5 in) in length, while adults average 100 mm (3.9 in) (Emmett et al., 1991). In the bay-delta estuary, abundance is positively correlated with the amount of freshwater inflow from February to September (Herbold and Moyle, 1989). Longfin smelt has been identified as a species of concern (Southern Energy Delta, LLC, 2000).

LONGFIN SMELT
(Spirinchus thaleichthys)

Family: Osmeridae (smelt).

Common names: Pacific smelt, Sacramento smelt.[a]

Similar species: Delta smelt.

Geographic range: Northern Pacific from Prince William Sound, Alaska to Monterey Bay, California.[a]

Habitat: Close to shore, in bays and estuaries.[a] Prefers rocky, hard or sandy substrates and aquatic vegetation for cover.[b]

Lifespan: Live up to 3 years.[a]

Fecundity: Females mature at 2 years and usually spawn only once, producing 18,000 to 24,000 eggs.[c]

Food sources:
- Diaphanosoma, Diaptomus, Epischura, mysid shrimp, and other small crustaceans.[b]

Prey for:
- Predatory fish, birds, and marine mammals.[b]

Life stage information:

***Eggs:* demersal**
- Eggs are approximately 1.2mm (0.04 in).[b]
- Eggs are deposited singly.[b]

***Larvae:* pelagic**
- Larvae are 6.9 to 8 mm (0.27 to 0.31 in) at hatching.[b]
- Larvae are found mostly on the surface of the water.[b]

Juveniles:
- Range from 22 to 28 mm (0.9 to 3.5 in) in length.[c]
- Juveniles are found in the middle to bottom of the water column.[b]

***Adults*:**
- Adults average 100 mm (3.9 in).[c]

[a] Froese and Pauly, 2001.
[b] Wang, 1986.
[c] Emmett et al., 1991.
Fish graphic from California Department of Fish and Game, 2002b.

Sacramento splittail (*Pogonichthys macrolepidotus*)

Sacramento splittail is a member of the minnow family (Cyprinidae) and a freshwater native of California's Central Valley (Moyle, 1976; Daniels and Moyle, 1983; Wang, 1986). Splittail are bottom foragers that can reach up to 40.6 cm (16 in) in length. Juveniles provide forage for squawfish and striped bass.

Historically, splittail were abundant in the lakes and rivers of the Central Valley, including upstream reaches of the Sacramento and San Joaquin rivers and their tributaries. However, dams and diversions have restricted upstream access, and splittail are now limited in their distribution to freshwater and brackish conditions in the lower reaches of the Sacramento River, the delta, Suisun Marsh, San Pablo Bay, and Napa Marsh. Over the past 15 years, the species has declined by over 60 percent, primarily as a result of increasing water exports and the loss of shallow-water habitat (Meng and Moyle, 1995). Sacramento splittail was listed as threatened under the Federal Endangered Species Act by the USFWS effective March 1999.

Splittail spawn in the delta in spring over flooded vegetation in tidal freshwater and oligohaline areas (Wang, 1986; Kennish, 2000). The spawning season can extend from late January to July, but most spawning occurs from March through May as water levels and temperatures increase. Females mature at 1-2 years and produce up to 250,000 eggs (Daniels and Moyle, 1983). Eggs are demersal and adhesive and therefore unlikely to be entrained, but larvae and small juveniles are vulnerable. The delta and Suisun Bay are important nursery areas (Kennish, 2000). Larvae are known to concentrate near the Pittsburg plant at New York Slough (Wang, 1986). Juveniles are particularly abundant in Suisun Marsh and the Montezuma Slough of Suisun Bay (Meng and Moyle, 1995). Most splittail complete their life cycle in 5 years.

SACRAMENTO SPLITTAIL
(Pogonichthys macrolepidotus)

Family: Cyprinidae (minnow).

Common names: Splittail.[a]

Similar species:

Geographic range: Formerly throughout the Sacramento-San Joaquin River drainage, now restricted to the San Francisco Bay Delta and lower Sacramento River.[a]

Habitat: Backwaters and pools of rivers and lakes.[a]

Lifespan: Live for 5 years.[b]

Fecundity: Females mature at 1-2 years and produce up to 250,000 eggs.[c]

Food sources:
- Bottom foragers.[d]
- Juveniles prey on algae, pelecypods, and amphipods.[e]

Prey for:
- Juveniles are prey for squawfish and striped bass.[d]

Life stage information:

***Eggs:* demersal**
- Eggs are adhesive, and unlikely to be entrained.[f]
- Mature eggs are 1.3 to 1.6 mm (0.05 to 0.06 in).[e]

***Larvae:* planktonic**
- Hatch at less than 6.5 mm (0.26 in).[e]

Juveniles:
- Found in shallow and open water from the delta to San Pablo Bay.[e]

***Adults*:**
- Spawn in the delta in spring over flooded vegetation in tidal freshwater and oligohaline areas.[e,f]
- May reach 40.6 cm (16 in) in length.[d]

[a] Froese and Pauly, 2001.
[b] Meng and Moyle, 1995.
[c] Daniels and Moyle, 1983.
[d] Moyle, 1976.
[e] Wang, 1986.
[f] Kennish, 2000.
Fish graphic from California Department of Fish and Game, 2002b.

Steelhead (*Oncorhynchus mykiss*)

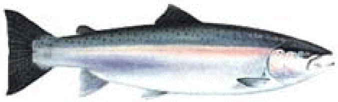
Steelhead is an anadromous form of rainbow trout and is part of the salmon and trout family (Salmonidae) (Moyle, 1976; Herbold and Moyle, 1989; Emmett et al., 1991). It is ecologically similar to chinook salmon.

There are at least two subspecies or races of steelhead in California, defined by when adult fish enter freshwater to spawn (Emmett et al., 1991). The winter run of steelhead that uses the Central Valley migrates upstream during fall, winter, and early spring and spawns from December to June, while the summer run migrates during spring, summer, and early fall and spawn the following spring.

Construction of Shasta Dam blocked access to half of the suitable spawning habitat for steelhead in the Sacramento River drainage, contributing to serious population declines (Herbold and Moyle, 1989). Other causes of decline include dewatered streams resulting from excessive water diversions, rapid flow fluctuations from water conveyance, high water temperatures in summer below reservoirs, and entrainment of juveniles into government water project pumps (McEwan, 1992). In March 1998, the winter run was listed as threatened by the NMFS. Much of the production of steelhead now occurs in hatcheries. Hatchery steelhead have lower survival and reproductive rates than wild steelhead and can reduce the genetic diversity of wild stocks by interbreeding (Emmett et al., 1991).

Steelhead eggs, larvae (alevins), and young juveniles (fry and parr) are riverine life stages that normally remain in freshwater for 1-4 years (Emmett et al., 1991). Alevins range from 14 mm (0.55 in.) at hatching to about 28 mm (1.1 in.). Eggs and alevins are benthic and infaunal. Fry and parr are found in areas with cover and move to deeper water as they grown. Parr transform into smolts as they move through rivers and estuaries on their migration to the ocean, where they remain for 1-5 years before returning to their natal river as adults to spawn. The average female produces 1,500 to 5,000 eggs (Emmett et al., 1991).

Juveniles are found in all habitats of the delta, but it is unknown how long the delta is used as a nursery area (Herbold and Moyle, 1989). Food sources in freshwater and estuarine areas include gammarid amphipods, crustaceans, and small fish (Moyle, 1976). Juveniles range from 28 mm (1.1 in.) to 400 mm (15.7 in.) (Emmett et al., 1991).



STEELHEAD
(Oncorhynchus mykiss)

Family: Salmonidae (salmon and trout).

Common names: Coast range trout, hardhead, rainbow trout, salmon trout.[a]

Similar species: Chinook salmon.

Geographic range: Eastern Pacific from Alaska to Baja California, Mexico.[a]

Habitat:

Lifespan: Adults may reach 11 years.[a]

Fecundity: Females produce from 1,500 to 5,000 eggs.[b]

Food sources:
- Gammarid amphipods, crustaceans, small fish.[c]

Prey for:

Life stage information:

***Eggs:* benthic**
- Spawned in riverine fresh water.

***Larvae:* benthic**
- Larvae range from 14 to 28 mm (0.55 to 1.1 in).[b]

Juveniles:
- Juveniles range from 28 to 400 mm (1.1 to 15.7 in).[b]
- Found in all habitats of the delta.[d]

***Adults*: Anadromous**
- Two subspecies or races of steelhead are defined by the timing of spawning (winter run & summer run).[b]
- May grow as large as 120 cm (47 in).[a]

[a] Froese and Pauly, 2001.
[b] Emmett et al., 1991.
[c] Moyle, 1976.
[d] Herbold and Moyle, 1989.
Fish graphic from Mason, 2002.

Striped bass (*Morone saxatilis*)

Striped bass was intentionally introduced to the Sacramento-San Joaquin River system during the 1870's (Moyle, 1976; Emmett et al., 1991; Stevens, 1992). Unlike some East Coast populations that make extensive coastal migrations, Sacramento-San Joaquin River populations appear to spend most of their lives in bays and estuaries. Adults move into bays (some into the delta) in the fall, overwinter in the bay and delta, and then after spawning in spring, move back to the ocean (Moyle, 1976).

Commercial fishing for striped bass in the San Francisco Bay system has been prohibited since 1935 because of demands by sport anglers (Stevens, 1992). The San Francisco striped bass recreational fishery is one of the most important recreational fisheries on the Pacific Coast. In 1985, it was valued at over $45 million annually (Stevens, 1992). However, the Sacramento-San Joaquin population has declined since the early 1960's. Poor recruitment of young striped bass is thought to be the primary reason for the decline in the adult stock (Stevens, 1992).

Striped bass spawn in schools at night (Stevens, 1992). Spawning occurs in freshwater, beginning in April in California and peaking in May and early June. Females mature at age 5, producing an average of 250,000 eggs per year. Striped bass can live up to 20 years, and exceed 22.7 kg (50 lb) in weight, thus showing high reproductive potential.

Larval striped bass feed on opossum shrimp in the delta and Suisun Bay, reaching about 3.8 cm (1.5 in) in length by late summer (Stevens, 1992). Large numbers of eggs and larvae are killed by the intakes of the Pittsburg and Contra Costa plants and government water projects, contributing to poor recruitment (Stevens, 1992; Southern Energy Delta, LLC, 2000). A number of restoration and management actions are in place to improve recruitment. However, striped bass are voracious predators on small fish, including several delta T&E species or species of concern such as delta smelt, longfin smelt, and Sacramento splittail, complicating management efforts.

STRIPED BASS
(Morone saxatilis)

Family: Moronidae (temperate basses).

Common names: Striper, rockfish, linesider, and sea bass.[a]

Similar species: White perch.

Geographic range: St. Lawrence River in Canada to the St. Johns River in Florida, and from the Suwannee River in western Florida to Lake Pontchartrain, Louisiana.[b] Intentionally introduced to Sacramento-San Joaquin River system.[c]

Habitat: Sacramento-San Joaquin River populations spend most of their lives in bays and estuaries.[c] Juveniles prefer shallow rocky to sandy areas. Adults in inshore areas use a variety of substrates, including rock, boulder, gravel, sand, detritus, grass, moss, and mussel beds.[b]

Lifespan: Adults may reach 30 years.[d]

Fecundity: Females mature at age 5 and produce an average of 250,000 eggs per year.[e]

Food sources:

- Larvae feed primarily on mobile planktonic invertebrates (beetle larvae, copepodids *Daphnia* spp.).[b]
- Juveniles eat larger aquatic invertebrates and small fishes.[b]
- Adults are piscivorous. Clupeid fish are the dominant prey and adults prefer soft-rayed fishes.[b]

Prey for: Any sympatric piscivorous fish.[b]

Life stage information:

Eggs: pelagic

- Eggs and newly hatched larvae require sufficient turbulence to remain suspended in the water column; otherwise, they can settle to the bottom and be smothered.[f]

Larvae: pelagic

- Larvae range from 5 to 30 mm (0.2 to 1.2 in).[b]

Juveniles:

- Most striped bass enter the juvenile stage at 30 mm (1.2 in) total length.[f]
- Juveniles school in larger groups after 2 years of age.[f]

***Adults*: Anadromous**

- Adults move into bays in the fall, overwinter in the bay and delta, and after spawning in the spring, return to the ocean.[c]
- May grow as large as 200 cm (79 in).[a]

[a] Froese and Pauly, 2001.
[b] Hill et al., 1989.
[c] Moyle, 1976.
[d] Atlantic States Marine Fisheries Commission, 2000d.
[e] Stevens, 1992.
[f] Bigelow and Schroeder, 1953.
Fish graphic from California Department of Fish and Game, 2002a.

B2-4 I&E DATA EVALUATED

Table B2-3 lists California facilities in scope of the Phase II rule and the facility I&E data evaluated by EPA. See Chapter A5 of Part A for a discussion of extrapolation methods.

Table B2-3: California Facilities In Scope of the Section 316(b) Phase II Rule and Facility I&E Data Evaluated

In Scope Facilities	I&E Data?	Years of Data
Contra Costa	Yes	1978, 1986-1992
Diablo Canyon Nuclear	Yes	1985, 1987-1988
El Segundo	Yes	1990-2001
Encina	Yes	1979
Harbor	Yes	1979
Haynes	Yes	1979, 2001
Humboldt Bay	Yes	1980
Hunter's Point	Yes	1978
Huntington Beach	Yes	1979-2001
Long Beach	No - extrapolated	
Mandalay	Yes	2001
Morro Bay	Yes	2000
Moss Landing	Yes	1979, 1999
Ormond Beach	Yes	1979, 1990-2001
Pittsburg	Yes	1978, 1986-1992
Potrero	Yes	1978, 2001
AES Redondo Beach	Yes	1979, 1991-2001
San Onofre Nuclear	Yes	1979, 1990-2001
Scattergood	Yes	1990-2002
South Bay	No - extrapolated	

B2-5 EPA'S ESTIMATE OF CURRENT I&E IN CALIFORNIA EXPRESSED AS AGE 1 EQUIVALENTS, FOREGONE YIELD, AND PRODUCTION FOREGONE

Table B2-4 provides EPA's estimate of the annual age 1 equivalents, foregone fishery yield, and production foregone resulting from the impingement of aquatic species at facilities located in California. Table B2-5 displays this information for entrainment.

Table B2-4: Current Annual Impingement in California Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species Group	Age 1 Equivalents (#s)	Yield (lbs)	Production Foregone
American shad	14	3	8
Anchovies	2,397,761	3,756	10,009
Blennies	3,370	0	2
Cabezon	672	1,131	372
California halibut	4,633	17,439	2,173
California scorpionfish	1,964	1,334	264
Chinook salmon	63	0	198
Commercial crabs	102,662	20	1,058
Commercial sea basses	7	2	0
Commercial shrimp	49,058	1	3
Delta smelt	638	0	1
Drums and croakers	366,466	21,226	6,936
Dungeness crab	6,084	2,807	763
Flounders	69,439	5,690	5,188
Forage shrimp	1,747	0	0
Gobies	19,141	0	8
Herrings	371,810	0	15,335
Longfin smelt	6,774	0	28
Other (commercial)	922	179	118
Other (forage)	325,787	0	35
Other (commercial & recreational)	23,877	4,642	3,063
Other (recreational)	16,989	3,303	2,179
Recreational sea basses	8,351	2,058	194
Rockfishes	102,570	24,711	7,693
Sacramento splittail	911	0	93
Salmon	2	7	5
Sculpins	88,869	2,711	2,121
Silversides	635,963	0	27,502
Smelts	36,502	830	991
Steelhead	1	0	3
Striped bass	44,501	37,516	10,613
Surfperches	782,637	48,722	41,470

Table B2-5: Current Annual Entrainment in California Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species Group	Age 1 Equivalents (#s)	Total Yield (lbs)	Production Foregone (lbs)
American shad	1	0	630
Anchovies	282,880	443	185,331
Blennies	80,359,464	0	395,364
Cabezon	500,110	842,357	743,502
California halibut	583,490	2,196,315	1,506
Chinook salmon	3	0	27
Commercial crabs	66,096,905	12,990	28,217,407
Commercial shrimp	5,305,810	138	13,165
Delta smelt	115	0	0
Drums and croakers	3,195,329	185,072	1,904,184
Dungeness crab	71,633	33,051	152,571
Flounders	147,615	12,096	170,697
Forage shrimp	16,808,030	0	25,841
Gobies	16,240,573	0	156,209
Herrings	2,728,452	0	350,759
Longfin smelt	51	0	1
Other (commercial)	44,341	8,621	101,838
Other (forage)	53,084,096	0	303,543
Other (recreational)	5,994	1,165	13,765
Recreational sea basses	4,548,657	1,121,173	129,024
Rockfishes	53,654,899	12,926,604	8,380,148
Sacramento splittail	1	0	1
Sculpins	3,684,908	112,404	424,884
Silversides	17,569	0	2,724
Smelts	1,695	39	2,198
Striped bass	102,238	86,189	1,810,779

B2-6 ASSUMPTIONS USED IN CALCULATING RECREATIONAL AND COMMERCIAL LOSSES

The lost yield estimates presented in Tables B2-4 and B2-5 are expressed as total pounds and include losses to both commercial and recreational catch. To estimate the economic value of these losses, total yield was partitioned between commercial and recreational fisheries based on the landings in each fishery. Table B2-6 presents the percentage impacts assumed for each species, as well as the value per pound for commercially harvested species.

Age-1 equivalent fish that are spared from I&E are not necessarily old enough or large enough to be attractive to anglers. It may take one more year for these fish to reach a harvestable age. For this reason, EPA discounts commercial and recreational benefits so that the cost and benefits estimates will be comparable. Tables B2-7 and B2-8 present the multiplicative discounting factors used in discounting benefits assuming a 3 percent real discount rate and a 7 percent real discount rate. For details on how these factors are developed, see Chapter A14.

Table B2-6: Percentage of Total Impacts Occurring to the Commercial and Recreational Fisheries and Commercial Value per Pound for Species Impinged and Entrained at California Facilities

Species Group	Percent Impact to Recreational Fishery[a,b]	Percent Impact to Commercial Fishery[a,b]	Commercial Value per Pound (2002$)[c]
American shad	0.0%	100.0%	$1.36
Anchovies	0.0%	100.0%	$0.06
Cabezon	45.9%	54.1%	$3.70
California halibut	85.6%	14.4%	$2.66
California scorpionfish	83.7%	16.3%	$1.83
Commercial sea basses	0.0%	100.0%	$1.63
Commercial shrimp	0.0%	100.0%	$0.99
Drums and croakers	69.1%	30.9%	$1.01
Dungeness crab	0.0%	100.0%	$1.68
Flounders	1.0%	99.0%	$0.39
Other (commercial)	0.0%	100.0%	$0.05
Other (recreational)	100.0%	0.0%	na
Other (commercial & recreational)	54.0%	46.0%	$0.25
Northern anchovy	0.0%	100.0%	$0.06
Other commercial crabs	0.0%	100.0%	$1.16
Recreational sea basses	100.0%	0.0%	na
Rockfishes	23.6%	76.4%	$0.52
Salmon	100.0%	0.0%	na
Sculpins	85.0%	15.0%	$2.55
Smelts	6.2%	93.8%	$0.27
Striped bass	100.0%	0.0%	na
Surfperches	93.0%	7.0%	$1.60
Other (forage)[d]	50.0%	50.0%	$0.27

[a] Based on landings from 1993 to 2001.

[b] Calculated using recreational landings data from NMFS (2003c, http://www.st.nmfs.gov/recreational/queries/catch/snapshot.html) and commercial landings data from NMFS (2003a, http://www.st.nmfs.gov/commercial/landings/annual_landings.html).

[c] Calculated using commercial landings data from NMFS (2003a).

[d] Assumed equally likely to be caught by recreational or commercial fishermen. Commercial value calculated as overall average for region based on data from NMFS (2003a).

Table B2-7: Factors Applied to Recreational Benefits to Implement Discounting in California

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Cabezon	0.865	0.723	0.891	0.774
California halibut	0.781	0.573	0.805	0.613
California scorpionfish	na	na	0.877	0.749
Drums and croakers	0.860	0.711	0.886	0.761
Flounders	0.945	0.878	0.973	0.940
Other recreational species	0.922	0.831	0.950	0.889
Other rec. and com. species	na	na	0.950	0.889
Recreational sea basses	0.817	0.632	0.842	0.677
Rockfishes	0.787	0.585	0.811	0.626
Sculpins	0.953	0.896	0.982	0.959
Smelts	0.954	0.899	0.983	0.962
Striped bass	0.864	0.717	0.879	0.749
Surfperches	na	na	0.935	0.859
Other unidentified fish (from forage losses)	0.919	0.829	0.919	0.829

Table B2-8: Factors Applied to Commercial Benefits to Implement Discounting in California

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
American shad	na	na	0.893	0.773
Anchovies	0.933	0.856	0.961	0.916
Cabezon	0.832	0.663	0.857	0.710
California halibut	0.755	0.532	0.778	0.569
California scorpionfish	na	na	0.818	0.643
Commercial sea basses	na	na	0.819	0.637
Commercial shrimp	0.969	0.932	0.999	0.997
Drums and croakers	0.842	0.680	0.868	0.727
Dungeness crab	0.916	0.819	0.944	0.877
Flounders	0.930	0.847	0.958	0.907
Other commercial species	0.913	0.813	0.940	0.870
Other rec. and com. species	na	na	0.940	0.870
Northern anchovy	0.938	0.865	na	na
Other commercial crabs	0.882	0.750	0.908	0.803
Rockfishes	0.764	0.547	0.787	0.586
Sculpins	0.943	0.875	0.971	0.936
Smelts	0.922	0.832	0.950	0.890
Surfperches	na	na	0.926	0.840
Other unidentified fish (from forage losses)	0.900	0.792	0.900	0.792

Chapter B3: Commercial Fishing Valuation

INTRODUCTION

This chapter presents the results of the commercial fishing benefits analysis for the California region. Section B3-1 details the estimated losses under current, or baseline, conditions. Section B3-2 presents the expected benefits in the region attributable to the rule. Chapter A10 details the methods used in this analysis. All results are for Northern California and Southern California combined.

CHAPTER CONTENTS

Note that all results have been sample weighted in this version. In the final revision results will be reported unweighted.

B3-1 BASELINE LOSSES

Table B3-1 provides EPA's estimate of the value of gross revenues lost in commercial fisheries resulting from the impingement of aquatic species at facilities in the California region. Table B3-2 displays this information for entrainment. Total annual revenue losses are approximately $6.1 million, assuming a 3 percent discount rate.

Table B3-1: Annual Commercial Fishing Gross Revenues Lost Due to Impingement at Facilities in the California Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002 dollars)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
Anchovies	3,756	223	214	204
Cabezon	612	2,265	1,941	1,607
California halibut	2,515	6,700	5,213	3,814
Flounders	5,631	2,173	2,082	1,971
Rockfishes	18,877	9,882	7,778	5,787
Sculpins	406	1,037	1,007	971
Smelts	778	209	198	186
Surfperches	3,412	5,475	5,071	4,602
American shad	3	5	4	4
Crabs (commercial)	20	23	21	19
Drums and croakers	6,553	6,621	5,745	4,815
Dungeness crab	2,807	4,711	4,446	4,129
Other (commercial)	179	9	9	8
Shrimp (commercial)	1	1	1	1
California scorpionfish	217	397	325	256
Other (rec. and com.)	2,136	541	509	471
Sea basses (commercial)	2	3	2	2
Other unidentified species (from forage losses)	4,342	1,177	1,059	932
TOTAL	52,248	41,453	35,627	29,778

Table B3-2: Annual Commercial Fishing Gross Revenues Lost Due to Entrainment at Facilities in the California Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002 dollars)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
Anchovies	442	26	24	22
Cabezon	456,096	1,686,720	1,403,524	1,118,679
California halibut	316,710	843,802	637,356	448,884
Flounders	11,970	4,620	4,297	3,915
Rockfishes	9,874,518	5,169,293	3,950,073	2,829,210
Sculpins	16,828	42,994	40,552	37,627
Smelts	36	10	9	8
Crabs (commercial)	12,990	15,009	13,235	11,257
Drums and croakers	57,141	57,733	48,636	39,239
Dungeness crab	33,051	55,465	50,821	45,439
Other (commercial)	8,621	436	399	355
Northern anchovy	128	7	7	6
Shrimp (commercial)	138	137	133	128
Other unidentified species (from forage losses)	614,088	166,453	149,827	131,852
TOTAL	11,402,757	8,042,706	6,298,892	4,666,621

B3-2 BENEFITS

As described in Chapter A10, EPA estimates that 0 to 40 percent of the gross revenue losses represent surplus losses to producers, assuming no change in prices or fishing costs. The 0 percent estimate, of course, results in loss estimates of $0. The 40 percent estimates, as presented in the Table B3-3, total approximately $2.5 million when a 3 percent discount rate is assumed.

The expected reductions in I&E attributable to changes at facilities required by the rule are 30.9 percent for impingement and 21.0 percent for entrainment. Total annual benefits are estimated by applying these estimated reductions to the annual producer surplus loss. As presented in Table B3-3, this results in total annual benefits of $0.5 million, assuming a 3 percent discount rate.

Table B3-3: Annual Commercial Fishing Benefits Attributable to Phase II Rule at Facilities in the California Region (million 2002$), Assumes Compliance in 2005

	Impingement	Entrainment	Total
Baseline loss - gross revenue			
Undiscounted	$0.04	$8.04	$8.08
3% discount rate	$0.03	$6.11	$6.14
7% discount rate	$0.03	$4.34	$4.37
Producer Surplus Lost - Low	**$0.0**	**$0.0**	**$0.0**
Producer Surplus Lost - High (gross revenue * 0.4)			
Undiscounted	$0.02	$3.22	$3.23
3% discount rate	$0.01	$2.44	$2.46
7% discount rate	$0.01	$1.74	$1.75
Expected reduction due to rule[a]	30.9%	21.0%	---
Benefits attributable to rule - Low	**$0.0**	**$0.0**	**$0.0**
Benefits attributable to rule - High			
Undiscounted	$0.01	$0.68	$0.68
3% discount rate	$0.00	$0.51	$0.52
7% discount rate	$0.00	$0.37	$0.37

[a] Estimated based on EPA's assumptions. EPA's assumption about the amount of electricity that will be produced in the future differs very slightly from DOE's. Using DOE's assumptions, the expected reductions would be 31.4 percent for impingement and 22.9 percent for entrainment.

Chapter B4: RUM Analysis

CHAPTER CONTENTS

INTRODUCTION

This case study uses a random utility model (RUM) approach to estimate the benefits of improved fishing opportunities due to reduced impingement and entrainment (I&E) in the Northern and Southern California regions. The Northern and Southern California regions are defined based on National Marine Fisheries Service (NMFS) regional boundaries. Northern California includes all northern counties to, and including, San Luis Obispo County. Southern California includes all southern counties to, and including, Santa Barbara County.

EPA included anglers intercepted at sites in both the Northern California region and the Southern California region in the RUM model. Thus, the model allows for substitution of sites across the two regions. When constructing each angler's choice set, EPA included all sites within 140 miles of the angler's home zip code. Thus, sites from the Southern California region were included for some Northern California anglers, and vice versa, to allow anglers to travel to all substitute sites located within a one day travel distance limit.

Cooling Water Intake Structures (CWIS) withdrawing water from California coastal waters and estuaries impinge and entrain many of the species sought by recreational anglers. These species include halibut, other flatfish, striped bass, sea basses, various bottom fish species, and other less prominent species. Accordingly, EPA included the following species and species groups in the model: flatfish, striped bass, sea basses, bottom fish, small game fish, salmon, sturgeon, other small fish, and other species. Some of these species inhabit a wide range of coastal waters, which can span the entire coast of California.

The study's main assumption is that, all else being equal, anglers will get greater satisfaction, and thus greater economic value, from sites with a higher catch rate. This benefit may occur in two ways: first, an angler may get greater enjoyment from a given fishing trip with higher catch rates, yielding a greater value per trip; second, anglers may take more fishing trips when catch rates are higher, resulting in greater overall value for fishing in the region.

The following sections focus on the data set used in the analysis and the analytic results. Chapter A-11 provides a detailed description of the RUM methodology used in this analysis.

B4-1 DATA SUMMARY

EPA's analysis of improvements in recreational fishing opportunities in California relies on data collected by the NMFS' Marine Recreational Fishery Statistics Survey (MRFSS) (NMFS, 2003b).[1] The model of recreational fishing behavior relies on a subset of the data that includes only single-day trips to sites located in California. In addition, the sample excludes respondents missing data on key variables (e.g., home town), and includes only private/rental boat and shore mode anglers. The Agency did not include charter boat anglers in the model. As explained below, the welfare gain to charter boat anglers from improved catch rates is approximated based on the regression coefficients developed for the boat anglers. Additionally,

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[1] For general discussion of the MRFSS, see Chapter A11 of the Regional Study Report or Marine Recreational Fisheries Statistics: Data User's Manual, http://www.st.nmfs.gov/st1/recreational/pubs/data_users/index.html (NMFS, 1999a).

values for single-day trips were used to value each day of a multi-day trip. The final sample used to estimate the RUM model includes 11,367 boat and shore anglers.

B4-1.1 Summary of Anglers' Characteristics

a. Fishing modes and targeted species

Fifty-one percent of the anglers in the sample fish from either a private or a rental boat (see Table B4-1). Approximately 24 percent fish from the shore, and 24 percent fish from a party or charter boat. In Northern California, most anglers (61 percent) fish from a private or rental boat; 28 percent fish from shore, and only 11 percent fish from party or charter boats. In Southern California, 44 percent fish from private or rental boats, 34 percent fish from party or charter boats, and 22 percent fish from shore.

Table B4-1: Fishing Mode Choice, Northern and Southern California

Fishing Mode	All California		Northern California		Southern California	
	Frequency	Percent	Frequency	Percent by Mode	Frequency	Percent by Mode
Shore	4,007	24.48%	1,892	27.79%	2,115	22.12%
Private/Rental Boat	8,383	51.21%	4,158	61.07%	4,225	44.19%
Party/Charter Boat	3,979	24.31%	759	11.15%	3,220	33.68%
All Modes	16,369	100.00%	6,809	100.00%	9,560	100.00%

Source: NMFS, 2003b.

In addition to the mode of fishing, the MRFSS contains information on the specific species targeted on the current trip (see Tables B4-2 and B4-3). In Northern California, approximately 26 percent of anglers did not have a designated target species. The most popular targeted species, targeted by 25 percent of anglers, is salmon. The second most popular species group, targeted by 20 percent of anglers, is bottom fish. Of the remaining anglers, 9 percent target striped bass, 9 percent target flatfish (primarily California halibut), 6 percent target sturgeon, 2 percent target other species, 2 percent target small game fish, one percent target big game fish, and 0.5 percent target other small fish.[2]

In Southern California, 45 percent of anglers do not target a particular species. The most popular targeted species, targeted by 13 percent of anglers, is jacks. The second most popular species group, targeted by 12 percent of anglers, is flatfish (mostly California halibut). Of the remaining anglers, 10 percent target sea basses, 9 percent target bottom fish, 5 percent target small game, 4 percent target big game fish, and less than one percent target each of the following species/species groups: other species, salmon, other small fish, and striped bass.[3]

The distribution of target species is not uniform by fishing mode. In Northern California, for example, 34 percent of private/rental boat anglers and 28 percent of charter anglers target salmon, while less than 2 percent of shore anglers target salmon. Forty-six percent of shore anglers do not target a particular species, while only 20 percent of private/rental boat anglers and 13 percent of charter boat anglers do not target a particular species. Almost 58 percent of charter boat anglers target bottom fish species, while only 12 percent of private/rental boat anglers and 22 percent of shore anglers target bottom fish. Fourteen percent of private/rental boat anglers target flatfish (primarily halibut), while no charter anglers and less than two percent of shore anglers target flatfish. Twenty-two percent of shore anglers target striped bass, while only 6 percent of private/rental boat anglers and no charter boat anglers target striped bass.

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[2] Bottom fish species include surfperches, seaperches, sheephead, croakers, rockfishes, scorpionfish, drums, hake, tomcod, opaleye, sargo, mullet, and queenfish. Small game fish include Pacific bonito, Pacific barracuda, and small tunas and mackerels. Flatfish include California halibut, sanddabs, starry flounder, and other flounders. Big game fish include sharks, dolphins, and tunas. Other small fish include the anchovy family, silverside family, pacific sardine, herrings, jacksmelt, and other smelts.

[3] Jacks include jack mackerel and yellowtail. Sea basses include kelp bass and sandbasses.

Table B4-2: Species Group Choice by Mode of Fishing, Northern California

Species Group	All Modes		Private/Rental Boat		Party/Charter Boat		Shore	
	Frequency	Percent	Frequency	Percent by Mode	Frequency	Percent by Mode	Frequency	Percent by Mode
Small Game	114	1.67%	102	2.45%	10	1.32%	2	0.11%
Striped Bass	641	9.41%	229	5.51%	0	0.00%	412	21.78%
Bottom Fish	1337	19.64%	490	11.78%	440	57.97%	407	21.51%
Flatfish	602	8.84%	566	13.61%	0	0.00%	36	1.90%
Big Game	95	1.40%	82	1.97%	0	0.00%	13	0.69%
Salmon	1669	24.51%	1,433	34.46%	209	27.54%	27	1.43%
Sturgeon	395	5.80%	371	8.92%	0	0.00%	24	1.27%
Other Species	130	1.91%	68	1.64%	0	0.00%	62	3.28%
Other Small Fish	34	0.50%	1	0.02%	0	0.00%	33	1.74%
No Target	1792	26.32%	816	19.62%	100	13.18%	876	46.30%
All Species	6,809	100.00%	4,158	100.00%	759	100.00%	1,892	100.00%

Source: NMFS, 2003b.

Table B4-3: Species Group Choice by Mode of Fishing, Southern California

Species Group	All Modes		Private/Rental Boat		Party/Charter Boat		Shore	
	Frequency	Percent	Frequency	Percent by Mode	Frequency	Percent by Mode	Frequency	Percent by Mode
Small Game	509	5.32%	251	5.94%	134	4.16%	124	5.86%
Other Small Fish	16	0.17%	0	0.00%	0	0.00%	16	0.76%
Striped Bass	1	0.01%	1	0.02%	0	0.00%	0	0.00%
Jacks	1,283	13.42%	748	17.70%	535	16.61%	0	0.00%
Sea Basses	964	10.08%	662	15.67%	204	6.34%	98	4.63%
Bottom Fish	852	8.91%	340	8.05%	369	11.46%	143	6.76%
Flatfish	1,153	12.06%	775	18.34%	176	5.47%	202	9.55%
Big Game	423	4.42%	247	5.85%	135	4.19%	41	1.94%
Salmon	24	0.25%	24	0.57%	0	0.00%	0	0.00%
Other	73	0.76%	21	0.50%	34	1.06%	18	0.85%
No Target	4,262	44.58%	1,156	27.36%	1,633	50.71%	1,473	69.65%
All Species	9,560	100.00%	4,225	100.00%	3220	100.00%	2,115	100.00%

Source: NMFS, 2003b.

In Southern California, no shore anglers target jacks, while 18 percent of private/rental boat anglers and 17 percent of charter anglers target jacks. Sixteen percent of private/rental boat anglers target sea basses, while only 6 percent of charter anglers and 5 percent of shore anglers target sea basses. Eighteen percent of private/rental boat anglers target flatfish, while 10 percent of shore anglers and 5 percent of charter anglers target flatfish. Seventy percent of shore anglers do not target a particular species, and 51 percent of charter anglers and 27 percent of boat anglers do not target a particular species.

b. Anglers' characteristics

This section presents a summary of angler characteristics for California, using the data included in the RUM model, i.e., only data for private/rental boat anglers and shore anglers. This data set includes 11,367 observations: 7,809 boat anglers and 3,558 shore anglers. Table B4-4 summarizes information on fishing trips and anglers.

The average income of the respondent anglers was $52,021. Because income was not reported by intercept survey respondents, EPA used median household income data by zip code, from the U.S. Census Bureau in 2000, to approximate income data for survey respondents.[4] Ninety-two percent of the anglers are male. The average angler spent 27 days fishing during the past year. The average trip cost for surveyed trips is $16 (2000$),[5] and the average one way travel time to the site was about 40 minutes.[6] The average duration of a fishing trip was four and a half hours. The California data did not include additional demographic statistics.

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[4] Census data for median income by zip code are in census Summary File 3 (U.S. Census Bureau, 2002).

[5] All costs are in 2000$, which represent the MRFSS survey year. All costs/benefits will be updated to 2002$ later in this analysis (e.g., for welfare estimation).

[6] Calculation of trip cost and travel time is explained in section B4-1.4.

Table B4-4: Data Summary for California Anglers

Variable	All Modes			Private/Rental Boat			Shore		
	N	Mean[a]	Std Dev	N	Mean[a]	Std Dev	N	Mean[a]	Std Dev
Travel Cost (2002$)	11,367	15.66	16.14	7,809	17.25	16.78	3,558	12.17	14.01
One Way Travel Time (hours)	11,367	0.60	0.62	7,809	0.66	0.65	3,558	0.47	0.54
Male	16,300	0.92	0.27	8,336	0.94	0.24	3,987	0.89	0.31
Annual Trips	16,117	27.13	41.34	8,261	26.36	33.67	3,918	36.80	57.24
Income	11,367	$52.021	$17.115	7,809	$53,353	$17,011	3,558	$49,096	$16,982
Average Trip Length (hours)	16,343	4.38	2.10	8,367	5.09	1.98	3,999	3.27	1.74

[a] For dummy variables such as “Male” that take the value of 0 or 1, the reported value represents a portion of the survey respondents possessing the relevant characteristic. For example, 92 percent of the surveyed anglers are males.

Sources: NMFS, 2003b; and U.S. Census Bureau, 2002.

B4-1.2 Recreational Fishing Choice Sets

The NMFS survey intercept sites included in the analysis are depicted in Figure B1-1 in Chapter B1 of this report. There are 126 fishing sites in the Northern California region total choice set, and 122 sites in the Southern California region choice set. Choice sets for individual anglers were generated based on NMFS sites located within 140 miles of the respondent's home zip code.[7] Distances from unique zip codes to each of the 248 NMFS sites located in California were estimated using ArcView 3.2a software. A maximum of 37 sites defines the choice set, inclusive of the site actually visited at the time of the survey. In cases where more than 37 additional sites per mode are within the 140 mile distance limit, 37 sites are randomly drawn from the available sites. Table B4-5 summarizes the number of sites available, and anglers intercepted, for each county in California.

Table B4-5: Number of California Sites and Anglers by County

County	Number of Sites	Number of Intercepted Anglers[a]
Northern CA		
Alameda	12	650
Contra Costa	5	409
Del Norte	6	119
Humboldt	11	379
Marin	11	388
Mendocino	10	233
Monterey	12	409
San Francisco	12	326
San Luis Obispo	10	239
San Mateo	15	602
Santa Clara	1	0
Santa Cruz	10	745
Solano	2	530
Sonoma	9	256
Total Northern CA	126	5,285
Southern CA		
Los Angeles	32	1,968
Orange	17	863
San Diego	35	2,595
Santa Barbara	18	166
Ventura	20	486
Total Southern CA	122	6,078

[a] Includes intercepted private/rental boat and shore mode anglers only. Charter boat anglers are not included as no specific charter boat model of site choice was estimated.

Source: NMFS, 2003b.

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[7] The distance limit was based on the 99th percentile for the distance traveled to a fishing site.

B4-1.3 Site Attributes

This analysis assumes that the angler chooses between site alternatives by comparing his/her utility for each alternative and choosing the one that maximizes his/her utility. Following McConnell and Strand (1994), we assume that the individual first chooses a mode and species and then, conditional on this choice, chooses the recreational site (Hicks et al., 1999).

To measure site quality, this analysis uses catch rates for the fish species of concern, as well as the presence of marinas and/or docks at each site, and the presence of piers or jetties at each site. Catch rate is the most important attribute of a fishing site from the angler's perspective (McConnell and Strand, 1994; Haab et al., 2000). This attribute is also a policy variable of concern because catch rate is a function of fish abundance, which is affected by fish mortality due to I&E. The catch rate variable in the RUM therefore provides the means to measure baseline losses in I&E and changes in anglers' welfare attributed to changes in I&E resulting from the final section 316(b) rule.

To specify the fishing quality of the case study sites, EPA calculated historic catch rate based on the NMFS catch rates from 1996 to 2000. Seven species or species groups were included in the model: sturgeon, salmon, flatfish, small game fish, big game fish, bottom fish, and other species. No-target anglers in California caught fish in all species groups included in the model. Thus, for no-target anglers, EPA calculated average catch for all species caught by anglers who did not target a specific species.

The catch rates represent the number of fish caught on a fishing trip divided by the number of hours spent fishing (i.e., the number of fish caught per hour per angler). The estimated catch rates are averages across all anglers by mode, target species, and site over the five-year period (1996-2000).

The catch rate variables include total catch, including fish caught and kept and fish released. Some NMFS studies use the catch-and-keep measure as the relevant catch rate. Although a greater error may be associated with the measured number of fish not kept, the total catch measure is most appropriate because a large number of anglers catch and release fish. The total catch rate variables include both targeted fish catch and incidental catch. For example, small game catch rates include fish caught by small game anglers, anglers targeting another species group but who actually caught a small game fish, and anglers who don't target any particular species. Anglers who target particular species generally catch more fish in the targeted category than anglers who do not target these species because of specialized equipment and skills. EPA considered using targeted species catch rates for this analysis, but discovered that this approach did not provide a sufficient number of observations to allow estimation of catch rates for all fishing sites included in the analysis. Tables B4-6 and B4-7 summarize average catch rates by species for Northern and Southern California sites.

- Northern California sites. Of the boat mode anglers who target particular species, bottom fish anglers catch the largest number of fish per hour (1.15), followed by anglers who target other small fish (0.71), those who target small game (0.62), those who target other species (0.56), those who target big game (0.45), those who target flatfish (0.40), those who target striped bass (0.36), those who target salmon (0.34), and those who target sturgeon (0.21). Of the shore mode anglers who target particular species, anglers who target other small fish catch the largest number of fish per hour (1.88), followed by anglers who target bottom fish (1.01), those who target small game (0.78), those who target flatfish (0.63), those who target other species (0.53), those who target sturgeon (0.52), those who target striped bass (0.47), and those who target salmon (0.28).

- Southern California sites. Of the boat mode anglers who target particular species, small game anglers catch the largest number of fish per hour (0.84), followed by anglers who target sea basses (0.76), those who target bottom fish (0.65), those who target other small fish (0.58), those who target salmon (0.52), those who target flatfish (0.45), those who target other species (0.44), those who target jacks (0.42), those who target big game (0.41), and those who target striped bass (0.20). Of the shore anglers who target particular species, anglers who target other small fish catch the largest number of fish per hour (1.50), followed by anglers who target small game (1.11), those who target bottom fish (1.05), those who target sea basses (0.65), those who target flatfish (0.55), and those who target other species (0.48).

Some RUM studies use predicted, rather than actual, catch rates (Haab et al., 2000; Hicks et al., 1999; McConnell and Strand, 1994). This practice allows for individual characteristics to affect catch rates; for example, anglers with different levels of experience may have different catch rates. Haab et al. (2000) compared historic catch-and-keep rates to predicted catch-and-keep rates and found that historic catch-and-keep rates were a better measure of site quality. Hicks et al. (1999) found that using historic catch rates resulted in more conservative welfare estimates than predicted catch rate models. Consequently, EPA favored this more conservative approach.

Table B4-6: Average Catch Rate by Species/Species Group for Northern California Sites by Mode of Fishing

Species/Species Group	Average Catch Rate (fish per angler per hour)			
	All Sites		Sites with Non Zero Catch Rates	
	Private/Rental Boat	Shore	Private/Rental Boat	Shore
Small Game	0.078	0.080	0.615	0.776
Striped Bass	0.060	0.160	0.360	0.469
Bottom Fish	0.420	0.697	1.152	1.009
Flatfish	0.116	0.140	0.404	0.628
Big Game	0.111	N/A	0.449	N/A
Salmon	0.085	0.020	0.336	0.280
Sturgeon	0.023	0.025	0.206	0.520
Other Species	0.186	0.248	0.557	0.530
Other Small Fish	0.107	0.731	0.713	1.880
No Target	0.294	0.645	0.881	0.992

Source: NMFS, 2002e.

Table B4-7: Average Catch Rate by Species/Species Group for Southern California Sites by Mode of Fishing

Species/Species Group	Average Catch Rate (fish per angler per hour)			
	All Sites		Sites with Non Zero Catch Rates	
	Private/Rental Boat	Shore	Private/Rental Boat	Shore
Small Game	0.192	0.418	0.837	1.109
Striped Bass	0.002	N/A	0.200	N/A
Bottom Fish	0.145	0.730	0.654	1.047
Flatfish	0.096	0.227	0.451	0.553
Big Game	0.057	N/A	0.408	N/A
Salmon	0.009	N/A	0.522	N/A
Sea Basses	0.231	0.353	0.761	0.652
Other Species	0.104	0.267	0.440	0.478
Other Small Fish	0.080	0.615	0.575	1.501
No Target	0.238	0.569	1.003	0.857
Jacks	0.065	N/A	0.415	N/A

Source: NMFS, 2002e.

B4-1.4 Travel Cost

EPA used ArcView 3.2a software to estimate distances from the household zip code to each NMFS fishing site in the individual opportunity sets. The Agency obtained fishing site locations from the Master Site Register supplied by NMFS. The Master Site Register includes both a unique identifier that corresponds to the visited site identifier used in the angler survey, and latitude and longitude coordinates. For some sites, the latitude and longitude coordinates were missing or demonstrably incorrect, in which case the town point, as identified in the U.S. Geological Survey (USGS) Geographic Names Information System, was used as the site location if a town was reported in the site address. The program measured the distance in miles of the shortest route, using state and U.S. highways, from the household zip code to each fishing site, then added the distances from the zip code location to the closest highway and from the site location to the closest highway. The average one-way distance to the visited site for all modes is 24.08 miles. Private/rental boat anglers traveled farther, on average, to the chosen site than shore anglers, going 26.53 miles versus 18.72 miles.

EPA estimated trip "price" as the sum of travel costs plus the opportunity cost of time following the procedure described in Haab et al. (2000). Based on Parsons and Kealy (1992), this study assumed that time spent "on-site" is constant across sites and can be ignored in the price calculation. To estimate anglers' travel costs, EPA multiplied round trip distance by average motor vehicle cost per mile ($0.325, 2000 dollars).[8] To estimate the opportunity cost of travel time, EPA first divided round trip distance by 40 miles per hour to estimate trip time, and used one-third of the household's wage to yield the opportunity cost of time. EPA estimated household wage by dividing household income by 2,080 (i.e., the number of full time hours potentially worked).

EPA calculated visit price as:

$$Visit\ Price = (Round\ Trip\ Distance \times \$.325) + \left[\frac{Round\ Trip\ Distance}{40\ mph} \times (Wage) \times 0.33 \right] \tag{B4-1}$$

B4-2 SITE CHOICE MODELS

The nature of the MRFSS data leads to the RUM as a means of examining anglers' preferences (Haab et al., 2000). Anglers arrive at each NMFS site by choosing among a set of feasible sites. The RUM assumes that the individual angler makes a choice among mutually exclusive site alternatives based on the attributes of those alternatives (McFadden, 1981). The number of feasible choices (*J*) in each angler's choice set was set to 37 sites within 140 miles of the angler's home.

An angler's choice of sites relies on utility maximization. An angler will choose site *j* if the utility (u_j) from visiting site *j* is greater than that from vising other sites (*h*), such that:

$$u_j > u_h \ for\ h = 1, ... , J\ and\ h \neq j \tag{B4-2}$$

Anglers choose the species to seek and the mode of fishing in addition to choosing a fishing site. Available fishing modes include shore fishing, fishing from charter boats, or fishing from private or rental boats. The target species or group of species include small game, striped bass, jacks, sea basses, bottom fish, flatfish, big game fish, salmon, sturgeon, and other fish. Anglers may also choose not to target any particular species.

Recreational fishing models generally assume that anglers first choose a mode and species, and then a site. The nested logit model is generally used for recreational demand models, as it avoids the independence of relevant alternatives (IIA) problem, in which sites with similar characteristics that are not included in the model have correlated error terms. However, the nested model did not work well for the California region, indicating that nesting may not be appropriate for the data. Consequently, EPA estimated separate logit models for boat and shore anglers. The Agency did not include the angler's choice of fishing

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[8] EPA used the 2000 government rate ($0.325) for travel reimbursement to estimate travel costs per mile traveled. This estimate includes vehicle operating cost only.

mode and target species in the model, instead assuming that the mode/species choice is exogenous to the model and that the angler simply chooses the site. EPA used the following general model to specify the deterministic part of the utility function:[9]

$$v\ (site\ j)\ =\ f\ (TC_j,\ SITE\text{-}ATTRIBUTES_j,\ SQRT(Q_{js})\ \times\ Flag(s)) \qquad \text{(B4-3)}$$

where:

v = the expected utility for site j (j=1,...37);
TC_j = travel cost for site j;
$SITE\text{-}ATTRIBUTES_j$ = presence of marinas or docks; or piers or jetties at site j;
$SQRT(Q_{js})$ = square root of the historic catch rate for species s at site j;[10] and
$Flag(s)$ = 1 if an angler is targeting this species; 0 otherwise.

The analysis assumes that each angler in the estimated model considers site quality based on the catch rate for the targeted species and site amenities such as the presence of marinas and/or docks and piers or jetties at each site. Theoretically, an angler may catch any of the available species at a given site (McFadden, 1981). If, however, an angler truly has a species preference, then including the catch variable for all species available at the site would inappropriately attribute utility to the angler for a species not pursued (Haab et al., 2000). To avoid this problem, the Agency used an interaction variable $SQRT(Q_{js}) \times Flag(s)$, such that the catch rate variable for a given species is turned on only if the angler targets a particular species [$Flag\ (s)$ =1]. The Agency calculated a separate catch rate for no-target anglers, using the average of all species caught by no-target anglers. The final model presented here is a site choice model that includes all fish species. The analysis therefore assumes that each angler has chosen a mode/species combination followed by a site based on the catch rates for that site and species. EPA estimated all RUM models with LIMDEP^{TM} software (Greene, 1995). Table B4-8 gives the parameter estimates for the boat and shore models.

One disadvantage of the specified model is that the model looks at site choice without regard to mode or species, whereas mode and species selection may be integral parts of the nested RUM. In the model presented here, once an angler chooses a target species and mode, no substitution is allowed across species or mode (i.e., the value of catching, or potentially catching, a different species, or fishing by a different mode, is not included in the calculation). Therefore, improvements in fishing circumstances related to species other than the target species will have no effect on angler's choices.

Table B4-8 shows that most coefficients have the expected signs and are statistically significant at the 95th percentile or better. The exceptions are the coefficients on sea basses and other small fish in the shore model. Trip cost has a negative effect on the probability of selecting a site, indicating that anglers prefer to visit sites closer to their homes (other things being equal). In the boat model, the positive coefficient on the marina/dock variable for Northern California and the negative coefficient on the pier/jetty variable indicates that anglers fishing from boats in Northern California are more likely to choose sites with marinas or docks, and less likely to choose sites with piers or jetties. The signs on these variables are reversed for shore anglers, for both Northern and Southern California, indicating that shore anglers prefer sites with piers or jetties, and are less likely to fish from marinas or docks. For the boat model, the Southern region has a negative coefficient on the marina/dock variable. This result is counter-intuitive, and is likely a result of insufficient data on site amenities in the Southern California region.

For all species, the probability of a site visit increases as the historic catch rate for fish species increases. EPA used historic catch rates averaged over all species caught by no-target anglers to characterize fishing site quality for no-target anglers. Many species can contribute to sites' perceived quality for no-target anglers because they catch whatever bites. In general, no-target anglers select sites with higher historic catch rates.

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[9] See Chapter A-11 for details on model specification.

[10] The analysis used the square root of the catch rate to allow for decreasing marginal utility of catching fish (McConnell and Strand, 1994).

Table B4-8: Estimated Coefficients for the Conditional Site Choice

Variable	Private/Rental Boat Model		Shore Model	
	Estimated Coefficient	t-statistic	Estimated Coefficient	t-statistic
Travel Cost	-0.0524	-73.39	-0.0827	-49.67
SQRT ($Q_{\text{small game}}$)	1.5578	12.10	1.9067	7.33
SQRT ($Q_{\text{striped bass - North}}$)	3.3437	7.82	1.9558	9.89
SQRT ($Q_{\text{jacks - South}}$)	11.9676	25.00	N/A	N/A
SQRT ($Q_{\text{sea basses - South}}$)	0.5443	5.51	0.1873	0.57
SQRT (Q_{bottom})	1.8420	15.58	0.7824	5.24
SQRT ($Q_{\text{flatfish - North}}$)	2.7179	12.71	2.4743	5.00
SQRT ($Q_{\text{flatfish - South}}$)	4.4960	21.81	1.6156	6.98
SQRT ($Q_{\text{big game - North}}$)	2.9221	5.51	N/A	N/A
SQRT ($Q_{\text{big game - South}}$)	1.5820	10.27	N/A	N/A
SQRT ($Q_{\text{salmon - North}}$)	5.5201	23.88	N/A	N/A
SQRT ($Q_{\text{salmon - South}}$)	4.2645	5.63	N/A	N/A
SQRT ($Q_{\text{sturgeon - North}}$)	17.3385	10.21	N/A	N/A
SQRT ($Q_{\text{other - North}}$)	N/A	N/A	3.0937	5.28
SQRT ($Q_{\text{other - South}}$)	1.4604	2.30	1.7437	1.50
SQRT ($Q_{\text{other small fish}}$)	N/A	N/A	1.1416	6.63
SQRT ($Q_{\text{no target}}$)	0.4074	10.22	0.5255	8.23
Marina/Dock	N/A	N/A	-0.2206	-3.86
Marina/Dock - North	0.4235	10.17	N/A	N/A
Marina/Dock - South	-1.1688	-17.40	N/A	N/A
Pier/Jetty	-0.7106	-23.30	0.4777	12.81

Source: U.S. EPA analysis for this report.

B4-3 WELFARE ESTIMATES

This section presents estimates of welfare losses to recreational anglers from fish mortality due to I&E, and potential welfare gains from improvements in fishing opportunities due to reduced fish mortality stemming from the final section 316(b) rule.

B4-3.1 Estimating Changes in the Quality of Fishing Sites

To estimate changes in the quality of fishing sites under different policy scenarios, EPA relied on the recreational fishery landings data by state and the estimates of recreational losses from I&E corresponding to different technology options. The NMFS provided recreational fishery landings data for the Northern and Southern California regions. EPA estimated the losses to recreational fisheries using the physical impacts of I&E on the relevant fish species, and the percentage of total fishery landings attributed to recreational fishing, as described in Chapter B2 of this document. I&E affects recreational species in two ways: by directly killing recreational species, and by killing forage species, thus indirectly affecting recreational species through the food chain. The indirect effects on recreational species were calculated in two steps. First, EPA estimated the total number of fish lost due to forage fish losses. Second, EPA allocated this total number of fish among recreational species according to each species' percent of total recreational landings.

The Agency estimated changes in the quality of recreational fishing sites under different policy scenarios in terms of the percentage change in the historic catch rate. EPA estimated changes in catch rates for each NMFS region, Northern and Southern California, separately. The Agency assumed that catch rates will change uniformly across all marine fishing sites in each NMFS region (i.e., Northern and Southern California), because species considered in the analysis inhabit the entire coast of each NMFS region.[11] For each species included in the model, EPA used five-year recreational landing data (1996 through 2000) for state waters to calculate an average landing per year for a given NMFS region in California.[12] EPA then divided losses to the recreational fishery from I&E by the total recreational landings for a given NMFS region to calculate the percent change in historic catch rate from eliminating I&E completely. Table B4-9 presents results of this analysis for Northern California, and Table B4-10 presents results for Southern California. EPA estimated that compliance with the Phase II rule would reduce impingement by 32.1 percent in Northern California and 30 percent in Southern California, and would reduce entrainment by 35.93 percent in Northern California and 9.5 percent in Southern California (see Chapter B2 for details). Tables B4-11 and B4-12 present estimated improvements in catch rates, over baseline losses, for the final section 316(b) rule in each region.

Table B4-9: Estimated Changes in Catch Rates from Eliminating All I&E of Affected Species in Northern California

Estimated Fishery I&E		Total Recreational Landings for Northern California (fish per year)[a]	Percent Increase in Recreational Catch from Elimination of I&E
Species by Species Group	**Total I&E**		
Flatfish	135,092	238,394	56.67%
Striped Bass	50,023	220,345	22.70%
Bottom Fish	3,093,249	3,245,932	95.23%
Small Game Fish	40,723	250,634[b]	16.25%
Other Fish	875,665	691,382	126.65%
Other Small Fish	234,466	1,442,356	16.26%
Total for All Species[c]	**4,429,218**	**6,089,043**	**72.71%**

[a] Total recreational Landings are calculated as a five year average (1996-2000) for state waters.
[b] Small game fish landings include landings of jacks and all other small game fish except striped bass.
[c] The "all species" totals are used to calculate I&E losses for no-target anglers.

Source: NMFS, 2002e; and U.S. EPA analysis for this report.

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[11] Fish lost to I&E are most often very small fish, which are too small to catch. Because of the migratory nature of most affected species, by the time these fish have grown to catchable size, they may have traveled some distance from the facility where I&E occurs. Without collecting extensive data on migratory patterns of all affected fish, it is not possible to evaluate whether catch rates will change uniformly or in some other pattern. Thus, EPA assumed that catch rates will change uniformly across the entire region.

[12] State waters include sounds, inlets, tidal portions of rivers, bay, estuaries, and other areas of salt or brackish water, plus ocean waters to three nautical miles from shore, http://www.st.nmfs.gov/st1/recreational/queries/catch/snapshot.html (NMFS, 2003b).

Table B4-10: Estimated Changes in Catch Rates from Eliminating All I&E of Affected Species in Southern California

Estimated Fishery I&E		Total Recreational Landings for Southern California (fish per year)[a]	Percent Increase in Recreational Catch from Elimination of I&E
Species by Species Group	**Total I&E**		
Flatfish	3,487	730,812	0.48%
Sea Basses	835,299	3,298,540	25.32%
Bottom Fish	466,316	2,089,320	22.32%
Small Game Fish	11,766	3,541,997[b]	0.33%
Other Fish	39,995	1,461,775	2.74%
Other Small Fish	1,580	475,689	0.33%
Total for All Species[c]	**1,358,442**	**8,056,136**	**11.71%**

[a] Total recreational landings are calculated as a five year average (1996-2000) for state waters.
[b] Small game fish landings include landings of jacks, striped bass, and all other small game fish.
[c] The "all species" totals are used to calculate I&E losses for no-target anglers.

Source: NMFS, 2002e; and U.S. EPA analysis for this report.

Table B4-11: Estimated Changes in Catch Rates from Reducing I&E of Affected Species in Northern California Under the Final Section 316(b) Rule

Estimated Fishery I&E		Total Recreational Landings for Northern California (fish per year)[a]	Percent Increase in Recreational Catch from Reduction of I&E
Species by Species Group	**Total Reduced I&E**		
Flatfish	48,524	238,394	20.35%
Striped Bass	17,802	220,345	8.08%
Bottom Fish	1,105,461	3,245,932	34.03%
Small Game Fish	14,626	250,634[b]	5.84%
Other Fish	313,921	691,382	45.40%
Other Small Fish	84,204	1,442,356	5.84%
Total for All Species[c]	**1,584,538**	**6,089,043**	**26.01%**

[a] Total recreational landings are calculated as a five year average (1996-2000) for state waters.
[b] Small game fish landings include landings of jacks and all other small game fish except striped bass.
[c] The "all species" totals are used to calculate I&E losses for no-target anglers.

Source: NMFS, 2002e; and U.S. EPA analysis for this report.

Table B4-12: Estimated Changes in Catch Rates from Reducing I&E of Affected Species in Southern California Under the Final Section 316(b) Rule

Estimated Fishery I&E		Total Recreational Landings for Southern California (fish per year)[a]	Percent Increase in Recreational Catch from Reduction of I&E
Species by Species Group	Total Reduced I&E		
Flatfish	648	730,812	0.09%
Sea Basses	80,258	3,298,540	2.43%
Bottom Fish	63,934	2,089,320	3.06%
Small Game Fish	1,878	3,541,997[b]	0.05%
Other Fish	4,159	1,461,775	0.28%
Other Small Fish	252	475,689	0.05%
Total for All Species[c]	**151,129**	**11,598,133**	**1.30%**

[a] Total recreational landings are calculated as a five year average (1996-2000) for state waters.
[b] Small game fish landings include landings of jacks, striped bass, and all other small game fish.
[c] The “all species” totals are used to calculate I&E losses for no-target anglers.

Source: NMFS, 2002e.

B4-3.2 Estimating Losses from I&E in Northern and Southern California

The recreational behavior model described in the preceding sections provides a means for estimating the economic effects of changes in recreational fishery losses from I&E in California. First, EPA estimated welfare gain to recreational anglers from eliminating fishery losses due to I&E. This estimate represents economic damages to recreational anglers from I&E of recreational fish species in California under the baseline scenario. EPA then estimated benefits to recreational anglers from implementing the preferred CWIS technologies.

EPA estimated anglers’ willingness-to-pay (WTP) for improvements in the quality of recreational fishing due to I&E elimination by first calculating an average per-day welfare gain based on the expected changes in catch rates from eliminating I&E. Table B4-13 presents the compensating variation per fishing day (averaged over all anglers in the sample) associated with reduced fish mortality from eliminating I&E for each fish species group of concern. Table B4-13 also shows the per-day welfare gain attributable to reduced I&E resulting from the final section 316(b) rule.[13,14]

Table B4-13 shows that shore anglers in Northern California targeting species in the “other” category have the largest per-day gain ($15.51) from eliminating I&E, followed by boat anglers targeting bottom fish in Northern California ($13.04). Anglers in Northern California targeting flatfish also have a relatively high per-day welfare gain of $6.98 for boat anglers and $6.66 for shore anglers. The high value for “other” species is due to the large predicted change in catch rates for these species.

Table B4-13 also reports the willingness-to-pay for a one-unit increase in historic catch rate by species. The value of increasing the historic catch rate varies significantly by species and by fishing mode. For boat anglers in Northern California who target specific species, sturgeon are the most highly valued fish, followed by salmon, striped bass, big game fish, flatfish, bottom fish, and small game fish. For boat anglers in Southern California who target specific species, jacks are the most highly valued fish, followed by flatfish, salmon, bottom fish, small game fish, other fish, big game fish, and sea basses. For shore anglers in Northern California who target specific species, other fish are the most highly valued, followed by flatfish, striped bass, small game fish, bottom fish, and other small fish. For shore anglers in Southern California who target specific species, other fish (includes unidentified sharks, greenling, and sculpins) are the most highly valued, followed by flatfish, small game fish, bottom fish, other small fish, and sea basses. Boat anglers have higher values than shore anglers for flatfish, striped bass, and bottom fish.

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[13] A compensating variation equates the expected value of realized utility under the baseline and post-compliance conditions.

[14] As the RUM model estimated values for single-day trips, the per-day value is equal to a per-trip value.

Table B4-13: Per-Day Welfare Gain from Eliminating I&E and From I&E Reductions with the Preferred Technology in Northern and Southern California

Targeted Species Group	Per-Day Welfare Gain (2002$)				WTP for an Additional Fish per Trip (2002$)	
	Eliminating I&E		Reduced I&E with Preferred Technology		Boat Anglers	Shore Anglers
	Boat Anglers	Shore Anglers	Boat Anglers	Shore Anglers		
Flatfish - N. CA	$6.98	$6.66	$2.59	$2.47	$6.21	$4.41
Flatfish - S. CA	$0.13	$0.03	$0.02	$0.01	$10.83	$3.12
Sea Basses - S. CA	$0.69	$0.20	$0.07	$0.02	$0.71	$0.35
Striped Bass - N. CA	$3.87	$1.70	$1.40	$0.62	$8.23	$4.22
Bottom Fish - N. CA	$13.04	$3.35	$4.90	$1.30	$2.70	$1.35
Bottom Fish - S. CA	$2.00	$1.06	$0.28	$0.17	$2.70	$1.35
Small Game Fish - N. CA	$0.98	$1.25	$0.35	$0.46	$2.21	$3.02
Small Game Fish - S. CA	$0.04	$0.04	$0.01	$0.01	$2.21	$3.02
Other Fish - N. CA[a]	N/A	$15.51	N/A	$6.11	N/A	$6.54
Other Fish - S. CA	$0.14	$0.31	$0.02	$0.06	$2.11	$4.21
Other Small Fish-N. CA[a]	N/A	$2.16	N/A	$0.78	N/A	$1.18
Other Small Fish - S. CA[a]	N/A	$0.13	N/A	$0.04	N/A	$1.18
No Target - N. CA [b]	$0.93	$1.79	$0.36	$0.46	$0.45	$0.92
No Target - S. CA [b]	$0.22	$0.34	$0.03	$0.05	$0.45	$0.92
Jacks - S. CA[c,d]	N/A	N/A	N/A	N/A	$28.54	N/A
Salmon - N. CA[c,d]	N/A	N/A	N/A	N/A	$15.23	N/A
Salmon - S. CA [e]	N/A	N/A	N/A	N/A	$8.28	N/A
Sturgeon - N. CA	N/A	N/A	N/A	N/A	$60.14	N/A
Big Game Fish - N. CA[d,e]	N/A	N/A	N/A	N/A	$6.33	N/A
Big Game Fish - S. CA[d,e]	N/A	N/A	N/A	N/A	$2.10	N/A

[a] Not targeted by boat anglers in the sample.
[b] The value is based on all species caught by no-target anglers.
[c] Not targeted by shore anglers in the sample.
[d] Values for jacks are included in small game values.

Source: U.S. EPA analysis for this report.

EPA calculated the total economic value of eliminating I&E in Northern California by combining the estimated per-day welfare gain with the total number of fishing days in the Northern California region. NMFS provided information on the total number of fishing trips by state and by fishing mode; this total number of fishing days includes both single- and multiple-day trips. Table B4-14 presents the NMFS number of fishing days by fishing mode.

The Agency assumed that the welfare gain per day of fishing is independent of the number of days fished per trip and therefore equivalent for both single- and multiple-day trips. Each day of a multiple-day trip is valued the same as a single-day trip.[15] Per-day welfare gain differs across recreational species and fishing mode.[16] EPA therefore estimated the number of fishing days associated with each species of concern and the number of days fished by no-target anglers. EPA used the MRFSS sample to calculate the proportion of recreational fishing trips taken by no-target anglers and anglers targeting each species of concern and applied these percentages to the total number of trips to estimate species-specific participation. Tables B4-15 and B4-16 show the calculation results.

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[15] See section B4-4.1 for limitations and uncertainties associated with ths assumption.

[16] EPA used the per-day values for private/rental boat anglers to estimate welfare gains for charter boat anglers.

Table B4-14: Recreational Fishing Participation in 2001 by Fishing Mode for Northern and Southern California

Fishing Mode	Total Number of Fishing Days per Year, Northern CA[a]	Total Number of Fishing Days per Year, Southern CA[a]
Private Rental Boat	1,065,009	1,742,369
Shore	864,178	1,315,430
Charter Boat	278,447	994,353
Total	2,207,634	4,052,152

[a] Total days includes each day of a multiple-day fishing trip.

Source: *http://www.st.nmfs.gov/recreational/queries/participation/par_time_series.html (NMFS, 2002d).*

Table B4-15: Recreational Fishing Participation by Species and Fishing Mode, Northern California

Species	Mode: Private Rental Boats Number of Fishing Days	Mode: Shore Number of Fishing Days	Mode: Charter Boat Number of Fishing Days	Total for All Modes [a]
Flatfish	144,948	16,419	0	161,367
Striped Bass	58,682	188,218	0	246,900
Bottom Fish	125,458	185,885	161,416	472,759
Other Small Fish	0	15,037	0	15,037
No Target	208,955	400,114	36,699	645,768
Total [a]	538,043	805,673	198,115	1,541,831

[a] Sum of individual values may not add up to totals due to rounding error.

Source: U.S. EPA analysis for this report.

Table B4-16: Recreational Fishing Participation by Species and Fishing Mode, Southern California

Species	Mode: Private Rental Boats Number of Fishing Days	Mode: Shore Number of Fishing Days	Mode: Charter Boat Number of Fishing Days	Total for All Modes [a]
Flatfish	319,550	125,624	54,391	499,565
Sea Basses	273,029	60,904	63,042	396,975
Bottom Fish	140,261	88,923	113,953	343,137
Other Small Fish	0	9,997	0	9,997
No Target	476,712	916,197	504,236	1,897,145
Total [a]	1,209,552	1,201,645	735,622	3,146,819

[a] Sum of individual values may not add up to totals due to rounding error.

Source: U.S. EPA analysis for this report.

In Northern California, no-target anglers account for the largest number of fishing days, followed by anglers targeting bottom fish, striped bass, flatfish, and other small fish. In Southern California, no-target anglers account for the largest number of fishing days, followed by anglers targeting flatfish, sea basses, bottom fish, and other small fish.

The estimated number of fishing days represents the baseline level of participation. Anglers may fish more when recreational fishing circumstances improve. However, EPA was unable to estimate a trip participation model for California, because the required data were not available. Therefore, the welfare estimates presented here do not account for likely increases in the number of trips due to elimination or reduction of I&E, and thus understate total welfare effects.

Tables B4-17 and B4-18 provide total annual welfare estimates for two policy scenarios. These values were discounted, to reflect the fact that fish must grow to a certain size before they will be caught by recreational anglers. EPA calculated discount factors separately for I&E of each species. To estimate discounted total benefits, EPA calculated weighted averages of these discount factors for each species group, and applied them to estimated willingness-to-pay values. Discount factors were calculated for both a three percent discount rate and a seven percent discount rate. For the final section 316(b) rule, an additional discount factor was applied to account for the one-year lag between the date when installation costs are incurred and the installation of the required cooling water technology is completed.

Table B4-17 presents annual losses to recreational anglers from baseline I&E effects in California. Total recreational losses from I&E to California anglers, before discounting, are $8.9 million per year (2002$). Total discounted baseline losses are $7.5 million, discounted using a three percent discount rate; and $6.1 million, discounted using a seven percent discount rate.

Table B4-18 presents the annual welfare gain to recreational anglers resulting from the final section 316(b) rule. Total gain to recreational anglers before discounting is $3 million under the final section 316(b) rule. Total discounted gain is $2.5 million and $1.9 million using a three and seven percent discount rate, respectively.

Table B4-17: Total Estimated Annual Baseline Losses From I&E for California Anglers (2002$)

Species	Total Losses Before Discounting				Total Losses with 3% Discounting				Total Losses with 7% Discounting			
	Boat	Shore	Charter	Totals	Boat	Shore	Charter	Totals	Boat	Shore	Charter	Totals
Flatfish	$1,052,504	$113,509	$6,968	$1,172,981	$867,417	$93,509	$6,279	$967,205	$687,022	$74,021	$5,546	$766,589
Striped Bass	$226,994	$320,117	$0	$547,111	$205,350	$289,593	$0	$494,943	$181,660	$256,184	$0	$437,844
Sea Basses	$187,937	$11,886	$43,367	$243,190	$153,850	$9,730	$35,501	$199,081	$119,395	$7,551	$27,551	$154,497
Bottom Fish	$1,916,883	$716,181	$2,332,755	$4,965,819	$1,580,960	$590,084	$1,917,757	$4,088,801	$1,252,856	$467,074	$1,514,014	$3,233,944
Small Game Fish	$40,914	$4,461	$11,261	$56,636	$37,707	$4,123	$10,403	$52,233	$34,141	$3,745	$9,444	$47,330
Other Fish	$1,244	$442,515	$1,508	$445,267	$1,181	$417,450	$1,432	$420,063	$1,107	$388,231	$1,342	$390,680
Other Small	$0	$33,850	$0	$33,850	$0	$31,119	$0	$31,119	$0	$28,095	$0	$28,095
No Target	$297,670	$1,028,627	$143,603	$1,469,900	$252,037	$871,272	$121,150	$1,244,459	$206,319	$713,934	$98,253	$1,018,506
Total Recreational Use Losses	$3,724,146	$2,671,146	$2,539,462	$8,934,754	$3,098,502	$2,306,880	$2,092,522	$7,497,904	$2,482,500	$1,938,835	$1,656,150	$6,077,485

Source: U.S. EPA analysis for this report.

Table B4-18: Total Estimated Annual Welfare Gain to California Anglers Under the Final Section 316(b) Rule (2002$)

Species	Total Gain Before Discounting				Total Gain with 3% Discounting				Total Gain with 7% Discounting			
	Boat	Shore	Charter	Totals	Boat	Shore	Charter	Totals	Boat	Shore	Charter	Totals
Flatfish	$382,876	$41,435	$1,310	$425,621	$305,687	$33,075	$1,129	$339,891	$232,373	$25,137	$944	$258,454
Striped Bass	$82,398	$116,617	$0	$199,015	$72,388	$102,450	$0	$174,838	$61,663	$87,271	$0	$148,934
Sea Basses	$18,755	$1,201	$4,328	$24,284	$14,928	$956	$3,445	$19,329	$11,175	$715	$2,579	$14,469
Bottom Fish	$653,649	$256,811	$822,157	$1,732,617	$520,528	$204,473	$653,566	$1,378,567	$394,583	$154,965	$494,348	$1,043,896
Small Game Fish	$11,551	$948	$2,499	$14,998	$10,337	$852	$2,245	$13,434	$9,012	$747	$1,966	$11,725
Other Fish	$130	$173,668	$157	$173,955	$120	$159,040	$145	$159,305	$108	$142,358	$131	$142,597
Other Small	$0	$12,212	$0	$12,212	$0	$10,902	$0	$10,902	$0	$9,476	$0	$9,476
No Target	$86,253	$318,265	$25,444	$429,962	$71,128	$262,456	$21,014	$354,598	$56,416	$208,167	$16,639	$281,222
Total Recreational Use Gain	$1,235,612	$921,157	$855,895	$3,012,664	$995,116	$774,204	$681,544	$2,450,864	$765,330	$628,836	$516,607	$1,910,773

Source: U.S. EPA analysis for this report.

B4-4 LIMITATIONS AND UNCERTAINTIES

B4-4.1 Extrapolating Single-Day Trip Results to Estimate Benefits from Multiple-Day Trips

Use of per-day welfare gain estimated for single-day trips to estimate per-day welfare gain associated with multiple-day trips can either understate or overstate benefits to anglers taking multiple-day trips. Inclusion of multi-day trips in the model of recreational anglers' behavior can be problematic because multi-day trips are frequently multi-activity trips. An individual might travel a substantial distance and participate in several recreational activities such as shopping and sightseeing, all as part of one trip. Recreational benefits from improved recreational opportunities for the primary activity are overstated if all travel costs are treated as though they apply to the one recreational activity of interest. EPA therefore limited the recreational behavior model to single-day trips only and then extrapolated single-day trip results to estimate benefits to anglers taking multiple-day trips.

There is evidence that multi-day trips are more valuable than single-day trips. McConnell and Strand (1994) estimated a RUM using the NMFS data for New England and the Mid-Atlantic. Their study was intended to supplement the RUM study of single-day trips for the same region conducted by Hicks et al. (1999). The reported values for a catch rate increase of one fish are consistently higher for overnight trips than for single-day trips. Lupi and Hoehn (1998) compared values for single- and multi-day fishing trips. Their comparison is based on a RUM for the Great Lakes, with single and multiple-day trips treated as distinct alternatives in the choice set, with separate parameters for different length trips. They found that multiple-day trips are less responsive to changes in travel cost, and thus relatively more valuable than single-day trips. Their case study results found that "over half the value of an across the board marginal change in catch rates was due to multiple-day trips even though multiple-day trips represent less than one fourth of the trips in the sample" (p. 45).

B4-4.2 Considering Only Recreational Values

This study understates the total benefits of improvements in fishing site quality because estimates are limited to recreational use benefits. Many other forms of benefits, such as habitat values for a variety of species (in addition to recreational fish), non-use values, etc., are also likely to be important.

B4-4.3 Species and Mode Substitution

EPA's estimated RUM model does not allow for anglers to substitute between modes or species. The analysis therefore assumes that each angler has chosen a mode/species combination followed by a site based on the catch rates for that site and species. One disadvantage of the specified model is that the model looks at site choice without regard to mode or species. Once an angler chooses a target species and mode, no substitution is allowed across species or mode (i.e., the value of catching, or potentially catching, a different species or fishing using a different mode is not included in the calculation). Therefore, improvements in fishing circumstances related to other species or modes will have no effect on anglers' choices, and thus will not be accounted for in the welfare estimates.

B4-4.4 Charter Anglers

EPA's model does not include charter boat anglers. Instead, the Agency used values for private/rental boat anglers to estimate values for charter anglers. It is not clear whether this will result in an overestimate or underestimate of per-day values for charter boat anglers.

B4-4.5 Potential Sources of Survey Bias

The survey results could suffer from bias, such as recall bias and sampling effects.

a. Recall bias

Recall bias can occur when respondents are asked, such as in the MRFSS, the number of their recreation days over the previous season. Some researchers believe that recall bias tends to lead to an overstatement of the number of recreation days, particularly by more avid participants. Avid participants tend to overstate the number of recreation days because they count days in a "typical" week and then multiply them by the number of weeks in the recreation season. They often neglect to consider days missed due to bad weather, illness, travel, or when fulfilling “atypical” obligations. Some studies also found that the more salient the activity, the more “optimistic” the respondent tends to be in estimating the number of recreation days.

Individuals also have a tendency to overstate the number of days they participate in activities that they enjoy and value. Taken together, these sources of recall bias may result in an overstatement of the actual number of recreation days.

b. Sampling effects

Recreational demand studies frequently face observations that do not fit general recreation patterns, such as observations of avid participants. These participants can be problematic because they claim to participate in an activity an inordinate number of times. This reported level of activity is sometimes correct but often overstated, perhaps due to recall bias. Even where the reports are correct, these observations tend to be overly influential (Thomson, 1991).

Chapter B5: Non-Use Benefits

CHAPTER CONTENTS

INTRODUCTION

Aquatic species without any direct uses account for the majority of losses due to impingement and entrainment (I&E) at cooling water intake structures (CWIS). However, EPA's analysis of direct use benefits includes values only for organisms with direct uses, which comprise a very small percentage of total losses (approximately two percent). Because the other 98 percent of losses, consisting of organisms without direct uses, are not without value, the potential exists for significant non-use values that have not been addressed under EPA's estimation of use benefits. For this reason it is important to consider non-use benefits to the human population, produced by the increased numbers of organisms without direct use values, under the final section 316(b) rule.

One way to consider the impact of the section 316(b) rule is to estimate the non-use value of baseline I&E losses and I&E reductions due to the final rule for each case study region using the non-use meta-analysis results. The non-use meta-analysis is presented in detail in Chapter A12, Non-Use Meta-Analysis Methodology, which includes discussions of the literature review process, the estimated regression models and results, and the general methodology used to estimate household and aggregate non-use benefits based on regression results. Total regional non-use benefits can be estimated using the following three steps:

1. Estimate annual changes in non-use value of the affected fishery resources per household due to the baseline impingement and entrainment (I&E) losses and the post-compliance reduction in impingement and entrainment;

2. Estimate the population of households in the California region holding non-use value for the affected resources; and

3. Estimate the total non-use value to the affected California populations for completely eliminating baseline I&E losses, and for reducing I&E losses from the baseline to post-compliance levels.

EPA explored this approach for the California region. However, EPA did not include the results of this approach in the benefit analysis because of limitations and uncertainties associated with estimation of non-use benefits on a regional scale. For further discussion of the limitations and uncertainties of this method, refer to Chapter A12.

B5-1 QUALITATIVE ASSESSMENT OF ECOLOGICAL BENEFITS FOR THE CALIFORNIA REGION

Changes in CWIS design or operations resulting from the section 316(b) regulations for existing facilities are expected to reduce I&E losses of fish, shellfish, and other aquatic organisms and, as a result, are expected to increase the numbers of individuals present, increase local and regional fishery populations, and ultimately contribute to the enhanced environmental functioning of affected waterbodies (rivers, lakes, estuaries, and oceans) and associated ecosystems. The economic welfare of human populations is expected to increase as a consequence of the improvements in fisheries and associated aquatic ecosystem functioning.

The aquatic resources affected by cooling water intake structures provide a wide range of services. Ecosystem services are the physical, chemical, and biological functions performed by natural resources and the human benefits derived from those functions, including both ecological and human use services (Daily, 1997; Daily et al., 1997). Scientific and public interest in protecting ecosystem services is increasing with the recognition that these services are vulnerable to a wide range of human activities and are difficult, if not impossible, to replace with human technologies (Meffe, 1992).

In addition to their importance in providing food and other goods of direct use to humans, the organisms lost to I&E are critical to the continued functioning of the ecosystems of which they are a part. Fish are essential for energy transfer in aquatic food webs, regulation of food web structure, nutrient cycling, maintenance of sediment processes, redistribution of bottom substrates, the regulation of carbon fluxes from water to the atmosphere, and the maintenance of aquatic biodiversity (Peterson and Lubchenco, 1997; Postel and Carpenter, 1997; Holmund and Hammer, 1999; Wilson and Carpenter, 1999). Examples of ecological and public services disrupted by I&E include:

- decreased numbers of ecological keystone, rare, or sensitive species;
- decreased numbers of popular species that are not fished, perhaps because the fishery is closed;
- decreased numbers of special status (e.g., threatened or endangered) species;
- increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E;
- disruption of ecological niches and ecological strategies used by aquatic species;
- disruption of organic carbon and nutrient transfer through the food web;
- disruption of energy transfer through the food web;
- decreased local biodiversity;
- disruption of predator-prey relationships;
- disruption of age class structures of species;
- disruption of natural succession processes;
- disruption of public uses other than fishing, such as diving, boating, and nature viewing; and
- disruption of public satisfaction with a healthy ecosystem.

Many of these services can only be maintained by the continued presence of all life stages of fish and other aquatic species in their natural habitats.

The traditional approach of EPA and other natural resource agencies to quantifying the environmental benefits of proposed regulations has focused on active use values, particularly direct use values such as recreational or commercial fishing. Nonconsumptive uses (such as the importance of fish for aquatic food webs), and passive use or non-use values (including the value of protecting a resource for its own sake), are seldom considered because they are difficult to monetize with available economic methods. However, even though economists debate methods for indirect and non-use valuation, there is general agreement that these values exist and can be important. The potential magnitude of non-use values remains an empirical matter. EPA believes that non-use values are applicable for the section 316(b)-related I&E and that these values are likely to be appreciable for the California region.

Chapter B6: Threatened and Endangered Species Analysis

INTRODUCTION

This chapter develops potential methods for the estimation of non-use values for special status species in California.[1] Non-use value estimates are particularly relevant for these species. Their populations have been depleted to the point where active use values based on previous studies would be misleading because of fishing restrictions or decreased effort or participation due to low catch rates.

Regulation-specific stated preference surveys are the preferred way to directly estimate total values (including use and non-use) for special status species. Such a survey has not been undertaken because it could not be completed within the time frame for the rulemaking process. Despite potential difficulties associated with benefit transfer approaches, if properly done they can constitute a second-best alternative to original stated preference studies to value improved protection of special status species. Chapter A13 of this report provides a detailed description of the benefits transfer approach used in this analysis. Section B6-2 describes the benefit transfer studies used in the analysis and presents analytic results.

CHAPTER CONTENTS

B6-1 A POTENTIAL METHOD FOR VALUING SPECIAL STATUS SPECIES

B6-1.1 Overview of Method

This method is based on the premise that under specific circumstances it is possible to infer how much value society places on a program or activity by observing how much society is willing to forego (in out-of-pocket expenses and opportunity costs) to implement the program. For example, the costs borne by society to implement programs that preserve and restore special status species can, under select conditions, be interpreted as a measure of how much society values the outcomes it anticipates receiving. This is analogous to the broadly accepted revealed preference method of inferring values for private goods and services based on observed individual behavior.

In the case of observed individual behavior, when a person willingly bears a cost (pays a price) to receive a good or service, it is deduced that the person's value for that acquired good or service must be at least as great as the price paid. This observation is, based on the presumption that individual behavior reflects the economic rationality of seeking to maximize utility (well-being), the person's willingness-to-pay (WTP) must exceed the observed price paid, otherwise they would not have purchased that unit of the commodity. The approach described in this section uses the same premise, but applies it to societal choices rather than to a single individual's choices.

A critical issue with the approach is determining when it is likely that a specific public sector activity (or other form of collective action) does indeed reflect a "societal choice." EPA recognizes clearly that not every policy enacted by a public sector entity can rightfully be interpreted as an indication of social choice. Hence, the costs imposed in such instances may

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[1] Consistent with the discussion in Chapter A13, "special status species" is the term used to refer to species that have been specifically identified as "threatened and endangered" (i.e., T&E) or that have been given a special status designation at the State or Federal level.

not reveal social values. For example, some regulatory actions may have social costs that outweigh the social benefits, but may be implemented anyway because of legal requirements or other considerations. In such a case, asserting that the costs imposed reflect a lower bound estimate of the "value" of the action would not be accurate (the values may be less than the imposed costs). Alternatively, there are some regulatory programs for which the benefits greatly exceed costs, and in such instances using costs as a reflection of value would greatly understate social benefits.

There are some public policy actions that can be suitably interpreted as expressions of societal preferences and values. In these instances, the incurred costs may be viewed as an indication of social values. The criteria to help identify when such situations arise include whether the actions taken are voluntary, or whether the actions reflect an open and broadly inclusive policy-making process that enables and encourages active participation by a broad spectrum of stakeholders. This is especially relevant where (1) plans and actions are developed in an inclusive, consensus-building manner; (2) implementation steps are pursued in an adaptive management framework that enables continuous feedback and refinement; or (3) the actions are ultimately supported by some positive indication of broad community support, such as voter approval of a referendum. In such instances, the policy choices made are the product of a broad-based, collective decision-making process, and such programs should be viewed as an expression of societal preferences. When programs or activities stem from such open collective processes, the actions (and costs incurred) reflect the revealed preference of society.

This approach incorporates the basic economic principle that holds a resource's value is defined in terms of its opportunity costs. The method builds on this principle by recognizing that public agencies and private individuals voluntarily and/or through a broad-based collective decision-making process undertake a range of actions intended to maintain or increase the populations of fish stocks, and that often these actions are directed to improve the stocks of special status species. As a result, the costs involved with implementing these actions, combined with the value of any foregone opportunities that need to be committed to the action to ensure its success (even if they may not involve a direct expenditure, e.g., maintaining instream water flows), can provide an estimate of the value of the intended improvement in the species population.

A key criterion for a project to be considered an expression of public values is that the project be voluntarily undertaken so that any costs and foregone opportunities provide a true indication of an opportunity cost of the action being realized. For projects undertaken by private individuals and organizations, it is assumed that this criterion is satisfied unless there is evidence that the action is undertaken to satisfy a strict regulatory compliance requirement or a mandated court requirement. For actions of public agencies to be considered, this criterion is assumed to be satisfied when the action is taken in response to legislative mandates that have been widely supported by lawmakers and/or the public (e.g., as evidenced by broad stakeholder involvement, especially in a consensus-oriented decision-making context, and/or where funding is supported by voters through referenda, such as evident in the CALFED process), or where the action has been approved through an internal project screening and selection process designed to allocate limited resources. In the second case, while subtle, the criterion is assumed satisfied if there were alternative projects/actions that could have been pursued but were not, as this provides evidence that an opportunity cost was involved with the selections that were made.

A second criterion that needs to be satisfied for a project to be considered in the analysis is that the project objectives and actions have a clear link to the resource being valued. In some cases the actions may be directed at a targeted group of resources (e.g., California condor population support programs clearly are targeting California condors). However, in other cases a project may benefit a number of resources outside of the scope of the valuation analysis. In these cases, it is necessary to determine whether the full scope of the activity was required to benefit the resources of concern or whether there were additional benefits. For example, if a certain level of instream flow may be required by a special status species, actions taken to maintain flows at this level because of the species would be appropriate for consideration in the analysis. However, if flows were increased above the level required by the species to provide additional benefits (e.g., improved downstream kayaking), only the share of actual costs or foregone value associated with the portion of the release required for the special status species should be considered.

The economic foundations for using this approach to value T&E species are firmly established through the widespread recognition and acceptance of revealed preference data as a source of nonmarket information that is acceptable for the valuation of resources. In EPA's approach, valuation estimates rely on the costs of actions or the value of foregone opportunities that are *voluntarily* undertaken or that have been approved through extensive public input and review (and developed in a consensus-oriented approach). With these sources of data, the method avoids the well-established problems associated with using "costs" as a measure of "value" — a problem that can arise when the cost is realized involuntarily (e.g., avoided cost-based measures of value). Specifically, because of the available evidence of the public's acceptance and willingness to incur the opportunity costs associated with the actions that are selected for evaluation, the fundamental criteria for defining the value of any resource are satisfied.

It is important to note that one issue that arises with the use of this method is that it is not clear that the resulting values can be distinctly categorized as direct use or non-use values because the underlying actions benefitting the T&E species could reflect an expressed mix of non-use values (e.g., preservation and existence) and discounted future use values (e.g., the actions are seen as an "investment" that could return the species to levels at which direct use would be permitted).

The principle source of information that can be used to determine expenditures for special status species in the San Francisco Estuary comes from actions being undertaken by the CALFED program to protect and enhance their populations. Other potentially relevant information includes the value of foregone water diversions used to maintain instream flows critical to special status species. These programs are discussed in the following section.

B6-1.2 CALFED

The CALFED program represents a cooperative effort on the part of more than 20 Federal and State agencies that work collaboratively with local communities to implement projects that address specific goals within the four main objective areas of the program: ecosystem restoration, water quality, water supply and reliability, and levee system integrity.[2] CALFED has an adaptive management process that provides the various participating agencies and private citizens/organizations with extensive opportunities to review and comment on materials presented for the purposes of determining policy. The commitment of financial resources to the program through State and Federal sources — through a combination of general fund allocations, revenues from approved State bonds and department allocations, and with funds and resources provided by local/private sources — satisfies the first criterion that the project is undertaken voluntarily.

In addition to State and Federal agencies that serve on the Policy Group (as listed in footnote 2), many environmental and resource conservation groups, unions, Tribal governments, and municipalities serve on the CALFED Public Advisory Committee, as listed in Table B6-1.

Table B6-1: Organizations Represented on CALFED Public Advisory Committee

- The Bay Institute
- Ducks Unlimited
- Glenn County
- City Of West Sacramento
- Kern County Water Agency
- City of Rio Vista
- Inland Empire Utilities Agency
- Northern California Power Agency
- Friant Water Users Authority
- Contra Costa Water District
- Northern California Water Association
- United Farm Workers of America, AFL-CIO
- Association of California Water Agencies
- California Strategies, LLC
- Paskenta Band of Nomlaki Indians
- Plumas County
- Planning and Conservation League
- Natural Resources Defense Council
- San Luis & Delta-Mendota Water Authority
- Pacific Coast Federation of Fishermen's Association
- California Farm Bureau Federation
- Metropolitan Water District of Southern California

Source: *CALFED website (accessed 11/27/02): http://calfed.ca.gov/BDPAC/BDPAC_Members.shtml (CALFED, 2001d).*

The goal of the Public Advisory Committee is to provide assistance and recommendations to the Secretary of the Interior, the Governor of California, the California Legislature, and other interested entities through the CALFED Policy Group. The Committee also serves as a liaison between the program's workgroups, subcommittees, State and Federal agencies, and the general public.[3]

Numerous additional stakeholders are also represented at the subcommittee level. For example, the Ecosystem Restoration Subcommittee membership includes representatives from the organizations listed in Table B6-2.

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[2] Participating Federal agencies include the Bureau of Reclamation, the Fish and Wildlife Service, the U.S. Geological Survey, the Bureau of Land Management, the Environmental Protection Agency, the Army Corps of Engineers, the Natural Resource Conservation Service, the U.S. Forest Service, the National Marine Fisheries Service, and the Western Area Power Administration. Participating State agencies include the Department of Water Resources, the California Department of Fish and Game (CDFG), The Reclamation Board, the Delta Protection Commission, the Department of Conservation, the San Francisco Bay Conservation and Development Commission, the State Water Resources Control Board, the Department of Health Services, and the Department of Food and Agriculture.

[3] CALFED website (accessed 11/27/02): http://calfed.ca.gov/BDPAC/US_Dept_of_Interior_Charter.pdf (CALFED, 2001a).

Table B6-2: Stakeholder Organizations Represented on Ecosystem Restoration Subcommittee

- Central Valley Project Water Association
- Supervisor, District 4 Glenn County
- Natural Heritage Institute
- Kern County Water Agency
- Mayor, City of Rio Vista
- California Trout
- Friends of the River
- Friant Water Users Authority
- Contra Costa Water District
- Northern California Water Association
- The Trust for Public Land
- MWD of Southern California
- Save the Bay
- Tribal Environmental Coordinator
- California Farm Bureau
- Environmental Defense Fund
- Matlock, Charles, Rowe & Co.

Source: *CALFED website (accessed 11/29/02): http://calfed.ca.gov/BDPAC/Subcommittees/EcosystemSubcommitteeMembers.shtml (CALFED, 2001b).*

With feedback from the general public, an independent science advisory board, and various government agencies, this subcommittee developed the plan for habitat restoration in the San Francisco Bay-Delta.

In addition to stakeholder organizations represented on the various committees and subcommittees, there also is broad involvement of the general public. According to CALFED director Patrick Wright: “Public involvement has been one of the hallmarks of the program.”[4] To ensure a thoroughly collective process, the general public is also strongly encouraged to participate through numerous subcommittees, workshops, and informational publications. The CALFED program was created to ensure that all interested parties were included in a collective process aimed at improving the water supply and restoring the Bay-Delta ecosystem.

The Sacramento River Conservation Area Forum (SRCAF) is another representative example of this inclusive process. Although not a government agency and having no regulatory power, the SRCAF was created over a decade ago to guide riparian habitat management along the river. The forum is convened monthly to facilitate discussion between landowners, government agencies, conservation groups, and the general public. The six non-voting members of the SRCAF board represent interested government agencies to share information on the progress of their restoration activities.[5] Based on information presented to the board, only the voting members, which include landowners and other interested members of the public, make recommendations and issue opinions about whether these restoration activities are conducted according to the inclusive principles of the CALFED program and SRCAF mission.

This example, along with the overall structure of the CALFED process, is representative of a restoration program that reflects an attempt to form and implement a broad-based societal consensus. The program is based on the cooperative participation of government agencies and the inclusion of a broad cross section of stakeholders and the general public in the decision and funding process. Accordingly, restoration efforts developed under this collective decision-making process can be considered as expressions of revealed social preferences.

A second criterion to be satisfied for considering specific actions requires demonstration that the action was intended to benefit the resource in question. With respect to CALFED, it is clear that certain program elements, the categories of activity defined by CALFED, are focused on special status species. Specifically, the Ecosystem Restoration Program Plan (ERPP) has identified the following specific goals:[6]

- Recover 19 at-risk native species and contribute to the recovery of 25 additional species;[7]
- Protect and restore functional habitats, including aquatic, upland, and riparian, to allow species to thrive;

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[4] CALFED website (accessed 11/29/02): http://calfed.ca.gov/Newsroom/NewsReleases_2001/Newsrelease_10-22-01.shtml (CALFED, 2001c).

[5] SRCAF website (accessed 12/8/02): http://www.sacramentoriver.ca.gov/publications/questions_to_date.pdf (SRCAF, 2002).

[6] Source http://calwater.ca.gov/Programs/EcosystemRestoration/Ecosystem.shtml, accessed 6/23/03 (CALFED, 2003).

[7] Among the species in this combined group are the following: delta smelt, longfin smelt, green sturgeon, Sacramento splittail, Sacramento winter-run chinook salmon, Central Valley spring-run chinook salmon, late-fall-run chinook salmon, fall-run chinook salmon, and Central Valley steelhead (see CALFED Ecosystem Restoration Plan) (CALFED, 2000).

- Maintain and enhance fish populations critical to commercial sport and recreational fisheries;
- Improve and maintain water and sediment quality to better support ecosystem health and allow species to flourish;
- Rehabilitate natural processes related to hydrology, stream channels, sediment, floodplains, and ecosystem water quality; and
- Reduce the negative impacts of invasive species and prevent additional introductions that compete with and destroy native species.

It is clear that the goals of the ERPP are focused, at least in part, on special status species. The Environmental Water Account program element within CALFED also includes actions undertaken to protect fish and habitats in addition to the regulatory actions required for project operations.

B6-1.3 Values for Water in California

"Restoration" programs need not be relied on exclusively to infer societal revealed WTP to preserve special status species. In many instances, other programs or restrictions are used in lieu of (or in conjunction with) restoration programs, and the costs associated with the nonrestoration components also reveal a WTP. For example, efforts to preserve fish species in the San Francisco Estuary also include water use restrictions that reduce the amount of fresh water diverted from the upstream portion of the Sacramento River to highly valued water uses in the central and southern parts of California. The foregone use values of these waters in agricultural and municipal applications are an important component of the cost society bears to protect and preserve special status fish species.

Several actions have been taken in northern California to increase stream flows to improve fish habitat. The most significant reduction in water use to meet these increases in stream flows has been experienced by urban and agricultural water users who obtain their supplies from the Bureau of Reclamation. The Bureau has had to cut back on supply to its Central Valley Project (CVP) customers to comply with the various water needs and restrictions of the Federal Endangered Species Act (FESA) and California Endangered Species Act (CESA), the CVP Improvement Act (CVPIA), and the new Bay-Delta water quality standards issued in 1995 by the State Water Resources Control Board. For these purposes, the Bureau has reduced by 40 to 60 percent its usual 7 million AF per year delivered to water users without water rights (personal communication, Earl Cummings, California Division of Water Resources, Environmental Services Office, March 2000; personal communication, Jeff Sandberg, Central Valley Project, March 2000). Thus, the Bureau has foregone 3 to 4 million AF per year for environmental water use intended for the Sacramento and San Joaquin rivers to protect special status species. EPA estimated that this represents a range of value to California water users from $155 to $425 per AF (the calculation is explained in Appendix B2), and is a weighted average reflecting agricultural and municipal uses. Using this estimate, the value to California water users of the water the Bureau has foregone ranges from $484 million to $1.8 billion annually in 2002 dollars.

EPA contacted the Bureau of Reclamation to verify the amount of water being diverted for special status species under the context of the CVPIA and bay delta water quality standards. Although the Bureau could not estimate the amount of water diversion cut back specifically for special status species, they estimated that approximately 50 percent of the water diverted for the CVPIA and the Bay-Delta water quality standards is to preserve or enhance the targeted fish populations through water quality or other habitat improvements (personal communication, Jeff McCracken, Public Information Office, Bureau of Reclamation, June 2003).

B6-1.4 Conclusions

EPA did not use the method described in this section in its benefits analysis for the final section 316(b) Phase 2 rule because of uncertainties about the percent of program funding assigned to the protection of special status species. Nonetheless, EPA believes this method holds promise.

B6-2 AN EXPLORATION OF BENEFITS TRANSFER TO ESTIMATE NON-USE BENEFITS OF REDUCED I&E IN NORTHERN CALIFORNIA

This section presents a benefits-transfer methodology explored by EPA to estimate public WTP for protection of special status fish species from I&E at the Pittsburg and Contra Costa power plants. The analysis focuses on four special status species affected by I&E: delta smelt, longfin smelt, Sacramento splittail, and chinook salmon.

B6-2.1 Benefit Transfer Approach

Case-specific estimates of non-use values for the protection of special status species can only be derived by primary research using stated preference techniques (e.g., the contingent valuation method). However, the cost, administrative burden, and time required to develop primary research estimates is beyond the schedule and resources available to EPA for the section 316(b) rulemaking. As an alternative, EPA explored a benefit transfer approach that relies on information from existing studies (U.S. EPA, 2000). Boyle and Bergstrom (1992) define benefit transfer as "the transfer of existing estimates of nonmarket values to a new study which is different from the study for which the values were originally estimated."

There are four types of benefit transfer studies: point estimate, benefit function, meta-analysis, and Bayesian techniques (U.S. EPA, 2000). The point estimate approach involves taking the mean value (or range of values) from the study case and applying it directly to the policy case (U.S. EPA, 2000). This approach may be used to transfer estimates of values for preserving certain endangered species in one region to another region or to another species. A conceptually preferred benefits transfer approach is to use the benefit function transfer approach, which is more refined but also more complex than the point estimate approach. If the study case provides a WTP function, valuation estimates can be updated by substituting applicable values of key variables, such as baseline risk and population characteristics (e.g., mean or median income, racial or age distribution) from the policy case into the benefit function (U.S. EPA, 2000).

Ideally, transfer studies would be available that value special status species that are identical to the species affected in the San Francisco Estuary. EPA, however, was unable to identify such studies. Thus, the Agency selected benefits transfer studies that valued aquatic species that have attributes similar to the affected species. One of the most important attributes to consider is whether the affected species have any use values. As shown in Table B6-3, the majority of I&E losses of special status species are associated with forage species that do not have direct use values.

Table B6-3: Comparison of Special Status Species Losses to I&E with Target Abundance in Bay-Delta Region

Special Status Fish Species	Type of Value	Current Population[a]	Total Baseline I&E Losses		I&E Losses as % of Current Population
			Number of Fish	Species Loss as % of Total I&E Loss of Special Status Species	
Delta smelt	Non-use	334,855	753	8.8%	0.2%
Longfin smelt	Primarily non-use	636,225	6,824	79.8%	1.1%
Sacramento splittail	Primarily non-use	7,973	911	10.6%	11.4%
Chinook salmon (all runs)	Use and non-use	301,877	67	0.8%	0.0%
Total	-	1,280,930	8,555	100.0%	0.7%

[a] Current abundance is equal to the median value for the period 1990-2000 or the median of the most recent values available from 1990 onward. See Appendix B3 for details.

Of the four special status species only one, chinook salmon, has high direct use values. The remaining three species — delta smelt, longfin smelt, and Sacramento splittail — have primarily non-use values. There are no known recreational or consumptive uses for the delta smelt. The longfin smelt is fished occasionally and it has also been sold seasonally at fish markets, but neither use appears to be widespread. Before the Sacramento splittail was listed as a threatened species it was used as bait for striped bass anglers, but not to a large extent (Federal Register, 1999). Given that I&E losses of chinook salmon represent only 0.8 percent of total I&E losses of special status species in the San Francisco Estuary, EPA focused on economic studies valuing preservation of obscure forage species in identifying benefit transfer candidates.

The Agency identified two studies that valued special status species that match closely characteristics of the species affected by I&E in the San Francisco Estuary. Boyle and Bishop (1987) found that citizens of Wisconsin are willing to pay $7.52 (2002$) to preserve the striped shiner, a small minnow of the Milwaukee River (which is listed by the State of Wisconsin as endangered, but is not listed as a Federally threatened or endangered species).[8] A study by Berrens et al. (1996) found that preservation of the endangered silvery minnow in New Mexico would be worth an average of $8.32 (2002$) per household per year.[9]

EPA considered using the point estimate approach to derive a range of WTP values for improving protection of the four special status species in the San Francisco Estuary. Neither the Boyle and Bishop (1987) nor the Berrens (1996) study contained sufficient or relevant information for applying any of the more elaborate benefits transfer techniques. Boyle and Bishop (1987) did not estimate a function which itself may be transferable to other regions. They obtained WTP values by asking citizens if they would accept or reject fixed membership fees to join a foundation that would conduct the necessary activities to preserve the species in question and reported the estimated results but not a regression function. Therefore, the benefit function transfer approach is not a feasible alternative using the Boyle and Bishop (1987) study. The Berrens et al. (1996) study also does not lend itself to benefits function transfer.

Using the two studies described in the preceding section and applying a range of the per taxpayer WTP to protect the striped shiner and silvery minnow to the 2000 population of California, it is possible to estimate WTP to prevent extinction of the delta smelt and other Federally-listed special status fish species in California.

Because I&E at the Pittsburgh and Contra Costa plants is only one of several factors that cause decline of the delta smelt, longfin smelt, Sacrament splittail, and chinook salmon populations, the societal benefit achieved from preventing all I&E losses at these two plants is lower than the benefit of reducing the risk of species extinction to zero. Thus, one would assign a fraction of the non-use estimates for species preservation programs based on the percent of the estimated standing stock that is adversely impacted under the baseline level of I&E losses. As shown in Table B6-3, the estimated impact of I&E amounts to 0.7 percent of the estimated current population of the special status species in the Bay-Delta area.

EPA notes, that although the Agency explored this approach to estimate non-use values of improved protection of the four special status species in the San Francisco Estuary, benefits based on this method were not included in the final section 316(b) rule benefit cost analysis due to the uncertainty and limitations discussed in Section A13-6.1 of this report.

EPA would like to further note the encouraging point that the valuation results are highly consistent across the relevant T&E studies available in the literature. As more studies become available, it may be possible to obtain insights into the effects of various variables (e.g., population and resource characteristics) and develop welfare estimates that may be adjusted for the attributes of the policy or region under consideration. For example, researchers and policy makers have placed increasing focus on meta-analysis and similar empirical approaches to improve the performance of benefit transfer in policy analysis.

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[8] The original WTP amount was converted to 2002$ using the Consumer Price Index (CPI) obtained from U.S. Department of Labor Bureau of Labor Statistics (U.S. Bureau of Labor Statistics, 2003).

[9] Berrens estimated a $28/year per household (1995$) WTP for a 5-year program. To place it on an equivalent basis to Boyle and Bishop, the 5-year payment needs to be converted to an equivalent annual payment over a longer time frame. Using a 25-year payment period and a 3 percent discount rate to convert the Berrens 5-year result to 25 years, and using the CPI to update from 1995$ to 2002$, the result of $8.32 (2002$) per household per year is derived. The 25-year period is used by EPA as a reasonable proxy for a longer-term indefinite period as implied by the other studies, because typical median aged household heads probably would not envision paying appreciable taxes or contributions after 25 or 30 years (i.e., past age 70).

Appendix B1: Life History Parameter Values Used to Evaluate I&E in the Northern and Southern California Regions

The tables in this appendix present the life history parameter values used by EPA to calculate age 1 equivalents, fishery yields, and production foregone from I&E data for the California region. Because of differences in the number of life stages represented in the loss data, there are cases where more than one life stage sequence was needed for a given species or species group. Alternative parameter sets were developed for this purpose and are indicated with a number following the species or species group name (i.e., Anchovies 1, Anchovies 2).

Table B1-1: American Shad Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.496	0	0	0.000000716
Larvae	3.01	0	0	0.000000728
Juvenile	7.40	0	0	0.000746
Age 1+	0.300	0	0	0.309
Age 2+	0.300	0	0	1.17
Age 3+	0.300	0	0	2.32
Age 4+	0.540	0.21	0.45	3.51
Age 5+	1.02	0.21	0.90	4.56
Age 6+	1.50	0.21	1.0	5.47
Age 7+	1.50	0.21	1.0	6.20
Age 8+	1.50	0.21	1.0	6.77

Sources: Able and Fahay, 1998; PSE&G, 1999; and U.S. Fish and Wildlife Service, 1978.

Table B1-2: Anchovies Life History Parameters 1[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.669	0	0	0.00000138
Larvae	7.99	0	0	0.00000151
Juvenile	2.12	0	0	0.0132
Age 1+	0.700	0.03	0.50	0.0408
Age 2+	0.700	0.03	1.00	0.0529
Age 3+	0.700	0.03	1.00	0.0609
Age 4+	0.700	0.03	1.00	0.0684
Age 5+	0.700	0.03	1.00	0.0763
Age 6+	0.700	0.03	1.00	0.0789

[a] Includes northern anchovy, deepbody anchovy, slough anchovy and other anchovies not identified to species.

[b] Life history parameters applied to losses from Contra Costa, Diablo, Encina, Harbor, Haynes, Humboldt, Hunter's Point, Huntington, Mandalay, Morro Bay, Moss Landing, Ormond, Pittsburg, Redondo Beach, Scattergood, Segundo, and San Onofre.

Sources: Ecological Analysts Inc., 1981b; Froese and Pauly, 2002; Pacific Fishery Management Council, 1998; Tenera Environmental Services, 2000a; Virginia Tech, 1998; and Wang, 1986.

Table B1-3: Anchovies Life History Parameters 2[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.669	0	0	0.00000138
Larvae 3 mm	0.172	0	0	0.00000151
Larvae 4 mm	0.172	0	0	0.00000173
Larvae 5 mm	0.172	0	0	0.00000334
Larvae 6 mm	0.172	0	0	0.00000572
Larvae 7 mm	0.172	0	0	0.00000901
Larvae 8 mm	0.172	0	0	0.0000134
Larvae 9 mm	0.172	0	0	0.0000189
Larvae 10 mm	0.172	0	0	0.0000258
Larvae 11 mm	0.172	0	0	0.0000342
Larvae 12 mm	0.172	0	0	0.0000442
Larvae 13 mm	0.172	0	0	0.0000559
Larvae 14 mm	0.172	0	0	0.0000696
Larvae 15 mm	0.172	0	0	0.0000853
Larvae 16 mm	0.172	0	0	0.000103
Larvae 17 mm	0.172	0	0	0.000123
Larvae 18 mm	0.172	0	0	0.000146
Larvae 19 mm	0.172	0	0	0.000171
Larvae 20 mm	0.172	0	0	0.000199
Larvae 21 mm	0.172	0	0	0.000230
Larvae 22 mm	0.172	0	0	0.000264

Table B1-3: Anchovies Life History Parameters 2[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Larvae 23 mm	0.172	0	0	0.000301
Larvae 24 mm	0.172	0	0	0.000341
Larvae 25 mm	0.172	0	0	0.000385
Larvae 26 mm	0.172	0	0	0.000432
Larvae 27 mm	0.172	0	0	0.000483
Larvae 28 mm	0.172	0	0	0.000538
Larvae 29 mm	0.172	0	0	0.000597
Larvae 30 mm	0.172	0	0	0.000659
Larvae 31 mm	0.172	0	0	0.000726
Larvae 32 mm	0.172	0	0	0.000798
Larvae 33 mm	0.172	0	0	0.000873
Larvae 34 mm	0.172	0	0	0.000954
Larvae 35 mm	0.172	0	0	0.00104
Larvae 36 mm	0.172	0	0	0.00113
Larvae 37 mm	0.172	0	0	0.00122
Larvae 38 mm	0.172	0	0	0.00132
Larvae 39 mm	0.172	0	0	0.00143
Larvae 40 mm	0.172	0	0	0.00154
Larvae 41 mm	1.249	0	0	0.00166
Larvae 59 mm	0.208	0	0	0.00485
Juvenile	2.12	0	0	0.0132
Age 1+	0.700	0.03	0.50	0.0408
Age 2+	0.700	0.03	1.0	0.0529
Age 3+	0.700	0.03	1.0	0.0609
Age 4+	0.700	0.03	1.0	0.0684
Age 5+	0.700	0.03	1.0	0.0763
Age 6+	0.700	0.03	1.0	0.0789

[a] Includes northern anchovy.

[b] Life history parameters applied to losses from Potrero.

Sources: Ecological Analysts Inc., 1980b, 1981b; Froese and Pauly, 2002; Pacific Fishery Management Council, 1998; Tenera Environmental Services, 2000a; and Wang, 1986.

Table B1-4: Anchovies Life History Parameters 3[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.669	0	0	0.00000138
Larvae 6 mm	0.104	0	0	0.00000572
Larvae 7 mm	0.207	0	0	0.00000901
Larvae 9 mm	0.104	0	0	0.0000189
Larvae 10 mm	0.104	0	0	0.0000258
Larvae 11 mm	0.104	0	0	0.0000342
Larvae 12 mm	0.104	0	0	0.0000442
Larvae 13 mm	0.104	0	0	0.0000559
Larvae 14 mm	0.104	0	0	0.0000696
Larvae 15 mm	0.207	0	0	0.0000853
Larvae 17 mm	0.207	0	0	0.000123
Larvae 19 mm	0.104	0	0	0.000171
Larvae 20 mm	0.104	0	0	0.000199
Larvae 21 mm	0.207	0	0	0.000230
Larvae 23 mm	0.311	0	0	0.000301
Larvae 26 mm	0.207	0	0	0.000432
Larvae 28 mm	0.104	0	0	0.000538
Larvae 29 mm	0.104	0	0	0.000597
Larvae 30 mm	0.104	0	0	0.000659
Larvae 31 mm	0.104	0	0	0.000726
Larvae 32 mm	0.622	0	0	0.000798
Larvae 38 mm	1.97	0	0	0.00132
Larvae 57 mm	0.519	0	0	0.00438
Larvae 62 mm	0.207	0	0	0.00561
Larvae 64 mm	0.104	0	0	0.00616
Larvae 65 mm	0.104	0	0	0.00645
Larvae 66 mm	0.104	0	0	0.00675
Larvae 67 mm	0.311	0	0	0.00706
Larvae 70 mm	0.519	0	0	0.00803
Larvae 75 mm	0.622	0	0	0.00984
Larvae 81 mm	0.104	0	0	0.0123
Larvae 82 mm	0.104	0	0	0.0128
Juvenile	2.12	0	0	0.0132
Age 1+	0.700	0.03	0.50	0.0408
Age 2+	0.700	0.03	1.0	0.0529
Age 3+	0.700	0.03	1.0	0.0609
Age 4+	0.700	0.03	1.0	0.0684
Age 5+	0.700	0.03	1.0	0.0763
Age 6+	0.700	0.03	1.0	0.0789

[a] Includes northern anchovy.
[b] Life history parameters applied to losses from Hunter's Point.

Sources: Ecological Analysts Inc., 1980b, 1981b, 1982a; Froese and Pauly, 2002; Pacific Fishery Management Council, 1998; Tenera Environmental Services, 2000a; and Wang, 1986.

Table B1-5: Blennies Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.105	0	0	0.00000176
Larvae	3.98	0	0	0.00000193
Juvenile	0.916	0	0	0.000501
Age 1+	1.34	0	0	0.00314
Age 2+	1.34	0	0	0.00745
Age 3+	1.34	0	0	0.0101
Age 4+	1.34	0	0	0.0113
Age 5+	1.34	0	0	0.0119
Age 6+	1.34	0	0	0.0122
Age 7+	1.34	0	0	0.0123
Age 8+	1.34	0	0	0.0123
Age 9+	1.34	0	0	0.0124

[a] Includes bay blenny, combtooth blenny, mussel blenny, orangethroat pikeblenny, rockpool blenny, tube blenny, and other blennies not identified to species.

Sources: Froese and Binohlan, 2000; Froese and Pauly, 2003; and Tenera Environmental Services, 2000b.

Table B1-6: Cabezon Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000430
Larvae	3.79	0	0	0.000605
Juvenile	0.916	0	0	0.00825
Age 1+	0.288	0	0	0.169
Age 2+	0.144	0.14	0.50	1.06
Age 3+	0.144	0.14	1.0	3.26
Age 4+	0.144	0.14	1.0	4.72
Age 5+	0.144	0.14	1.0	5.30
Age 6+	0.144	0.14	1.0	6.13
Age 7+	0.144	0.14	1.0	6.78
Age 8+	0.144	0.14	1.0	7.37
Age 9+	0.144	0.14	1.0	8.76
Age 10+	0.144	0.14	1.0	9.23
Age 11+	0.144	0.14	1.0	10.5
Age 12+	0.144	0.14	1.0	12.0
Age 13+	0.144	0.14	1.0	13.7

Sources: Cailliet, 2000; Leet et al., 2001; O'Connell, 1953; Tenera Environmental Services, 1988; and personal communication with Y. DeReynier (NMFS, November 19, 2002).

Table B1-7: California Halibut Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.223	0	0	0.000000548
Larvae	2.86	0	0	0.00000444
Juvenile	0.555	0	0	0.0170
Age 1+	0.160	0	0	0.130
Age 2+	0.160	0	0	0.739
Age 3+	0.160	0	0	1.94
Age 4+	0.160	0	0	3.87
Age 5+	0.160	0	0	6.21
Age 6+	0.160	0.16	1.0	8.89
Age 7+	0.160	0.16	1.0	12.2
Age 8+	0.160	0.16	1.0	15.3
Age 9+	0.160	0.16	1.0	18.9
Age 10+	0.160	0.16	1.0	21.3
Age 11+	0.160	0.16	1.0	23.8
Age 12+	0.160	0.16	1.0	26.6
Age 13+	0.160	0.16	1.0	28.6
Age 14+	0.160	0.16	1.0	30.7
Age 15+	0.160	0.16	1.0	33.0
Age 16+	0.160	0.16	1.0	35.3
Age 17+	0.160	0.16	1.0	37.7
Age 18+	0.160	0.16	1.0	40.2
Age 19+	0.160	0.16	1.0	42.9
Age 20+	0.160	0.16	1.0	45.7
Age 21+	0.160	0.16	1.0	48.5
Age 22+	0.160	0.16	1.0	51.5
Age 23+	0.160	0.16	1.0	54.7
Age 24+	0.160	0.16	1.0	57.9
Age 25+	0.160	0.16	1.0	61.3
Age 26+	0.160	0.16	1.0	64.8
Age 27+	0.160	0.16	1.0	68.4
Age 28+	0.160	0.16	1.0	72.2
Age 29+	0.160	0.16	1.0	76.1
Age 30+	0.160	0.16	1.0	80.1

Sources: Cailliet, 2000; Froese and Pauly, 2002; Kucas and Hassler, 1986; Leet et al., 2001; Tenera Environmental Services, 2000a; and personal communication with Y. DeReynier (NMFS, November 19, 2002).

Table B1-8: California Scorpionfish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000200
Larvae	1.00	0	0	0.00000219
Juvenile	1.00	0	0	0.000712
Age 1+	0.130	0	0	0.281
Age 2+	0.130	0.13	0.50	0.445
Age 3+	0.130	0.13	1.0	0.662
Age 4+	0.130	0.13	1.0	0.940
Age 5+	0.130	0.13	1.0	1.42
Age 6+	0.130	0.13	1.0	1.80
Age 7+	0.130	0.13	1.0	2.19
Age 8+	0.130	0.13	1.0	2.58
Age 9+	0.130	0.13	1.0	2.95
Age 10+	0.130	0.13	1.0	3.31
Age 11+	0.130	0.13	1.0	3.65
Age 12+	0.130	0.13	1.0	3.96
Age 13+	0.130	0.13	1.0	4.25
Age 14+	0.130	0.13	1.0	4.51
Age 15+	0.130	0.13	1.0	4.75
Age 16+	0.130	0.13	1.0	4.97
Age 17+	0.130	0.13	1.0	5.17
Age 18+	0.130	0.13	1.0	5.35
Age 19+	0.130	0.13	1.0	5.51
Age 20+	0.130	0.13	1.0	5.65
Age 21+	0.130	0.13	1.0	6.18

[a] Includes California scorpionfish and spotted scorpionfish.

Sources: Cailliet, 2000; Froese and Binohlan, 2000; and Leet et al., 2001.

Table B1-9: Chinook Salmon Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.000317
Larvae	5.04	0	0	0.000349
Juvenile	0.916	0	0	0.199
Age 1+	0.160	0	0	0.397
Age 2+	0.160	0	0	4.50
Age 3+	0.160	0	0	12.2
Age 4+	0.160	0	0	23.8
Age 5+	0.160	0	0	33.8

Sources: Allen and Hassler, 1986; Beauchamp et al., 1983; Froese and Pauly, 2001; and Wang, 1986.

Table B1-10: Commercial Sea Basses/Recreational Sea Basses Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.288	0	0	0.00000101
Larvae	1.00	0	0	0.0000216
Juvenile	0.190	0	0	0.000138
Age 1+	0.190	0	0	0.0313
Age 2+	0.190	0	0	0.0625
Age 3+	0.190	0	0	0.125
Age 4+	0.190	0	0	0.312
Age 5+	0.190	0.26	0.50	0.531
Age 6+	0.190	0.26	1.0	0.813
Age 7+	0.287	0.26	1.0	1.13
Age 8+	0.287	0.26	1.0	1.50
Age 9+	0.287	0.26	1.0	1.88
Age 10+	0.287	0.26	1.0	2.19
Age 11+	0.287	0.26	1.0	2.30
Age 12+	0.287	0.26	1.0	2.41
Age 13+	0.287	0.26	1.0	2.67
Age 14+	0.287	0.26	1.0	2.93
Age 15+	0.287	0.26	1.0	3.19
Age 16+	0.287	0.26	1.0	3.44
Age 17+	0.287	0.26	1.0	3.69
Age 18+	0.287	0.26	1.0	3.94
Age 19+	0.287	0.26	1.0	4.19
Age 20+	0.287	0.26	1.0	4.42
Age 21+	0.287	0.26	1.0	4.66
Age 22+	0.287	0.26	1.0	4.88

Table B1-10: Commercial Sea Basses/Recreational Sea Basses Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Age 23+	0.287	0.26	1.0	5.10
Age 24+	0.287	0.26	1.0	5.31
Age 25+	0.287	0.26	1.0	5.51
Age 26+	0.287	0.26	1.0	5.71
Age 27+	0.287	0.26	1.0	5.90
Age 28+	0.287	0.26	1.0	6.08
Age 29+	0.287	0.26	1.0	6.25
Age 30+	0.287	0.26	1.0	6.42
Age 31+	0.287	0.26	1.0	6.58
Age 32+	0.287	0.26	1.0	6.73
Age 33+	0.287	0.26	1.0	6.88

[a] Commercial sea bass species includes giant sea bass; recreational sea bass species includes barred sand bass, paralabrax species, broomtail grouper, kelp bass, spotted bass, and spotted sand bass.

Sources: Cailliet, 2000; California Department of Fish and Game, 2000a; Froese and Binohlan, 2000; Froese and Pauly, 2002; and Leet et al., 2001.

Table B1-11: Commercial Shrimp Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.693	0	0	0.000000249
Larvae	3.00	0	0	0.000000736
Juvenile	2.16	0.14	1.0	0.0000865
Age 1+	2.16	0.14	1.0	0.000452
Age 2+	2.16	0.14	1.0	0.00236

[a] Includes Alaskan bay shrimp, bay shrimp, black tailed bay shrimp, blackspotted shrimp, Franscican bay shrimp, ghost shrimp, smooth bay shrimp, spot shrimp, and spotted bay shrimp.

Sources: Bielsa et al., 1983; Leet et al., 2001; Siegfried, 1989; Tenera Environmental Services, 2001; and Virginia Tech, 1998.

Table B1-12: Delta Smelt Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.90	0	0	0.00000115
Larvae	4.89	0	0	0.00000120
Juvenile	0.916	0	0	0.0000462
Age 1+	1.28	0	0	0.00418

Sources: Brown and Kimmerer, 2002; Buckley, 1989a; Froese and Pauly, 2001, 2003; Moyle et al., 1992; and Wang, 1986.

Table B1-13: Drums/Croakers Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.500	0	0	0.000000722
Larvae	4.61	0	0	0.00000464
Juvenile	3.38	0	0	0.000212
Age 1+	0.420	0	0	0.120
Age 2+	0.420	0	0	0.156
Age 3+	0.210	0.21	0.50	0.195
Age 4+	0.210	0.21	1.0	0.239
Age 5+	0.210	0.21	1.0	0.287
Age 6+	0.210	0.21	1.0	0.340
Age 7+	0.210	0.21	1.0	0.398
Age 8+	0.210	0.21	1.0	0.458
Age 9+	0.210	0.21	1.0	0.519
Age 10+	0.210	0.21	1.0	0.584
Age 11+	0.210	0.21	1.0	0.648
Age 12+	0.210	0.21	1.0	0.723

[a] Includes black croaker, California corbina, queenfish, spotfin croaker, white croaker, white seabass, yellowfin croaker, and other drums or croakers not identified to species.

Sources: Cailliet, 2000; Isaacson, 1964; and Tenera Environmental Services, 1988, 2000b, 2001.

Table B1-14: Dungeness Crab Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.223	0	0	0.000000153
Zoea/Larvae[a]	1.20	0	0	0.000134
Megalopae	1.20	0	0	0.590
Age 1+	0.500	0	0	1.10
Age 2+	0.500	0.50	0.50	1.37
Age 3+	0.500	0.50	1.0	2.48
Age 4+	1.71	0.50	1.0	4.04
Age 5+	1.71	0.50	1.0	4.41
Age 6+	1.71	0.50	1.0	4.79
Age 7+	1.71	0.50	1.0	5.20
Age 8+	1.71	0.50	1.0	5.63
Age 9+	1.71	0.50	1.0	6.08
Age 10+	1.71	0.50	1.0	6.56

[a] Life stages reported as larvae and zoea were assigned the same life history parameters.

Sources: Carroll, 1982; Leet et al., 2001; Pauley et al., 1989; Tenera Environmental Services, 2000a; University of Washington, 2000; Virginia Tech, 1998; and Wild and Tasto, 1983.

Table B1-15: Flounders Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.223	0	0	0.000000303
Larvae	6.28	0	0	0.00121
Juvenile	1.14	0	0	0.00882
Age 1+	0.363	0.24	0.50	0.0672
Age 2+	0.649	0.43	1.0	0.226
Age 3+	0.752	0.50	1.0	0.553
Age 4+	0.752	0.50	1.0	1.13

[a] Includes bigmouth sole, CO turbot, California halibut, curlfin sole, diamond turbot, dover sole, english sole, fantail sole, hornyhead turbot, longfin sanddab, pacific sanddab, petrale sole, rock sole, sand sole, slender sole, speckled sanddab, spotted turbot, starry flounder, and other flounders not identified to species.

Sources: Cailliet, 2000; ENSR and Marine Research Inc., 2000; Leet et al., 2001; Tenera Environmental Services, 2000a, 2001; and personal communication with Y. DeReynier (NMFS, November 19, 2002).

Table B1-16: Forage Shrimp Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.693	0	0	0.000000249
Larvae	3.00	0	0	0.000000736
Juvenile	2.30	0	0	0.0000865
Age 1+	2.30	0	0	0.000131
Age 2+	2.30	0	0	0.00236

[a] Includes anemone shrimp, blue mud shrimp, broken back shrimp, brown shrimp, California green shrimp, dock shrimp, mysids, opossum shrimp, oriental shrimp, pistol shrimp, sidestriped shrimp, skeleton shrimp, stout bodied shrimp, striped shrimp, tidepool shrimp, twistclaw pistol shrimp, and other shrimp not identified to species.

Sources: Siegfried, 1989; Tenera Environmental Services, 2001; and Virginia Tech, 1998.

Table B1-17: Gobies Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0	0	0	0.0000115
Larvae	5.77	0	0	0.0000190
Juvenile	0.871	0	0	0.000169
Age 1+	1.10	0	0	0.00194
Age 2+	1.10	0	0	0.00414
Age 3+	1.10	0	0	0.00763
Age 4+	1.10	0	0	0.0310
Age 5+	1.10	0	0	0.0810

[a] Includes arrow goby, bay goby, blackeye goby, blind goby, chameleon goby, cheekspot goby, longjaw mudsucker shadow goby, yellowfin goby, and other gobies not identified to species.

Sources: Froese and Pauly, 2000, 2002; NMFS, 2003a; Tenera Environmental Services, 2000a; and Wang, 1986.

Table B1-18: Herrings Life History Parameters 1[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000164
Larvae	4.61	0	0	0.00000180
Juvenile	0.693	0	0	0.00161
Age 1+	0.473	0	0	0.0408
Age 2+	0.474	0	0	0.128
Age 3+	0.474	0	0	0.167
Age 4+	0.474	0	0	0.211
Age 5+	0.474	0	0	0.258
Age 6+	0.474	0	0	0.288
Age 7+	0.474	0	0	0.330
Age 8+	0.474	0	0	0.345
Age 9+	0.474	0	0	0.353
Age 10+	0.474	0	0	0.364
Age 11+	0.474	0	0	0.375

[a] Includes middle thread herring, pacific herring, pacific sardine, round herring, threadfin shad, and other herrings not identified to species.

[b] Life history parameters applied to losses from Contra Costa, Diablo, Encina, Humboldt Bay, Hunter’s Point, Huntington, Morro Bay, Moss Landing, Ormond, Pittsburg, Redondo Beach, Scattergood, Segundo, and San Onofre.

Sources: Ecological Analysts Inc., 1981b, 1982a; Froese and Pauly, 2002; Lassuy, 1989; NMFS, 2003a; and Tenera Environmental Services, 2001.

Table B1-19: Herrings Life History Parameters 2[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000164
Larvae 6 mm	0.140	0	0	0.00000182
Larvae 7 mm	0.121	0	0	0.00000299
Larvae 8 mm	0.107	0	0	0.00000461
Larvae 9 mm	0.096	0	0	0.00000675
Larvae 10 mm	0.087	0	0	0.00000948
Larvae 11 mm	0.079	0	0	0.0000129
Larvae 12 mm	0.221	0	0	0.0000171
Larvae 13 mm	0.221	0	0	0.0000221
Larvae 14 mm	0.221	0	0	0.0000281
Larvae 15 mm	0.221	0	0	0.0000352
Larvae 16 mm	0.221	0	0	0.0000433
Larvae 17 mm	0.221	0	0	0.0000527
Larvae 18 mm	0.221	0	0	0.0000634
Larvae 19 mm	0.221	0	0	0.0000755
Larvae 20 mm	0.221	0	0	0.0000891
Larvae 22 mm	0.221	0	0	0.000121
Larvae 23 mm	0.221	0	0	0.000140
Larvae 24 mm	0.221	0	0	0.000161
Larvae 25 mm	0.221	0	0	0.000183
Larvae 26 mm	0.221	0	0	0.000208
Larvae 27 mm	0.221	0	0	0.000235
Larvae 28 mm	0.221	0	0	0.000264
Larvae 29 mm	0.221	0	0	0.000296
Larvae 30 mm	0.221	0	0	0.000330
Juvenile	0.693	0	0	0.00161
Age 1+	0.473	0	0	0.0408
Age 2+	0.474	0	0	0.128
Age 3+	0.474	0	0	0.167
Age 4+	0.474	0	0	0.211
Age 5+	0.474	0	0	0.258
Age 6+	0.474	0	0	0.288
Age 7+	0.474	0	0	0.330
Age 8+	0.474	0	0	0.345
Age 9+	0.474	0	0	0.353
Age 10+	0.474	0	0	0.364
Age 11+	0.474	0	0	0.375

[a] Includes pacific herring and other herrings not identified to species.

[b] Life history parameters applied to losses from Potrero.

Sources: Ecological Analysts Inc., 1981b; Froese and Pauly, 2002; Lassuy, 1989; NMFS, 2003a; Tenera Environmental Services, 2001; and Wang, 1986.

Table B1-20: Herrings Life History Parameters 3[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000164
Larvae 6 mm	0.107	0	0	0.00000182
Larvae 7 mm	0.107	0	0	0.00000299
Larvae 8 mm	0.107	0	0	0.00000461
Larvae 9 mm	0.107	0	0	0.00000675
Larvae 10 mm	0.107	0	0	0.00000948
Larvae 11 mm	0.107	0	0	0.0000129
Larvae 12 mm	0.107	0	0	0.0000171
Larvae 13 mm	0.214	0	0	0.0000221
Larvae 15 mm	0.107	0	0	0.0000352
Larvae 16 mm	0.107	0	0	0.0000433
Larvae 17 mm	0.107	0	0	0.0000527
Larvae 18 mm	0.107	0	0	0.0000634
Larvae 19 mm	0.107	0	0	0.0000755
Larvae 20 mm	0.107	0	0	0.0000891
Larvae 21 mm	0.107	0	0	0.000104
Larvae 22 mm	0.107	0	0	0.000121
Larvae 23 mm	0.107	0	0	0.000140
Larvae 24 mm	0.107	0	0	0.000161
Larvae 25 mm	2.36	0	0	0.000183
Larvae 47 mm	0.107	0	0	0.00141
Larvae 48 mm	0.107	0	0	0.00151
Juvenile	0.693	0	0	0.00161
Age 1+	0.473	0	0	0.0408
Age 2+	0.474	0	0	0.128
Age 3+	0.474	0	0	0.167
Age 4+	0.474	0	0	0.211
Age 5+	0.474	0	0	0.258
Age 6+	0.474	0	0	0.288
Age 7+	0.474	0	0	0.330
Age 8+	0.474	0	0	0.345
Age 9+	0.474	0	0	0.353
Age 10+	0.474	0	0	0.364
Age 11+	0.474	0	0	0.375

[a] Includes pacific herring.

[b] Life history parameters applied to losses from Hunter's Point.

Sources: Ecological Analysts Inc., 1981b, 1982a; Froese and Pauly, 2002; Lassuy, 1989; NMFS, 2003a; Tenera Environmental Services, 2001; and Wang, 1986.

Table B1-21: Longfin Smelt Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.90	0	0	0.00000115
Larvae	6.38	0	0	0.00000186
Juvenile	0.916	0	0	0.000213
Age 1+	0.670	0	1.0	0.00355
Age 2+	0.670	0	1.0	0.0157
Age 3+	0.670	0	1.0	0.0434

Sources: Buckley, 1989a; Froese and Pauly, 2001; U.S. Fish and Wildlife Service, 1996b; and Wang, 1986.

Table B1-22: Northern Anchovy Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.669	0	0	0.00000138
Larvae 5 mm	1.71	0	0	0.00000334
Larvae 6 mm	0.196	0	0	0.00000572
Larvae 7 mm	0.196	0	0	0.00000901
Larvae 8 mm	0.196	0	0	0.0000134
Larvae 9 mm	0.196	0	0	0.0000189
Larvae 10 mm	0.196	0	0	0.0000258
Larvae 11 mm	0.196	0	0	0.0000342
Larvae 12 mm	0.196	0	0	0.0000442
Larvae 13 mm	0.196	0	0	0.0000559
Larvae 14 mm	0.196	0	0	0.0000696
Larvae 15 mm	0.196	0	0	0.0000853
Larvae 16 mm	0.196	0	0	0.000103
Larvae 17 mm	0.196	0	0	0.000123
Larvae 18 mm	0.196	0	0	0.000146
Larvae 19 mm	0.196	0	0	0.000171
Larvae 20 mm	0.196	0	0	0.000199
Larvae 21 mm	0.196	0	0	0.000230
Larvae 22 mm	0.196	0	0	0.000264
Larvae 23 mm	0.196	0	0	0.000301
Larvae 24 mm	0.196	0	0	0.000341
Larvae 25 mm	0.196	0	0	0.000385
Larvae 26 mm	0.196	0	0	0.000432
Larvae 27 mm	0.196	0	0	0.000483
Larvae 28 mm	0.196	0	0	0.000538
Larvae 29 mm	0.196	0	0	0.000597
Larvae 30 mm	0.196	0	0	0.000659
Larvae 31 mm	0.196	0	0	0.000726

Table B1-22: Northern Anchovy Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Larvae 32 mm	0.196	0	0	0.000798
Larvae 33 mm	0.196	0	0	0.000873
Larvae 34 mm	0.196	0	0	0.000954
Larvae 35 mm	0.196	0	0	0.00104
Larvae 36 mm	0.196	0	0	0.00113
Larvae 37 mm	0.196	0	0	0.00122
Juvenile	2.12	0	0	0.0132
Age 1+	0.700	0.03	0.50	0.0408
Age 2+	0.700	0.03	1.0	0.0529
Age 3+	0.700	0.03	1.0	0.0609
Age 4+	0.700	0.03	1.0	0.0684
Age 5+	0.700	0.03	1.0	0.0763
Age 6+	0.700	0.03	1.0	0.0789

Sources: Ecological Analysts Inc., 1980b; Froese and Pauly, 2002; Virginia Tech, 1998; Tenera Environmental Services, 2000a; and Wang, 1986.

Table B1-23: Other Commercial Crabs Life History Parameters 1[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0	0	0	0.000000153
Zoea 1	1.58	0	0	0.00000195
Zoea 2	0.948	0	0	0.00000726
Zoea 3	0.948	0	0	0.0000177
Zoea 4	0.948	0	0	0.0000347
Zoea 5	1.26	0	0	0.0000598
Megalopae	2.31	0	0	0.000134
Age 1+	2.43	0	0	0.289
Age 2+	2.43	0	0	0.654
Age 3+	2.43	0	0	1.26
Age 4+	1.82	0.61	0.50	1.97
Age 5+	1.82	0.61	1.0	2.55
Age 6+	1.82	0.61	1.0	3.00

[a] Includes Anthony's rock crab, black clawed crab, brown rock crab, common rock crab, cryptic kelp crab, dwarf crab, elbow crab, graceful kelp crab, hairy crab, hairy rock crab, kelp crab, lined shore crab, lumpy crab, majid crab, masking crab, mole crab, moss crab, northern kelp crab, porcelain crab, purple shore crab, red crab, red rock crab, sharp nosed crab, shore crab family, slender crab, southern kelp crab, spider crab, striped shore crab, thickclaw porcelain crab, yellow crab, yellow shore crab, and other commercial crabs not identified to species.

[b] Life history parameters applied to losses from Diablo, Encina, Morro Bay, and Moss Landing.

Sources: Carroll, 1982; Leets et al., 2001; Tenera Environmental Services, 2000a; and University of Washington, 2000.

Table B1-24: Other Commercial Crabs Life History Parameters 2[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0	0	0	0.000000153
Larvae	7.99	0	0	0.0000192
Megalopae	2.31	0	0	0.000134
Age 1+	2.43	0	0	0.289
Age 2+	2.43	0	0	0.654
Age 3+	2.43	0	0	1.26
Age 4+	1.82	0.61	0.50	1.97
Age 5+	1.82	0.61	1.0	2.55
Age 6+	1.82	0.61	1.0	3.00

[a] Includes brown rock crab, European green crab, hairy rock crab, hermit crab, lined shore crab, mud crab, pacific sand crab, pea crab, pebble crab, porcelain crab, red crab, red rock crab, shore crab, slender crab, slender rock crab, spider crab, stone crab, yellow crab, yellow rock crab, yellow shore crab, and other commercial crabs not identified to species.

[b] Life history parameters applied to losses from Humboldt Bay, Hunter's Point, Morro Bay, Moss Landing, and Potrero.

Sources: Carroll, 1982; Leets et al., 2001; Tenera Environmental Services, 2000a, 2001; and University of Washington, 2000.

Table B1-25: Pacific Herring Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000164
Larvae 6 mm	1.44	0	0	0.00000182
Larvae 7 mm	0.703	0	0	0.00000299
Larvae 8 mm	0.609	0	0	0.00000461
Larvae 9 mm	0.537	0	0	0.00000675
Larvae 10 mm	0.481	0	0	0.00000948
Larvae 11 mm	0.435	0	0	0.0000129
Larvae 12 mm	0.397	0	0	0.0000171
Juvenile	0.693	0	0	0.00161
Age 1+	0.473	0	0	0.243
Age 2+	0.474	0	0	0.351
Age 3+	0.474	0	0	0.388
Age 4+	0.474	0	0	0.410
Age 5+	0.474	0	0	0.434
Age 6+	0.474	0	0	0.450
Age 7+	0.474	0	0	0.472
Age 8+	0.474	0	0	0.485

Sources: Ecological Analysts Inc., 1981b; Froese and Pauly, 2002, 2003; Lassuy, 1989; NMFS, 2003a; Tenera Environmental Services, 2001; and Washington Dept. of Fish and Wildlife, 1997.

Table B1-26: Rockfish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Larvae	1.00	0	0	0.000181
Juvenile	1.00	0	0	0.00760
Age 1+	0.215	0	0	0.0444
Age 2+	0.215	0	0	0.150
Age 3+	0.261	0	0	0.308
Age 4+	0.131	0.13	0.25	0.458
Age 5+	0.131	0.13	0.50	0.689
Age 6+	0.131	0.13	0.75	0.878
Age 7+	0.131	0.13	1.0	1.05
Age 8+	0.131	0.13	1.0	1.21
Age 9+	0.131	0.13	1.0	1.34
Age 10+	0.131	0.13	1.0	1.46
Age 11+	0.131	0.13	1.0	1.55
Age 12+	0.131	0.13	1.0	1.63
Age 13+	0.131	0.13	1.0	1.70
Age 14+	0.131	0.13	1.0	1.75
Age 15+	0.131	0.13	1.0	1.80
Age 16+	0.131	0.13	1.0	1.83
Age 17+	0.131	0.13	1.0	1.86
Age 18+	0.131	0.13	1.0	1.88
Age 19+	0.131	0.13	1.0	1.90
Age 20+	0.131	0.13	1.0	1.92
Age 21+	0.131	0.13	1.0	1.93
Age 22+	0.131	0.13	1.0	1.94
Age 23+	0.131	0.13	1.0	1.95
Age 24+	0.131	0.13	1.0	1.95

[a] Includes aurora rockfish, black and yellow rockfish, black rockfish, blue rockfish, bocaccio, brown rockfish, calico rockfish, chilipepper, copper rockfish, flag rockfish, gopher rockfish, grass rockfish, kelp rockfish, olive rockfish, shortbelly rockfish, treefish, vermilion rockfish, yellowtail rockfish, and other rockfish not identified to species.

Sources: Cailliet, 2000; Leet et al., 2001; Froese and Binohlan, 2000; Russell and Hanson, 1990; and Tenera Environmental Services, 2001.

Table B1-27: Sacramento Splittail Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000352
Larvae	11.3	0	0	0.0000140
Juvenile	0.916	0	0	0.00103
Age 1+	0.370	0	1.0	0.0683
Age 2+	0.370	0	1.0	0.252
Age 3+	0.370	0	1.0	0.480
Age 4+	0.370	0	1.0	0.704
Age 5+	0.370	0	1.0	1.05

Sources: California Department of Water Resources and U.S. Bureau of Reclamation, 1994; Daniels and Moyle, 1983; and Froese and Pauly, 2001.

Table B1-28: Salmon Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.000317
Larvae	5.04	0	0	0.000349
Juvenile	0.916	0	0	0.199
Age 1+	0.160	0.16	0.50	0.397
Age 2+	0.160	0.16	1.0	4.50
Age 3+	0.160	0.16	1.0	12.2
Age 4+	0.160	0.16	1.0	23.8
Age 5+	0.160	0.16	1.0	33.8

Sources: Allen and Hassler, 1986; Beauchamp et al., 1983; California Dept. of Fish and Game, 2003; Froese and Pauly, 2001; and Wang, 1986.

Table B1-29: Sculpins Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000338
Larvae	3.79	0	0	0.00000371
Juvenile	0.916	0	0	0.0120
Age 1+	0.420	0.50	0.50	0.0400
Age 2+	0.420	0.50	1.0	0.104
Age 3+	0.420	0.50	1.0	0.219

[a] Includes bonehead sculpin, brown Irish lord, buffalo sculpin, coralline sculpin, fluffy sculpin, manacled sculpin, pacific staghorn sculpin, prickly sculpin, rosy sculpin, roughcheek sculpin, roughneck sculpin, smoothhead sculpin, snubnose sculpin, spotted scorpionfish, staghorn sculpin, tidepool sculpin, woolly sculpin, and other sculpins not identified to species.

Sources: Cailliet, 2000; Froese and Pauly, 2002; Leet et al., 2001; and personal communication with Y. DeReynier (NMFS, November 19, 2002).

Table B1-30: Silversides Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.669	0	0	0.00000924
Larvae	7.99	0	0	0.0000528
Juvenile	0.420	0	0	0.000472
Age 1+	0.420	0	0	0.0207
Age 2+	0.420	0	0	0.106
Age 3+	0.420	0	0	0.166
Age 4+	0.420	0	0	0.246
Age 5+	0.420	0	0	0.349
Age 6+	0.420	0	0	0.476
Age 7+	0.420	0	0	0.632
Age 8+	0.420	0	0	0.818
Age 9+	0.420	0	0	1.04
Age 10+	0.420	0	0	1.30
Age 11+	0.420	0	0	1.59

[a] Includes California grunion, jacksmelt, topsmelt, and other silversides not identified to species.

Sources: Cailliet, 2000; Froese and Pauly, 2002; Leet et al., 2001; NMFS, 2003a; and Wang, 1986.

Table B1-31: Smelts Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.90	0	0	0.00000154
Larvae	7.99	0	0	0.000389
Juvenile	0.740	0.15	0.50	0.00520
Age 1+	0.740	0.15	1.0	0.0364
Age 2+	0.740	0.15	1.0	0.147
Age 3+	0.740	0.15	1.0	0.393
Age 4+	0.740	0.15	1.0	0.738
Age 5+	0.740	0.15	1.0	1.25

[a] Includes night smelt, popeye smelt, surf smelt, and other smelts not identified to species.

Sources: Buckley, 1989a; Cailliet, 2000; Dryfoos, 1965; Froese and Pauly, 2002; and Leet et al., 2001.

Table B1-32: Steelhead Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.000317
Larvae	5.04	0	0	0.000349
Juvenile	0.916	0	0	0.199
Age 1+	0.160	0	0	0.397
Age 2+	0.160	0	0.50	4.50
Age 3+	0.160	0	1.0	12.2
Age 4+	0.160	0	1.0	23.8
Age 5+	0.160	0	1.0	33.8
Age 6+	0.160	0	1.0	37.9
Age 7+	0.160	0	1.0	40.1
Age 8+	0.160	0	1.0	41.9
Age 9+	0.160	0	1.0	43.0

Sources: Beauchamp et al., 1983; Froese and Pauly, 2001; and Wang, 1986.

Table B1-33: Striped Bass Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.50	0	0	0.0000416
Larvae 5 to 6 mm	1.00	0	0	0.0000457
Larvae 7 to 10 mm	2.01	0	0	0.0000503
Larvae 11 to 14 mm	0.939	0	0	0.0000553
Larvae 15 to 18 mm	0.651	0	0	0.0000898
Larvae 19 mm	0.0610	0	0	0.000135
Larvae 20 to 24 mm	0.312	0	0	0.000207
Larvae 25 to 29 mm	0.286	0	0	0.000397
Larvae 30 to 34 mm	0.334	0	0	0.000616
Larvae 35 to 39 mm	0.375	0	0	0.000977
Larvae 40 to 44 mm	0.441	0	0	0.00136
Larvae 45 to 49 mm	0.904	0	0	0.00194
Larvae 51 to 75 mm	0.700	0	0	0.00421
Larvae 76 to 100 mm	0.350	0	0	0.0105
Juvenile	0.916	0	0	0.0174
Age 1+	0.320	0	0	0.100
Age 2+	0.320	0.18	0.06	0.500
Age 3+	0.320	0.18	0.20	2.30
Age 4+	0.320	0.18	0.63	4.30
Age 5+	0.320	0.18	0.94	6.00
Age 6+	0.320	0.18	1.0	8.50
Age 7+	0.320	0.18	1.0	11.8
Age 8+	0.320	0.18	1.0	13.8
Age 9+	0.320	0.18	1.0	16.0

[a] Life history parameters applied to losses from Contra Costa and Pittsburg.

Sources: California Dept. of Fish and Game, 2000a; Ecological Analysts Inc., 1981b; Froese and Pauly, 2001; Leet et al., 2001; PSE&G, 1999; Setzler et al., 1980.

Table B1-34: Striped Bass Life History Parameters 2[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.50	0	0	0.0000416
Larvae	7.44	0	0	0.0000457
Juvenile	0.916	0	0	0.0174
Age 1+	0.320	0	0	0.100
Age 2+	0.320	0.18	0.06	0.500
Age 3+	0.320	0.18	0.20	2.30
Age 4+	0.320	0.18	0.63	4.30
Age 5+	0.320	0.18	0.94	6.00
Age 6+	0.320	0.18	1.0	8.50
Age 7+	0.320	0.18	1.0	11.8
Age 8+	0.320	0.18	1.0	13.8
Age 9+	0.320	0.18	1.0	16.0

[a] Life history parameters applied to losses from Hunter's Point.

Sources: California Dept. of Fish and Game, 2000a; Ecological Analysts Inc., 1981b; Froese and Pauly, 2001; Leet et al., 2001; PSE&G, 1999; and Setzler et al., 1980.

Table B1-35: Surfperches Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Juvenile	0.560	0	0	0.00443
Age 1+	0.280	0	0	0.0429
Age 2+	0.280	0.28	0.50	0.125
Age 3+	0.280	0.28	1.0	0.203
Age 4+	0.280	0.28	1.0	0.261
Age 5+	0.280	0.28	1.0	0.300
Age 6+	0.280	0.28	1.0	0.324

[a] Includes barred surfperch, black surfperch, calico surfperch, dwarf surfperch, island surfperch, kelp surfperch, pile surfperch, pink seaperch, rainbow surfperch, rubberlip surfperch, shiner surfperch, silver surfperch, spotfin surfperch, striped surfperch, walleye surfperch, white seaperch, and other surfperches not identified to species.

Sources: Cailliet, 2000; Froese and Binohlan, 2000; Froese and Pauly, 2002; and Leet et al., 2001.

Table B1-36: Other Commercial Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per Stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.50	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] See Table B1-40 for a list of species.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table B1-37: Other Recreational Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per Stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.50	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] See Table B1-41 for a list of species.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table B1-38: Other Rec/Com Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Yolk-sac larvae	2.85	0	0	0.000000728
Post yolk-sac larvae	2.85	0	0	0.00000335
Juvenile 1	1.43	0	0	0.000746
Juvenile 2	1.43	0	0	0.0472
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.50	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] Includes barracuda, California sheephead, jack mackerel, lingcod, piked dogfish, and spiny dogfish.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table B1-39: Other Forage Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000186
Larvae	7.70	0	0	0.00000158
Juvenile	1.29	0	0	0.000481
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] See Table B1-42 for a list of species.

Sources: Derickson and Price, 1973; and PSE&G, 1999.

Table B1-40: Other Commercial Species[a]

Basketweave cusk-eel	Monkeyface eel	Pacific hake	Spotted cusk-eel
California moray	Monkeyface prickleback	Pricklebreast poacher	Yellow snake-eel
Catalina conger	Moray eel	Ribbon prickleback	
Leopard shark	Pacific hagfish	Rock prickleback	

[a] Includes other organisms not identified to species.

Table B1-41: Other Recreational Species[a]

Angel shark	Chub mackerel	Pacific angel shark	Round stingray
Bat ray	Diamond stingray	Pacific bonito	Senorita
Big skate	Gray smoothhound	Pacific bumper	Sevengill shark
Black skate	Halfmoon	Pacific electric ray	Soupfin shark
Broadnose sevengill shark	Horn shark	Pacific mackerel	Striped mullet
Brown smoothhound	Kelp greenling	Pacific moonfish	Swell shark
California butterfly ray	Mexican scad	Pacific pompano	Thornback ray
California electric ray	Monterey Spanish mackerel	Painted greenling	
California ray	Opaleye	Rock wrasse	

[a] Includes other organisms not identified to species.

Table B1-42: Other Forage Species[a]

Barcheek pipefish	Finescale triggerfish	Ocean sunfish	Sea porcupine
Bay pipefish	Flathead mullet	Ocean whitefish	Sharksucker
Bigscale goatfish	Fringehead	Onespot fringehead	Shovelnose guitarfish
Bigscale logperch	Garibaldi	Pacific butterfish	Slimy snailfish
Black bullhead	Giant kelpfish	Pacific cornetfish	Smalleye squaretail
Blacksmith	Grunt	Pacific cutlassfish	Snailfishes
Blue lanternfish	Gunnels	Pacific lamprey	Snubnose pipefish
Broadfin lampfish	Hatchet fish	Pacific sand lance	Southern poacher
Bullseye puffer	High cockscomb	Penpoint gunnel	Southern spearnose poacher
California clingfish	Hitch	Pipefishes	Specklefin midshipman
California flyingfish	Island kelpfish	Plainfin midshipman	Spotted kelpfish
California killifish	Kelp gunnel	Pygmy poacher	Spotted ratfish
California lizardfish	Kelp pipefish	Ratfish	Squid
California needlefish	Kelpfish	Red brotula	Stickleback
California tonguefish	Lampfish	Reef finspot	Striped kelpfish
Californian needlefish	Lanternfish	Ribbonfish	Sunfish family
Catfish family	Longfin lanternfish	Rockweed gunnel	Thornback
Clingfishes	Longspine combfish	Ronquils	Threespine stickleback
Clinids	Medusafish	Saddleback gunnel	Tubesnout
Codfishes	Mexican lampfish	Salema	White catfish
Combfish	Northern clingfish	Sarcastic fringehead	Zebra perch
Cortez angelfish	Northern lampfish	Sargo	
Crevice kelpfish	Northern spearnose poacher	Scarlet kelpfish	

[a] Includes other organisms not identified to species.

Appendix B2: Valuing Water Use Foregone

INTRODUCTION

APPENDIX CONTENTS

It is difficult to identify the precise value of the water lost to municipal and agricultural users as a result of programs that increase freshwater flows to the San Francisco Bay-Delta. Water is not an actively traded commodity, such as a farm crop or gasoline, where market transactions provide clear market prices. Information is available, however, that can be used to approximate water values. This appendix discusses available evidence and makes an estimate of expected water values.

Identifying water value translates into answering the question, “How much would water agencies be willing to pay today to secure permanent water supplies of delta surface waters?” To answer this question EPA investigated both what water users are currently paying for delta surface waters delivered by the California State Water Project (SWP) and recent California water market transactions.

B2-1 STATE WATER PROJECT

The SWP is the largest state-built, multipurpose water project in the nation. Its main purpose is water supply — to store surplus water during wet periods and distribute it to areas of need throughout California. Construction began after passage of a $1.75 billion public bond issue in 1960. The main storage reservoir is Lake Oroville in northern California. Water is transported through the Feather and Sacramento rivers and a system of canals, pipelines, pumping plants, and power plants for use by agricultural and urban users (29 water agencies). It is likely that SWP water deliveries will be lowered to increase delta flows, in the same manner that Central Valley Project (CVP) diversions already have been reduced.

Table B2-1 shows what SWP water customers currently pay for SWP water. Water costs vary widely by geographic region largely because of differences in conveyance costs. SWP water is least expensive in the San Joaquin and Feather River areas, between $65 and $69 per acre foot (AF) of entitlement, or between $83 and $88 per AF for water delivered (assuming 78 percent of entitlement is delivered in an average year). The delivered price of SWP water to coastal areas (e.g., Santa Barbara) is as great as $986/per AF.[1] The average weighted cost of delivered SWP water is $182/AF.

These costs provide information on the lower bound of water value. The 29 purchasing water agencies value the water by at least the amount they pay for the water, or else they would dispose or sell their interest in the SWP. The $83/AF cost estimate provides a firm lower bound of the value of water to its current buyers (users). Most of the water used in the San Joaquin area is used for agriculture. Hence, the $83/AF estimate provides a firm lower bound for agricultural water. In other words, if CALFED offered to buy SWP users’ entitlement rights at $83/AF of delivered water ($65/AF of entitlement water), there would be very few, if any, sellers. Thus, EPA applied a range of from $100 to $200 per AF as the value of water to agricultural users, given that it costs these users at least $83/AF to obtain the water.

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[1] This is only the SWP cost. Many users pay additional costs to transport water from SWP facilities to their location. For example, Santa Barbara pays the Central Coast Water Authority to move water to their service area. Additional costs are also associated with treating water.

Table B2-1: State Water Project Costs

Service Area	Cost of Entitlement ($/AF)[a]	Effective Cost for Water Delivered ($/AF)[b]	Entitlement (AF/yr)[a]	% Entitlement
San Joaquin	$65	$83	1,178,937	50.2%
Feather River	$69	$88	1,421	0.1%
South Bay Area	$113	$145	147,186	6.3%
North Bay Area	$180	$231	37,871	1.6%
Southern California	$233	$299	973,254	41.5%
Coastal Area	$769	$986	8,538	0.4%
Average/Total	$142	$182	2,347,207	100.0%

[a] Information from Davis et al., 1999. Excludes other deliveries.

[b] Adjusted to reflect actual delivery of entitlement averages of 78 percent (e.g., $65/0.78 = $83).

The SWP water costs also indicate that an offered water price would have to be high for municipal users to surrender their SWP water entitlements. In the central coast counties of San Luis Obispo and Santa Barbara, the offer would need to exceed $986/AF, the effective price that this area is currently willing to pay for SWP water. That is, municipal users in some portions of California are paying nearly $1,000/AF for water from the SWP. The value of water is high in this area because of the limited and expensive alternative water supply options (e.g., desalination). The acceptance price might be lower for other municipal agencies that have other, less expensive alternative water supplies.

B2-2 WATER MARKET TRANSACTIONS

Another approach that can be used to estimate the value of water is to review recent California water transactions. EPA identified 20 transactions in California from January 1998 to March 2000 (see Table B2-2). Most of the transactions (14) involved municipal agencies purchasing water supplies to serve growing populations. The water price associated with these municipal transactions ranged from $90 to $412/AF, averaging $267/AF. Every transaction had unique circumstances and conditions that may affect the transaction price (e.g., reliability of water yield, water quality, duration of the purchase agreement). The water transactions involving groundwater in West Coast Basin, Central Basin, and the Main San Gabriel Basin showed municipal users selling water in the $300 to $320/AF range.

Four transactions involved municipal users purchasing SWP water. These transactions included a one-time payment of $1,000/AF entitlement (1,000 AF per year, indefinitely), plus assumption of SWP expenses. This translates into an average price of $290/AF on an annual AF basis.

From this information, EPA estimated the approximate value of water for municipal agencies to be at least $300/AF. The SWP deliveries to southern California cost about $299/AF delivered. Given expected future water shortages, EPA surmises that not many municipal customers (e.g., Metropolitan Water District of Southern California) would sell their interests in SWP water for $300. Hence, the value is most likely much higher.

Table B2-2: Recent California Water Transactions

No.	$/AF[a]	AF/yr	Use[b]	Source	Transaction	Date	Acquirer	Supplier	Comments
1	$45	1,000	I	Surface	Lease	1998	Garfield WD	Madera Irrigation District	Ag transfer of surplus water supplies
2	$90	5,000	M	Surface	Lease	1998	Alameda County FCWCD#7	Byron Bethany ID	15-year lease near S.F.
3	$177	8,000	M	Surface	Purchase	1998	Western Hills WD	Berrenda Mesa Water District	Transfer of SWP entitlement; $1,000/AF + SWP costs
4	$300	4,531	M	Ground	Purchase	7/98 - 6/99	Various	Various	2 adjudicated basins in Southern CA
5	$150	10,000	M	Ground	Lease	Feb-99	Orange County	San Bernardino Valley	1-year lease Bunker Hill Basin near L.A.
6	$320	2,748	M	Ground	Purchase	7/98 - 6/99	Various	Various	Main San Gabriel Basin near L.A.
7	$241	15,000	M	Surface	Purchase	Oct-99	Alameda County FCWCD#7	Lost Hills Water District (Ag)	Transfer of SWP entitlement; $1,000/AF + SWP costs
8	$164	54,352	M	Ground	Lease	7/98 - 6/99	Various	Various	2 adjudicated basins in Southern CA
9	$200	5,950	M	Surface	Lease	1998	City of Inglewood	Western Water Company	5-year lease near L.A.
10	$240	23,416	M	Ground	Lease	7/98 - 6/99	Various	Various	1-year lease; Main San Gabriel Basin near L.A.
11	$361	4,000	M	Surface	Purchase	Jun-99	Palmdale WD	Belridge WD	Transfer of SWP entitlement; $1,000/AF + SWP costs
12	$297	13,697	M	Surface	Lease	1998	Mojave Water Agency	CA Dept of Water Resources	Reduce aquifer overdraft in Southern CA
13	$380	41,000	M	Surface	Purchase	May-99	Castaic Lake WA	Wheeler Ridge WD	Transfer of SWP entitlement; $1,150/AF + SWP costs
14	$409	20,000	M	Surface	Lease	Oct-99	City of San Diego	Western Water Company	1-year lease in Southern CA
15	$412	10,000	M	Surface	Lease	Jun-99	Santa Margarita WD	Western Water Company	1-year lease in Southern CA
16	$55	30,000	M & I	Surface	Lease	Nov-99	Stockton East Water District	Oakdale & South San Joaquin Ids	10-year lease of Stanislaus River water
17	$30	10,000	PT	Surface	Lease	2000	Bureau of Rec	Semitropic Water Storage District	1-year lease for San Joaquin Valley Wildlife Refuges
18	$60	50,000	PT	Surface	Lease	Oct-99	Bureau of Rec	Oakdale & South San Joaquin Ids	1-year lease to augment San Joaquin River flows
19	$60	30,000	PT	Surface	Lease	Jun-99	Bureau of Rec	Vernalis Adaptive Management IDs	San Joaquin River augmentation
20	$65	10,000	PT	Both	Lease	2000	Bureau of Rec	San Luis Canal Company	1-year lease for San Joaquin Valley Wildlife Refuges
Average Price $/AF			All	203					
Average Price $/AF			M	267					
Average Price $/AF			PT	54					

[a] Price for purchases are converted into $/AF terms using an infinite time horizon and a 10 percent annual discount rate. Dollars are current for the year of the transaction (1998, 1999, or 2000).

[b] I = irrigation, M = municipal, PT = public trust.

B2-3 SUMMARY

Our review indicates that the value to agricultural and municipal users of water use foregone is at least $100 and $300/AF, respectively. These estimates are probably biased downward, and we therefore show an upper bound value of $200/AF and $1,000/AF for agricultural and municipal users, respectively.

For the purposes of this project, we need to identify a weighted average value of water lost because of enhancements in water flows in the delta for environmental purposes. We weighed the value per AF estimates based on the assumption of a proportional cutback in water supplies between agricultural and municipal users. We used CVP and SWP water uses as a basis for our weighting. Table B2-3 shows the results and a weighted value of water from $155/AF to $425/AF. Applying these values to 3 to 4 million AF per year, the opportunity cost of the water use foregone is in the range of $465 million to $1.7 billion annually.

Table B2-3: Summary of Uses and Values for Foregone Water to SWP and CVP Water Users

Water User Type	SWP and CVP Water Delivered (AF/yr)	% of Use	Estimated Value to Users ($/AF)
Municipal	2,569,328	28%	$300 to $1000
Agricultural	6,697,256	72%	$100 to $200
Total	9,266,584	100%	$155 to $425

Source: Davis et al., 1999.

Appendix B3: Special Status Species Population Estimates

The historical (target) and current abundances of delta smelt, longfin smelt, and Sacramento splittail were estimated to calculate the number of fish needed to restore current populations to pre-decline levels. This appendix describes the method used to estimate historical and current abundances of these special status species.

In their 1990 report to the California Fish and Game Commission, Stevens et al. (1990) calculated the delta smelt population by using the ratio of juvenile delta smelt to young striped bass caught in the fall midwater trawl survey. This ratio was multiplied by striped bass population numbers that were derived from a life table analysis. The resulting population estimate of delta smelt is the only known attempt to approximate total delta smelt populations in the Sacramento-San Joaquin Delta. Using the 8 years of available striped bass data, EPA extrapolated longfin, delta smelt, and Sacramento splittail populations through the 1990's and into 2000. This extrapolation involved:

- averaging (across the 8 years) the percentage of the total striped bass population caught in the trawling runs; and
- dividing the average percentage of the striped bass population caught in the trawling runs by delta smelt, Sacramento splittail, and longfin smelt abundance indices taken from the fall midwater trawl survey conducted annually for more than 30 years.

Tables B3-1 and B3-2 show annual population numbers derived for delta smelt, longfin smelt, and Sacramento splittail using this method. Table B3-1 shows population estimates for the baseline 8 years from 1968 to 1985 (nonsequential years are due to trawling surveys not conducted in that specific year). Table B3-2 presents population estimates for 1990-2000 based on the average striped bass index of 0.13 percent (striped bass caught versus estimate of total striped bass population) that was calculated across the baseline range (1968-1985).

Table B3-1: Sacramento-San Joaquin Delta Population Estimates of Striped Bass, Sacramento Splittail, Delta Smelt, and Longfin Smelt (1968-1985)[a]

Species	1968	1970	1971	1972	1975	1977	1984	1985
Striped bass	1,800,000	8,100,000	11,900,000	12,700,000	1,600,000	400,000	11,800,000	4,700,000
Delta smelt	302,390	1,634,065	1,630,634	2,620,372	245,207	217,894	326,333	293,750
Longfin smelt	1,433,744	6,382,913	20,006,867	1,574,295	991,733	95,130	13,374,290	2,649,091
Sacramento splittail	7,820	24,418	22,526	26,929	1,407	0	28,689	40,057

[a] Note: Population estimates for **delta smelt**, **longfin smelt**, and **Sacramento splittail** in this table are equal to each year's ratio of striped bass caught vs. estimated total striped bass population (Stevens et al., 1990), divided by annual trawling abundance indices for these special status species. See text for explanation.

Table B3-2: Sacramento-San Joaquin Delta Population Estimates of Striped Bass, Sacramento Splittail, Delta Smelt, and Longfin Smelt (1990-2000)[a]

Species	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Striped bass	1,053,199	752,627	1,630,426	1,241,356	1,003,768	385,881	312,532	452,852	975,864	431,325	310,937
Delta smelt	290,208	549,322	124,375	859,462	81,322	716,750	101,254	241,574	334,855	688,845	602,739
Longfin smelt	193,738	106,835	60,593	636,225	434,514	6,893,233	1,106,617	550,119	5,305,063	4,179,312	2,741,029
Splittail	6,378	14,351	2,392	7,973	2,392	60,593	17,540	797	224,034	31,094	6,378

[a] Note: Population estimates for **striped bass**, **delta smelt**, **longfin smelt,** and **splittail** in this table are equal to the average of the 1968-1985 population estimates developed in Table B3-1. See text for explanation.

Part C

North Atlantic

Chapter C1: Background

INTRODUCTION

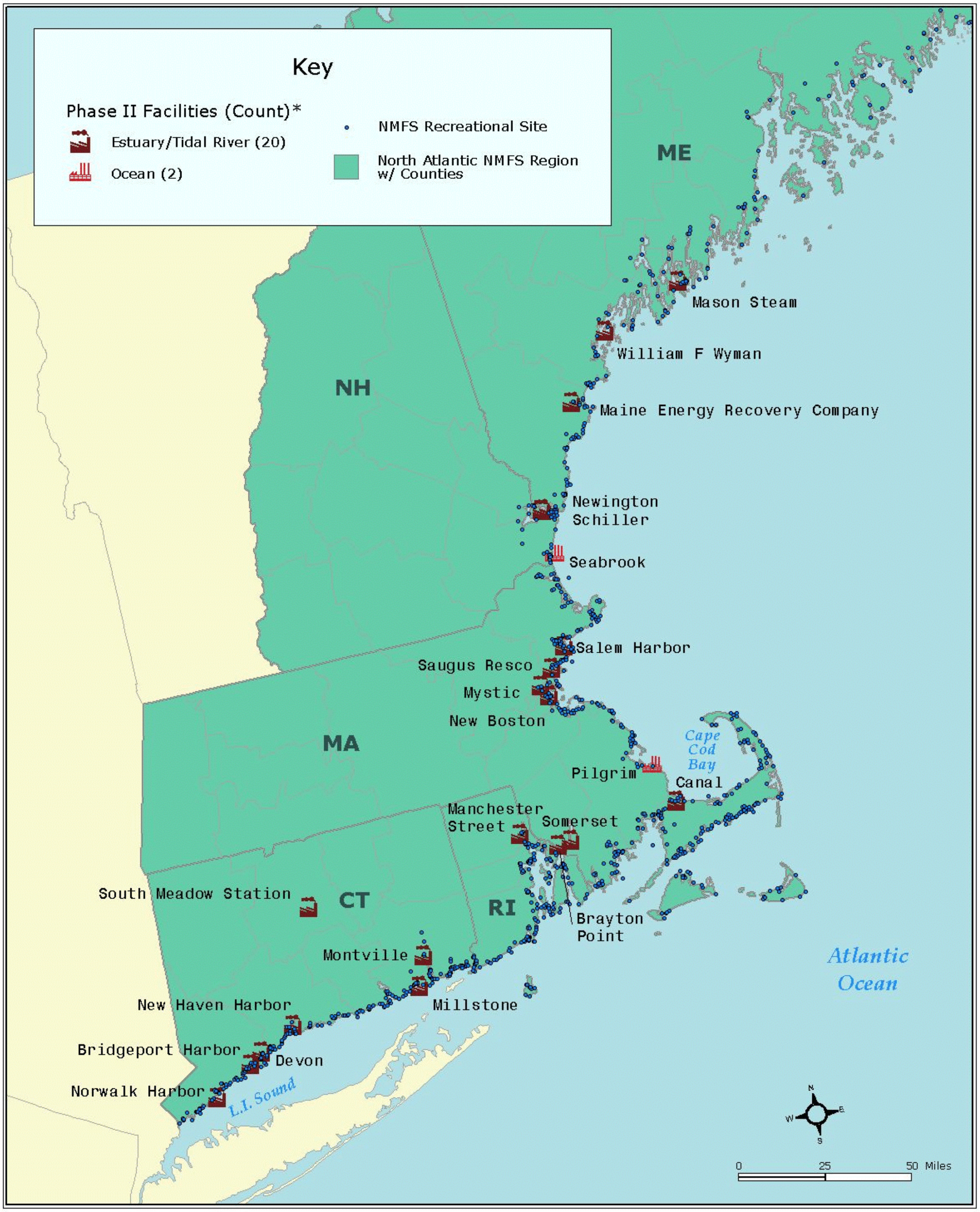
This chapter presents an overview of the Phase II facilities in the North Atlantic study region and summarizes their key operating, economic, technical, and compliance characteristics. For further discussion of operating and economic characteristics of Phase II facilities, refer to Chapter A3 of the *Economic and Benefits Analysis for the Final Section 316(b) Phase II Existing Facilities Rule*; for further discussion of the technical and compliance characteristics of Phase II facilities, refer to the *Technical Development Document for the Final Section 316(b) Phase II Existing Facilities Rule* (U.S. EPA, 2004a,b).

CHAPTER CONTENTS

C1-1 OVERVIEW

The North Atlantic Study includes 22 facilities that are in scope for the final Phase II regulation. Twenty of the 22 facilities withdraw cooling water from an estuary or tidal river while 2 withdraw water from the Atlantic Ocean. Figure C1-1 presents a map of the 22 in-scope Phase II facilities located in the North Atlantic Study area.

Figure C1-1: In-Scope Phase II Facilities in the North Atlantic Regional Study



Source: U.S. EPA analysis for this report.

C1-2 OPERATING AND ECONOMIC CHARACTERISTICS

Half of the 22 North Atlantic Study facilities (11) are oil/gas facilities; four are coal steam facilities; three are nuclear facilities; three facilities use another type of steam electric prime mover; and one is a combined-cycle facility. In 2001, these 22 facilities accounted for 14 gigawatts of generating capacity, 59,000 gigawatt hours of generation, and $2 billion in revenues.

The operating and economic characteristics of the North Atlantic Study facilities are summarized in Table C1-1. Section C1-4 provides further information on each facility [including facility state, North American Electric Reliability Council (NERC) region, plant type, capacity, 2001 generation, and whether impingement and entrainment estimates were developed for the facility].

Table C1-1: Operating and Economic Characteristics of Phase II Facilities

Waterbody Type	Number of Facilities by Plant Type[a]						Total Capacity (MW)[b]	Total Generation (MWh)[b]	Electric Revenue (millions)
	Coal Steam	Combined Cycle	Nuclear	Oil/Gas Steam	Other Steam	Total			
Estuary/Tidal									
CT	1	-	1	4	1	7	4,549	20,897,629	$673
MA	2	-	-	4	1	7	5,620	19,709,028	$728
ME	-	-	-	2	1	3	975	1,255,362	$60
NH	1	-	-	1	-	2	585	1,241,215	$89
RI	-	1	-	-	-	1	489	2,023,063	$76
Subtotal	*4*	*1*	*1*	*11*	*3*	*20*	*12,218*	*45,126,297*	*$1,625*
Ocean									
MA	-	-	1	-	-	1	670	5,144,033	$147
NH	-	-	1	-	-	1	1,242	8,692,743	$243
Subtotal	-	-	*2*	-	-	*2*	*1,912*	*13,836,776*	*$390*
TOTAL	**4**	**1**	**3**	**11**	**3**	**22**	**14,130**	**58,963,073**	**$2,015**

[a] Based on largest steam-electric capacity at facilities.
[b] MW is an abbreviation for megawatt; MWh is an abbreviation for megawatt hour.

Sources: Plant type (IPM Analysis, U.S. EPA, 2002; Form EIA-860, U.S. DOE, 2001a); capacity (Form EIA-860, U.S. DOE, 2001a); generation (Form EIA-906, U.S. DOE, 2001c); revenue (Form EIA-861, U.S. DOE, 2001b; Form EIA-906, U.S. DOE, 2001c).

C1-3 TECHNICAL AND COMPLIANCE CHARACTERISTICS

The 22 North Atlantic Study facilities have a combined design intake flow of almost 14,000 million gallons per day (MGD). All 22 facilities employ a once-through cooling system in the baseline and incur a combined pre-tax compliance cost of $13.3 million. Table C1-2 summarizes the flow, compliance responses, and compliance costs for these 22 facilities.

Table C1-2: Technical and Compliance Characteristics of Phase II Facilities

	Cooling Water System (CWS) Type
	Once-Through
Design Flow (MGD)	**13,804**
Number of Facilities by Compliance Response	
Fish H&R	1
Fine Mesh Traveling Screens w/Fish H&R	8
Relocate Intake to Submerged Offshore with Passive Screen	1
Double-Entry, Single-Exit with Fine Mesh and Fish H&R	1
Multiple	2
None	9
Total	**22**
Compliance Cost (2002$; millions)	**$13.3**

Source: U.S. EPA analysis for this report.

C1-4 PHASE II FACILITIES IN THE NORTH ATLANTIC REGIONAL STUDY

Table C1-3 presents economic and operating characteristics of the North Atlantic Study facilities.

Table C1-3: Phase II Facilities in the North Atlantic Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
Estuary/Tidal River							
544	Devon	CT	NPCC	O/G Steam	398	742,474	N
546	Montville	CT	NPCC	O/G Steam	495	637,057	N
548	Norwalk Harbor	CT	NPCC	O/G Steam	343	823,435	N
566	Millstone	CT	NPCC	Nuclear	2,163	13,816,761	Y
568	Bridgeport Harbor	CT	NPCC	Coal Steam	600	2,442,420	N
6156	New Haven Harbor	CT	NPCC	O/G Steam	460	1,899,022	N
54945	South Meadow Station	CT	NPCC	Other Steam	90	536,460	N
1588	Mystic	MA	NPCC	O/G Steam	1,100	1,742,706	N
1589	New Boston	MA	NPCC	O/G Steam	736	1,133,960	N
1599	Canal	MA	NPCC	O/G Steam	1,164	4,381,910	N
1613	Somerset	MA	NPCC	Coal Steam	150	782,332	N
1619	Brayton Point	MA	NPCC	Coal Steam	1,611	8,205,951	Y
1626	Salem Harbor	MA	NPCC	O/G Steam	805	3,224,942	N
50880	Saugus Resco	MA	NPCC	Other Steam	54	237,227	N
1496	Mason Steam	ME	NPCC	O/G Steam	107	0	N
1507	William F Wyman	ME	NPCC	O/G Steam	846	1,106,656	N
10338	Maine Energy Recovery Co.	ME	NPCC	Other Steam	22	148,706	N
2367	Schiller	NH	NPCC	Coal Steam	171	799,052	N
8002	Newington	NH	NPCC	O/G Steam	414	442,163	N
3236	Manchester Street	RI	NPCC	Combined Cycle	489	2,023,063	N
Ocean							
1590	Pilgrim	MA	NPCC	Nuclear	670	5,144,033	Y
6115	Seabrook	NH	NPCC	Nuclear	1,242	8,692,743	Y

Source: U.S. EPA analysis for this report.

Chapter C2: Evaluation of Impingement and Entrainment in the North Atlantic Region

CHAPTER CONTENTS

BACKGROUND: NORTH ATLANTIC MARINE FISHERIES

Commercial and recreational fisheries of the North Atlantic region are managed by the New England Fisheries Management Council (NEFMC) according to Fishery Management Plans (FMPs) developed by NEFMC (NMFS, 2002a)**.** The NMFS Northeast Fisheries Science Center provides scientific and technical support for management, conservation, and fisheries development.

The multispecies groundfish fishery is the most valuable commercial fishery of the North Atlantic region, followed by American lobster (*Homarus americanus*) (NMFS, 1999b). Important groundfish species include Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), yellowtail flounder (*Pleuronectes ferrugineus*), windowpane flounder (*Scophthalmus aquosus*), and winter flounder (*Pleuronectes americanus*). Atlantic pelagic fisheries are dominated by Atlantic mackerel (*Scomber scombrus*), Atlantic herring (*Clupea harengus*), bluefish (*Pomatomus saltatrix*), and butterfish (*Peprilus triacanthus*) (NMFS, 1999b). Important recreational fisheries of the region include Atlantic cod, winter flounder, Atlantic mackerel, striped bass (*Morone saxatilis*), bluefish, and bluefin tuna (*Thunnus thynnus*) (NMFS, 1999b).

Offshore fisheries for crustaceans and molluscs, particularly American lobster (*Homarus americanus*) and sea scallop (*Placopecten magellanicus*), are among the most valuable fisheries in the Northeast (NMFS, 1999b). Surfclams (*Spisula solidissima*), ocean quahogs (*Arctica islandica*), squids (*Loligo pealeii* and *Illex illecebrosus*), northern shrimp (*Pandalus borealis*), and red crab (*Chaceon quinquedens*) also provide important invertebrate fisheries.

The Northeast lobster fishery is second in commercial value after the multispecies groundfish fishery. The most recent comprehensive stock assessment, completed in 1996, indicated that lobster fishing mortality rates for both inshore and offshore populations greatly exceed the levels needed to provide maximum yields (NMFS, 1999b). Lobster fishing mortality in the Gulf of Maine was almost double the overfishing level. Inshore from Cape Cod through Long Island Sound, fishing mortality was three times the overfishing level.

C2-1 FISHERY SPECIES IMPINGED AND ENTRAINED

Fifteen groundfish species making up 25 stocks are managed under the Northeast Multispecies FMP of the NEFMC (NMFS, 2002a). Stocks of another 12 North Atlantic species are under the jurisdiction of the ASMFC (NMFS, 2002a). Tables C2-1 and C2-2 summarize the status of these stocks, indicating in bold the stocks subject to impingement and entrainment (I&E). In these tables, overfishing refers to the condition when fishing mortality is above a management threshold, jeopardizing the long-term capacity of the stock to produce the potential maximum sustainable yield on a continuing basis. A stock is considered overfished when biomass falls below a given threshold. In some cases, heavy fishing in the past may have reduced a stock to low abundance, so that it is now considered overfished even though the stock is not currently subject to overfishing.

Table C2-1: Summary of Stock Status for Harvested Species of the North Atlantic Region Included in Federal Fishery Management Plans

Stock (Species in bold are subject to I&E)		Overfishing? (Fishing mortality above threshold)	Overfished? (Biomass below threshold)	Approaching Overfished Condition?
Cod	Gulf of Maine	Yes	Rebuilding	No
	Georges Bank	No	Rebuilding	No
Haddock	Gulf of Maine	Yes	Rebuilding	No
	Georges Bank	No	Rebuilding	No
American plaice		Yes	No	No
Redfish (ocean perch)		No	Yes	N/A
Witch flounder		No	No	No
Yellowtail flounder	Georges Bank	No	No	No
	Southern New England	No	Yes	N/A
	Cape Cod	No	Rebuilding	No
	Middle Atlantic	Yes	Yes	N/A
White hake		Yes	Yes	N/A
Pollock		Unknown	Unknown	Unknown
Ocean pout		No	Yes	N/A
Atlantic halibut		Unknown	Yes	N/A
Windowpane flounder	Gulf of Maine/Georges Bank	No	No	No
	Southern New England/Middle Atlantic	No	No	Yes
Winter flounder	Gulf of Maine	Unknown	Undefined	Unknown
	Georges Bank	No	Rebuilding	No
	Southern New England	No	No	No
Silver hake	Gulf of Maine/Northern Georges Bank	Unknown	Rebuilding	No
	Southern Georges Bank/Middle Atlantic	Unknown	Yes	N/A
Offshore hake		Unknown	Unknown	Unknown
Red hake	Gulf of Maine/Northern Georges Bank	No	No	No
	Southern Georges Bank/Middle Atlantic	No		Unknown

Source: Table 4 in NMFS (2002a).

Table C2-2: Summary of Stock Status of Harvested Species of the North Atlantic Region Under AFSMC Jurisdiction and Not Included in Federal Fishery Management Plans

Stock (Species in bold are subject to I&E)	Overfishing? (Fishing mortality above threshold)	Overfished? (Biomass below threshold)	Approaching Overfished Condition?
American eel	Unknown	Unknown	Unknown
American lobster	Yes	Undefined	Unknown
Atlantic croaker	Unknown	Unknown	Unknown
Atlantic menhaden	No	No	Unknown
Atlantic sturgeon	No	Yes	N/A
Horseshoe crab	Unknown	Unknown	Unknown
Northern shrimp	Yes	Undefined	Unknown
Spot	Unknown	Unknown	Unknown
Spotted seatrout	Unknown	Unknown	Unknown
Striped bass	No	No	Unknown
Tautog	Yes	Undefined	Unknown
Weakfish	Undefined	No	No

Source: Table 6 in NMFS (2002a).

As indicated in Table C2-1, seven of the 25 stocks managed under the Northeast Multispecies FMP are classified as overfished, including redfish (*Sebastes* spp.), the southern New England and Middle Atlantic stocks of yellowtail flounder, white hake (*Urophycis tenuis*), ocean pout (*Macrozoarces americanus*), Atlantic halibut (*Hippoglossus hippoglossus*), and the Southern Georges Bank/Middle Atlantic stock of silver hake (*Merluccius bilinearis*). Other stocks are in the process of being rebuilt from levels below the maximum sustainable yield, including the Gulf of Maine and Georges Bank stocks of Atlantic cod and haddock, the Cape Cod stock of yellowtail flounder, the Georges Bank stock of winter flounder, and the Gulf of Maine/Northern Georges Bank stock of silver hake (NMFS, 2002a). The status of many other stocks is poorly known. As indicated in the table, the majority of the stocks requiring management are also subject to I&E.

C2-2 I&E SPECIES AND SPECIES GROUPS EVALUATED

Table C2-3 provides a list of species evaluated by EPA that are subject to I&E in the North Atlantic region. Appendix C-1 provides the life history parameters that were used to express these losses as age 1 equivalents, foregone fishery yield, and production foregone.

Table C2-3: Species Evaluated by EPA that are Subject to I&E in the North Atlantic Region

Species Group	Species	Recreational	Commercial	Forage
Alewife	Alewife		X	
American plaice	American plaice		X	
American sand lance	American sand lance			X
American shad	American shad		X	
Atlantic cod	Atlantic cod	X	X	
Atlantic cod	Haddock	X	X	
Atlantic herring	Atlantic herring		X	
	Hickory shad		X	
	Round herring		X	
Atlantic mackerel	Atlantic mackerel	X	X	
Atlantic menhaden	Atlantic menhaden		X	

Table C2-3: Species Evaluated by EPA that are Subject to I&E in the North Atlantic Region

Species Group	Species	Recreational	Commercial	Forage
Atlantic silverside	Atlantic silverside			X
Atlantic tomcod	Atlantic tomcod			X
Bay anchovy	Bay anchovy			X
	Striped anchovy			X
Blueback herring	Blueback herring			X
Bluefish	Bluefish	X	X	
Butterfish	Butterfish		X	
Commercial crabs	Green crab		X	
	Jonah crab		X	
	Lady crab		X	
	Lesser blue crab		X	
	Mud crab		X	
	Narrow mud crab		X	
	Spider crabs		X	
Cunner	Cunner	X		
Fourbeard rockling	Fourbeard rockling			X
Grubby	Grubby			X
Hogchoker	Hogchoker			X
Lumpfish	Lumpfish		X	
Lumpfish	Lumpsucker		X	
Other (commercial)	Goosefish		X	
	Redfish		X	
	Spot		X	
	Wolffish		X	
Other (forage)	African pompano			X
	Alligatorfish			X
	Atlantic bigeye			X
	Atlantic moonfish			X
	Atlantic seasnail			X
	Banded rudderfish			X
	Bigeye scad			X
	Black ruff			X
	Brown trout			X
	Cornet fish			X
	Crevalle jack			X
	Flying gurnard			X
	Glasseye			X
	Gulf snailfish			X
	Long finned squid			X
	Lookdown			X
	Mackerel scad			X
	Northern sennet			X
	Northern shortfin squid			X
	Ocean pout			X

Table C2-3: Species Evaluated by EPA that are Subject to I&E in the North Atlantic Region

Species Group	Species	Recreational	Commercial	Forage
	Orange filefish			X
	Oyster toadfish			X
	Pearlside			X
	Planehead filefish			X
	Rough scad			X
	Round scad			X
	Sand tiger			X
	Sea lamprey			X
	Sheepshead minnow			X
	Short bigeye			X
	Silver rag			X
	Spotfin butterflyfish			X
	Striped burrfish			X
	Trumpetfish			X
	Wrymouth			X
Other (recreational)	American eel	X		
	Atlantic torpedo	X		
	Black sea bass	X		
	Blue runner	X		
	Conger eel	X		
	Cownose ray	X		
	Dusky smooth hound	X		
	Flathead mullet	X		
	Northern puffer	X		
	Piked dogfish	X		
	Smooth dogfish	X		
	Spiny dogfish	X		
	Striped cusk-eel	X		
	White catfish	X		
	White mullet	X		
Northern pipefish	Lined seahorse			X
	Northern pipefish			X
	Seahorse			X
Pollock	Pollock	X	X	
Radiated shanny	Radiated shanny			X
Rainbow smelt	Rainbow smelt		X	
Red hake	Red hake		X	
	Spotted hake		X	
	White hake		X	
Rock gunnel	Rock gunnel			X
Sculpin species	Longhorn sculpin	X	X	
	Moustache sculpin	X	X	
	Sea raven	X	X	
	Shorthorn sculpin	X	X	

Table C2-3: Species Evaluated by EPA that are Subject to I&E in the North Atlantic Region

Species Group	Species	Recreational	Commercial	Forage
Scup	Scup	X	X	
Seaboard goby	Seaboard goby			X
Searobin	Northern searobin	X	X	
	Striped searobin	X	X	
Silver hake	Silver hake		X	
Skate species	Clearnose skate		X	
	Little skate		X	
Striped bass	Striped bass	X		
Striped killifish	Mummichog			X
	Striped killifish			X
Tautog	Tautog	X	X	
Threespine stickleback	Blackspotted stickleback			X
	Fourspine stickleback			X
	Ninespine stickleback			X
	Threespine stickleback			X
Weakfish	Northern kingfish	X	X	
	Weakfish	X	X	
White perch	White perch	X	X	
Windowpane	American fourspot flounder		X	
	Smallmouth flounder		X	
	Summer flounder		X	
	Windowpane		X	
Winter flounder	Fourspot flounder	X	X	
	Lefteye flounder	X	X	
	Righteye flounder	X	X	
	Smooth flounder	X	X	
	Winter flounder	X	X	
	Witch flounder	X	X	
	Yellowtail flounder	X	X	

Life histories of the species with the highest losses are summarized in the following section. The life history data used in EPA’s analysis and associated data sources are provided in Appendix C1 of this report.

C2-3 LIFE HISTORIES OF PRIMARY SPECIES IMPINGED AND ENTRAINED IN THE NORTH ATLANTIC REGION

Alewife (*Alosa pseudoharengus*)

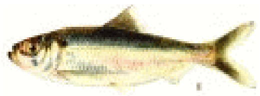
Alewife is a member of the herring family, Clupeidae, and ranges along the Atlantic coast from Newfoundland to North Carolina (Scott and Crossman, 1998). Alewife tend to be more abundant in the mid-Atlantic and along the northeastern coast. They are anadromous, migrating inland from coastal waters in the spring to spawn. Adult alewife overwinter along the northern continental shelf, settling at the bottom in depths of 56 to 110 m (184 ft to 361 ft) (Able and Fahay, 1998). Adults feed on a wide variety of food items, while juveniles feed mainly on plankton (Waterfield, 1995).

Alewife has been introduced to a number of lakes to provide forage for sportfish (Jude et al., 1987b). Ecologically, alewife is an important prey item for many fish, and commercial landings of river herring along the Atlantic coast have ranged from a high of 33,974 metric tons (74.9 million lb) in 1958 to a low of less than 2,268 metric tons (5 million lb) in recent years (Atlantic States Marine Fisheries Commission, 2000b).

Spawning is temperature-driven, beginning in the spring as water temperatures reach 13 to 15 ˚C (55 to 59 ˚F) and ending when they exceed 27 ˚C (80.6 ˚F) (Able and Fahay, 1998). Spawning takes place in the upper reaches of coastal rivers, in slow-flowing sections of slightly brackish or freshwater.

Females lay demersal eggs in shallow water less than 2 m (6.6 ft) deep (Wang and Kernehan, 1979). They may lay from 60,000 to 300,000 eggs at a time (Kocik, 2000). The demersal eggs are 0.8 to 1.27 mm (0.03 to 0.05 in.) in diameter. Larvae hatch at a size of approximately 2.5 to 5.0 mm (0.1 to 0.2 in.) total length (Able and Fahay, 1998). Larvae remain in the upstream spawning area for some time before drifting downstream to natal estuarine waters. Juveniles table a diurnal vertical migration in the water column, remaining near the bottom during the day and rising to the surface at night (Fay et al., 1983a). In the fall, juveniles move offshore to nursery areas (Able and Fahay, 1998).

Maturity is reached at an age of 3 to 4 years for males, and 4 to 5 years for females (Able and Fahay, 1998). The average size at maturity is 265 to 278 mm (10.4 to 10.9 in.) for males and 284 to 308 mm (11.2 to 12.1 in.) for females (Able and Fahay, 1998). Alewife can live up to 8 years, but the average age of the spawning population tends to be 4 to 5 years (Waterfield, 1995; PSEG, 1999).



ALEWIFE
(Alosa pseudoharengus)

Family: Clupeidae (herrings).

Common names: River herring, sawbelly, kyak, branch herring, freshwater herring, bigeye herring, gray herring, grayback, white herring.

Similar species: Blueback herring.

Geographic range: Along the western Atlantic coast from Newfoundland to North Carolina.[a]

Habitat: Wide-ranging, tolerates fresh to saline waters, travels in schools.

Lifespan: May live up to 8 years.[b,c]

Fecundity: Females may lay from 60,000 to 300,000 eggs at a time.[d]

Food source: Small fish, zooplankton, fish eggs, amphipods, mysids.[c]

Prey for: Striped bass, weakfish, rainbow trout.

Life stage information:

Eggs: *demersal*
- Found in waters less than 2 m (6.6 ft) deep.[d]
- Are 0.8 to 1.27 mm (0.03 to 0.05 in.) in diameter.[f]

Larvae:
- Approximately 2.5 to 5.0 mm (0.1 to 0.2 in.) at hatching.[f]
- Remain in upstream spawning area for some time before drifting downstream to natal estuarine waters.

Juveniles:
- Stay on the bottom during the day and rise to the surface at night.[g]
- Emigrate to ocean in summer and fall.[f]

Adults: *anadromous*
- Reach maturity at 3-4 years for males and 4-5 years for females.[f]
- Average size at maturity is 265-278 mm (10.4-10.9 in.) for males and 284-308 mm (11.2-12.1 in.) for females.[f]
- Overwinter along the northern continental shelf.[f]

[a] Scott and Crossman, 1998.
[b] PSEG, 1999.
[c] Waterfield, 1995.
[d] Kocik, 2000.
[e] Wang and Kernehan, 1979.
[f] Able and Fahay, 1998.
[g] Fay et al., 1983a.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Atlantic menhaden (*Brevoortia tyrannus*)

The Atlantic menhaden, a member of the Clupeidae (herring) family, is a eurohaline species, occupying coastal and estuarine habitats. It is found along the Atlantic coast of North America, from Maine to northern Florida (Hall, 1995). Adults congregate in large schools in coastal areas; these schools are especially abundant in and near major estuaries and bays. They consume plankton, primarily diatoms and dinoflagellates, which they filter from the water through elaborate gill rakers. In turn, menhaden are consumed by almost all commercially and recreationally important piscivorous fish, as well as by dolphins and birds (Hall, 1995).

The menhaden fishery, one of the most important and productive fisheries on the Atlantic coast, is a multimillion-dollar enterprise (Hall, 1995). Menhaden are considered an “industrial fish” and are used to produce products such as paints, cosmetics, margarine (in Europe and Canada), and feed, as well as bait for other fisheries. Landings in New England declined to their lowest level of approximately 2.7 metric tons (5,952 lb) in the 1960s because of overfishing. Since then, landings have varied, ranging from approximately 240 metric tons (529,100 lb) in 1989 to 1,069 metric tons (2,356,742 lb) in 1998 (personal communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, Maryland, March 19, 2001).

Atlantic menhaden spawn year round at sea and in larger bays (Scott and Scott, 1988). Spawning peaks during the southward fall migration and continues throughout the winter off the North Carolina coast. There is limited spawning during the northward migration and during summer months (Hall, 1995). The majority of spawning occurs over the inner continental shelf, with less activity in bays and estuaries (Able and Fahay, 1998).

ATLANTIC MENHADEN
(*Brevoortia tyrannus*)

Family: Clupeidae (herrings).

Common names: menhaden, bunker, fatback, bugfish.

Similar species: Gulf menhaden, yellowfin menhaden.

Geographic range: From Maine to northern Florida along the Atlantic coast.[a]

Habitat: Open-sea, marine waters. Travels in schools.[b]

Lifespan:
- Approximately 7 to 8 years.[a]

Fecundity:
- Females may produce between 100,000 to 600,000 eggs.[c]

Food Source: Phytoplankton, zooplankton, annelid worms, detritus[b]

Prey for: Sharks, cod, pollock, hakes, bluefish, tuna, swordfish, seabirds, whales, porpoises.[b]

Life stage information:

Eggs: *pelagic*
- Spawning takes place along the inner continental shelf, in open marine waters.[d]
- Eggs hatch after approximately 24 hours.

Larvae: *pelagic*
- Larvae hatch out at sea, and enter estuarine waters 1 to 2 months later.[a]
- Remain in estuaries through the summer, emigrating to ocean waters as juveniles in September or October.[d]

Adults:
- Congregate in large schools in coastal areas.
- Spawn year round.[b]

[a] Hall, 1995.
[b] Scott and Scott, 1988.
[c] Dietrich, 1979.
[d] Able and Fahay, 1998.
Fish graphic from South Carolina Department of Natural Resources, 2001.

Females mature just before age 3, and release buoyant, planktonic eggs during spawning (Hall, 1995). Atlantic menhaden annual egg production ranges from approximately 100,000 to 600,000 eggs for fish age 1 to age 5 (Dietrich, 1979). Eggs are spherical and between 1.3 to 1.9 mm (0.05 to 0.07 in.) in diameter (Scott and Scott, 1988).

Larvae hatch after approximately 24 hours and remain in the plankton. Larvae hatched in offshore waters enter the Delaware Estuary 1 to 2 months later to mature (Hall, 1995). Juveniles then migrate south in the fall, joining adults off North Carolina in January (Hall, 1995). Water temperatures below 3 ˚C (37 ˚F) kill the larvae, and therefore larvae that fail to reach estuaries before the fall are more likely to die than those arriving in early spring (Able and Fahay, 1998). Larvae hatchout at 2.4 to 4.5 mm (0.09 to 0.18 in.). The transition to the juvenile stage occurs between 30 and 38 mm (1.2 and 1.5 in.) (Able and Fahay, 1998). The juvenile growth rate in some areas is estimated to be 1 mm (0.04 in.) per day (Able and Fahay, 1998).

During the fall and early winter, most menhaden migrate south off of the North Carolina coast, where they remain until March and early April. They avoid waters below 3 ˚C, but can tolerate a wide range of salinities from less than 1 percent up to 33-37 percent (Hall, 1995). Sexual maturity begins at age 2, and all individuals are mature by age 3 (Scott and Scott, 1988).

Adult fish are commonly between 30 and 35 cm (11.8 and 13.8 in.) in length. The maximum age of a menhaden is approximately 7 to 8 years (Hall, 1995), although individuals of 8-10 years have been recorded (Scott and Scott, 1988).

Atlantic silverside (*Menidia menidia*)

The Atlantic silverside is a member of the silverside family, Atherinidae. Its geographic range extends from coastal waters of New Brunswick to northern Florida (Fay et al., 1983b), but it is most abundant between Cape Cod and South Carolina (Able and Fahay, 1998). Atlantic silversides inhabit sandy seashores and the mouths of inlets (Froese and Pauly, 2001). Silversides are an important species of forage fish, eaten by valuable fishery species such as striped bass (*Morone saxatilis*), bluefish (*Pomatomus salatrix*), weakfish (*Cynoscion regalis*), and Atlantic mackerel (*Scomber scombrus*) (Fay et al., 1983b; McBride, 1995).

Atlantic silversides spawn in the upper intertidal zone during spring and summer. Spawning appears to be stimulated by new and full moons, in association with spring tides. On average, females produce 4,500 to 5,000 demersal eggs per spawning season, which may include four to five separate spawning bouts (Fay et al., 1983b). The eggs are 0.9 to 1.2 mm (0.04 to 0.05 in.) in diameter. Larvae range in size from 5.5 to 15.0 mm (0.2 to 0.6 in.) (Fay et al., 1983b). The sex of Atlantic silversides is determined during the larval stage, at approximately 32 to 46 days after hatching. Water temperatures between 11 and 19 ˚C (52 and 66 ˚F) produce significantly more females, whereas temperatures between 17 and 25 ˚C (63 and 77 ˚F) produce significantly more males (Fay et al., 1983b).

Juveniles occur in estuaries during the summer months, occupying intertidal creeks, marshes, and shore zones of bays and estuaries. Silversides typically migrate offshore in the winter (McBride, 1995). In studies of seasonal distribution in Massachusetts, all individuals left inshore waters during winter months (Able and Fahay, 1998).

The diet of juveniles and adults consists of copepods, mysids, amphipods, cladocerans, fish eggs, squid, worms, molluscs, insects, algae, and detritus (Fay et al., 1983b). Atlantic silversides feed in large schools, preferring gravel and sand bars, open beaches, tidal creeks, river mouths, and marshes (Fay et al., 1983b).

Silversides live for only 1 or 2 years, usually dying after completing their first spawning (Fay et al., 1983b). Adults can reach sizes of up to 15 cm (5.9 in.) in total length (Froese and Pauly, 2001).

ATLANTIC SILVERSIDE
(*Menidia menidia*)

Family: Atherinidae (silversides).

Common names: Spearing, sperling, green smelt, sand smelt, white bait, capelin, shiner.[a]

Similar species: Inland silverside (*Menidia beryllina*).[a]

Geographic range: New Brunswick to northern Florida.[a]

Habitat: Sandy seashores and the mouths of inlets.[b]

Lifespan: One or 2 years. Often die after their first spawning.[a]

Fecundity: Females produce an average of 4,500 to 5,000 eggs per spawning season.[a]

Food Source: Zooplankton, fish eggs, squid, worms, molluscs, insects, algae, and detritus.[a]

Prey for: Striped bass, bluefish, weakfish, and Atlantic mackerel.[a,c]

Life stage information:

Eggs: *demersal*
- Found in shallow waters of estuarine intertidal zones.[a]
- Can be found adhering to submerged vegetation.[a]

Larvae:
- Range from 5.5 to 15.0 mm (0.2 to 0.6 in.) in size.[a]
- Sex is determined during the larval stage by the temperature regime. Colder temperatures tend to produce more females, and warmer temperatures produce more males.[a]

Adults:
- Overwinter in offshore marine waters.[d]
- Can reach sizes of up to 15 cm (5.9 in.) total length.[d]

[a] Fay et al., 1983b.
[b] Froese and Pauly, 2001.
[c] McBride, 1995.
[d] Able and Fahay, 1998.
Fish graphic from Government of Canada, 2001.

Tautog (*Tautoga onitis*)

The tautog is a member of the Labridae family, found in coastal areas from New Brunswick south to South Carolina. It is most abundant from Cape Cod, Massachusetts, to the Delaware Estuary (Atlantic States Marine Fisheries Commission, 2000e). Tautog are most frequently found close to shore, preferring rocky areas or other discontinuities such as pilings, jetties, or wrecks and salinities of greater than 25 ppt (Jury et al., 1994). They generally consume mussels, small crustaceans, and other molluscs (Steimle and Shaheen, 1999).

Tautog have historically supported a primarily recreational fishery. Since 1980, landings have averaged about 3,700 metric tons (8.1 million lb), with recreational catches accounting for 90 percent of the total (Atlantic States Marine Fisheries Commission, 2000e). The majority of Tautog are harvested by hook and line from private boats (Auster, 1989); however, there are also significant charter and party boat fisheries. Although commercial landings accounted for only 8.7 percent of the total from 1982 to 1991, commercial fishing has been increasing because of higher market prices (Atlantic States Marine Fisheries Commission, 2000h). There is evidence that the fishery is declining, with lower recreational and commercial catch rates. A survey conducted in Narragansett Bay in 1994 showed the lowest abundance of tautog ever recorded. Tautog are susceptible to overfishing, particularly because they experience slow growth and reproduction and tend to be easily found near wrecks and rock piles (Atlantic States Marine Fisheries Commission, 2000e).

Tautog migrate inshore in the spring to spawn in inshore waters. Spawning generally occurs between mid-May and August, peaks in June (Auster, 1989), and primarily takes place at the mouths of estuaries and along the inner continental shelf. In Narragansett Bay, tautog are known to return to the same spawning sites in the upper estuary each year. Fecundity increases with age until approximately age 16, when it begins to decline (Steimle and Shaheen, 1999). Females between 3 and 20 years were documented to contain between 5,000 and 673,500 mature eggs. The eggs are buoyant, and hatch out in approximately 2 to 3 days (Auster, 1989).

Larvae hatch out at 2 to 4 mm (0.079 to 0.157 in.) and migrate vertically in the water column, surfacing during the day and remaining near the bottom at night. Tautog are the most abundant larval species in Narragansett Bay. As they get older, they become more benthic (Steimle and Shaheen, 1999). Small juveniles will remain in estuaries year-round, in a home range of only several hundred meters, becoming torpid over the winter (Jury et al., 1994), while larger ones will join adults in deeper water. Small juveniles prefer vegetated habitats in depths of less than 1 m (3.3 ft) and are not observed in Narragansett Bay water deeper than 9 m (30 ft). Older juveniles and adults inhabit reef-like habitats that provide some type of cover (Steimle and Shaheen, 1999).

Tautog do not tend to migrate far offshore; however, adults move to deeper water in the fall, responding to decreases in temperature. Although they move to waters as deep as 45 m (148 ft), tautog select areas with rugged topography for cover. Adults return to coastal waters and estuaries to spawn when waters warm in the spring. Maturity is reached at about 3 to 4 years of age. Age 7 tautogs in Rhode Island had mean lengths of 348 mm (14 in.) for males and 301 mm (12 in.) for females. Males may live for over 30 years, while females may live to about 25 years of age (Steimle and Shaheen, 1999).

TAUTOG
(*Tautoga onitis*)

Family: Labridae (wrasses).

Common names: tautog, blackfish, white chin, chub, black porgy.[a]

Similar species: Cunner (*Tautogolabrus adspersus*).

Geographic range: Most abundant from Cape Cod, Massachusetts to the Delaware Estuary.[b]

Habitat: Rocky shoals around coastal shores.[c]

Lifespan: Maturity is reached at about 3 to 4 years. Maximum age of over 30 years for males, 25 years for females.[a]

Fecundity: Mature females may contain between 5,000 and 673,500 mature eggs.[d]

Food Source: Juveniles feed on amphipods and copepods. Adults feed mainly on blue mussels, small crustaceans, and other molluscs.[a]

Prey for: Smooth dogfish, barndoor skate, red hake, sea raven, goosefish, striped bass, silver hake, bluefish, seabirds.[a]

Life stage information:

Eggs: *buoyant*
- Hatch out in 2 to 3 days.[a]

Larvae: *pelagic*
- Young larvae migrate vertically in the water column, surfacing during the day and remaining near the bottom at night.[a]

Juveniles: *benthic*
- Small juveniles prefer vegetated areas in depths less than 1 m (3.3 ft).[a]
- Larger juveniles prefer covered, reef-like habitats.[a]

Adults:
- Inhabit reef-like habitats that provide some type of cover.[a]
- Migrate inshore in late spring to spawn at the mouths of estuaries and along the inner continental shelf.[a]

[a] Steimle and Shaheen, 1999.
[b] Atlantic States Marine Fisheries Commission, 2000e.
[c] Scott and Scott, 1988.
[d] Auster, 1989.
Fish graphic from: State of Maine Division of Marine Resources, 2001b.

Windowpane (*Scophthalmus aquosus*)

Windowpane is a member of the Scophthalmidae family (left-eye flounders) found from the Gulf of St. Lawrence to Florida, inhabiting estuarine and shallow continental shelf waters less than 56 m (184 ft) deep (Able and Fahay, 1998). They have been found in areas with muddy or sandy bottoms, water temperatures ranging from 0 to 24 ºC (0 to 75 ºF), and salinities of 5.5 to 36 ppt (Chang et al., 1999).

Spawning occurs over the continental shelf and in estuaries, but not in waters over 20 ºC (68 ºF) (Kaiser and Neuman, 1995). The timing of spawning varies with location: in Mid-Atlantic Bight waters, spawning occurs from April through December, peaking in May and October, while on Georges Bank spawning occurs during summer and peaks in July and August (Hendrickson, 2000). The estimated average lifetime fecundity of females is 100,000 eggs (New England Power Company and Marine Research Inc., 1995). Eggs are buoyant and hatch out in 8 days at a water temperature of 11°C (52 ºF) (Chang et al., 1999). Eggs and larvae are planktonic, but movements are poorly understood. Between 6.5 and 13.0 mm (0.256 and 0.512 in.), eye migration occurs and the body becomes more laterally compressed (Able and Fahay, 1998). Juveniles appear to use estuaries as nursing areas, and then move to offshore waters in the fall (Kaiser and Neuman, 1995).

Although windowpane have been found to migrate 130 km (81 miles) in a few months, most researchers agree that windowpane generally do not migrate long distances (Chang et al., 1999).

Windowpane reach sexual maturity at age 3 or 4 (Hendrickson, 2000). Adults reach a maximum length of approximately 46 cm (18 in.), and may live up to 7 years (Scott and Scott, 1988).

While windowpane has not been a particularly important commercial fish, it may become more so as stocks of summer flounder are overfished. Commercial catches began in 1943, and through 1975 windowpane was harvested as part of an industrial fishery. Landings in southern New England peaked in 1985 at 2,100 metric tons (4.6 million lb), decreased to a low of 100 metric tons (0.2 million lb) in 1995, and have remained below 200 metric tons (0.4 million lb) since then. Populations have also decreased since the 1980's, and overfishing is suspected as a main cause (Hendrickson, 2000).

WINDOWPANE
(*Scophthalmus aquosus*)

Family: Scophthalmidae (left-eye flounder).

Common names: windowpane.

Similar species: turbot (*Scophthalmus maximus*), brill (*Scophthalmus rhombus*).

Geographic range: From the Gulf of St. Lawrence to Florida.[a]

Habitat: Estuarine and shallow continental shelf waters of depths less than 56 m (184 ft).[a]

Lifespan: Approximately 7 years.[b]

Fecundity: Average lifetime fecundity of 100,000 eggs.[c]

Food Source: Young consume mysids; adults feed on sand shrimp, small fish (up to 10 cm), crustaceans, molluscs, and seaweed.

Prey for: Spiny dogfish, thorny skate, goosefish, Atlantic cod, black sea bass, weakfish, and summer flounder.[d]

Life stage information:

Eggs: *buoyant*
- Eggs are buoyant and hatch out in 8 days at a water temperature of 11 ˚C.[d]

Larvae: *pelagic*
- Eye migration occurs and the body becomes more laterally compressed.[d]

Juveniles:
- Use estuaries as nursing areas, returning to offshore waters in the fall.[e]

Adults:
- Reach a maximum length of approximately 46 cm.[b]
- Seasonally migrate to deeper waters in late autumn to overwinter.[d]

[a] Able and Fahay, 1998.
[b] Scott and Scott, 1988.
[c] New England Power Company and Marine Research Inc., 1995.
[d] Chang et al., 1999.
[e] Kaiser and Neuman, 1995.
Fish graphic from NEFSC, 2001.

Winter flounder (*Pleuronectes americanus*)

Winter flounder is a benthic flatfish of the family Pleuronectidae (righteye flounders), which is found in estuarine and continental shelf habitats. Its range extends from the southern edge of the Grand Banks south to Georgia (Buckley, 1989b). It is a bottom feeder, occupying sandy or muddy habitats and feeding on bottom-dwelling organisms such as shrimp, amphipods, crabs, urchins, and snails (Froese and Pauly, 2001).

Both commercial and recreational fisheries for winter flounder are important. U.S. commercial and recreational fisheries are managed under the New England Fishery Management Council’s Multispecies Fishery Management Plan and the Atlantic States Marine Fisheries Commission’s Fishery Management Plan for Inshore Stocks of Winter Flounder (NEFSC, 2000). Three groups are recognized for management and assessment purposes: Gulf of Maine, Southern New England-Mid Atlantic, and Georges Bank. Management currently focuses on reducing fishing levels to reverse declining trends and rebuild stocks. The Gulf of Maine stock is currently considered overfished (NEFSC, 2000). Although improvements in stock condition will depend on reduced harvest, the long-term potential catch (maximum sustainable yield) has not been determined.

The winter flounder is essentially nonmigratory, but there are seasonal patterns in movements within the estuary. Winter flounder south of Cape Cod generally move to deeper, cooler water in summer and return to shallower areas in the fall, possibly in response to temperature changes (Howe and Coates, 1975; Scott and Scott, 1988).

Spawning occurs between January and May in New England, with peaks in the Massachusetts area in February and March (Bigelow and Schroeder, 1953). Spawning habitat is generally in shallow water over a sandy or muddy bottom (Scott and Scott, 1988). Adult fish tend to leave the shallow water in autumn to spawn at the head of estuaries in late winter. The majority of spawning takes place in a salinity range of 31 to 33 ppt and a water temperature range of 0 to 3 ˚C (32 to 37 ˚F). Females will usually produce between 500,000 and 1.5 million eggs annually, which sink to the bottom in clusters. The eggs are about 0.74 to 0.85 mm (approximately 0.03 in.) in diameter, and hatch in approximately 15 to 18 days (Bigelow and Schroeder, 1953).

Larvae are about 3.0 to 3.5 mm (0.1 in.) total length when they hatch out. They develop and metamorphose over 2 to 3 months, with growth rates controlled by water temperature (Bigelow and Schroeder, 1953). Larval growth appears to be optimal with a slow increase from spawning temperatures of 2 ˚C (36 ˚F) to approximately 10 ˚C (50 ˚F; Buckley, 1982). Larvae depend on light and vision to feed during the day and do not feed at night (Buckley, 1989b). Juveniles tend to remain in shallow spawning waters, and stay on the ocean bottom (Scott and Scott, 1988).

Fifty percent of females reach maturity at age 2 or 3 in the waters of Georges Bank, while they may not mature until age 5 in more northern areas such as near Newfoundland. Females are generally 22.5 to 31.5 cm (8 to 12.4 in.) long at maturity (Howell et al., 1992).

Winter flounder supports important commercial and recreational fisheries in the area, as it is the thickest and meatiest of the common New England flatfish (Bigelow and Schroeder, 1953). Annual commercial landings in New England declined from 17,083 metric tons (37.7 million lb) in 1981 to 3,223 metric tons (7.1 million lb) in 1994. The harvest has increased somewhat since then, rising to 5,123 metric tons (11.3 million lb) in 2000 (personal communication, National Marine Fisheries Society, Fish Statistics and Economics Division, Silver Spring, MD, January 16, 2002.). Winter flounder is ecologically important as a prey species for larger estuarine and coastal fish such as striped bass (*Morone saxatilis*) and bluefish (*Pomatomus saltatrix*) (Buckley, 1989b).

WINTER FLOUNDER
(*Pleuronectes americanus*)

Family: Pleuronectidae (righteye flounders).

Common names: Blackback flounder, lemon sole, black flounder.[a]

Similar species: American plaice (*Hippoglossoides platessoides*), European plaice (*P. platessus*).

Geographic range: From the southern edge of the Grand Banks south to Georgia.[b]

Habitat: Bottom dweller. Found in coastal marine waters.[c]

Lifespan: May live up to 15 years.

Fecundity: Females produce between 500,000 and 1.5 million eggs annually.[a]

Food source: Bottom-dwelling organisms such as shrimp, annelid worms, amphipods, crabs, urchins and snails.[a]

Prey for: Striped bass, bluefish.[b]

Life stage information:

Eggs: *demersal*
- Approximately 0.74 to 0.85 mm (0.03 in.) in diameter.[a]
- Hatch in approximately 15 to 18 days.[a]

Larvae: *semi-pelagic*
- Approximately 3.0 to 3.5 (0.1 in.) mm total length when they hatch out.[a]

Juveniles: *demersal*
- Once winter flounder enter the juvenile stage, they remain benthic, preferring sandy bottomed substrates.[d]

Adults:
- Females mature at ages 2 and 3.[e]
- Migrate seasonally to offshore waters in the summer, and inshore waters in the winter.[b]

[a] Bigelow and Schroeder, 1953.
[b] Buckley, 1989b.
[c] Scott and Scott, 1988.
[d] Grimes et al., 1989.
[e] Howell et al., 1992.
Fish graphic from State of Maine Division of Marine Resources, 2001c.

C2-4 I&E DATA EVALUATED

Table C2-4 lists North Atlantic facilities in scope of the Phase II rule and the facility I&E data evaluated by EPA to estimate current I&E rates for the region. See Chapter A5 of Part A for a discussion of extrapolation methods.

Table C2-4: North Atlantic Species In Scope of the Section 316(b) Phase II Rule and Facility I&E Data Evaluated

In Scope Facilities	I&E Data?	Years of Data
Brayton Point (MA)	Yes	1972 - 1998
Bridgeport Harbor (CT)	No - extrapolated	
Devon (CT)	No - extrapolated	
Southern Energy-Canal LLC (MA)	No - extrapolated	
Maine Energy Recovery Company (ME)	No - extrapolated	
Manchester Street (RI)	No - extrapolated	
Mason Steam (ME)	No - extrapolated	
Millstone (CT)	Yes	1973 - 2001
Montville (CT)	No - extrapolated	
Sithe Energy-Mystic LLC (MA)	No - extrapolated	
New Boston (MA)	No - extrapolated	
New Haven Harbor (CT)	No - extrapolated	
Newington (NH)	No - extrapolated	
Norwalk Harbor (CT)	No - extrapolated	
Pilgrim Nuclear (MA)	Yes	1974 - 1999
Salem Harbor (MA)	No - extrapolated	
Saugus Resco (MA)	No - extrapolated	
Schiller (NH)	No - extrapolated	
Seabrook Nuclear (NH)	Yes	1990 - 1998
Somerset (MA)	No - extrapolated	
South Meadow Station (CT)	No - extrapolated	
William F Wyman (ME)	No - extrapolated	

C2-5 EPA'S ESTIMATE OF CURRENT I&E IN THE NORTH ATLANTIC REGION EXPRESSED AS AGE 1 EQUIVALENTS, FOREGONE YIELD, AND PRODUCTION FOREGONE

Table C2-5 provides EPA's estimate of the annual age 1 equivalents, foregone fishery yield, and production foregone resulting from the impingement of aquatic species at facilities located in the North Atlantic region. Table C2-5 displays this information for entrainment.

The lost yield estimates presented in Tables C2-5 and C2-6 are expressed as total pounds and include losses to both commercial and recreational catch. To estimate the economic value of these losses, total yield was partitioned between commercial and recreational fisheries based on the landings in each fishery. Table C2-7 presents the percentage impacts assumed for each species and the value per pound for commercially harvested species.

Table C2-5: Current Annual Impingement in the North Atlantic Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species	Age 1 Equivalents (#s)	Total Yield (lbs)	Production Foregone
American plaice	1	0	0
American sand lance	54,035	0	12
American shad	0	0	0
Atlantic cod	1,177	385	135
Atlantic herring	6,935	981	574
Atlantic mackerel	2	0	0
Atlantic menhaden	589	69	51
Atlantic silverside	823,743	0	166
Atlantic tomcod	10	0	0
Alewife	28,500	0	541
Bay anchovy	25,035	0	3
Blueback herring	3,280	0	150
Bluefish	12	18	8
Butterfish	11,894	194	198
Crabs (commercial)	42,616	310	335
Cunner	2,399	11	13
Fourbeard rockling	30	0	0
Grubby	39,222	0	101
Hogchoker	15,649	0	7
Lumpfish	5,192	596	137
Other (commercial)	62	12	8
Other (forage)	81,858	0	9
Other (rec. and com.)	1,167	227	150
Other (recreational)	612	119	79
Northern pipefish	13,099	0	12
Pollock	27	39	12
Radiated shanny	520	0	0
Rainbow smelt	41,440	0	248
Red hake	193	59	45
Rock gunnel	6,225	0	28
Sculpins	5,116	314	214
Scup	239	38	25
Searobin	1,376	51	82
Silver hake	2,772	363	249
Skates	4,645	961	447
Striped bass	1	2	0
Striped killifish	5,005	0	31
Tautog	358	200	61
Threespine stickleback	30,097	0	8
Weakfish	128	26	13
White perch	13	0	0
Windowpane	4,306	80	197
Winter flounder	34,571	4,176	13,008

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Table C2-6: Current Annual Entrainment in the North Atlantic Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species	Age 1 Equivalents (#s)	Total Yield (lbs)	Production Foregone
American plaice	4,460	781	902
American sand lance	4,895,002	0	203,374
Atlantic cod	16,021	5,245	4,751
Atlantic herring	150,898	21,347	337,430
Atlantic mackerel	25,674	3,550	487,791
Atlantic menhaden	47,881	5,578	2,067,422
Atlantic silverside	25,712	0	7,487
Alewife	1,478	0	633
Bay anchovy	4,237,067	0	234,356
Bluefish	0	0	32
Butterfish	152	2	7
Cunner	5,213,386	23,512	555,300
Fourbeard rockling	1,627,524	0	29,031
Grubby	3,637,090	0	24,408
Hogchoker	109,764	0	248,461
Lumpfish	233	27	147
Other (commercial)	93	18	213
Other (forage)	47,043	0	1,721
Other (rec. and com.)	2	0	4
Other (recreational)	51	10	118
Northern pipefish	2,386	0	79
Pollock	23	33	11,046
Radiated shanny	5,405,950	0	9,406
Rainbow smelt	163,111	0	13,643
Rock gunnel	23,480,022	0	325,811
Sculpins	2,423,596	148,924	268,852
Scup	1,637	261	18,353
Seaboard goby	4,866,006	0	1,989
Searobin	12,606	465	1,910
Silver hake	2,479	324	35,277
Tautog	138,009	77,057	221,905,343
Threespine stickleback	2,098	0	89
Weakfish	1,725	352	13,928,389
White perch	0	0	232
Windowpane	25,609	477	1,060,579
Winter flounder	7,841,124	947,142	47,322,311

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C2-6 ASSUMPTIONS USED IN CALCULATING RECREATIONAL AND COMMERCIAL LOSSES

The lost yield estimates presented in Tables C2-5 and C2-6 are expressed as total pounds and include losses to both commercial and recreational catch. To estimate the economic value of these losses, total yield was partitioned between commercial and recreational fisheries based on the landings in each fishery. Table C2-7 presents the percentage impacts assumed for each species, as well as the value per pound for commercially harvested species.

Table C2-7: Percentage of Total Impacts Occurring to the Commercial and Recreational Fisheries and Commercial Value per Pound for Species Impinged and Entrained at North Atlantic Facilities

Species Group	Percent Impact to Recreational Fishery[a,b]	Percent Impact to Commercial Fishery[a,b]	Commercial Value per Pound (2002$)[c]
Atlantic cod[d]	50.0%	50.0%	$1.00
American plaice	0.0%	100.0%	$1.22
American shad	0.0%	100.0%	$0.42
Atlantic herring	0.0%	100.0%	$0.06
Atlantic mackerel	22.2%	77.8%	$0.22
Atlantic menhaden	0.0%	100.0%	$0.06
Bluefish	89.1%	10.9%	$0.28
Butterfish	0.0%	100.0%	$0.59
Commercial crabs	0.0%	100.0%	$0.54
Cunner	100.0%	0.0%	na
Other (commercial)	0.0%	100.0%	$0.66
Other (recreational)	100.0%	0.0%	na
Pollock[d]	50.0%	50.0%	$0.74
Rainbow smelt	0.0%	100.0%	$1.04
Red hake	0.0%	100.0%	$0.22
Sculpins	79.0%	21.0%	$0.59
Scup[d]	50.0%	50.0%	$1.06
Searobin	83.9%	16.1%	$0.12
Silver hake	0.0%	100.0%	$0.38
Skate species	0.0%	100.0%	$0.15
Striped bass	100.0%	0.0%	na
Tautog	92.2%	7.8%	$1.11
Weakfish	14.6%	85.4%	$0.90
White perch	78.8%	21.2%	$0.80
Windowpane	0.0%	100.0%	$1.68
Winter flounder[d]	50.0%	50.0%	$1.24
Other (forage)[e]	50.0%	50.0%	$1.00

[a] Based on landings from 1993 to 2001.

[b] Calculated using recreational landings data from NMFS (2003b, http://www.st.nmfs.gov/recreational/queries/catch/snapshot.html) and commercial landings data from NMFS (2003a, http://www.st.nmfs.gov/commercial/landings/annual_landings.html).

[c] Calculated using commercial landings data from NMFS (2003a).

[d] A 50 percent, 50 percent split was assumed because landings, which largely occur in the ocean, are not considered to be an accurate indicator of impact for these species, which are largely caught near-shore.

[e] Assumed equally likely to be caught by recreational or commercial fishermen. Commercial value calculated as overall average for region based on data from NMFS (2003a).

Age-1 equivalent fish that are spared from I&E are not necessarily old enough or large enough to be attractive to anglers. It may take one or more years for these fish to reach a harvestable age. For this reason, EPA discounts commercial and recreational benefits so that the cost and benefits estimates will be comparable. Tables C2-8 and C2-9 present the multiplicative discounting factors used in discounting benefits assuming a 3 percent real discount rate and a 7 percent real discount rate. For details on how these factors are developed, see Chapter A14.

Table C2-8: Factors Applied to Recreational Benefits to Implement Discounting in the North Atlantic

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Atlantic cod	0.905	0.798	0.932	0.853
Atlantic mackerel	0.901	0.790	0.928	0.845
Bluefish	0.940	0.870	0.968	0.931
Cunner	0.910	0.808	0.938	0.864
Other (recreational)	0.922	0.831	0.950	0.889
Pollock	0.880	0.750	0.906	0.803
Sculpins	0.943	0.875	0.971	0.937
Scup	0.887	0.763	0.914	0.816
Searobin	0.912	0.813	0.940	0.870
Tautog	0.728	0.486	0.750	0.520
Weakfish	0.950	0.890	0.979	0.953
White perch	0.900	0.786	0.904	0.796
Winter flounder	0.884	0.759	0.911	0.812
Other (forage)	0.919	0.829	0.919	0.829

Table C2-9: Factors Applied to Commercial Benefits to Implement Discounting in the North Atlantic

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Atlantic cod	0.881	0.750	0.908	0.802
American plaice	0.840	0.677	0.865	0.725
American shad			0.893	0.773
Atlantic herring	0.879	0.749	0.905	0.802
Atlantic mackerel	0.892	0.772	0.918	0.826
Atlantic menhaden	0.930	0.847	0.958	0.906
Bluefish	0.897	0.785	0.924	0.840
Butterfish	0.934	0.856	0.962	0.916
Commercial crabs			0.976	0.947
Lumpfish	0.886	0.760	0.913	0.813
Other (commercial)	0.913	0.813	0.940	0.870
Pollock	0.832	0.664	0.857	0.711
Red hake			0.944	0.879
Sculpins	0.913	0.814	0.941	0.871
Scup	0.873	0.735	0.899	0.786
Searobin	0.884	0.758	0.911	0.811
Silver hake	0.886	0.759	0.912	0.813
Skate species			0.940	0.870
Tautog	0.720	0.475	0.742	0.508
Weakfish	0.924	0.836	0.951	0.895
White perch	0.895	0.777	0.899	0.785
Windowpane	0.810	0.618	0.883	0.756
Winter flounder	0.859	0.711	0.885	0.761
Other (forage)	0.901	0.793	0.901	0.793

Chapter C3: Commercial Fishing Valuation

INTRODUCTION

This chapter presents the results of the commercial fishing benefits analysis for the North Atlantic region.
Section C3-1 details the estimated losses under current, or baseline, conditions. Section C3-2 presents the expected benefits in the region attributable to the rule.
Chapter A10 details the methods used in this analysis.

CHAPTER CONTENTS

Note that all results have been sample weighted in this version. In the final revision results will be reported unweighted.

C3-1 BASELINE LOSSES

Table C3-1 provides EPA's estimate of the value of gross revenues lost in commercial fisheries resulting from the impingement of aquatic species at facilities in the North Atlantic region. Table C3-2 displays this information for entrainment. Total annual revenue losses are approximately $0.5 million, assuming a 3 percent discount rate.

Table C3-1: Annual Commercial Fishing Gross Revenues Lost Due to Impingement at Facilities in the North Atlantic Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002 dollars)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
American plaice	0	0	0	0
American shad	0	0	0	0
Atlantic cod	193	189	172	152
Atlantic herring	981	58	53	47
Atlantic mackerel	0	0	0	0
Atlantic menhaden	69	4	4	4
Bluefish	2	1	1	0
Butterfish	194	112	108	103
Crabs (commercial)	310	164	160	155
Lumpfish	596	89	81	72
Other (commercial)	12	8	7	7
Pollock	19	14	12	10
Red hake	59	13	12	11
Sculpins	66	38	36	33S
Scup	19	20	18	16
Searobin	8	1	1	1
Silver hake	363	135	123	110
Skates	961	145	136	126
Tautog	16	17	13	9
Weakfish	22	20	19	18
White perch	0	0	0	0
Windowpane	80	132	117	100
Winter flounder	2,088	2,533	2,241	1,927
Other unidentified species (from forage losses)	137	134	121	106
TOTAL	6,195	3,828	3,434	3,007

Table C3-2: Annual Commercial Fishing Gross Revenues Lost Due to Entrainment at Facilities in the North Atlantic Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002 dollars)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
American plaice	781	932	783	631
Atlantic cod	2,622	2,580	2,273	1,934
Atlantic herring	21,347	1,266	1,112	948
Atlantic mackerel	2,761	608	542	469
Atlantic menhaden	5,578	319	297	271
Bluefish	0	0	0	0
Butterfish	2	1	1	1
Lumpfish	27	4	4	3
Other (commercial)	18	12	11	10
Pollock	17	12	10	8
Sculpins	31,273	18,144	16,571	14,771
Scup	130	136	119	100
Searobin	75	9	8	7
Silver hake	324	121	107	92
Tautog	6,009	6,512	4,691	3,092
Weakfish	301	264	244	221
White perch	0	0	0	0
Windowpane	477	786	636	485
Winter flounder	473,571	574,527	493,437	408,468
Other unidentified species (from forage losses)	8,974	8,759	7,888	6,944
TOTAL	554,288	614,991	528,734	438,455

C3-2 BENEFITS

As described in Chapter A10, EPA estimates that 0 to 40 percent of the gross revenue losses represent surplus losses to producers, assuming no change in prices or fishing costs. The 0 percent estimate, of course, results in loss estimates of $0. The 40 percent estimates, as presented in Table C3-3, total $0.2 million when a 3 percent discount rate is assumed.

The expected reductions in I&E attributable to changes at facilities required by the rule are 43.8 percent for impingement and 29.1 percent for entrainment. Total annual benefits are estimated by applying these estimated reductions to the annual producer surplus loss. As presented in Table C3-3, this results in total annual benefits of $0.1 million, assuming a 3 percent discount rate.

Table C3-3: Annual Commercial Fishing Benefits Attributable to Phase II Rule at Facilities in the North Atlantic Region (million 2002$), Assumes Compliance in 2005

	Impingement	Entrainment	Total
Baseline loss - gross revenue			
Undiscounted	$0.00	$0.6	$0.6
3% discount rate	$0.00	$0.5	$0.5
7% discount rate	$0.00	$0.4	$0.4
Producer surplus lost - low	$0.0	$0.0	$0.0
Producer surplus lost - high (gross revenue * 0.4)			
Undiscounted	$0.0	$0.2	$0.2
3% discount rate	$0.0	$0.2	$0.2
7% discount rate	$0.0	$0.2	$0.2
Expected reduction due to rule[a]	**43.8%**	**29.1%**	---
Benefits attributable to rule - low	**$0.0**	**$0.0**	**$0.0**
Benefits attributable to rule - high			
Undiscounted	$0.0	$0.1	$0.1
3% discount rate	$0.0	$0.1	$0.1
7% discount rate	$0.0	$0.0	$0.0

[a] Estimated based on EPA's assumptions. EPA's assumption about the amount of electricity that will be produced in the future differs very slightly from DOE's. Using DOE's assumptions, the expected reductions would be 48.6 percent for impingement and 32.8 percent for entrainment.

Chapter C4: RUM Analysis

INTRODUCTION

This case study estimates the effects of improved fishing opportunities due to reduced impingement and entrainment (I&E) in the North Atlantic region. The case study focuses on Atlantic coastal marine fishing sites in Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut. The study applies benefit-function transfer, using a fishing site choice model developed by Robert Hicks from the National Marine Fisheries Service (NMFS), Office of Science and Technology (Hicks et al., 1999).

Cooling Water Intake Structures (CWIS) withdrawing water from North Atlantic coastal waters impinge and entrain many of the species sought by recreational anglers. These species include winter flounder, tautog, Atlantic cod, striped bass, bluefish, scup, and other less prominent species. Some of these species (e.g., weakfish, flounder, striped bass) inhabit a wide range of coastal waters spanning several states (e.g., striped bass are found throughout the North Atlantic region).

CHAPTER CONTENTS

The main assumption of this analysis is that, all else being equal, anglers will get greater satisfaction, and thus greater economic value, from sites with a higher catch rate. This benefit may occur in two ways: first, an angler may get greater enjoyment from a given fishing trip with higher catch rates, yielding a greater value per trip; second, anglers may take more fishing trips when catch rates are higher, resulting in greater overall value for fishing in the region.

The following sections describe the data used in the analysis and the analytic results. Chapter A11 provides a detailed description of the RUM methodology used in this analysis.

C4-1 DATA SUMMARY

The Hicks et al. (1999) analysis of improvements in recreational fishing opportunities in the New England and Mid-Atlantic region relies on a subset of the NMFS Marine Recreational Fishery Statistics Survey (MRFSS), combined with the 1994 Add-on MRFSS Economic Survey (NMFS, 2003b; QuanTech, 1998).[1] The model of recreational fishing behavior developed in the study relies on a subset of the survey respondents that includes only single-day trips to sites located along the Atlantic coast. As explained further below, values for single-day trips were used to value each day of a multi-day trip. This section provides a summary of anglers' characteristics who took one-day trips to fishing sites in the five North Atlantic states. This analysis is based a sample of 9,314 respondents to the MRFSS survey.

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[1] For general discussion of the MRFSS, see Chapter A11 of the Regional Study Report or Marine Recreational Fisheries Statistics: Data User's Manual, http://www.st.nmfs.gov/st1/recreational/pubs/data_users/index.html (NMFS, 1999a).

C4-1.1 Summary of Anglers' Characteristics

a. Fishing modes and targeted species

Based on the data set used in developing the NMFS model, a majority of the interviewed anglers (62 percent) fish from either a private or a rental boat (see Table C4-1). Approximately 24 percent fish from the shore; the remaining 14 percent fish from a party or charter boat. In addition to the mode of fishing, the MRFSS contains information on the specific species targeted on the surveyed trip. The most popular species group, targeted by 56 percent of all anglers, is small game. The second most popular species group, targeted by 18 percent of all anglers, is bottom fish. Approximately 12 percent of all anglers did not target a particular species. Of the remaining anglers, 10, 2, and 1 percent target flatfish, other species, and big game, respectively.

Table C4-1: Species Group Choice by Mode of Fishing in the North Atlantic Region

Species	All Modes		Private/Rental Boat		Party/Charter Boat		Shore	
	Frequency	Percent	Frequency	Percent by Mode	Frequency	Percent by Mode	Frequency	Percent by Mode
Small game	5,246	56.32%	3,429	59.33%	478	37.67%	1,339	59.12%
Bottom fish	1,705	18.31%	975	16.87%	510	40.19%	220	9.71%
Flatfish	914	9.81%	738	12.77%	10	0.79%	166	7.33%
Big game	116	1.25%	55	0.95%	53	4.18%	8	0.35%
No target	1,136	12.20%	541	9.36%	218	17.18%	377	16.64%
Other	197	2.12%	42	0.73%	0	0.00%	155	6.84%
All species	9,314	100.00%	5,780	62.00%	1,269	14.00%	2,265	24.00%

Source: NMFS, 2003b.

The distribution of target species is not uniform by fishing mode. For example, more than 76 percent of the anglers fishing from private/rental boats target either small game fish (59 percent) or bottom fish (17 percent). The majority of the anglers fishing from shore, on the other hand, target small game fish (59 percent) or do not have a targeted species (17 percent). Small game and bottom fish remain the most popular species groups among anglers fishing from a charter/party boat (38 and 40 percent, respectively).[2] A relatively large percentage of charter boat anglers target big game species (4 percent), compared to a small percentage of anglers targeting big game species from either private or rental boats (1 percent) or shore (0.35 percent).

b. Anglers' characteristics

This section presents a summary of angler characteristics for the North Atlantic region as defined above. Table C4-2 summarizes characteristics of the sample anglers fishing the NMFS sites in the North Atlantic region.

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[2] Note that bottom species targeted by offshore anglers and charter boat anglers are different. Charter boat anglers usually target tautog, black sea basses, and drums, while offshore anglers target white perch, catfish, and dogfish sharks.

Table C4-2: Data Summary for the North Atlantic Coast Anglers

Variable	All Modes			Private/Rental Boat			Party/Charter Boat			Shore		
	N	Mean[a]	Std Dev	N	Mean[a]	Std Dev	N	Mean[a]	Std Dev	N	Mean[a]	Std Dev
Trip Cost	8,165	38.12	59.92	5,182	$33.36	$51.54	1,050	$72.34	$92.11	1,933	$32.30	$52.08
Travel Time	8,689	2.55	3.13	5,501	2.24	2.68	1,129	4.64	4.32	2,059	2.23	3.03
Visits	1,446	6.15	8.97	934	6.38	8.72	135	2.07	5.47	377	7.05	10.17
Own a Boat	1,880	0.55	0.50	1,104	0.75	0.43	298	0.19	0.39	478	0.29	0.45
High School	1,858	0.41	0.49	1,093	0.41	0.49	293	0.37	0.48	472	0.43	0.50
College Degree	1,858	0.18	0.39	1,093	0.20	0.40	293	0.19	0.39	472	0.15	0.36
Retired	1,873	0.15	0.35	1,100	0.13	0.34	296	0.14	0.34	477	0.19	0.39
Employed	1,873	0.79	0.41	1,100	0.82	0.38	296	0.79	0.41	477	0.71	0.45
Age	1,859	43.31	13.95	1,092	43.74	12.97	294	41.38	14.60	473	43.50	15.56
Years Fishing	1,914	20.72	15.30	1,131	21.19	14.62	303	17.98	15.93	480	21.34	16.25
Household Size	1,864	3.03	1.34	1,097	3.01	1.31	294	3.16	1.33	473	2.98	1.40
Flexible Time	1,456	0.69	0.46	892	0.69	0.46	230	0.70	0.46	334	0.68	0.47
Male	1,880	0.94	0.25	1,104	0.94	0.23	298	0.90	0.30	478	0.94	0.24
White	1,844	0.95	0.22	1,083	0.96	0.20	290	0.93	0.25	471	0.93	0.26
Household Income	1,667	$47,994	$29,233	990	$51,129	$29,229	265	$51,047	$29,554	412	$38,501	$26,967
Average Trip Length in Hours	8,676	3.95	2.12	5,499	4.22	2.13	1,128	4.65	1.96	2,049	2.84	1.73
Annual Trips	9,254	31.46	43.93	5,741	31.63	40.13	1,263	9.53	24.36	2,250	43.33	55.55

[a] For dummy variables, such as "Own a Boat," that take the value of 0 or 1, the reported value represents a portion of the survey respondents possessing the relevant characteristic. For example, 55 percent of the surveyed anglers own a boat.

Source: NMFS, 2003b; and U.S. Census Bureau, 2002.

The average income of respondent anglers was $47,994 (1994$).[3,4] Ninety-five percent of the anglers are white, with an average age of about 43 years. Educational attainment information indicates that 41 percent of the anglers had received a high school diploma, while only 18 percent had graduated from college. The average household size was three individuals.

Nearly 15 percent of the anglers are retired, while 79 percent are employed. Sixty-nine percent of the anglers indicated that they had flexible time when setting their work schedule.

Table C4-2 shows that on average anglers spent 31 days fishing during the past year. The average duration of a fishing trip was about 4 hours per day. Anglers made an average of 6.2 trips to the current site, with an average trip cost of $38.12 (1994$).[5] Average round trip travel time was about two and a half hours. Fifty-five percent of the North Atlantic anglers own their own boat. Finally, the average number of years of fishing experience was 21. This analysis does not include anglers under the age of 16, which may result in overestimation of the average age of recreational anglers and years of experience.

C4-1.2 Recreational Fishing Choice Sets

For consistency with Hicks et al. (1999), the Agency aggregated NMFS intercept sites (see Figure C1-1 in Chapter C1 for the survey intercept sites included in the analysis) to the county level, resulting in 26 sites from Maine through Connecticut. The 26 fishing sites, along with the angler's state of residence, define the individual's choice set. The choice set is defined according to the approach developed by Hicks et al. (1999). If the closest site is within 30 miles from the angler's home, then all sites within 150 miles are assumed to be in their choice set; otherwise, all sites within 400 miles are assumed to be in their choice set. Distances in the original study were estimated using PCMiler software. EPA used ArcView 3.2a software to determine the distance from an angler's residence to each NMFS intercept site. Further discussion of distance estimation is presented in section C4-1.4. Based on this method of site choice construction, EPA found that anglers in the five North Atlantic states have from 4 to 26 fishing sites in their choice sets.

C4-1.3 Site Attributes

This analysis assumes that the angler chooses between site alternatives by comparing his utility for each alternative and choosing the one that maximizes his utility. Following Hicks et al. (1999), this assumption states that the individual first chooses fishing mode and target species and then, conditional on this choice, chooses the recreational site.

Catch rate is the most important attribute of a fishing site from the angler's perspective (McConnell and Strand, 1994; Haab et al., 2000). This attribute is also a policy variable of concern as catch rate is a function of fish abundance, which is affected by fish mortality due to I&E. The catch rate variable in the model provides a means to measure baseline losses from I&E and changes in anglers' welfare attributed to changes from I&E due to the final section 316(b) rule.

To specify the baseline fishing quality of the case study sites, EPA followed the approach used by Hicks et al. (1999). The Agency calculated average historic catch rates based on the NMFS intercept survey data from 1990 to 1994 for recreationally important species, such as striped bass, bluefish, summer flounder, Atlantic cod, tautog, and winter flounder (McConnell and Strand, 1994; Hicks et al., 1999). EPA aggregated all species into five species groups — big game fish, bottom fish, flatfish, small game fish, and no-target — and calculated the average group-specific historic catch rates. Following the species groups definitions in Hicks et al. (1999), the following species are included in the four specific groups listed below. The "No-target" category covers all species caught by anglers that are not included in big game, bottom fish, small game fish, or flatfish.

- ***Big game:*** albacore, blue shark, bluefin tuna, shortfin mako shark, tuna, smooth hammerhead, thresher shark, billfish, cobia, great hammerhead, tiger shark, scalloped hammer, sailfish, wahoo, marlin, swordfish, white shark, tarpon, and dolphin.

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[3] Income was not reported by most survey respondents. Median household income data by zip code, from the U.S. Census Bureau, was used to provide income information for respondents not reporting income.

[4] All costs are in 1994$, which represent the MRFSS survey year. All costs/benefits will be updated to 2002$ later in this analysis (e.g., for welfare estimation).

[5] All costs are in 1994$, which represent the MRFSS survey year. All costs/benefits will be updated to 2002$ later in this analysis (e.g., for welfare estimation).

- ***Bottom fish:*** Atlantic cod, Atlantic wolffish, black sea basses, blue angelfish, butterfish, codfishes, cunner, dwarf sand perch, gray triggerfish, haddock, perch family, pollock, porgies, reef bass, scup, skate, snapper, snowy grouper, spiny dogfish shark, striped searobin, tautog, white perch, sandbar shark, sand tiger shark, catfish, kingfish, black drum, dogfish shark, smooth dog shark, toadfish, hake, sawfish, mullett, nurse shark, sheepshead, cat shark, carp, grunt, and pinfish.

- ***Flatfish:*** Atlantic halibut, killifishes, flounders, mummichog, windowpane, and sole.

- ***Small game:*** Atlantic bonito, mackerels, Atlantic salmon, bluefish, brown trout, cero, hickory shad, little tunny, striped bass, weakfish, pompano, barracuda, snook, jack, bonefish, and red drum.

The species listed above inhabit waters from Maine through Virginia, the region covered in the Hicks et al. (1999) study. Not all of the listed species are present in the North Atlantic region, which includes only Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut. The catch rates represent the number of fish caught on a fishing trip per angler by aggregated species group. The estimated catch rates are averaged across all anglers by wave, mode, target species group, and site over the five-year period (1990-1994).[6] Catch rates for earlier years were not included in the analysis due to significant changes in species populations for recreational fisheries.

The catch rate variables include total catch, which includes both fish caught and kept and fish released. Several NMFS studies use only the catch-and-keep measure as the relevant catch rate. Although a greater error may be associated with the measured number of fish not kept, the total catch measure is more appropriate because a large number of anglers catch and release fish. As noted above, EPA followed Hicks et al. (1999) in estimating the total catch rate variable. The total catch rate variable includes only targeted fish catch and not incidental catch. For example, flatfish catch rates include flatfish caught only by anglers targeting flatfish and do not include flatfish caught by anglers targeting another species group (e.g., small game). If an angler targeted a species group and caught no fish or caught fish of another species group, their catch rate was set to zero. Aggregated sites for which no historic catch rate was available were assigned an average historic catch rate of zero.

Anglers who target particular species groups generally catch more fish in the targeted category because of specialized equipment and skills than anglers who don’t target these species. Of the anglers who target particular species groups, bottom fish anglers catch the largest number of fish per hour (1.28), followed by anglers who catch small game (0.65). Anglers who target big game fish catch fewer fish than anglers targeting any other species group. Table C4-3 summarizes average catch rates by species for all sites in the study area.

Table C4-3: Average Catch Rate by Species Group for the North Atlantic Region Sites[a]

Species Group	Average Catch Rate (fish per angler per trip)
Big Game	0.07
Bottom Fish	1.28
Flatfish	0.24
Small Game	0.65
No Target	0.35

[a] This includes aggregated sites (counties) in Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut.

Source: NMFS, 2002e.

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[6] “Wave” is a two month period (e.g., May-June). Fishing conditions such as catch rates may differ significantly across six waves.

C4-1.4 Travel Cost

EPA used ArcView 3.2a software to estimate distances from the household zip code to each NMFS fishing site in the individual opportunity sets. The Agency obtained fishing site locations from the Master Site Register supplied by the NMFS. The Master Site Register includes both a unique identifier that corresponds to the visited site used in the angler survey, and latitude and longitude coordinates. For some sites, the latitude and longitude coordinates were missing or demonstrably incorrect, in which case the town point, as identified in the U.S. Geological Survey (USGS) Geographic Names Information System, was used as the site location if a town was reported in the site address. The Arc View program measured the distance in miles of the shortest route, using state and U.S. highways, from the household zip code to each fishing site, then added the distances from the zip code location to the closest highway and from the site location to the closest highway. The average one-way distance to the visited site is 58.6 miles.

Based on the procedure described in Hicks et al. (1999), EPA estimated trip "price" as the sum of travel costs plus the opportunity cost of time. To estimate consumers' travel costs, EPA multiplied round trip distance by average motor vehicle cost per mile ($0.30, 1994$).[7] To estimate the opportunity cost of travel time, EPA first divided round trip distance by 40 miles per hour to estimate trip time, and used the household's wage to yield the opportunity cost of time. EPA estimated household wage by dividing household income by 2,040.[8]

Only those respondents who reported that they can work extra hours for extra pay (*FLEXHR*=1) are assigned a time cost in the trip cost variable. Otherwise, the trip cost variable was calculated based on the round trip distance and the reimbursement rate of $0.30 per mile. EPA calculated visit price as:

$$Visit\ Price = \begin{cases} Round\ Trip\ Distance \times \$.30 + \dfrac{Round\ Trip\ Distance}{40\ mph} \times (Wage) & If\ FLEXHR = 1 \\ Round\ Trip\ Distance \times \$.30 & If\ FLEXHR = 0 \end{cases} \qquad \text{(C4-1)}$$

For those respondents who cannot work extra hours for extra pay, the time cost is accounted for in an additional variable equal to the amount of time spent on travel. EPA therefore estimated time cost as the round trip distance divided by 40 mph:

$$Travel\ Time = \begin{cases} Round\ Trip\ Distance/40 & If\ FLEXHR = 0 \\ 0 & If\ FLEXHR = 1 \end{cases} \qquad \text{(C4-2)}$$

C4-2 THE NESTED RANDOM UTILITY MODEL OF RECREATIONAL DEMAND

For the purpose of this analysis, EPA did not estimate its own random utility model (RUM) and relied on the study completed by Hicks et al. (1999) from the NMFS Office of Science and Technology (Volume II: The Economic Value of New England and Mid-Atlantic Sportfishing in 1994). Based on the Hicks et al. (1999) approach, each angler selects a fishing mode and target species first and, given this choice, selects the fishing site. Chapter 3 of the NMFS study describes the model in detail. The Hicks et al. (1999) model includes 10 variables: travel cost, travel time, five variables for catch rates (one for each species group), the log of the number of NMFS intercept sites contained in an aggregated site, a private/rental dummy, and a cold-private/rental dummy. The private/rental dummy equals 1 if the angler chose the private/rental fishing mode and owns their own boat and 0 otherwise. The cold-private/rental dummy equals 1 if the private/rental dummy equals one and the angler took his/her fishing trip in November or December (i.e., during cold months).[9] The model estimates are shown in Table C4-4.

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[7] The Federal Travel Regulations set the reimbursement rate at $0.29 per mile in 1994. This estimate includes vehicle operating cost only. This value per mile was taken from Hicks et. al., 1999.

[8] Based on Hicks assumption (Hicks et. al., 1999).

[9] Data are not collected for January and February in the North Atlantic region due to cold weather and, as a result, very low participation in recreational fishing.

Table C4-4: Estimated Coefficients for the Conditional Site Choice

Variable	Mean of the Variable	Estimated Coefficient (t-statistic)
Travel Cost ($)	61.84	-0.036 (-10.46)
Travel Time (hours)	3.69	-1.141 (-16.12)
Log of Number of NMFS Interview Sites in Aggregated Sites	3.11	1.247 (33.99)
Big Game Fish Catch	0.003	0.974 (2.69)
Small Game Fish Catch	0.39	0.579 (8.68)
Bottom Fish Catch	0.19	0.572 (100.68)
Flatfish Catch	0.26	0.665 (58.23)
No-target Catch	0.20	0.324 (15.23)
Mode/Species Choice Model		
Inclusive Value	4.90	0.612 (19.99)
Private/Rental Dummy	0.15	2.490 (42.02)
Cold Private/Rental Dummy	0.20	-0.553 (-4.08)

Source: U.S. EPA analysis for this report.

Table C4-4 shows that the coefficients have the expected signs. Travel cost and travel time have a negative effect on the probability of selecting a site, indicating that anglers prefer to visit sites closer to their homes (other things being equal). A positive sign on the private/rental dummy indicates that anglers who own a boat are more likely to go fishing. The probability of a site visit increases as the historic catch rate for fish species increases. The positive signs on the catch rate variables verify this assumption. The cold private/rental dummy has a negative sign suggesting that cold months (November and December) negatively affect the probability of site selection for boat anglers (i.e., boat anglers are less likely to visit a site during cold weather, all else being equal).

C4-3 TRIP FREQUENCY MODEL

EPA also examined effects of changes in fishing circumstances on an individual's choice concerning the number of trips to take during a recreation season. EPA used the negative binomial form of the Poisson regression model to estimate the number of fishing trips per recreational season. The participation model relies on socio-economic data and estimates of individual utility (the inclusive value) derived from the site choice model (Parsons et al., 1999; Feather et al., 1995). EPA estimated a combined participation model for the North Atlantic and Mid-Atlantic regions.[10] This section discusses results from the Poisson model of recreational fishing participation, including statistical and theoretical implications of the model. A detailed discussion of the Poisson model is presented in Chapter A11 of this report.

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[10] EPA combined data for the North and Mid-Atlantic regions, as these regions are part of a single NMFS data set, to estimate the model. The Agency calculated separate estimates of participation and changes in participation for each region, based on average values of variables for that region.

The dependent variable, the number of recreational trips within the past 12 months, is an integer value ranging from 1 to 365. To avoid over-prediction of the number of fishing trips, EPA set the number of trips for anglers reporting over 125 trips per year to 125 in the model estimation.[11] The Agency first tested the data on the number of fishing trips for overdispersion to determine whether to use the Poisson model or the negative binomial model. If the dispersion parameter is equal to zero, then the Poisson model is appropriate; otherwise the negative binomial is more appropriate. The analysis found that the overdispersion parameter is significantly different from zero and therefore the negative binomial model is the most appropriate for this case study.

Independent variables of importance include gender, ethnicity, education, household size, hourly wage, whether the angler targets a species, whether the angler fishes from shore or from a boat, whether the angler is employed, whether the angler is self-employed, and whether the angler owns a boat. The model also includes a dummy variable to indicate whether the angler is from the North Atlantic region. Variable definitions for the trip participation model are:

- Constant: a constant term;
- IVBASE: the inclusive value estimated using the coefficients from the site choice model;
- HIGH_ED: equals 1 if the individual completed college or an advanced degree, 0 otherwise;
- HH_SIZE: household size;
- EMPLYED: equals 1 if the individual is employed; 0 otherwise;
- SELFEMP: equals 1 if the individual is self-employed; 0 otherwise;
- MALE: equals 1 if the individual is male; 0 if female;
- WHITE: equals 1 if the individual is white; 0 otherwise;
- OWNBT: equals 1 if individual owns a boat, 0 otherwise;
- NOTARG: equals 1 if the individual did not target a particular species; 0 otherwise;
- SHORE: equals 1 if the individual fished from shore; 0 if the individual fished from a boat;
- WAGE: household hourly wage (household income divided by 2,080);
- N_ATL: equals 1 if the individual is from the North Atlantic region; and
- α (alpha): overdispersion parameter estimated by the negative binomial model.

Table C4-5 presents the results of the trip participation model. Where a particular sign is expected, all estimated parameters have the expected signs. The model shows that the most significant determinants of the number of fishing trips taken by an angler are region (N_ATL), whether the angler fishes from shore (SHORE), whether the angler targets a species (NOTARG), boat ownership (OWNBT), whether the angler is male (MALE), whether the angler is employed (EMPLOYED), and the perceived quality of fishing sites (IVBASE).

The positive coefficient on the inclusive value index (IVBASE) indicates that the quality of recreational fishing sites has a positive effect on the number of fishing trips per recreational season. EPA therefore expects improvements in recreational fishing opportunities, such as an increase in fish abundance and catch rate, to result in an increase in the number fishing trips to the affected sites.

The model shows that anglers in the North Atlantic region take less fishing trips than those in the Mid-Atlantic region. Anglers who completed college or an advanced degree tend to take less fishing trips than those with less education. Anglers with larger households take fewer trips than those with smaller households, and those who are employed take fewer trips than those who are retired or otherwise not employed. However, self-employed anglers take more trips than those who are not self-employed. Male anglers fish more frequently than female anglers, and white anglers take more trips than non-white anglers. Anglers who own boats, those who target a specific species, those with higher incomes, and those who fish from shore take more trips each year.

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[11] The number of trips was truncated at the 95th percentile, 125 trips per year.

Table C4-5: Trip Participation Model (Negative Binomial Model)

Variable	Coefficient	t-statistic
Constant	2.428	32.48
IVBASE	0.167	18.26
HIGH_ED	-0.146	-3.96
HH_SIZE	-0.033	-3.27
EMPLYD	-0.210	-5.84
SELFEMP	0.137	3.44
MALE	0.221	5.46
WHITE	0.124	2.64
OWNBT	0.379	11.78
NOTARG	-0.391	-11.43
SHORE	0.400	11.23
WAGE	0.003	2.40
N_ATL	-0.685	-18.29
α (alpha)	1.034	38.02

Source: U.S. EPA analysis for this report.

C4-4 WELFARE ESTIMATES

This section presents estimates of welfare losses to recreational anglers from fish mortality due to I&E, and potential welfare gains as a result of the final section 316(b) rule. These gains would result from improvements in fishing opportunities due to reduced fish mortality.

C4-4.1 Estimating Changes in the Quality of Fishing Sites

To estimate changes in the quality of fishing sites under different policy scenarios, EPA relied on the recreational fishery landings data by state and the estimates of recreational losses from I&E corresponding to different technology options. The NMFS provided recreational fishery landings data for the North Atlantic region states. EPA estimated the losses to recreational fisheries using the physical impacts of I&E on the relevant fish species, and the percentage of total fishery landings attributed to recreational fishing, as described in Chapter C2 of this document. I&E affects recreational species in two ways: by directly killing recreational species, and by killing forage species, thus indirectly affecting recreational species through the food chain. The indirect effects on recreational species were calculated in two steps. First, EPA estimated the total number of fish lost due to forage fish losses. Second, EPA allocated this total number of fish among recreational species according to each species' percent of total recreational landings.

The Agency measured changes in the quality of recreational fishing sites in terms of a percentage change applied to the historic catch rate. EPA assumed that catch rates will change uniformly across all marine fishing sites along the North Atlantic coast because species considered in this analysis (i.e., striped bass, bluefish, and flounder) inhabit a wide range of states (e.g., from North Carolina to Maine).[12] To estimate the expected change in catch rates, EPA used the most recent data

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[12] Fish lost to I&E are most often very small fish, which are too small to catch. Because of the migratory nature of most affected species, by the time these fish have grown to catchable size, they may have traveled some distance from the facility where I&E occurs. Without collecting extensive data on migratory patterns of all affected fish, it is not possible to evaluate whether catch rates will change uniformly or in some other pattern. Thus, EPA assumed that catch rates will change uniformly across the entire region.

on total recreational landings in the North Atlantic region.[13] EPA used a five-year average of recreational landing data (1997 through 2001) for sites within state waters to calculate an average number of landings per year.[14] EPA then divided baseline losses to the recreational fishery from I&E by the total recreational landings to derive the percentage change in historic catch rates from completely eliminating I&E losses. EPA estimates the complete elimination of I&E losses to increase small game catch rates by 0.01 percent, bottom fish catch rates by 8.71 percent, flatfish catch rates by 16.11 percent, and no-target catch rates by 4.13 percent.

EPA also estimated percentage changes to species group historic catch rates resulting from reduced I&E losses resulting from the final section 316(b) rule. Dividing the reduced I&E losses by the 5-year average recreational landings leads to increases in the historic catch rates of 2.54 percent for bottom, 4.71 percent for flatfish, 1.21 percent for no-target, and 0.002 percent for small game. Table C4-6 presents the recreational landings, I&E loss estimates, and percentage changes in historic catch rates.

Table C4-6: Estimated Changes in Historic Catch Rates From Eliminating and Reducing I&E in the North Atlantic Region

Species Group	Total Recreational Landings for Five States Combined (fish per year)[a]	Baseline Losses		Reduced Losses Under the Final Section 316(b) Rule	
		Total Recreational Losses From I&E	Percent Increase in Recreational Catch From Elimination of I&E	Combined I&E	Percent Increase in Recreational Catch From Reduction of I&E
Small Game	13,713,213	1,155	0.01%	337	0.002%
Bottom Fish	6,106,054	532,078	8.71%	155,264	2.54%
Flatfish	2,377,698	383,164	16.11%	111,935	4.71%
No Target [b]	23,904,569	916,396	4.13%	267,536	1.21%

[a] Total recreational landings are calculated as a five-year average (1997-2001) for state waters.

[b] No target includes small game, bottom fish, and flatfish as well as other fish not included in those groupings. The other fish represent only a small number of impinged and entrained species and combined I&E for these other fish are 126 fish in the baseline and 16 fish under the final section 316(b) rule.

Source: NMFS, 2002e; and U.S. EPA analysis for this report.

C4-4.2 Estimating Losses from I&E in the North Atlantic Region

The recreational behavior model described in the preceding sections provides a means for estimating the economic effects of changes in recreational fishery losses from I&E in the North Atlantic region. First, EPA estimated welfare gain to recreational anglers from eliminating fishery losses due to I&E. This estimate represents economic damages to recreational anglers from I&E of recreational fish species under the baseline scenario. Then EPA estimated the gain in welfare from I&E reductions due to installation of the technology under the final section 316(b) rule. To estimate per-day welfare gain (loss), the Agency combined the Hicks' model coefficients with the estimated percentage changes in historic catch rates from eliminating or reducing I&E losses at the cooling water intake structures located in the North Atlantic Region, to get anglers' willingness-to-pay (WTP) for improvements in the quality of recreational fishing due to changes in I&E. Table C4-7 presents

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[13] Note that the Agency followed Hicks et al. (1999) and used 1990-1994 data to characterize site-specific catch rates. The Agency used the most recent data on total recreational landings (1997-2001) to reflect the current conditions in estimating the expected change in total catch rate from changes in impingement and entrainment.

[14] State waters include sounds, inlets, tidal portions of rivers, bays, estuaries, and other areas of salt or brackish water; and ocean waters to three nautical miles offshore (NMFS, 2003b).

Table C4-7: Per-Day Welfare Gain from Eliminating and Reducing I&E in the North Atlantic Region (2002$)

Targeted Species	Baseline Per-Day Welfare Losses from I&E	Reduced Losses Under the Final Section 316(b) Rule (per-day welfare gain)	WTP for an Additional Fish Per Trip
Small Game	$0.002	$0.0001	$2.53
Bottom Fish	$0.19	$0.06	$1.06
Flatfish	$0.44	$0.13	$3.57
Big Game[a]	N/A	N/A	$5.90
No Target	$0.04	$0.01	$1.66

[a] Not estimated because of limitations of I&E data.

Source: U.S. EPA analysis for this report.

the compensating variation per day (averaged over all anglers in the sample) associated with reduced fish mortality from changes in I&E for each fish species of concern.[15,16]

The estimated per-day welfare gain resulting from eliminating all I&E at the cooling water intake structures is $0.44, $0.19, and $0.04 for flatfish, bottom fish, and no target, respectively (2002$). The estimated per-day welfare gain from reducing I&E at the cooling water intake structures under the final section 316(b) rule is $0.13, $0.06, and $0.01 for flatfish, bottom fish, and no target, respectively (2002$). As shown in Table C4-7, EPA expects flatfish anglers to experience the greatest welfare gain from reducing or eliminating I&E at the cooling water intake structures in the North Atlantic.

The results presented in Table C4-7 are not surprising. The more desirable the fish, the greater the per-day welfare gain as evidenced by the willingness-to-pay for catching one additional fish per trip. Of the species groups affected by I&E reductions, anglers value flatfish the most ($3.57 for an additional fish), followed by small game ($2.53). Anglers targeting big game, not surprisingly, place the highest value on catching an additional fish ($5.90). The estimated WTP for an additional fish per trip are consistent with those available from previous studies.

The Agency assumed that the welfare gain per day of fishing is independent of the fishing mode and the number of days fished per trip and therefore equivalent for all modes (i.e., private or rental boat, shore, and charter boat) for both single- and multiple-day trips. Each day of a multiple-day trip is valued the same as a single-day trip.[17] The model developed by Hicks et al. (1999) includes the fishing mode choice as well as the targeted species group choice. Thus, for every angler, regardless of mode or species choice, changes in historic catch rates for a particular species group offer a gain in welfare. Every fishing trip taken is the result of a choice decision affected by the changes in I&E. Therefore, all fishing trips taken should be included in estimating total losses from I&E.

EPA calculated total recreational losses to North Atlantic anglers by multiplying the estimated per-day welfare gain from eliminating I&E for a given species group by the total number of recreational fishing days in the North Atlantic. The total number of fishing days used in the analysis is the average of the those reported by NMFS and the predicted number of fishing trips estimated with the trip frequency model described in section C4-3. The total number of fishing trips reported by NMFS includes both single and multiple-day trips by state and fishing mode (Table C4-8). The Agency assumed that the welfare gain per day of fishing is independent of the number of days fished per trip and therefore equivalent for both single- and multiple-day trips. Each day of a multiple-day trip is valued the same as a single-day trip.

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[15] A compensating variation equates the expected value of realized utility under the baseline and post-compliance conditions. For more detail, see the Proposed Section 316(b) Phase II Existing Facilities Rule Case Study Analysis.

[16] As the RUM model estimated values for single-day trips, the per-day value is equal to a per-trip value.

[17] See section C4-4.2 for limitations and uncertainties associated with ths assumption.

Table C4-8: Recreational Fishing Participation by Fishing Mode, Species Group, and State

State	Big Game	Bottom Fish	Flatfish	Small Game	Other	No Target	Total
Private/Rental Boat							
CT	15,894	143,246	252,741	494,591	4,906	69,759	981,137
ME	6,886	62,061	109,500	214,282	2,125	30,223	425,078
MA	32,168	289,906	511,505	1,000,970	9,928	141,180	1,985,657
NH	1,881	16,954	29,913	58,537	581	8,256	116,122
RI	9,599	86,507	152,631	298,685	2,963	42,128	592,512
Subtotal	66,428	598,674	1,056,290	2,067,065	20,503	291,546	4,100,506
Party/Charter Boat							
CT	1,999	15,498	8,799	15,118	N/A	4,848	46,262
ME	85	657	373	641	N/A	206	1,961
MA	1,685	13,063	7,417	12,743	N/A	4,087	38,994
NH	667	5,173	2,937	5,046	N/A	1,618	15,441
RI	292	2,263	1,285	2,207	N/A	708	6,754
Subtotal	4,728	36,654	20,811	35,755	N/A	11,467	109,412
Shore							
CT	1,530	56,189	148,121	362,446	42,698	84,422	695,406
ME	1,032	37,894	99,893	244,432	28,795	56,934	468,980
MA	4,007	147,173	387,967	949,336	111,837	221,123	1,821,442
NH	219	8,061	21,251	52,000	6,126	12,112	99,770
RI	1,735	63,731	168,003	411,094	48,429	95,754	788,745
Subtotal	8,523	313,048	825,235	2,019,308	237,885	470,345	3,874,343
Total	79,679	948,376	1,902,336	4,122,128	258,388	773,358	8,084,261

Source: NMFS, 2002d.

The trip frequency model is utilized to account for anglers increasing the number of trips they take in response to an improvement in fishing conditions. The increased estimates are shown in Table C4-9 and are estimated for eliminating I&E and reduced losses under the final section 316(b) rule.

Table C4-9: Increased Recreational Fishing Participation

Number of Fishing Days in 2001 Reported by NMFS	Predicted Percent Change in Annual Fishing Trips		Increased Recreational Fishing Participation	
	Baseline I&E	Reduced I&E	Baseline I&E	Reduced I&E
8,084,261	0.33%	0.10%	8,111,065	8,092,106

Sources: NMFS MRFSS Survey, 2003b; and U.S. EPA analysis for this report.

Table C4-10 summarizes the calculated total welfare gain to recreational anglers. These values were discounted to reflect the fact that fish must grow to a certain size before they will be caught by recreational anglers. EPA calculated discount factors separately for impingement and entrainment of each species. To estimate discounted total benefits, EPA calculated weighted averages of these discount factors, and applied them to estimated willingness-to-pay values. Discount factors were calculated for both a three percent discount rate and a seven percent discount rate. For the final section 316(b) rule, an additional discount factor was applied to account for the one-year lag between the date when installation costs are incurred and the installation of the required cooling water technology is completed.

Table C4-10: Estimated Total Welfare Gain to Recreational Anglers From Eliminating and Reducing I&E in the North Atlantic Region (2002$)

Species Group	Eliminating Recreational Fishery Losses From I&E			Reduced Losses Under the Final Section 316(b) Rule		
	Undiscounted	3% Discount Factor	7% Discount Factor	Undiscounted	3% Discount Factor	7% Discount Factor
Small Game	$13,223	$11,901	$10,447	$508	$444	$375
Bottom Fish	$1,563,511	$1,454,066	$1,328,985	$450,570	$406,824	$357,930
Flatfish	$3,534,229	$3,110,122	$2,686,014	$1,033,625	$883,094	$734,164
Big Game	N/A	N/A	N/A	N/A	N/A	N/A
No Target	$326,842	$297,426	$264,742	$101,728	$89,876	$77,009
All Species	$5,437,805	$4,873,515	$4,290,188	$1,586,431	$1,380,238	$1,169,478

Source: U.S. EPA analysis for this report.

The total value of recreational losses for all species impinged and entrained at the cooling water intake structures in the North Atlantic is $5.44 million per year (2002$), for all anglers, before discounting. The discounted recreational losses are $4.87 million and $4.29 million (2002$) per year, discounted at three and seven percent, respectively.

Total recreational losses based on reduced I&E from cooling water intake structures were also estimated. Multiplying the per-day welfare changes from reduced I&E under the final section 316(b) rule by the total number of fishing trips in 2001 yielded an undiscounted value of $1.59 million. Discounting the welfare gain by three and seven percent results in total welfare gains of $1.38 million and $1.17 million, respectively. For the final section 316(b) rule, an additional discount factor was applied to account for the one-year lag between the date when installation costs are incurred and installation of the required cooling water technology.

C4-5 LIMITATIONS AND UNCERTAINTIES

C4-5.1 Considering Only Recreational Values

This study understates the total benefits of improvements in fishing site quality because estimates are limited to recreation benefits. Many other forms of benefits, such as habitat values for a variety of species (in addition to recreational fish), non-use values, etc., are also likely to be important.

C4-5.2 Extrapolating Single-Day Trip Results to Estimate Benefits from Multiple-Day Trips

Use of per-day welfare gain estimated for single-day trips to estimate per-day welfare gain associated with multiple-day trips can either understate or overstate benefits to anglers taking multiple-day trips. Inclusion of multi-day trips in the model of recreational anglers' behavior can be problematic because multi-day trips are frequently multi-activity trips. An individual might travel a substantial distance and participate in several recreational activities such as shopping and sightseeing, all as part of one trip. Recreational benefits from improved recreational opportunities for the primary activity are overstated if all travel costs are treated as though they apply to the one recreational activity of interest. EPA therefore limited the recreational behavior model to single-day trips only and then extrapolated single-day trip results to estimate benefits to anglers taking multiple-day trips.

There is evidence that multi-day trips are more valuable than single-day trips. McConnell and Strand (1994) estimated a RUM using the NMFS data for New England and the Mid-Atlantic. Their study was intended to supplement the RUM study of single-day trips for the same region conducted by Hicks et al. (1999). The reported values for a catch rate increase of one fish are consistently higher for overnight trips than for single-day trips. Lupi and Hoehn (1998) compared values for single- and multi-day fishing trips. Their comparison is based on a RUM for the Great Lakes, with single- and multiple-day trips treated as distinct alternatives in the choice set, with separate parameters for different length trips. They found that multiple-day trips are less responsive to changes in travel cost, and thus relatively more valuable than single-day trips. Their case study results found that "over half the value of an across the board marginal change in catch rates was due to multiple-day trips even though multiple-day trips represent less than one fourth of the trips in the sample" (p. 45).

C4-5.3 Potential Sources of Survey Bias

The survey results could suffer from bias, such as recall bias and sampling effects.

a. Recall bias

Recall bias can occur when respondents are asked, such as in the MRFSS, the number of their recreation days over the previous season. Some researchers believe that recall bias tends to lead to an overstatement of the number of recreation days, particularly by more avid participants. Avid participants tend to overstate the number of recreation days because they count days in a "typical" week and then multiply them by the number of weeks in the recreation season. They often neglect to consider days missed due to bad weather, illness, travel, or when fulfilling "atypical" obligations. Some studies also found that the more salient the activity, the more "optimistic" the respondent tends to be in estimating the number of recreation days. Individuals also have a tendency to overstate the number of days they participate in activities that they enjoy and value. Taken together, these sources of recall bias may result in an overstatement of the actual number of recreation days.

b. Sampling effects

Recreational demand studies frequently face observations that do not fit general recreation patterns, such as observations of avid participants. These participants can be problematic because they claim to participate in an activity an inordinate number of times. This reported level of activity is sometimes correct but often overstated, perhaps due to recall bias. Even where the reports are correct, these observations tend to be overly influential (Thomson, 1991).

Chapter C5: Non-Use Benefits

INTRODUCTION

CHAPTER CONTENTS

Aquatic species without any direct uses account for the majority of losses due to impingement and entrainment (I&E) at cooling water intake structures (CWIS). However, EPA's analysis of direct use benefits includes values only for organisms with direct uses, which comprise a very small percentage of total losses (approximately two percent). Because the other 98 percent of losses, consisting of organisms without direct uses, are not without value, the potential exists for significant non-use values that have not been addressed under EPA's estimation of use benefits. For this reason it is important to consider non-use benefits to the human population, produced by the increased numbers of organisms without direct use values, under the final section 316(b) rule.

One way to consider the impact of the section 316(b) rule is to estimate the non-use value of baseline I&E losses and I&E reductions due to the final rule for each case study region using the non-use meta-analysis results. The non-use meta-analysis is presented in detail in Chapter A12, Non-Use Meta-Analysis Methodology, which includes discussions of the literature review process, the estimated regression models and results, and the general methodology used to estimate household and aggregate non-use benefits based on regression results. Total regional non-use benefits can be estimated using the following three steps:

1. Estimate annual changes in non-use value of the affected fishery resources per household due to the baseline impingement and entrainment (I&E) losses and the post-compliance reduction in impingement and entrainment;

2. Estimate the population of households in the North Atlantic region holding non-use value for the affected resources; and

3. Estimate the total non-use value to the affected North Atlantic populations for completely eliminating baseline I&E losses, and for reducing I&E losses from the baseline to post-compliance levels.

EPA explored this approach for the North Atlantic region. However, EPA did not include the results of this approach in the benefit analysis because of limitations and uncertainties associated with estimation of non-use benefits on a regional scale. For further discussion of the limitations and uncertainties of this method, refer to Chapter A12.

C5-1 QUALITATIVE ASSESSMENT OF ECOLOGICAL BENEFITS FOR THE NORTH ATLANTIC REGION

Changes in CWIS design or operations resulting from the section 316(b) regulations for existing facilities are expected to reduce I&E losses of fish, shellfish, and other aquatic organisms and, as a result, are expected to increase the numbers of individuals present, increase local and regional fishery populations, and ultimately contribute to the enhanced environmental functioning of affected waterbodies (rivers, lakes, estuaries, and oceans) and associated ecosystems. The economic welfare of human populations is expected to increase as a consequence of the improvements in fisheries and associated aquatic ecosystem functioning.

The aquatic resources affected by cooling water intake structures provide a wide range of services. Ecosystem services are the physical, chemical, and biological functions performed by natural resources and the human benefits derived from those functions, including both ecological and human use services (Daily, 1997; Daily et al., 1997). Scientific and public interest in protecting ecosystem services is increasing with the recognition that these services are vulnerable to a wide range of human activities and are difficult, if not impossible, to replace with human technologies (Meffe, 1992).

In addition to their importance in providing food and other goods of direct use to humans, the organisms lost to I&E are critical to the continued functioning of the ecosystems of which they are a part. Fish are essential for energy transfer in aquatic food webs, regulation of food web structure, nutrient cycling, maintenance of sediment processes, redistribution of bottom substrates, the regulation of carbon fluxes from water to the atmosphere, and the maintenance of aquatic biodiversity (Peterson and Lubchenco, 1997; Postel and Carpenter, 1997; Holmund and Hammer, 1999; Wilson and Carpenter, 1999). Examples of ecological and public services disrupted by I&E include:

- decreased numbers of ecological keystone, rare, or sensitive species;
- decreased numbers of popular species that are not fished, perhaps because the fishery is closed;
- decreased numbers of special status (e.g., threatened or endangered) species;
- increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E;
- disruption of ecological niches and ecological strategies used by aquatic species;
- disruption of organic carbon and nutrient transfer through the food web;
- disruption of energy transfer through the food web;
- decreased local biodiversity;
- disruption of predator-prey relationships;
- disruption of age class structures of species;
- disruption of natural succession processes;
- disruption of public uses other than fishing, such as diving, boating, and nature viewing; and
- disruption of public satisfaction with a healthy ecosystem.

Many of these services can only be maintained by the continued presence of all life stages of fish and other aquatic species in their natural habitats.

The traditional approach of EPA and other natural resource agencies to quantifying the environmental benefits of proposed regulations has focused on active use values, particularly direct use values such as recreational or commercial fishing. Nonconsumptive uses (such as the importance of fish for aquatic food webs), and passive use or non-use values (including the value of protecting a resource for its own sake), are seldom considered because they are difficult to monetize with available economic methods. However, even though economists debate methods for indirect and non-use valuation, there is general agreement that these values exist and can be important. The potential magnitude of non-use values remains an empirical matter. EPA believes that non-use values are applicable for the section 316(b)-related I&E and that these values are likely to be appreciable for the North Atlantic region.

Chapter C6: Habitat Based Analysis

INTRODUCTION

Aquatic species without primary or direct uses account for the majority of losses at cooling water intake structures (CWIS). These species are not, however, without value to society. It is important to consider the non-use benefits to the human population produced by the increased number of these fish under the final section 316(b) rulemaking.

An alternative way to consider impingement and entrainment (I&E) losses is to value the habitat necessary to replace the lost organisms. The value of fish habitat can provide an indirect basis for valuing the fish that are supported by the habitat. Existing wetland valuation studies found that members of the general public are aware of the fish production services provided by eelgrass (submerged aquatic vegetation, SAV) and wetlands, and that they express support for steps that include increasing SAV and wetland areas to restore reduced fish and shellfish populations (Opaluch et al., 1995, 1998; Mazzotta, 1996).

CHAPTER CONTENTS

EPA explored this approach for the North Atlantic region. However, EPA did not include the results of this approach in the benefit analysis because of certain limitations and uncertainties regarding the application of this methodology to the national level. These limitations and uncertainties are discussed in Chapter A15. Thus, this chapter outlines the approach explored by EPA, but does not present benefit estimates.

The approach discussed here uses values that survey respondents indicated for preservation/restoration of eelgrass (SAV), and wetlands to evaluate I&E non-use losses. This analysis is not intended to value directly benefits provided by the lost fish and shellfish, but to provide another perspective on the I&E losses by looking at values of habitat necessary to replace them. The method first estimates the quantity of wetland and eelgrass habitat required to replace fish and shellfish lost to I&E, and then assesses respondents' values for these habitats. These data would then be combined to yield an estimate of household values for improvements in fish and shellfish habitat, which provides an indirect estimate of the benefits of reducing or eliminating I&E. However, EPA does not present benefit estimates.

This benefit transfer approach involves four general steps, which are described in detail in Chapter A15:

1. Estimate the amount of restored wetlands and/or eelgrass needed to produce organisms at a level necessary to offset I&E losses for the subset of species for which potential production information is available.
2. Develop willingness-to-pay (WTP) values for fish production services of wetlands and eelgrass ecosystems.
3. Estimate the total value of baseline I&E losses by multiplying the WTP values for fish and shellfish services of restored wetlands and eelgrass by the number of acres of each needed to offset I&E losses.
4. Estimate the total benefits of the final section 316(b) rule, in terms of the value of decreased I&E losses, by multiplying the WTP values for fish and shellfish services of restored habitat by the number of acres of each habitat type needed to offset decreased I&E losses.

The rest of this chapter describes EPA's exploratory application of this method to the North Atlantic region.

C6-1 DATA SUMMARY

For each habitat type, EPA used available fish sampling data for the habitats of interest to determine the number of acres required to offset I&E losses. To estimate public WTP, EPA used information from two studies of public values for wetlands and eelgrass: a study of the Peconic Estuary, located on the East End of Long Island, New York (Johnston et al., 2001a, 2001b; Opaluch et al., 1995, 1998; Mazzotta, 1996); and a stated preference study from Narragansett Bay, Rhode Island (Johnston et al., 2002). These studies are described in detail in Chapter A15.

EPA based the benefit transfer of both total and non-use values for fish habitat provided by eelgrass and wetlands on the Peconic Estuary study.[1] The valuation of fish habitat services provided by wetlands was based on the Johnston et al. (2002) study.

C6-2 BENEFIT TRANSFER FOR THE NORTH ATLANTIC REGION

C6-2.1 Estimating the Amount of Wetlands and Eelgrass (SAV) Needed to Offset Losses for Specific Species

The first step in the analysis involves calculating the area of habitat needed to offset I&E losses for the subset of species for which restoration of these habitats was identified by local experts as the preferred restoration alternative, and for which production information is available (i.e., the habitat that will produce the equivalent quantity of fish impinged and entrained at CWIS). Habitats that support fish and shellfish include seagrasses, tidal wetlands, coral reefs, and estuarine soft-bottom sediments. The analysis may also consider man-made habitat enhancements, such as artificial reefs or fish passageways. The most suitable habitat restoration option was selected for each affected species.

Table C6-1 presents the fish species impinged and entrained in the North Atlantic region, along with an indication of whether SAV, tidal wetland, or some other habitat restoration action was identified as the preferred method for offsetting I&E losses by the expert panel. Of the 18 fish species lost to I&E in the region, experts determined that losses of 3 species would be best offset by tidal wetland restoration, and losses of a further 3 species would be best offset by SAV restoration.

Table C6-2 presents estimated age 1 equivalent densities in wetland or SAV habitat for the six fish species for which restoration of these habitats was identified as the preferred alternative for offsetting I&E losses.[2] These estimates are derived from abundance data for these species in wetland and SAV habitats. Abundance data were used because estimates of production rates in these habitats were not available for the species of interest. Individuals were counted within subsampling areas of the habitats (e.g., 100 square meters), and the resulting counts were scaled up to derive per acre density estimates by species.

Using a typical restoration scaling rule, the estimates of the acres of required SAV and wetlands restoration reflect the acreage needed for the species requiring the maximum quantity of habitat restoration to offset its I&E losses. For the Brayton Point case study, the amount of tidal wetland restoration is based on the number of acres needed to offset losses to winter flounder. The amount of SAV restoration is based on the acreage needed for scup.

For any given species, the number of acres of restored habitat needed to offset I&E losses is determined by dividing the species average annual age 1 equivalent I&E loss by its estimated abundance per acre in that habitat.

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[1] Conducted in 1995, the Peconic study provides information for the Peconic Estuary Program's Comprehensive Conservation and Management Plan (Peconic Estuary Program, 2001).

[2] Specific data sources for these estimates and details of data analyses are provided in Chapters F5 and G5 of the section 316(b) Phase II Case Study Document.

Table C6-1: Average Annual Age 1 Equivalent I&E Losses and Preferred Habitat Restoration Alternative (SAV or Tidal Wetland) for I&E Species Lost in the North Atlantic Region

I&E Species	Preferred Habitat Restoration Alternative
Winter flounder	tidal wetland
Atlantic silverside	tidal wetland
Striped killifish	tidal wetland
Threespine stickleback	SAV
Weakfish	SAV
Scup	SAV
Seaboard goby	other
Bay anchovy	other
American sand lance	other
Hogchoker	other
Rainbow smelt	other
Alewife	other
Tautog	other
Silver hake	other
Atlantic menhaden	other
Windowpane	other
White perch	other
Butterfish	other

Table C6-2: Estimated Age 1 Equivalent Densities in Tidal Wetland and SAV for I&E Species

Species	Tidal Wetland Age 1 Equivalent Density, Fish/Acre[a,b,c]	SAV Age 1 Equivalent Density, Fish/Acre[a,b,d]	
		Low Sampling Gear Efficiency	High Sampling Gear Efficiency
Winter flounder	205	n/a	
Atlantic silverside	202		
Striped killifish	721		
Threespine stickleback	n/a	3,031	699
Weakfish		no abundance data	
Scup		21	5

[a] Differences in the abundance estimates for a specific species between Brayton Point and Pilgrim reflect incorporation of differences in site-specific life history.

[b] Abundance estimates per unit of habitat are rounded to the nearest fish.

[c] A single abundance estimate is calculated from the incorporation of a point estimate of gear sampling efficiency.

[d] The range of abundance estimates reflects incorporation of alternative estimates of sampling gear efficiency.

C6-2.2 Developing WTP Values for Fish Production Services Provided by Submerged Aquatic Vegetation and Wetlands

EPA based the benefit transfer of both total and non-use values for fish habitat provided by eelgrass and wetlands on the Peconic Estuary study, described in Chapter A15.

C6-2.2.1 Wetland values for fish habitat services

a. Methodology for estimating the proportion of wetland value attributable to fish habitat

Because coastal wetlands provide a number of services (e.g., habitat, water purification, storm buffering, and aesthetics), EPA attempted to separate values for fish habitat from values for other wetland services. Given survey data available from the Peconic study, however, there is no direct means to estimate the proportion of total wetland value associated with fish habitat services alone. EPA therefore used the stated preference study from Narragansett Bay, Rhode Island, described in Chapter A15, to adjust wetland values to reflect fish habitat services (Johnston et al., 2002). The calculation of adjustment factors is also described in Chapter A15.

b. Applicability of the Narragansett Bay study's value proportions to the Peconic study's total wetland values

As noted above, no direct means is available for assessing the exact proportion of Peconic wetland values associated with fish habitat services. However, the Johnston et al. (2002) value proportions provide a reasonable, average approximation, based on a random-sample survey of Rhode Island residents. As with any type of benefit transfer, the applicability of the Johnston et al. (2002) value proportions to the Peconic wetland values depends on certain assumptions. The primary assumptions concern the approximate constancy of value *proportions* with respect to changes in policy scale.

Unlike the Peconic survey, which addressed total and marginal wetland values over large, long-term changes in wetland acreage (i.e., up to 4,000 acres over the entire Peconic region), the Rhode Island study estimates restoration values over the scale of a single salt water wetland (i.e., between 3 and 12 acres). Although this difference in scale is likely to influence the marginal WTP for wetland preservation or restoration, EPA does not expect the difference in scale to significantly influence the proportion of marginal WTP associated with fish habitat services. That is, the Agency assumed that if fish habitat services each account for approximately 25 percent of the total value for the tenth acre of restoration in a region, then each service will also account for approximately 25 percent of value for the hundredth or thousandth acre in the same region, even though the total value of each acre, on the margin, may change. That is, the assumption of fixed value proportions associated with fish habitat services concerns only the *relative* proportion of value associated with fish habitat, which may remain constant even as the absolute marginal value of a wetland acre diminishes with scale.[3]

A second key assumption of this analysis is that residents of the Peconic region and residents of Rhode Island maintain similar relative values with respect to the services provided by salt water wetlands. Although this presumption cannot be proven using results from Johnston et al. (2002) or Opaluch et al. (1995, 1998), and while value proportions may differ to a small degree, there is no overriding reason to suspect (and the literature results do not suggest) that relative value proportions would differ to a significant degree across the two sites.

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[3] Technical note regarding the robustness of value proportions: Following standard practice (e.g., Adamowicz et al., 1998), the survey's underlying model results are based on an orthogonal array of attribute levels. No imposed functional linkage exists between wetland size and habitat services. This independence is preserved by the linear form of the utility function. The model therefore allows one to vary wetland size and habitat services independently when estimating public values, even if such independence is highly unlikely in real situations. This specification allows the researcher a large degree of leeway when specifying "reasonable" restoration scenarios. It also allows the valuation of clearly unrealistic scenarios in which, for example, the restoration of huge wetlands provides negligible habitat gains. In such unrealistic scenarios, it is possible to illustrate cases in which proportions of value diminish to a significant degree as wetland size increases. However, if one specifies more realistic scenarios in which increases in restored wetland acreage and resulting increases in habitat services change (approximately) proportionately, then the proportion of wetland values associated with fish habitat is robust. That is, assuming that the marginal gain in habitat (fish, shellfish, etc.) provided by the tenth acre of restoration is equivalent to the gain provided by the hundredth acre, the proportion of value associated with fish will remain constant as one increases the scale of restoration.

Finally, while the Johnston et al. study enumerates a number of wetland functions, the Peconic study does not enumerate specific wetlands functions, but assumes that respondents are valuing all functions of wetlands, as they perceive and understand them. Based on the similarities, including vegetation, wetland size, water body characteristics, and population characteristics, between the Peconic Estuary and Narragansett Bay, it is reasonable to assume that services of wetlands are similar in the two regions, and that people will have similar values and rankings for such services.

C6-2.2.2 Values per acre of SAV and wetlands for the Peconic Estuary

a. Wetlands values for fish habitat services in the Peconic Estuary

EPA first multiplied the value per household by the proportion of wetlands value attributed to fish habitat, to get the value per acre per household for fish habitat services of wetlands. The Agency then multiplied this value per acre by the total number of households in the Peconic study area (73,423), yielding the value per acre of wetlands for the population surrounding the Peconic Estuary. Table C6-3 shows these values.

The Peconic study defined the affected population as the total number of households (both year-round and seasonal) in the five towns bordering the Peconic Estuary. As noted above, this definition of the study area results in conservative total values because it does not include the values for people who live on Long Island beyond these five towns, the values for visitors to the area, or anyone else. For example, past visitors to Long Island and residents of New York or elsewhere who've never even been to Long Island might all hold some value for preserving its resources. For the Peconic Estuary region, the total annual value per acre for fish habitat services of wetlands is $1,053, whereas the total non-use value only is $1,009.[4]

Table C6-3: Estimated WTP Values for Fish Habitat Services Provided by Wetlands from the Peconic Study (2002$)

	$/HH/Acre/Year[a]	Total WTP/Acre/Year[b]
Total Value	$0.014	$1,053
Non-Use Value[c]	$0.014	$1,009

[a] Values shown are WTP per household per *additional* (i.e, marginal) acre per year.
[b] Total WTP per acre is calculated as household WTP per acre times 73,423 total households in the study area.
[c] Total non-use value is calculated as value per acre for non-users only times all households in the region.

b. Eelgrass values for fish habitat services in the Peconic Estuary

Multiplying the value per household by the total number of households in the Peconic study area (73,423) yields the value per acre of eelgrass for the population surrounding the Peconic Estuary. Table C6-4 shows these values. The study defined the benefit population as the total number of households (both year-round and seasonal) in the five towns bordering the Peconic Estuary. For the Peconic Estuary region, the total annual value per acre for eelgrass is $4,656; and the total non-use only value is $3,837.[5]

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[4] This analysis assumes that non-use values are the same for both users and non-users of the affected resources. Some studies found that users of the resource have higher non-use values than non-users. This may result from additional information about water resources associated with past or expected future use, which is likely to enhance non-use values (Whitehead and Blomquist, 1991b). The data, however, do not allow us to evaluate non-use values specific to users.

[5] This analysis assumes that non-use values are the same for both users and non-users of the affected resources. Users of the resource likely have higher non-use values than non-users, but the data do not allow us to test this hypothesis.

Table C6-4: Estimated WTP Values for Eelgrass (SAV) from the Peconic Study (2002$)[6]

	$/HH/Acre/Year[a]	Total WTP/Acre/Year[b]
Total Value	$0.063	$4,656
Non-Use Value[c]	$0.052	$3,837

[a] Values shown are WTP per household per *additional* (i.e, marginal) acre per year.
[b] Total WTP per acre is calculated as household WTP per acre times 73,423 total households in the study area.
[c] Total non-use value is calculated as value per acre for non-users only times all households in the study area.

C6-2.3 Applicability of Study Area to Policy Area

In the Peconic study, corrections were made to WTP values to account for differences in demographics between survey respondents and the general population of the East End of Long Island. EPA compared demographics of the affected population for one North Atlantic facility — the Brayton Point Station — to demographics of the East End of Long Island. Households in the Brayton Point region (Bristol County, MA; Newport County, RI; and Bristol County, RI) are quite similar to those of the general population of the East End. Table C6-5 compares survey respondent demographics to residents of the East End and residents of the Brayton Point region, based on education and income categories used to estimate WTP. The Brayton Point region has slightly lower education levels, and slightly higher income levels, on average, than the Peconic region. While values presented in the analysis were adjusted to the Peconic levels, they could be easily re-adjusted to reflect New England levels. However, based on the small differences in demographics between the regions, the effect is likely to be negligible.

Table C6-5: Comparison of Demographics

	Ed. 1-3[a]	Ed. 4[a]	Ed 5-7[a]	Inc. 1-2[b]	Inc. 3,4[b]	Inc. 5-7[b]	Inc. 8[b]
Brayton Region	52.75%	16.63%	30.62%	28.62%	26.18%	41.47%	3.72%
Peconic	50.76%	18.35%	30.9%	33.77%	33.77%	30.86%	3.41%
Survey	16.86%	21.26%	61.88%	17.05%	17.05%	46.4%	5.61%

[a] Ed. 1-3 = high school graduate or less; Ed. 4 = some college; Ed. 5-7 = associate’s, bachelor’s or advanced degree.
[b] Inc. 1-2 = $24,999 or less; Inc. 3-4 = $25,000-$49,999; Inc. 5-7 = $50,000-$149,999; Inc. 8 - $150,000 and over.

C6-2.4 Determining the Affected Population

Evaluating the total value per acre of wetlands and SAV for the coastal population of the region requires a definition of the geographical extent of the affected population. The Peconic study defined the affected population as the total number of households in the towns bordering the Peconic Estuary. Similarly, as described in Chapter A15, EPA defines the affected population as households residing in the counties that abut affected water bodies. These households are likely to value gains of fish in the affected water body, due to their close proximity to the affected resource. As discussed further in Chapter A15, households in counties that do not directly abut the affected water body will also likely value the water body’s resources.

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[6] EPA made dollar value adjustments using the Consumer Price Index (CPI) for all urban consumers for the first half of 2003 (U.S. Bureau of Labor Statistics, 2003).

C6-2.5 Habitat Values per Acre for the Affected Population

The total value per acre for the affected population is calculated by multiplying the value per acre per household by the total number of affected households.

C6-2.6 Estimating the Value of Habitat Needed to Offset I&E Losses for the Region

Due to limitations and uncertainties that make this valuation approach difficult to implement on a regional scale, EPA does not present aggregate values for I&E losses. These values would be calculated by multiplying the total number of acres of each habitat required to offset losses by the value per acre for the affected population.

C6-3 LIMITATIONS AND UNCERTAINTY

A number of issues are common to all benefit transfers. Benefit transfer involves adapting research conducted for another purpose in the available literature to address the policy questions at hand. Because benefits analysis of environmental regulations rarely affords enough time to develop original stated preference surveys that are specific to the policy effects, benefit transfer is often the only option to inform a policy decision. Specific issues associated with this approach are discussed in Chapter A15.

Appendix C1: Life History Parameter Values Used to Evaluate I&E in the North Atlantic Region

The tables in this appendix present the life history parameter values used by EPA to calculate age 1 equivalents, fishery yields, and production foregone from I&E data for the North Atlantic Region. Because of differences in the number of life stages represented in the loss data, there are cases where more than one life stage sequence was needed for a given species or species group. Alternative parameter sets were developed for this purpose and are indicated with a number following the species or species group name (i.e., Winter flounder 1, Winter flounder 2).

Table C1-1: Alewife Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.544	0	0	0.00000128
Larvae	5.50	0	0	0.00000141
Juvenile	2.57	0	0	0.00478
Age 1+	1.04	0	0	0.0443
Age 2+	1.04	0	0	0.139
Age 3+	1.04	0	0	0.264
Age 4+	1.04	0	0	0.386
Age 5+	1.04	0	0	0.489
Age 6+	1.04	0	0	0.568
Age 7+	1.04	0	0	0.626
Age 8+	1.04	0	0	0.667
Age 9+	1.04	0	0	0.696

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table C1-2: American Plaice Life History Parameters				
Stage Name	**Natural Mortality (per stage)**	**Fishing Mortality (per stage)**	**Fraction Vulnerable to Fishery**	**Weight (lbs)**
Eggs	2.30	0	0	0.0000115
Larvae	8.22	0	0	0.0000126
Juvenile	0.916	0	0	0.000110
Age 1+	0.200	0	0	0.00903
Age 2+	0.200	0.32	0.50	0.0871
Age 3+	0.200	0.32	1.0	0.190
Age 4+	0.200	0.32	1.0	0.328
Age 5+	0.200	0.32	1.0	0.494
Age 6+	0.200	0.32	1.0	0.711
Age 7+	0.200	0.32	1.0	0.986
Age 8+	0.200	0.32	1.0	1.24
Age 9+	0.200	0.32	1.0	1.53
Age 10+	0.200	0.32	1.0	1.86
Age 11+	0.200	0.32	1.0	2.24
Age 12+	0.200	0.32	1.0	2.68
Age 13+	0.200	0.32	1.0	3.17
Age 14+	0.200	0.32	1.0	3.52
Age 15+	0.200	0.32	1.0	3.91
Age 16+	0.200	0.32	1.0	4.32
Age 17+	0.200	0.32	1.0	4.77
Age 18+	0.200	0.32	1.0	5.24
Age 19+	0.200	0.32	1.0	5.75
Age 20+	0.200	0.32	1.0	6.28
Age 21+	0.200	0.32	1.0	6.86
Age 22+	0.200	0.32	1.0	7.46
Age 23+	0.200	0.32	1.0	8.11
Age 24+	0.200	0.32	1.0	8.44
Age 25+	0.200	0.32	1.0	8.55

Sources: Froese and Pauly, 2001; Schultz, 2000; NOAA, 1993; O'Brien, 2000; Scott and Scott, 1988; and Stone & Webster Engineering Corporation, 1977.

Table C1-3: American Sand Lance Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.41	0	0	0.00000126
Larvae	2.97	0	0	0.00000139
Juvenile	2.90	0	0	0.00119
Age 1+	1.89	0	0	0.00384
Age 2+	0.364	0	0	0.00730
Age 3+	0.364	0	0	0.0113
Age 4+	0.364	0	0	0.0153
Age 5+	0.364	0	0	0.0191
Age 6+	0.364	0	0	0.0225
Age 7+	0.720	0	0	0.0255
Age 8+	0.720	0	0	0.0280
Age 9+	0.720	0	0	0.0301
Age 10+	0.720	0	0	0.0319
Age 11+	0.720	0	0	0.0333

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table C1-4: American Shad Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.496	0	0	0.000000716
Yolksac larvae	0.496	0	0	0.000000728
Post-yolksac larvae	2.52	0	0	0.00000335
Juvenile	7.40	0	0	0.000746
Age 1+	0.300	0	0	0.309
Age 2+	0.300	0	0	1.17
Age 3+	0.300	0	0	2.32
Age 4+	0.540	0.21	0.45	3.51
Age 5+	1.02	0.21	0.90	4.56
Age 6+	1.50	0.21	1.0	5.47
Age 7+	1.50	0.21	1.0	6.20
Age 8+	1.50	0.21	1.0	6.77

Sources: Able and Fahay, 1998; Froese and Pauly, 2001; PSE&G, 1999; and U.S. Fish and Wildlife Services, 1978.

Table C1-5: Atlantic Cod Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	4.87	0	0	0.00000567
Larvae	5.83	0	0	0.00000624
Juvenile	0.916	0	0	0.000337
Age 1+	0.400	0	0	0.0225
Age 2+	0.200	0.29	0.50	0.245
Age 3+	0.200	0.29	1.0	0.628
Age 4+	0.200	0.29	1.0	1.29
Age 5+	0.200	0.29	1.0	2.45
Age 6+	0.200	0.29	1.0	3.33

Sources: Entergy Nuclear Generation Company, 2000; Froese and Pauly, 2001, 2003; Mayo and O'Brien, 2000; NOAA, 2001c; and Scott and Scott, 1988.

Table C1-6: Atlantic Herring Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	3.36	0	0	0.00000473
Larvae	3.26	0	0	0.00000531
Juvenile	3.26	0	0	0.00126
Age 1+	0.200	0.28	0.50	0.0314
Age 2+	0.200	0.28	1.0	0.173
Age 3+	0.200	0.28	1.0	0.302
Age 4+	0.200	0.28	1.0	0.420
Age 5+	0.200	0.28	1.0	0.463
Age 6+	0.200	0.28	1.0	0.525
Age 7+	0.200	0.28	1.0	0.588
Age 8+	0.200	0.28	1.0	0.642
Age 9+	0.200	0.28	1.0	0.699
Age 10+	0.200	0.28	1.0	0.732
Age 11+	0.200	0.28	1.0	0.766
Age 12+	0.200	0.28	1.0	0.848
Age 13+	0.200	0.28	1.0	0.855
Age 14+	0.200	0.28	1.0	0.862
Age 15+	0.200	0.28	1.0	0.869
Age 16+	0.200	0.28	1.0	0.877

[a] Includes Atlantic herring, hickory shad, round herring, and other herring not identified to species.

Sources: Able and Fahay, 1998; ASMFC, 2001a; Entergy Nuclear Generation Company, 2000; Froese and Pauly, 2001; NOAA, 2001c; Overholtz, 2002a; and Scott and Scott, 1988.

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.39	0	0	0.00000176
Larvae	5.30	0	0	0.00000193
Juvenile	5.30	0	0	0.000833
Age 1+	0.520	0	0	0.309
Age 2+	0.370	0.25	0.50	0.510
Age 3+	0.370	0.25	1.0	0.639
Age 4+	0.370	0.25	1.0	0.752
Age 5+	0.370	0.25	1.0	0.825
Age 6+	0.370	0.25	1.0	0.918
Age 7+	0.370	0.25	1.0	1.02
Age 8+	0.370	0.25	1.0	1.10
Age 9+	0.370	0.25	1.0	1.13
Age 10+	0.370	0.25	1.0	1.15
Age 11+	0.370	0.25	1.0	1.22
Age 12+	0.370	0.25	1.0	1.22
Age 13+	0.370	0.25	1.0	1.22
Age 14+	0.370	0.25	1.0	1.22

Table C1-7: Atlantic Mackerel Life History Parameters

Sources: Entergy Nuclear Generation Company, 2000; Froese and Pauly, 2001, 2003; NOAA, 2001c; Overholtz et al., 1991; Overholtz 2002b; Scott and Scott, 1988; and Studholme et al., 1999.

Table C1-8: Atlantic Menhaden Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.20	0	0	0.00000482
Larvae	4.47	0	0	0.00000530
Juvenile	6.19	0	0	0.000684
Age 1+	0.540	0	0	0.0251
Age 2+	0.450	1.1	1.0	0.235
Age 3+	0.450	1.1	1.0	0.402
Age 4+	0.450	1.1	1.0	0.586
Age 5+	0.450	1.1	1.0	0.863
Age 6+	0.450	1.1	1.0	1.08
Age 7+	0.450	1.1	1.0	1.27
Age 8+	0.450	1.1	1.0	1.43

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table C1-9: Atlantic Silverside Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.41	0	0	0.00000473
Larvae	5.81	0	0	0.00000520
Juvenile 1	2.63	0	0	0.00490
Age 1+	3.00	0	0	0.0205
Age 2+	6.91	0	0	0.0349

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table C1-10: Atlantic Tomcod Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	8.46	0	0	0.00000126
Larvae	8.46	0	0	0.0000185
Juvenile	8.46	0	0	0.0145
Age 1+	8.46	0	0	0.0804
Age 2+	2.83	0	0	0.270
Age 3+	2.83	0	0	0.486

Sources: McLaren et al., 1988; NMFS, 2003a; Stewart and Auster, 1987; and Virginia Tech, 1998.

Table C1-11: Bay Anchovy Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.10	0	0	0.000000517
Larvae	7.19	0	0	0.000000569
Juvenile	2.09	0	0	0.00104
Age 1+	2.30	0	0	0.00370
Age 2+	2.30	0	0	0.00765
Age 3+	2.30	0	0	0.0126

[a] Includes bay anchovy, striped anchovy, and other anchovies not identified to species.

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table C1-12: Blueback Herring Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.558	0	0	0.00000115
Yolksac larvae	1.83	0	0	0.00321
Post-yolksac larvae	1.74	0	0	0.00640
Juvenile 1	3.13	0	0	0.00959
Juvenile 2	3.13	0	0	0.0128
Age 1+	0.300	0	0	0.0160
Age 2+	0.300	0	0	0.0905
Age 3+	0.300	0	0	0.204
Age 4+	0.900	0	0	0.318
Age 5+	1.50	0	0	0.414
Age 6+	1.50	0	0	0.488
Age 7+	1.50	0	0	0.540
Age 8+	1.50	0	0	0.576

Sources: PSE&G, 1999; and PG&E National Energy Group, 2001.

Table C1-13: Bluefish Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.35	0	0	0.0000123
Larvae	8.24	0	0	0.0000135
Juvenile	5.07	0.06	1.0	0.194
Age 1+	0.350	0.28	1.0	1.06
Age 2+	0.350	0.28	1.0	2.81
Age 3+	0.350	0.28	1.0	5.21
Age 4+	0.350	0.28	1.0	7.95
Age 5+	0.350	0.28	1.0	10.7
Age 6+	0.350	0.28	1.0	13.4
Age 7+	0.350	0.28	1.0	15.9
Age 8+	0.350	0.28	1.0	18.0
Age 9+	0.350	0.28	1.0	19.9
Age 10+	0.350	0.28	1.0	21.6
Age 11+	0.350	0.28	1.0	22.9
Age 12+	0.350	0.28	1.0	24.1
Age 13+	0.350	0.28	1.0	25.0
Age 14+	0.350	0.28	1.0	25.8

Sources: PG&E National Energy Group, 2001; and Wang, 1979.

Table C1-14: Butterfish Life History Parameters				
Stage Name	**Natural Mortality**	**Fishing Mortality**	**Fraction Vulnerable**	**Weight**
Eggs	2.30	0	0	0.000000396
Larvae	6.64	0	0	0.000000436
Juvenile	0.916	0	0	0.000251
Age 1+	0.800	0.28	0.50	0.0272
Age 2+	0.800	0.28	1.0	0.0986
Age 3+	0.800	0.28	1.0	0.944

Sources: Able and Fahay, 1998; Froese and Pauly, 2001; NOAA, 2001b; Scott and Scott, 1988; and Stone & Webster Engineering Corporation, 1977.

Table C1-15: Commercial Crab Life History Parameters[a]				
Stage Name	**Natural Mortality (per stage)**	**Fishing Mortality (per stage)**	**Fraction Vulnerable to Fishery**	**Weight (lbs)**
Megalops	1.30	0	0	0.00000291
Juvenile	1.73	0.48	0.50	0.00000293
Age 1+	1.10	0.48	1.0	0.00719
Age 2+	1.38	0.48	1.0	0.113
Age 3+	1.27	0.48	1.0	0.326

[a] Includes green crab, jonah crab, lady crab, lesser blue crab, narrow mud crab, and spider crab.

Sources: Hartman, 1993; and PSE&G, 1999.

Table C1-16: Cunner Life History Parameters				
Stage Name	**Natural Mortality (per stage)**	**Fishing Mortality (per stage)**	**Fraction Vulnerable to Fishery**	**Weight (lbs)**
Eggs	3.49	0	0	0.000000787
Larvae	2.90	0	0	0.00000236
Juvenile	2.90	0	0	0.0000814
Age 1+	0.831	0	0	0.00311
Age 2+	0.831	0.10	0.50	0.0246
Age 3+	0.286	0.10	1.0	0.0749
Age 4+	0.342	0.10	1.0	0.145
Age 5+	0.645	0.10	1.0	0.229
Age 6+	1.26	0.10	1.0	0.624

Sources: Able and Fahay, 1998; Entergy Nuclear Generation Company, 2000; Scott and Scott, 1988; and Serchuk and Cole, 1974.

Table C1-17: Fourbeard Rockling Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.000000637
Larvae	4.25	0	0	0.000000700
Juvenile	0.916	0	0	0.00187
Age 1+	0.490	0	0	0.0142
Age 2+	0.490	0	0	0.0209
Age 3+	0.490	0	0	0.0402
Age 4+	0.490	0	0	0.0617
Age 5+	0.490	0	0	0.0906
Age 6+	0.490	0	0	0.151
Age 7+	0.490	0	0	0.188
Age 8+	0.490	0	0	0.251
Age 9+	0.490	0	0	0.323

Sources: Deree, 1999; Froese and Pauly, 2001, 2003; and NMFS, 2003a.

Table C1-18: Grubby Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000473
Larvae	3.79	0	0	0.00000520
Juvenile	0.916	0	0	0.0000197
Age 1+	0.460	0	0	0.00633
Age 2+	0.460	0	0	0.0115
Age 3+	0.460	0	0	0.0190
Age 4+	0.460	0	0	0.0292
Age 5+	0.460	0	0	0.0424
Age 6+	0.460	0	0	0.0592
Age 7+	0.460	0	0	0.0799
Age 8+	0.460	0	0	0.105
Age 9+	0.460	0	0	0.135

Sources: Able and Fahay, 1998; Clayton et al., 1978; Froese and Pauly, 2001, 2003; NMFS, 2003a; and Scott and Scott, 1988.

Table C1-19: Hogchoker Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.000000487
Larvae	5.20	0	0	0.00110
Juvenile	2.31	0	0	0.00207
Age 1+	2.56	0	0	0.0113
Age 2+	0.705	0	0	0.0313
Age 3+	0.705	0	0	0.0610
Age 4+	0.705	0	0	0.0976
Age 5+	0.705	0	0	0.138
Age 6+	0.705	0	0	0.178

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table C1-20: Lumpfish Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000317
Larvae	8.48	0	0	0.0000169
Juvenile	0.916	0	0	0.00472
Age 1+	0.190	0.26	0.50	0.0138
Age 2+	0.190	0.26	1.0	0.0573
Age 3+	0.190	0.26	1.0	0.149
Age 4+	0.190	0.26	1.0	0.686
Age 5+	0.190	0.26	1.0	1.86

Sources: Able and Fahay, 1998; Bigelow and Schroeder, 1953; Froese and Pauly, 2001; NMFS, 2003a; and Scott and Scott, 1988.

Table C1-21: Northern Pipefish Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.000000773
Larvae	2.40	0	0	0.0000122
Juvenile	0.916	0	0	0.00785
Age 1+	0.750	0	0	0.0151
Age 2+	0.750	0	0	0.0180
Age 3+	0.750	0	0	0.0212
Age 4+	0.750	0	0	0.0247
Age 5+	0.750	0	0	0.0285

Sources: Able and Fahay, 1998; Froese and Pauly, 2001; NMFS, 2003a; and Scott and Scott, 1988.

Table C1-22: Pollock Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.922	0	0	0.00000154
Larvae	4.07	0	0	0.00000169
Juvenile	6.93	0	0	0.00166
Age 1+	0.200	0	0	0.657
Age 2+	0.200	0.20	0.50	1.30
Age 3+	0.200	0.20	1.0	1.73
Age 4+	0.200	0.20	1.0	3.24
Age 5+	0.200	0.20	1.0	4.93
Age 6+	0.200	0.20	1.0	5.70
Age 7+	0.200	0.20	1.0	6.83
Age 8+	0.200	0.20	1.0	8.46
Age 9+	0.200	0.20	1.0	9.93
Age 10+	0.200	0.20	1.0	12.0
Age 11+	0.200	0.20	1.0	14.8
Age 12+	0.200	0.20	1.0	16.4
Age 13+	0.200	0.20	1.0	18.1
Age 14+	0.200	0.20	1.0	19.9
Age 15+	0.200	0.20	1.0	21.2

Sources: Able and Fahay, 1998; Froese and Pauly, 2001; NOAA, 2001c; and Saila et al., 1997.

Table C1-23: Radiated Shanny Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000430
Larvae	2.20	0	0	0.00000473
Juvenile	0.916	0	0	0.0000559
Age 1+	0.440	0	0	0.000472
Age 2+	0.440	0	0	0.00163
Age 3+	0.440	0	0	0.00374
Age 4+	0.440	0	0	0.00719
Age 5+	0.440	0	0	0.00988
Age 6+	0.440	0	0	0.0132
Age 7+	0.440	0	0	0.0258
Age 8+	0.440	0	0	0.0448

Sources: Froese and Pauly, 2001; NMFS, 2003a; Pepin et al., 2002; and Scott and Scott, 1988.

Table C1-24: Rainbow Smelt Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	4.44	0	0	0.000000990
Larvae	3.12	0	0	0.00110
Juvenile	1.39	0	0	0.00395
Age 1+	1.00	0	0	0.0182
Age 2+	1.00	0	0	0.0460
Age 3+	1.00	0	0	0.0850
Age 4+	1.00	0	0	0.131
Age 5+	1.00	0	0	0.180
Age 6+	1.00	0	0	0.228

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table C1-25: Red Hake Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.22	0	0	0.000000487
Larvae 2mm	0.670	0	0	0.000000536
Larvae 2.5mm	0.670	0	0	0.000000589
Larvae 3.0mm	0.670	0	0	0.000000744
Larvae 3.5mm	0.670	0	0	0.00000118
Larvae 4.0mm	0.670	0	0	0.00000176
Larvae4.5mm	3.35	0	0	0.00000251
Juvenile	4.83	0	0	0.00345
Age 1+	0.400	0.39	0.50	0.231
Age 2+	0.400	0.39	1.0	0.805
Age 3+	0.400	0.39	1.0	0.991
Age 4+	0.400	0.39	1.0	1.22
Age 5+	0.400	0.39	1.0	1.55
Age 6+	0.400	0.39	1.0	1.93
Age 7+	0.400	0.39	1.0	2.36
Age 8+	0.400	0.39	1.0	2.86
Age 9+	0.400	0.39	1.0	3.42
Age 10+	0.400	0.39	1.0	3.66

[a] Includes red hake, spotted hake, and white hake.

Sources: Able & Fahay, 1998; Froese and Pauly, 2001; NOAA, 2001c; Saila et al., 1997; and Scott and Scott, 1988.

Table C1-26: Rock Gunnel Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000924
Larvae	1.66	0	0	0.0000102
Juvenile	0.916	0	0	0.000701
Age 1+	0.440	0	0	0.00382
Age 2+	0.440	0	0	0.0128
Age 3+	0.440	0	0	0.0223
Age 4+	0.440	0	0	0.0371
Age 5+	0.440	0	0	0.0490

Sources: Froese and Pauly, 2001; NMFS, 2003a; and Scott and Scott, 1988.

Table C1-27: Sculpin Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.0000107
Larvae	3.79	0	0	0.0000118
Juvenile	0.916	0	0	0.000754
Age 1+	0.460	0.50	0.50	0.00404
Age 2+	0.460	0.50	1.0	0.139
Age 3+	0.460	0.50	1.0	0.332
Age 4+	0.460	0.50	1.0	0.420
Age 5+	0.460	0.50	1.0	0.475
Age 6+	0.460	0.50	1.0	0.541
Age 7+	0.460	0.50	1.0	0.576
Age 8+	0.460	0.50	1.0	0.612
Age 9+	0.460	0.50	1.0	0.637

[a] Includes longhorn sculpin, moustache sculpin, shorthorn sculpin, and other sculpin not identified to species.

Sources: Clayton et al., 1978; Froese and Pauly, 2001; Scott and Scott, 1988; and personal communication with Y. DeReynier (NMFS, November 19, 2002).

Table C1-28: Scup Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.43	0	0	0.000000773
Larvae	4.55	0	0	0.00110
Juvenile	3.36	0	0	0.0280
Age 1+	0.383	0	0	0.132
Age 2+	0.383	0	0	0.322
Age 3+	0.383	0.26	1.0	0.572
Age 4+	0.383	0.26	1.0	0.845
Age 5+	0.383	0.26	1.0	1.12
Age 6+	0.383	0.26	1.0	1.37
Age 7+	0.383	0.26	1.0	1.59
Age 8+	0.383	0.26	1.0	1.78
Age 9+	0.383	0.26	1.0	1.94
Age 10+	0.383	0.26	1.0	2.07
Age 11+	0.383	0.26	1.0	2.23

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table C1-29: Seaboard Goby Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.288	0	0	0.0000164
Larvae	4.09	0	0	0.0000180
Juvenile	2.30	0	0	0.000485
Age 1+	2.55	0	0	0.00205

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table C1-30: Searobin Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000132
Larvae	3.66	0	0	0.00000145
Juvenile	0.916	0	0	0.000341
Age 1+	0.420	0.10	0.50	0.0602
Age 2+	0.420	0.10	1.0	0.176
Age 3+	0.420	0.10	1.0	0.267
Age 4+	0.420	0.10	1.0	0.386
Age 5+	0.420	0.10	1.0	0.537
Age 6+	0.420	0.10	1.0	0.721
Age 7+	0.420	0.10	1.0	0.944
Age 8+	0.420	0.10	1.0	1.21

[a] Includes northern searobin, striped searobin, and other searobin not identified to species.

Sources: Entergy Nuclear Generation Company, 2000; Froese and Pauly, 2001, 2003; and Virginia Tech, 1998.

Table C1-31: Silver Hake Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.43	0	0	0.0000203
Larvae	6.62	0	0	0.0000223
Juvenile	4.58	0	0	0.00516
Age 1+	0.400	0	0	0.0729
Age 2+	0.400	0	0	0.242
Age 3+	0.400	0.40	1.0	0.456
Age 4+	0.400	0.40	1.0	0.646
Age 5+	0.400	0.40	1.0	0.788
Age 6+	0.400	0.40	1.0	0.889
Age 7+	0.400	0.40	1.0	0.958
Age 8+	0.400	0.40	1.0	1.00
Age 9+	0.400	0.40	1.0	1.03
Age 10+	0.400	0.40	1.0	1.05
Age 11+	0.400	0.40	1.0	1.06
Age 12+	0.400	0.40	1.0	1.06

Source: PG&E National Energy Group, 2001.

Table C1-32: Skate Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	3.00	0	0	0.0125
Larvae	2.30	0	0	0.0138
Juvenile	0.916	0	0	0.0593
Age 1+	0.400	0.40	0.50	0.157
Age 2+	0.400	0.40	1.0	0.394
Age 3+	0.400	0.40	1.0	0.750
Age 4+	0.400	0.40	1.0	1.15
Age 5+	0.400	0.40	1.0	1.51
Age 6+	0.400	0.40	1.0	1.62
Age 7+	0.400	0.40	1.0	1.65
Age 8+	0.400	0.40	1.0	1.72

[a] Includes clearnose skate, little skate and other skates not identified to level.

Sources: Froese and Pauly, 2000; NOAA, 1993, 2001c; and Scott and Scott, 1988.

Table C1-33: Striped Bass Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.28	0	0	0.0000282
Larvae	6.28	0	0	0.0000310
Juvenile	5.63	0	0	0.0405
Age 1+	1.11	0	0	0.386
Age 2+	0.150	0.02	1.0	1.37
Age 3+	0.150	0.06	1.0	3.06
Age 4+	0.150	0.20	1.0	5.35
Age 5+	0.150	0.29	1.0	8.07
Age 6+	0.150	0.31	1.0	11.0
Age 7+	0.150	0.31	1.0	14.1
Age 8+	0.150	0.31	1.0	17.1
Age 9+	0.150	0.31	1.0	20.0
Age 10+	0.150	0.31	1.0	22.8
Age 11+	0.150	0.31	1.0	25.3
Age 12+	0.150	0.31	1.0	27.6
Age 13+	0.150	0.31	1.0	29.7
Age 14+	0.150	0.31	1.0	31.6
Age 15+	0.150	0.31	1.0	33.3
Age 16+	0.150	0.31	1.0	34.7
Age 17+	0.150	0.31	1.0	36.0
Age 18+	0.150	0.31	1.0	37.2
Age 19+	0.150	0.31	1.0	38.2
Age 20+	0.150	0.31	1.0	39.0
Age 21+	0.150	0.31	1.0	39.8
Age 22+	0.150	0.31	1.0	40.4
Age 23+	0.150	0.31	1.0	41.0
Age 24+	0.150	0.31	1.0	41.5

Source: PG&E National Energy Group, 2001.

Table C1-34: Striped Killifish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.0000180
Larvae	3.00	0	0	0.0000182
Juvenile	0.916	0	0	0.000157
Age 1+	0.777	0	0	0.0121
Age 2+	0.777	0	0	0.0327
Age 3+	0.777	0	0	0.0551
Age 4+	0.777	0	0	0.0778
Age 5+	0.777	0	0	0.0967
Age 6+	0.777	0	0	0.113
Age 7+	0.777	0	0	0.158

[a] Includes mummichog, striped killifish, and other killifish not identified to species.

Sources: Able and Fahay, 1998; Carlander, 1969; Meredith and Lotrich, 1979; and NMFS, 2003a.

Table C1-35: Tautog Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.40	0	0	0.00000123
Larvae	5.86	0	0	0.0221
Juvenile	5.02	0	0	0.0637
Age 1+	0.175	0	0	0.217
Age 2+	0.175	0	0	0.440
Age 3+	0.175	0	0	0.734
Age 4+	0.175	0	0	1.08
Age 5+	0.175	0	0	1.48
Age 6+	0.175	0	0	1.89
Age 7+	0.175	0	0	2.32
Age 8+	0.175	0	0	2.76
Age 9+	0.175	0.24	1.0	3.18
Age 10+	0.175	0.24	1.0	3.60
Age 11+	0.175	0.24	1.0	4.00
Age 12+	0.175	0.24	1.0	4.38
Age 13+	0.175	0.24	1.0	4.73
Age 14+	0.175	0.24	1.0	5.07
Age 15+	0.175	0.24	1.0	5.38
Age 16+	0.175	0.24	1.0	5.67
Age 17+	0.175	0.24	1.0	5.94
Age 18+	0.175	0.24	1.0	6.19
Age 19+	0.175	0.24	1.0	6.42
Age 20+	0.175	0.24	1.0	6.63
Age 21+	0.175	0.24	1.0	6.82
Age 22+	0.175	0.24	1.0	6.99
Age 23+	0.175	0.24	1.0	7.15
Age 24+	0.175	0.24	1.0	10.0

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table C1-36: Threespine Stickleback Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.288	0	0	0.00000567
Larvae	2.12	0	0	0.00110
Juvenile	1.70	0	0	0.00377
Age 1+	1.42	0	0	0.00917
Age 2+	1.42	0	0	0.0112
Age 3+	1.42	0	0	0.0116

[a] Includes blackspotted stickleback, fourspine stickleback, ninespine stickleback, threespine stickleback, and other stickleback not identified to species.

Sources: PG&E National Energy Group, 2001; and Wang, 1986.

Table C1-37: Weakfish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.498	0	0	0.00000115
Larvae	2.84	0	0	0.0650
Juvenile 1	3.39	0	0	0.130
Juvenile 2	5.47	0	0	0.195
Age 1+	0.694	0.25	1.0	0.260
Age 2+	0.730	0.50	1.0	0.680
Age 3+	0.657	0.50	1.0	1.12
Age 4+	0.511	0.50	1.0	1.79
Age 5+	0.511	0.50	1.0	2.91
Age 6+	0.511	0.50	1.0	6.21
Age 7+	0.511	0.50	1.0	7.14
Age 8+	0.511	0.50	1.0	9.16
Age 9+	0.511	0.50	1.0	10.8
Age 10+	0.511	0.50	1.0	12.5
Age 11+	0.511	0.50	1.0	12.5
Age 12+	0.511	0.50	1.0	12.5
Age 13+	0.511	0.50	1.0	12.5
Age 14+	0.511	0.50	1.0	12.5
Age 15+	0.511	0.50	1.0	12.5

[a] Includes northern kingcroaker and weakfish.

Sources: Froese and Pauly, 2003; PG&E National Energy Group, 2001; and PSE&G, 1999.

Table C1-38: White Perch Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.42	0	0	0.000000842
Larvae	4.59	0	0	0.00110
Juvenile	9.06	0	0	0.00302
Age 1+	0.693	0	0	0.0516
Age 2+	0.693	0	0	0.156
Age 3+	0.543	0.15	1.0	0.248
Age 4+	0.543	0.15	1.0	0.331
Age 5+	1.46	0.15	1.0	0.423
Age 6+	1.46	0.15	1.0	0.523
Age 7+	1.46	0.15	1.0	0.613
Age 8+	1.46	0.15	1.0	0.658
Age 9+	1.46	0.15	1.0	0.794

Sources: PG&E National Energy Group, 2001; and Stanley and Danie, 1983.

Table C1-39: Windowpane Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.41	0	0	0.00000154
Larvae	6.99	0	0	0.00165
Juvenile	2.98	0	0	0.00223
Age 1+	0.420	0	0	0.0325
Age 2+	0.420	0	0	0.122
Age 3+	0.420	0	0	0.265
Age 4+	0.420	0	0	0.433
Age 5+	0.420	0	0	0.603
Age 6+	0.420	0.10	1.0	0.761
Age 7+	0.420	0.10	1.0	0.899
Age 8+	0.420	0.10	1.0	1.01
Age 9+	0.420	0.10	1.0	1.11
Age 10+	0.420	0.10	1.0	1.19

[a] Includes American fourspot flounder, smallmouth flounder, summer flounder, and windowpane.

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table C1-40: Winter Flounder Life History Parameters 1[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.288	0	0	0.00000115
Larvae 1	2.05	0	0	0.00441
Larvae 2	3.42	0	0	0.0110
Larvae 3	3.52	0	0	0.0176
Larvae 4	0.177	0	0	0.0221
Juvenile	2.38	0	0	0.0330
Age 1+	1.10	0.0066	1.0	0.208
Age 2+	0.924	0.082	1.0	0.562
Age 3+	0.200	0.20	1.0	0.997
Age 4+	0.200	0.33	1.0	1.42
Age 5+	0.200	0.33	1.0	1.78
Age 6+	0.200	0.33	1.0	2.07
Age 7+	0.200	0.33	1.0	2.29
Age 8+	0.200	0.33	1.0	2.45
Age 9+	0.200	0.33	1.0	2.57
Age 10+	0.200	0.33	1.0	2.65
Age 11+	0.200	0.33	1.0	2.71
Age 12+	0.200	0.33	1.0	2.75
Age 13+	0.200	0.33	1.0	2.78
Age 14+	0.200	0.33	1.0	2.80
Age 15+	0.200	0.33	1.0	2.82
Age 16+	0.200	0.33	1.0	2.83

[a] Includes winter flounder, yellowtail founder, and other flounder not identified to species.
[b] Life history parameters applied to losses from Pilgrim, Brayton Point, and Millstone.

Sources: Able and Fahay, 1998; and PG&E National Energy Group, 2001.

Table C1-41: Winter Flounder Life History Parameters 2[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.288	0	0	0.00000115
Larvae 3.0 mm	0.705	0	0	0.00000127
Larvae 3.5 mm	0.705	0	0	0.00000137
Larvae 4.0 mm	0.705	0	0	0.00000146
Larvae 4.5 mm	0.705	0	0	0.00000156
Larvae 5.0 mm	0.705	0	0	0.00000216
Larvae 5.5 mm	0.705	0	0	0.00000291
Larvae 6.0 mm	0.705	0	0	0.00000382
Larvae 6.5 mm	0.705	0	0	0.00000489
Larvae 7.0 mm	0.705	0	0	0.00000616
Larvae 7.5 mm	0.705	0	0	0.00000764
Larvae 8.0 mm	0.705	0	0	0.00000933
Larvae 8.5 mm	0.705	0	0	0.0000113
Larvae 9.0 mm	0.705	0	0	0.0000135
Juvenile	2.38	0	0	0.0330
Age 1+	1.10	0.0066	1.0	0.208
Age 2+	0.924	0.082	1.0	0.562
Age 3+	0.200	0.20	1.0	0.997
Age 4+	0.200	0.33	1.0	1.42
Age 5+	0.200	0.33	1.0	1.78
Age 6+	0.200	0.33	1.0	2.07
Age 7+	0.200	0.33	1.0	2.29
Age 8+	0.200	0.33	1.0	2.45
Age 9+	0.200	0.33	1.0	2.57
Age 10+	0.200	0.33	1.0	2.65
Age 11+	0.200	0.33	1.0	2.71
Age 12+	0.200	0.33	1.0	2.75
Age 13+	0.200	0.33	1.0	2.78
Age 14+	0.200	0.33	1.0	2.80
Age 15+	0.200	0.33	1.0	2.82
Age 16+	0.200	0.33	1.0	2.83

[a] Includes winter flounder, witch founder, and other flounder not identified to species.

[b] Life history parameters applied to losses from Seabrook.

Sources: Able and Fahay, 1998; Colarusso, 2000; PG&E National Energy Group, 2001; and Saila et al., 1997.

Table C1-42: Winter Flounder Life History Parameters 3[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.288	0.00	0.00	0.00000115
Larvae	9.17	0.00	0.00	0.00441
Juvenile	2.38	0.00	0.00	0.0330
Age 1+	1.10	0.0066	1.0	0.208
Age 2+	0.924	0.082	1.0	0.562
Age 3+	0.200	0.20	1.0	0.997
Age 4+	0.200	0.33	1.0	1.42
Age 5+	0.200	0.33	1.0	1.78
Age 6+	0.200	0.33	1.0	2.07
Age 7+	0.200	0.33	1.0	2.29
Age 8+	0.200	0.33	1.0	2.45
Age 9+	0.200	0.33	1.0	2.57
Age 10+	0.200	0.33	1.0	2.65
Age 11+	0.200	0.33	1.0	2.71
Age 12+	0.200	0.33	1.0	2.75
Age 13+	0.200	0.33	1.0	2.78
Age 14+	0.200	0.33	1.0	2.80
Age 15+	0.200	0.33	1.0	2.82
Age 16+	0.200	0.33	1.0	2.83

[a] Includes fourspot flounder, smooth flounder, witch flounder, yellowtail flounder, and other flounder not identified to species.

[b] Life history parameters applied to losses from Seabrook and Pilgrim.

Sources: Able and Fahay, 1998; Colarusso, 2000; and PG&E National Energy Group, 2001.

Table C1-43: Other Commercial Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.50	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] Includes goosefish, redfish, spot, and wolffish.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Services, 1978.

Table C1-44: Other Recreational Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.50	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] Includes Atlantic torpedo, blue runner, cownose ray, dusky smooth hound, flathead mullet, northern puffer, smooth dogfish, striped cusk-eel, white catfish, and white mullet.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table C1-45: Other Rec/Com Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile 1	1.43	0	0	0.000746
Juvenile 2	1.43	0	0	0.0472
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.50	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] Includes American eel, black sea bass, conger eel, and piked dogfish.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table C1-46: Other Forage Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000186
Larvae	7.70	0	0	0.00000158
Juvenile	1.29	0	0	0.000480
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] See Table C1-47 for a list of species.

Sources: Derickson and Price, 1973; and PSE&G, 1999.

Table C1-47: Other Forage Species[a]

African pompano	Cornet fish	Northern shortfin squid	Sea lamprey
Alligatorfish	Crevalle jack	Ocean pout	Sheepshead minnow
Atlantic bigeye	Flying gurnard	Orange filefish	Short bigeye
Atlantic moonfish	Glasseye	Oyster toadfish	Silver rag
Atlantic seasnail	Gulf snailfish	Pearlside	Spotfin butterflyfish
Banded rudderfish	Long finned squid	Planehead filefish	Striped burrfish
Bigeye scad	Lookdown	Rough scad	Trumpetfish
Black ruff	Mackerel scad	Round scad	Wrymouth
Brown trout	Northern sennet	Sand tiger	

[a] Includes other organisms not identified to species.

Appendix C2:
Scaling of Habitat Restoration

INTRODUCTION

This appendix presents the data and methods used to develop (1) estimates of fish production in tidal wetland and submerged aquatic vegetation (SAV) habitats for species dependent on these habitats that are lost to impingement and entrainment (I&E) at the Brayton Point Station and (2) estimates of the acres of each habitat type that would need to be restored to offset I&E losses of these species.

APPENDIX CONTENTS

C2-1 IDENTIFY HABITAT RESTORATION ACTIONS FOR SPECIES WITH I&E LOSSES

EPA categorized and prioritized habitat restoration alternatives for species lost to I&E at Brayton Point in collaboration with local experts from several Federal, State, and local organizations at a meeting on September 10, 2001 (Table C2-1) and through follow-up discussions that were held with numerous additional organizations (Table C2-2). Attendees discussed habitat needs and restoration options for each species with significant I&E losses at the facility. They then ranked these restoration options for each species by determining what single option would most benefit that species. Species for which tidal wetland or SAV restoration was selected are shown in Table C2-3. The scale of restoration for these habitats is used in Chapter C6 to estimate the non-use value of I&E losses at the Brayton Point facility.

Table C2-1: Attendees at the Meeting on Habitat Prioritization for Species Impinged and Entrained at Brayton Point September 10, 2001, in Fall River, Massachusetts

Attendee	Organization
Anthony Chatwin	Conservation Law Foundation
Robert Lawton	Massachusetts Division of Marine Fisheries
Andrea Langhauser	Massachusetts Watershed Initiative — Ten Mile and Mount Hope Bay Watersheds
Kathi Rodrigues	National Marine Fisheries Service — Restoration Center
Chris Powell	Rhode Island Department of Environmental Management — Fish and Wildlife Division
Tom Ardito	Rhode Island Department of Environmental Management — Narragansett Bay Estuary Program
Andy Lipsky	Save the Bay
John Torgan	Save the Bay
Phil Colarusso	U.S. EPA Region I
John Nagle	U.S. EPA Region I

Table C2-2: Other Local Agencies and Organizations Contacted for Information

Organization
Applied Sciences Associates
Atlantic States Marine Fisheries Council
Connecticut College
Duxbury Conservation Agency
Fall River Conservation Commission
Jones River Watershed Association
Massachusetts Office of Coastal Zone Management
Massachusetts Department of Environmental Protection
Massachusetts Department of Fisheries, Wildlife, and Law Enforcement — Division of Marine Fisheries
Massachusetts Institute of Technology Sea Grant Program: Center for Coastal Resources
Massachusetts Watershed Initiative
Metropolitan Area Planning Commission
Narragansett Estuarine Research Reserve
National Estuary Program — Massachusetts Bays program
National Estuary Program — Narragansett Bay Estuary Program
New Jersey Department of Environmental Protection
New Jersey Marine Sciences Consortium
NOAA — National Marine Fisheries Service
NOAA — National Marine Fisheries Service — Restoration Center (Gloucester, MA)
NOAA — National Marine Fisheries Service — Restoration Center (Providence, RI)
NOAA — National Marine Fisheries Service (NC)
Rhode Island Coastal Resource Management Council
Rhode Island Department of Environmental Management
Rhode Island Department of Environmental Management — Dept. of Planning and Development, Land Acquisition Program
Rhode Island Department of Environmental Management — Division of Fish and Wildlife
Rhode Island Department of Environmental Management — Marine Fisheries Section
Roger Williams University
Rutgers University
Save The Bay (RI)
Somerset Conservation Commission
University of California — Santa Cruz: Department of Ecology and Evolutionary Biology
University of New Hampshire
University of Rhode Island
USEPA — Region 1
USEPA Environmental Effects Research Laboratory — Atlantic Ecology Division/ORD
US Fish and Wildlife Service
USGS
Wetlands Restoration Program, (Mass Exec. Office of Env. Affairs)
Woods Hole Oceanographic Institution

Table C2-3: Experts Selection of Species for Tidal Wetland or SAV Restoration to Offset I&E Losses at Brayton Point

Species	Selected Restoration Alternative
Threespine stickleback	SAV restoration
Weakfish	SAV restoration
Scup	SAV restoration
Winter flounder	Tidal wetlands restoration
Atlantic silverside	Tidal wetlands restoration
Striped killifish	Tidal wetlands restoration

C2-2 EXPECTED INCREASE IN FISH PRODUCTION FROM RESTORATION OF TIDAL WETLAND AND SAV HABITATS

Unfortunately, available quantitative data are not sufficient to estimate reliably the increase in fish production that is expected to result from tidal wetland or SAV restoration in the region around Brayton Point. Therefore, in this analysis EPA relied on quantitative information on fish species abundance in the habitats to be restored as a proxy for production. The relationship between the measured abundance of a species in a given habitat and the increase in that species' production that would result from restoring additional habitat is complex and unique for each species. In some cases the use of abundance data may underestimate the true production that would be gained through habitat restoration, and in other cases it may overestimate the true production. Nevertheless, this assumption was necessary given the limited amount of quantitative data on fish species habitat production that is currently available.

This analysis assumes that estimates of age-1 equivalent abundance in wetlands provide reasonable estimates of the age-1 equivalent production that would be realized, on a per-acre basis, if additional acres of tidal wetland and SAV habitat were restored. This assumption implies that, when restored acres have reached their full potential, they will produce additional age-1 fish in the same mix of species and at the quantities observed in sampling of existing undisturbed habitats.

C2-2.1 Calculating Age 1 Fish Abundance in SAV to Estimate Increased Production from SAV Restoration

SAV provides forage and refuge for many fish species, increases sediment stability, and dampens the energy of waves and currents affecting nearby shorelines (Fonseca, 1992). SAV restoration is most effective where water quality is adequate and SAV coverage once existed.

No studies were available that provided direct estimates of increased fish production following SAV restoration for the SAV-dependent species impinged and entrained at Brayton Point. Therefore, EPA used abundance estimates to estimate increases in production following restoration. Abundance estimates are often the best available estimates of fish habitat productivity. The sampling efforts that provide abundance estimates in SAV habitat and that were selected for restoration scaling are described below.

a. Species abundance in Buzzards Bay SAV

Wyda et al. (2002) provide abundance estimates as fish per 100 m^2 of SAV for species caught in otter trawls in July and August 1996 at 24 sites within 13 Buzzards Bay estuaries, near Nantucket, Massachusetts, and at 28 sites within 6 Chesapeake Bay estuaries. These locations were selected based on information that eelgrass was present or had existed at the location.

The sampling at each location consisted of six, 2-minute sampling runs using a 4.8 m semi-balloon otter trawl with a 3 mm mesh cod end liner that was towed at 5-6 km/hour. Late summer sampling was selected because eelgrass abundance is greatest then, and previous research had shown that late-summer fish assemblages are stable.

Forty-three fish species were caught in Buzzards Bay and 60 in Chesapeake Bay. Abundance estimates per 100 m^2 of SAV were reported for all fish species, and abundance estimates for specific SAV density categories were reported for species caught in more than 10 percent of the total number of trawls (15 species). EPA used only results from Buzzards Bay sampling because of the Bay's proximity to the Brayton Point facility. These SAV density-based results are presented in Table C2-4 for species impinged and entrained at Brayton Point and identified as benefitting most from restoration of SAV.

Table C2-4: Average Abundance in Buzzards Bay SAV (eelgrass) Habitats for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from SAV Restoration

Common Name	Species Abundance (# fish per 100 m^2)[a]	
	Low Density SAV Habitats	High Density SAV Habitats
Threespine stickleback	0.22	0.13
Weakfish[b]	no obs.	no obs.
Scup	0.32	1.03

[a] High density habitats are eelgrass areas with shoot densities > 100 per m^2 and shoot biomass (wet) > 100 g/m^2. Low density habitats do not meet these criteria.
[b] Weakfish were not among the species caught in more than 10 percent of the Buzzards Bay trawls.

Source: Wyda et al. (2002).

b. Species abundance in Rhode Island Coastal Salt Pond SAV

Hughes et al. (2000) conducted trawl samples in the SAV habitats of four Rhode Island coastal estuarine salt ponds and in four Connecticut estuaries during July 1999. As in Wyda et al. (2002), the sampling at each location involved six, 2-minute sampling runs using a 4.8 m semi-balloon otter trawl with a 3 mm mesh cod end liner towed at 5-6 km/hour.

The report does not provide abundance estimates by species. However, a principal investigator provided EPA with abundance estimates expressed as the number of fish per 100 m^2 of SAV for the locations sampled in Rhode Island (Point Judith Pond, Ninigret Pond, Green Hill Pond, and Quonochontaug Pond; personal communication, J. Hughes, NOAA Marine Biological Laboratory, 2001). Average abundance estimates per 100 m^2 of SAV were calculated for each species and allocated to the same SAV habitat categories that were designated in Wyda et al. (2002) using shoot density and wet weight of shoots from Hughes et al. (2000). The sampling results for species impinged and entrained at Brayton Point and identified as benefitting most from SAV restoration are presented in Table C2-5.

Table C2-5: Average Abundance from Rhode Island SAV Sites for Brayton Point Species that Would Benefit Most from SAV Restoration

Species	Species Abundance (# fish per 100 m^2 of SAV habitat)[a]	
	Low Density SAV Habitats	High Density SAV Habitats
Threespine stickleback	no obs.	19.67
Weakfish	no obs.	no obs.
Scup	0.17	0.69

[a] High density habitats are defined as areas with eelgrass shoot densities > 100 per m^2 and shoot biomass (wet) > 100 g/m^2. Low density habitats do not meet these criteria.

Source: personal communication, J. Hughes, NOAA, Marine Biological Laboratory, 2001.

c. Species abundance in Nauset Marsh (Massachusetts) Estuarine Complex SAV

Heck et al. (1989) provide capture totals for day and night trawl samples taken between August 1985 and October 1986 in the Nauset Marsh Estuarine Complex in Orleans/Eastham, Massachusetts, including two eelgrass beds: Fort Hill and Nauset Harbor. As in the other SAV sampling efforts, an otter trawl was used for the sampling, but with slightly larger mesh size openings in the cod end liner (6.3 mm versus 3.0 mm) than in Hughes et al. (2000) or Wyda et al. (2002).

With the reported information on the average speed, duration, and number of trawls used in each sampling period and an estimate of the width of the SAV habitat covered by the trawl from one of the study authors (personal communication, M. Fahay, NOAA, 2001), EPA calculated abundance estimates per 100 m^2 of SAV habitat.

Heck et al. (1989) also report that the dry weight of the SAV shoots is over 180 g/m^2 at both the Fort Hill and Nauset Harbor eelgrass habitat sites. Therefore, these locations would fall into the high SAV habitat category used in Wyda et al. (2002) and Hughes et al. (2000) because the dry weight exceeds the wet weight criterion of 100 g/m^2 used in those studies.

Finally, Heck et al. (1989) provide separate monthly capture results from their trawls. The maximum monthly capture results for each species was used for the abundance estimates from this sampling. Because these maximum values generally occur in the late summer months, sampling time is consistent with the results from Wyda et al. (2002) and Hughes et al. (2000).

The abundance values estimated from the sampling of the Fort Hill and Nauset Harbor SAV habitats for species impinged and entrained at Brayton Point and identified as benefitting most from SAV restoration are presented in Table C2-6.

Table C2-6: Average Abundance in Nauset Marsh Estuarine Complex SAV for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from SAV Restoration

Species	Species Abundance (# fish per 100 m^2)[a]	
	Fort Hill — High Density SAV	Nauset Harbor — High Density SAV
Threespine stickleback	5.92	47.08
Weakfish	No obs.	No obs.
Scup	No obs.	0.08

[a] High density habitats are defined as areas with eelgrass shoot densities > 100 per m^2 and shoot biomass (wet) > 100 g/m^2.

Source: Heck et al., 1989.

C2-2.1.1 Adjusting SAV sampling results to estimate annual average increase in production of age 1 fish

EPA adjusted sampling-based abundance estimates to account for:

- sampling efficiency
- capture of life stages other than age 1
- differences in the measured abundances in natural SAV habitat versus expected productivity in restored SAV habitat.

The basis and magnitude of the adjustments are discussed in the following sections.

a. Adjusting for sampling efficiency

Fish sampling techniques are unlikely to capture or record all of the targeted fish(e.g., fish of a certain lifestage) present in a sampled area because some fish avoid the sampling gear and some are captured but not collected and counted. An estimated range for the sampling efficiency for 4.9 meter otter trawls of 6 percent to 26 percent (PSE&G, 1999 — see Table 5 in Appendix G-4). EPA incorporated the endpoints from this range to provide a similar range of abundance estimates.

b. Adjusting sample abundance estimates to age 1 life stages

All sampled life stages were converted to age 1 equivalents for comparison to I&E losses, which were expressed as age 1 equivalents. The average life stage of the fish caught in Buzzards Bay (Wyda et al., 2002) and the Rhode Island coastal salt pond (Hughes et al., 2000) was juveniles (i.e., life stage younger than age 1) (personal communication, J. Hughes, NOAA Marine Biological Laboratory, 2001). Since the same sampling technique and gear were used in Heck et al. (1989), EPA assumed juveniles to be the average life stage captured in this study as well.

The abundance estimates from the studies were multiplied by the survival rates from juveniles to age 1 for each species to provide an age 1 equivalent abundance. The juvenile to age-1 survival fractions and data sources used by EPA are presented in Appendix C1 of this report and in Table C2-7.

Table C2-7: Life Stage Adjustment Factors for Species Present at Brayton Point — SAV Restoration

Species	Estimated Survival Fraction for Juveniles to Age 1
Threespine stickleback	0.3077
Weakfish	0.0654
Scup	0.0671

c. Adjusting sampled abundance for differences between restored and undisturbed habitats

No reviewed studies suggested that restored SAV habitat would produce fish at a level different from undisturbed SAV habitat. In addition, limited anecdotal evidence suggests some restored SAV habitats may begin recruiting and producing fish very quickly (personal communication, A. Lipsky, Save the Bay, 2001). Based on this information, EPA made no adjustment for differences between restored and undisturbed SAV habitats to account for the final levels of fish production or potential lags in realizing these levels following restoration of SAV habitat.

C2-2.1.2 Final estimates of annual average age 1 fish production from SAV restoration

EPA calculated age 1 fish production in restored SAV by multiplying the abundance estimates from Wyda et al. (2002), Hughes et al. (2000), and Heck et al. (1989) by the survival fractions presented in Table C2-7 and then averaging across sampling locations. Table C2-8 presents the final estimates of the increase in age 1 production for two of the three Brayton Point species that benefit most from SAV restoration (weakfish were not sampled in any of the studies providing abundance estimates). This averaged value was then adjusted by the alternative estimates of the sampling gear efficiency of 6 percent and 26 percent and then results were expressed on a per-acre basis (i.e., multiplied by 40.47 based on 4,047 m^2 per acre). The resulting range of abundance estimates are presented in Table C2-9.

Table C2-8: Final Estimates of the Increase in Production of Age 1 Fish for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from SAV Restoration

Species	Source of Initial Species Abundance Estimate	Species Abundance Estimate per 100 m^2 of SAV	Life Stage Adjustment Factor	Restored Habitat Service Flow Adjustment Factor	Expected Increase in Production of Age 1 Fish per 100 m^2 of Restored SAV
Threespine stickleback	Heck et al. (1989) — Fort Hill	5.92	0.3077	1.0	1.82
	Heck et al. (1989) — Nauset Harbor	47.08	0.3077	1.0	14.49
	Hughes et al. (2000) — RI coastal ponds (high SAV)	19.67	0.3077	1.0	6.05
	Wyda et al. (2002) — Buzzards Bay (low SAV)	0.22	0.3077	1.0	0.07
	Wyda et al. (2002) — Buzzards Bay (high SAV)	0.13	0.3077	1.0	0.04
	Species average				**4.49**
Weakfish	Unknown				
Scup	Heck et al. (1989) — Nauset Harbor	0.08	0.0671	1.0	0.01
	Hughes et al. (2000) — RI coastal ponds (low SAV)	0.17	0.0671	1.0	0.01
	Hughes et al. (2000) — RI coastal ponds (high SAV)	0.69	0.0671	1.0	0.05
	Wyda et al. (2002) — Buzzards Bay (low SAV)	0.32	0.0671	1.0	0.02
	Wyda et al. (2002) — Buzzards Bay (high SAV)	1.03	0.0671	1.0	0.07
	Species average				**0.03**

Table C2-9: Life Stage Adjustment Factors for Species Present at Brayton Point — SAV Restoration

Species	Expected Increase in Production of Age 1 Fish per 100 m^2 of Restored SAV	Assumed Sampling Gear Efficiency	Expected Increase in Production of Age 1 Fish per Acre of Restored SAV (rounded to nearest unit)
Threespine stickleback	4.49	6%	3,031
		26%	699
Weakfish	No data		
Scup	0.03	6%	21
		26%	5

C2-2.2 Estimates of Increased Age 1 Fish Production from Tidal Wetland Restoration

Table C2-10 identifies the I&E losses for fish species at Brayton Point that would benefit most from tidal wetland restoration, along with their estimated annual average age-1 equivalent I&E losses.

Table C2-10: Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from Tidal Wetland Restoration

Species	Annual Average I&E Loss of Age 1 Equivalents
Winter flounder	512,081
Atlantic silverside	39,815
Striped killifish	796
Total	552,692

EPA used results from tidal wetland sampling efforts in Rhode Island to calculate the potential increased fish production from restored tidal wetland habitat in Mount Hope Bay where Brayton Point is located. In selecting data for consideration, EPA decided to not to incorporate data from recently restored sites because in most cases the data were available from only 1 or 2 years following the restoration action and therefore may not be indicative of the long-term average.

a. Species abundance at Sachuest Point Tidal Wetland, Middletown, Rhode Island

Roman et al. (2002) sampled the fish populations in a 6.3 ha tidal wetland at Sachuest Point in Middletown, Rhode Island. The sampling was conducted during August, September, and October of 1997, 1998, and 1999 using a 1 m^2 throw trap in the creeks and pools of each area during low tide after the wetland surface had drained. Additional sampling was conducted monthly from June through October in 1998 and 1999 using 6 m^2 bottomless lift nets to sample the flooded wetland surface. Table C2-11 presents results as abundance per square meter.

Table C2-11: Abundance Estimates from the Unrestricted Tidal Wetlands at Sachuest for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from Tidal Wetland Restoration

Species	Sampling Technique	Fish Density Estimates in Unrestricted Tidal Wetlands (fish per m^2)		
		1997	1998	1999
Winter flounder	Throw trap	No obs.	No obs.	No obs.
	Lift net	No sampling	No obs.	No obs.
Atlantic silverside	Throw trap	1.23	0.20	0.07
	Lift net	No sampling	No obs.	No obs.
Striped killifish	Throw trap	0.70	0.17	0.55
	Lift net	No sampling	0.01	0.01

Source: Roman et al. (2002).

b. Galilee Marsh, Narragansett Rhode, Island

Raposa (2002) sampled the fish populations in the Galilee tidal wetland monthly from June through September of 1997, 1998, and 1999 using 1 m^2 throw trap in the creeks and pools in the tidal wetland parcels during low tide after the wetland surface had drained. Raposa presents the sampling results as number of fish per square meter. As with the results from Roman et al. (2002), EPA did not use the results from a recently restored portion of the wetland to avoid a downward bias in the species density results. The results from this sampling effort are presented in Table C2-12 for the species impinged and entrained at Brayton Point and identified as benefitting most from tidal wetlands restoration.

Table C2-12: Abundance Estimates from the Unrestricted Tidal Wetlands at Galilee for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from Tidal Wetland Restoration

Species	Sampling Technique	Fish Density Estimates in Unrestricted Tidal Wetlands (fish per m^2)		
		1997	1998	1999
Winter flounder	Throw trap	No obs.	No obs.	No obs.
Atlantic silverside	Throw trap	4.78	1.73	14.38
Striped killifish	Throw trap	4.35	3.50	12.40

Source: Raposa, 2002.

c. Coggeshall Marsh, Prudence Island, Rhode Island

Discussions with Kenny Raposa of the Narragansett Estuarine Research Reserve (NERR) revealed that additional fish abundance estimates from tidal wetland sampling were available for the Coggeshall Marsh located on Prudence Island in the NERR. These abundance estimates were based on sampling conducted in July and September 2000. The sampling of the Coggeshall tidal wetland was conducted using 1 m^2 throw traps in the tidal creeks and pools of the wetland during ebb tide after the wetland surface had drained (personal communication, K. Raposa, Narragansett Estuarine Research Reserve, 2001). The sampling results from this effort are presented in Table C2-13 for the species impinged and entrained at Brayton Point and identified as benefitting most from tidal wetlands restoration.

Table C2-13: Abundance Estimates from the Unrestricted Tidal Wetlands at Coggeshall for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from Tidal Wetland Restoration

Species	Sampling Technique	Fish Density Estimates in Tidal Wetlands (fish per m^2)	
		July 2000	September 2000
Winter flounder	Throw trap	0.10	0.10
Atlantic silverside	Throw trap	0.17	0.07
Striped killifish	Throw trap	2.40	0.53

d. Winter flounder data from Rhode Island juvenile finfish survey at the Chepiwanoxet and Wickford sample locations

The Rhode Island juvenile finfish survey samples 18 locations once a month from June through October using a beach seine that is approximately 60 m (200 ft) long and 3 m (10 ft) wide/deep. The sampled sites vary from cobble reef to sandy substrate. Winter flounder prefer shallow water habitats with sandy substrate, and such substrate conditions can be restored in large coastal ponds or pools. Therefore, EPA obtained winter flounder abundance estimates from this survey (personal communication, C. Powell, Rhode Island Department of Environmental Management, 2001). The two sample locations with the highest average winter flounder abundance estimates for 1990 through 2000 were in coastal ponds with sandy bottoms. The average abundance estimates from these sites, Chepiwanoxet and Wickford, are presented in Table C2-14 for samples taken from 1990 through 2000.

Table C2-14: Average Winter Flounder Abundance, 1990-2000, at the Sites with the Highest Results from the Rhode Island Juvenile Finfish Survey

Species	Sampling Technique	Fish Density Estimates in Sandy Nearshore Substrate (fish per m^2)	
		Chepiwanoxet 1990-2000	Wickford 1990-2000
Winter flounder	Beach seine	0.09	0.20

e. Winter flounder data from Rhode Island coastal pond survey at Narrow River, Winnapaug Pond, and Point Judith Pond

In addition to its juvenile finfish survey, Rhode Island conducts a survey of fish in its coastal ponds. The habitat characteristics in these locations are similar to those that can be restored through tidal wetland restoration. A Rhode Island coastal pond survey has been conducted since 1998 at the same 16 sites using an approximately 40 m (130 ft) long seine that is set offshore by boat and then drawn in from shore by hand. For each site, the average of the three highest winter flounder capture results for 1998-2001, adjusted for the average area covered by each seine set, is presented in Table C2-15 (personal communication, J. Temple, Rhode Island Division of Fish and Wildlife, 2002).

Table C2-15: Average Winter Flounder Abundance for 1998-2001 at the Sites with the Highest Results from the Rhode Island Coastal Pond Survey

Species	Sampling Technique	Average Winter Flounder Density Estimates in Sandy Nearshore Substrate (fish per m^2)		
		Narrow River	Winnapaug Pond	Point Judith Pond
Winter flounder	Beach seine	0.32	0.21	0.21

C2-2.2.1 Adjusting tidal wetland sampling results to estimate annual average increase in production of age 1 fish

The sampling abundance results presented in Section C2-2.2.1 were adjusted to account for the following:

- sampling efficiency
- conversion to the age 1 life stage
- differences in production between restored and undisturbed tidal wetlands
- the impact of sampling timing and location.

a. Sampling efficiency

As previously described, sampling efficiency adjustments are made to account for the fact that sampling techniques do not capture all fish that are present. Jordan et al. (1997) estimated that 1 m^2 throw traps have a sampling efficiency of 63 percent. Therefore, EPA applied an adjustment factor of 1.6 (i.e., 1.0/0.63) to tidal wetland abundance data that were collected with 1 m^2 throw traps.

Species-specific estimates of sampling efficiencies of bottomless lift nets are provided in Rozas (1992) as 93 percent for striped mullet (*Mugil cephalus*), 81 percent for gulf killifish (*Fundulus grandis*), and 58 percent for sheepshead minnow (*Cyprinodon variegatus*). The average of these three sampling efficiencies is 77 percent (adjustment factor of 1.3, or 1.0/0.77) and is assumed to be applicable to species lost to I&E at Brayton Point.

Lastly, although specific studies of the sample efficiency of a beach seine net were not identified, an estimated range of 50 percent to 75 percent was provided by the staff involved with the Rhode Island coastal pond survey (personal communication, J. Temple, Rhode Island Division of Fish and Wildlife, 2002). Using the lower end of this range as a cost reducing assumption, EPA applied a sample efficiency adjustment factor of 2.0 (i.e., 1.0/0.5) for the abundance estimates for both the Rhode Island juvenile finfish survey and the Rhode Island coastal pond survey.

b. Conversion to age 1 life stage

The sampling techniques described in Section C2-2.2.1 are intended to capture juvenile fish (personal communication, K. Raposa, Narragansett Estuarine Research Reserve, 2001). That juvenile fish were the dominant age class taken was confirmed by the researchers involved in these efforts (personal communication, K. Raposa, Narragansett Estuarine Research Reserve, 2001; personal communication, C. Powell, Rhode Island Department of Environmental Management, 2001; personal communication, J. Temple, Rhode Island Division of Fish and Wildlife, 2001). As a result, the sampling results presented in Section C2-2.2.1 required adjustment to account for expected mortality between the juvenile and age 1 life stages. The juvenile to age-1 survival fractions and data sources used by EPA are presented in Appendix C1 of this report and in Table C2-16.

Table C2-16: Life Stage Adjustment Factors for Species Present at Brayton Point — SAV Restoration

Species	Estimated Survival Fraction for Juveniles to Age 1
Winter flounder	0.1697
Atlantic silverside	0.1347
Striped killifish	0.5714

c. Adjusting for differences between restored and undisturbed habitats

Restoring full tidal flows rapidly eliminates differences in fish populations between unrestricted and restored sites (Roman et al., 2002), resulting in very similar species composition and density (Dionne et al., 1999; Fell et al., 2000; Warren et al., 2002). However, there can be a lag before this occurs following restoration (Raposa, 2002). Given uncertainty over the length of this lag, and the rate at which increased productivity in a restored tidal wetland approaches its long-term average rate, EPA incorporated an adjustment factor of 1.0 to signify that no quantitative adjustment was made for any potential lag.

d. Adjusting sampled abundance for timing and location of sampling

At high tide, fish have access to the full range of acreage in a tidal wetland, including the flooded vegetation, ponds, and creeks that discharge into or drain the tidal wetland. In contrast, at low tide, fish are restricted to tidal pools and subtidal creeks. To account for these differences, EPA incorporated a simplifying assumption that the juvenile fish using the tidal wetland that are being captured in the sampling efforts would be concentrated in tidal pools and subtidal creeks in sampling conducted at low tide. To account for this presumed concentration, EPA divided abundance estimates based on samples taken at low tide by the inverse of the proportion of subtidal habitat to total wetland habitat at a site. In contrast, no adjustment was applied to abundance estimates based on samples such as those from lift nets or seines, taken at high tide or in open water offshore of a tidal wetland. The site-specific adjustment factors to account for this assumption are presented in Table C2-17 are based on information on the subtidal proportion of each tidal wetland sampled at low tide (personal communication, K. Raposa, Narragansett Estuarine Research Reserve, 2001).

Table C2-17: Adjustment Factors for Tidal Wetland Sampling Conducted at Low Tide

Tidal Wetland	Ratio of Open Water (creeks, pools) to Total Habitat in the Wetland	Adjustment Factor
Sachuest Marsh	0.055	18.2
Galilee Marsh	0.084	11.9
Coggeshall Marsh	0.052	19.2

C2-2.2.2 Final estimates of annual average age 1 fish production from tidal wetland restoration

Based on the average value across all locations, Table C2-18 presents the final estimates of annual increased production of age 1 fish resulting from tidal wetland restoration for species impinged and entrained at Brayton Point and identified as benefitting most from tidal wetland restoration.

The average abundance estimates for the tidal wetland species presented in Table C2-18 are presented below in Table C2-19 in terms of their equivalent per acre values, following multiplication by 4,047 to account for the number of square meters per acre.

Table C2-18: Final Estimates of the Annual Increase in Production of Age 1 Equivalent Fish per Square Meter of Restored Tidal Wetland for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from Tidal Wetland Restoration

Species	Source of Initial Species Density Estimate	Sampling Location and Date[a]	Reported/Calculated Species Density Estimate per m^2 of Tidal Wetland	Sampling Efficiency Adjustment Factor	Life Stage Adjustment Factor	Restored Habitat Service Flow Adjustment Factor	Sampling Time and Location Adjustment Factor	Increased Production of Age 1 Fish per m^2 of Restored Tidal Wetland[bc]
Winter flounder	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall - July 2000	0.10	1.6	0.1697	1	19.23	0.00
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — Sept. 2000	0.10	1.6	0.1697	1	19.23	0.00
	C Powell pers comm 2001	Chepiwanoxet average 1990-2000 (seine)	0.09	2.0	0.1697	1	1.00	0.03
	C Powell pers comm 2001	Wickford average 1990-2000 (seine)	0.20	2.0	0.1697	1	1.00	0.07
	J. Temple pers comm 2002	Narrow River average 1998-2001 (seine)	0.32	2.0	0.1697	1	1.00	0.11
	J. Temple pers comm 2002	Winnapaug Pond average 1998-2001 (seine)	0.21	2.0	0.1697	1	1.00	0.07
	J. Temple pers comm 2002	Point Judith Pond average 1998-2001 (seine)	0.21	2.0	0.1697	1	1.00	0.07
	Species average							**0.05**
Atlantic silverside	Roman et al., 2002	Sachuest Point — 1997	1.23	1.6	0.1347	1	18.18	0.01
	Roman et al., 2002	Sachuest Point — 1998	0.20	1.6	0.1347	1	18.18	0.00
	Roman et al., 2002	Sachuest Point — 1999	0.07	1.6	0.1347	1	18.18	0.00
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall - July 2000	0.17	1.6	0.1347	1	19.23	0.00
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — Sept. 2000	0.07	1.6	0.1347	1	19.23	0.00
Atlantic silverside	Raposa, 2002	Galilee Marsh — 1997	4.78	1.6	0.1347	1	11.90	0.09
	Raposa, 2002	Galilee Marsh — 1998	1.73	1.6	0.1347	1	11.90	0.03
	Raposa, 2002	Galilee Marsh — 1999	14.38	1.6	0.1347	1	11.90	0.26
	Species average							**0.05**

Table C2-18: Final Estimates of the Annual Increase in Production of Age 1 Equivalent Fish per Square Meter of Restored Tidal Wetland for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from Tidal Wetland Restoration

Species	Source of Initial Species Density Estimate	Sampling Location and Date[a]	Reported/Calculated Species Density Estimate per m^2 of Tidal Wetland	Sampling Efficiency Adjustment Factor	Life Stage Adjustment Factor	Restored Habitat Service Flow Adjustment Factor	Sampling Time and Location Adjustment Factor	Increased Production of Age 1 Fish per m^2 of Restored Tidal Wetland[bc]
Striped killifish	Roman et al., 2002	Sachuest Point — 1997	0.70	1.6	0.5714	1	18.18	0.04
	Roman et al., 2002	Sachuest Point — 1998	0.17	1.6	0.5714	1	18.18	0.01
	Roman et al., 2002	Sachuest Point — 1999	0.55	1.6	0.5714	1	18.18	0.03
	Roman et al., 2002	Sachuest Point — 1998 (lift net)	0.01	1.3	0.5714	1	1.00	0.01
	Roman et al., 2002	Sachuest Point — 1999 (lift net)	0.01	1.3	0.5714	1	1.00	0.01
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — July 2000	2.40	1.6	0.5714	1	19.23	0.11
	Raposa pers comm 2001	NERR — Prudence Isl. Coggeshall — Sept. 2000	0.53	1.6	0.5714	1	19.23	0.03
	Raposa, 2002	Galilee Marsh — 1997	4.35	1.6	0.5714	1	11.90	0.33
Striped killifish	Raposa, 2002	Galilee Marsh — 1998	3.50	1.6	0.5714	1	11.90	0.27
	Raposa, 2002	Galilee Marsh — 1999	12.40	1.6	0.5714	1	11.90	0.95
	Species average							**0.18**

[a] Sampling results are based on collections using 1 m^2 throw traps unless otherwise noted.

[b] Calculated by multiplying the initial species density estimate by the sampling efficiency, life stage, and restored habitat service flow adjustment factors and dividing by the sampling time and location adjustment factor. Values are rounded for presentation purposes only

[c] Values of 0.00 presented in the table have an abundance of less than 0.005 fish per m^2 so do not appear in the rounding of results for purposes of presentation.

Table C2-19: Estimates of the Annual Increase in Production of Age 1 Equivalent Fish per Acre of Restored Tidal Wetland for Fish Species Impinged or Entrained at Brayton Point that Would Benefit Most from Tidal Wetland Restoration

Species	Expected Increase in Production of Age 1 Fish per Acre of Restored Tidal Wetland
Winter flounder	205
Atlantic silverside	202
Striped killifish	721

C2-3 SCALING OF I&E LOSSES WITH HABITAT PRODUCTION ABUNDANCE ESTIMATES

Table C2-20 presents the estimates of the average annual age-1 equivalent I&E losses of fish at Brayton Point by species.

Table C2-20: Mean Annual Age 1 Equivalent I&E Losses of Fishes at Brayton Point, 1974-1983 ACO

Species	I&E Total
Seaboard goby	1,513,836
Bay anchovy	1,233,697
Winter flounder	512,081
American sand lance	453,236
Rainbow smelt	50,872
Atlantic silverside	39,815
Hogchoker	37,169
Tautog	30,196
Atlantic menhaden	10,594
Windowpane	7,725
Other forage species	7,195
Alewife	3,580
Threespine stickleback	2,260
Striped killifish	796
Weakfish	557
Scup	509
Silver hake	438
Blueback herring	342
Butterfish	271
White perch	2
Total age 1 equivalent losses	**3,905,171**

The following subsections calculate the required scale of implementation for SAV and tidal wetlands. To determine the appropriate scale of restoration, the species-specific quantified I&E losses are first divided by the corresponding estimates of increased fish production in the relevant habitats. This produces a range of restoration acreage estimates for a given set of assumptions. Second, following a commonly used restoration scaling selection rule, the estimates for the species requiring the maximum amount of restoration, for a given set of assumptions (e.g., sampling gear efficiency) is selected as the estimate of required restoration. This decision rule is used to ensure that the losses for all other species will also be offset under the selected scale of action.

C2-3.1 Submerged Aquatic Vegetation Scaling

The information used to scale SAV restoration is presented in Table C2-21 incorporating the loss estimates from Table C2-20 and the SAV production estimates of age-1 equivalent fish per acre of restored SAV from Table C2-9.

Table C2-21: Scaling of SAV Restoration Species Impinged or Entrained at Brayton Point

Species	Annual Average I&E Loss of Age 1 Equivalents	Estimated increase in Production of Age-1 Equivalent Fish per Acre of Restored SAV (rounded to nearest fish)		Estimated Acres of Restored SAV Required to Offset Annual Average Loss of Age-1 Equivalent Fish (rounded to nearest acre)	
		Low	High	Low	High
Scup	509	5	21	24	102
Threespine stickleback	2,260	699	3,031	1	3
Weakfish	557	No data		n/a	
Acres of SAV restoration required to offset I&E losses for these species				**24**	**102**

C2-3.2 Tidal Wetlands Scaling

The information used to scale tidal wetland restoration is presented in Table C2-22 incorporating the loss estimates from Table C2-20 and the tidal wetland production estimates of age-1 equivalent fish per acre of restored tidal wetland from Table C2-19.

Table C2-22: Scaling of Tidal Wetland Restoration Species Impinged or Entrained at Brayton Point

Species	Annual Average I&E Loss of Age 1 Equivalents	Expected Increase in Production of Age-1 Fish per Acre of Restored Tidal Wetland (rounded to nearest fish)	Estimated Acres of Restored Tidal Wetlands Required to Offset Annual Average Loss of Age-1 Equivalent Fish (rounded to nearest acre)
Winter flounder	512,081	205	2,498
Atlantic silverside	39,815	202	197
Striped killifish	796	721	1
Acres of tidal wetland restoration required to offset I&E losses for these species			**2,498**

Part D

Mid-Atlantic Region

Chapter D1: Background

CHAPTER CONTENTS

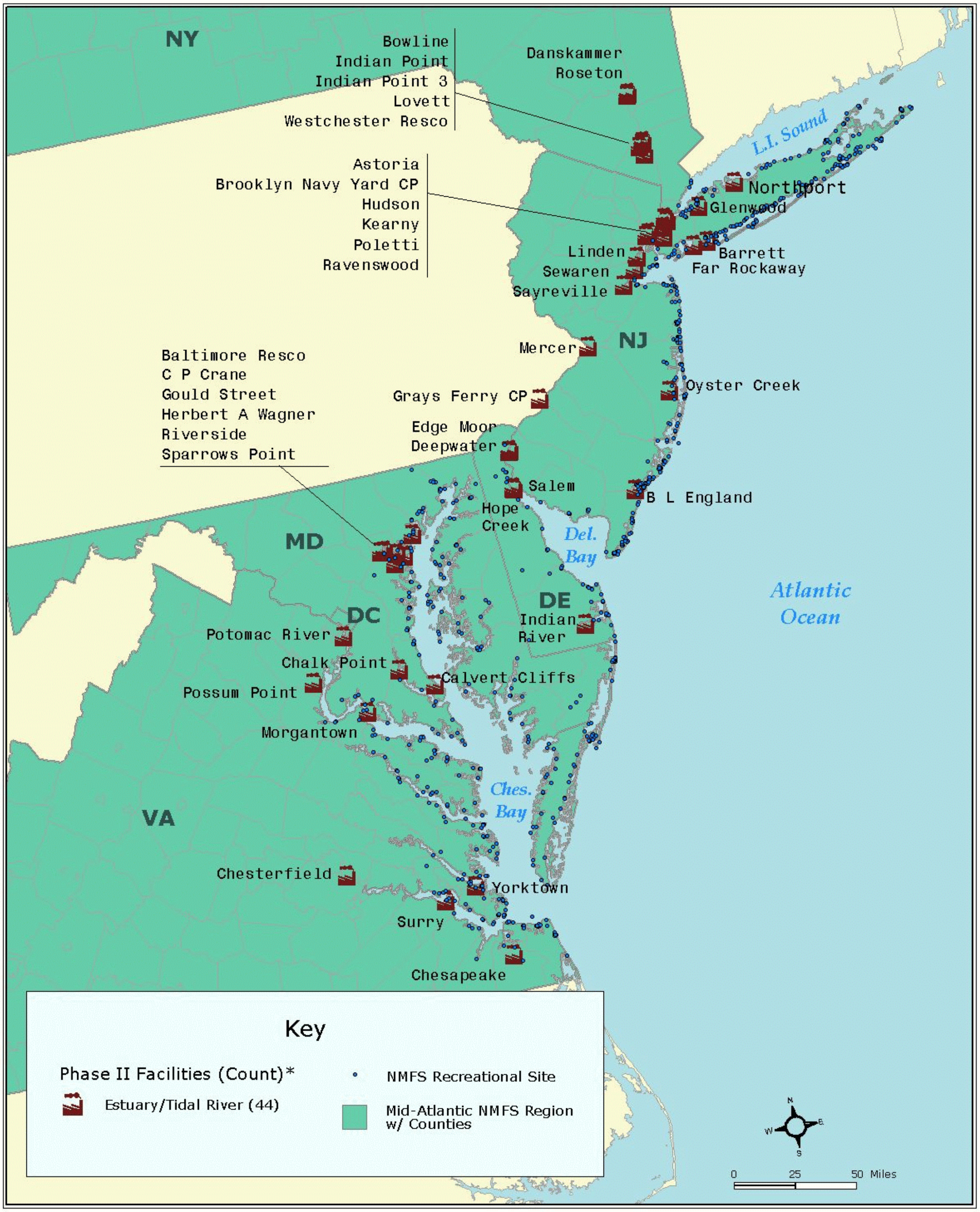
INTRODUCTION

This chapter presents an overview of the Phase II facilities in the Mid-Atlantic study region and summarizes their key operating, economic, technical, and compliance characteristics. For further discussion of operating and economic characteristics of Phase II facilities, refer to Chapter A3 of the *Economic and Benefits Analysis for the Final Section 316(b) Phase II Existing Facilities Rule*; for further discussion of the technical and compliance characteristics of Phase II facilities, refer to the *Technical Development Document for the Final Section 316(b) Phase II Existing Facilities Rule* (U.S. EPA, 2004a,b).

D1-1 OVERVIEW

The Mid-Atlantic Study includes 44 facilities that are in scope for the final Phase II regulation. All 44 facilities withdraw cooling water from an estuary or tidal river. Figure D1-1 presents a map of the 44 in-scope Phase II facilities located in the Mid-Atlantic study region.

Figure D1-1: In-Scope Phase II Facilities in the Mid-Atlantic Regional Study



Source: U.S. EPA analysis for this report.

D1-2 OPERATING AND ECONOMIC CHARACTERISTICS

Nearly half of the 44 Mid-Atlantic Study facilities (21) are oil/gas facilities; eleven are coal steam facilities; seven are nuclear facilities; three facilities use another type of steam electric prime mover; and two are combined-cycle facilities. In 2001, these 44 facilities accounted for 40.4 gigawatts of generating capacity, nearly 158,000 gigawatt hours of generation, and $8.6 billion in revenues.

The operating and economic characteristics of the Mid-Atlantic Study facilities are summarized in Table D1-1. Section D1-4 provides further information on each facility [including facility state, North American Electric Reliability Council (NERC) region, plant type, capacity, 2001 generation, and whether impingement and entrainment estimates were developed for the facility].

Table D1-1: Operating and Economic Characteristics of Phase II Facilities

Waterbody Type	Number of Facilities by Plant Type[a]						Total Capacity (MW)[b]	Total Generation (MWh)[b]	Electric Revenue (millions)
	Coal Steam	Combined Cycle	Nuclear	Oil/Gas Steam	Other Steam	Total			
Estuary/Tidal									
DE	1	-	-	1	-	2	1,510	4,286,451	$356
MD	2	-	1	4	2	9	8,030	30,708,580	$2,414
NJ	3	-	3	5	-	11	9,732	38,549,683	$2,700
NY	2	1	2	9	1	15	13,384	45,979,169	$1,307
PA	-	1	-	-	-	1	193	677,311	$78
VA	3	-	1	2	-	6	7,547	37,382,028	$1,743
TOTAL	**11**	**2**	**7**	**21**	**3**	**44**	**40,394**	**157,583,222**	**$8,598**

[a] Based on largest steam-electric capacity at facilities.
[b] MW is an abbreviation for megawatt; MWh is an abbreviation for megawatt hour.

Sources: Plant type (IPM Analysis, U.S. EPA, 2002; Form EIA-860, U.S. DOE, 2001a); capacity (Form EIA-860, U.S. DOE, 2001a); generation (Form EIA-906, U.S. DOE, 2001c); revenue (Form EIA-861, U.S. DOE, 2001b; Form EIA-906, U.S. DOE, 2001c).

D1-3 TECHNICAL AND COMPLIANCE CHARACTERISTICS

Thirty-nine of the 44 Mid-Atlantic Study facilities employ a once-through cooling system in the baseline; four employ a combination cooling system; and one facility utilizes a recirculating cooling system. These 39 facilities with once-through systems incur a combined pre-tax compliance cost of $60.1 million, and the four facilities with combination cooling systems incur a combined pre-tax compliance cost of $2.4 million. Table D1-2 summarizes the flow, compliance responses, and compliance costs for these 44 facilities.

Table D1-2: Technical and Compliance Characteristics of Phase II Facilities

	Cooling Water System (CWS) Type[a]			
	Once-Through	**Recirculating**	**Combination**	**All**
Design Flow (MGD)	**45,452**	**115**	**2,272**	**47,839**
Number of Facilities by Compliance Response				
Fish H&R	3	-	-	3
Fine Mesh Traveling Screens w/Fish H&R	6	-	2	8
New Larger Intake Structure with Fine Mesh and Fish H&R	2	-	-	2
Passive Fine Mesh Screens	12	-	-	12
Fish Barrier Net/Gunderboom	4	-	-	4
Double-Entry, Single-Exit with Fine Mesh and Fish H&R	5	-	1	6
Multiple	3	-	-	3
None	4	1	1	6
Total	**39**	**1**	**4**	**44**
Compliance Cost (2002$; millions)[b]	**$60.1**	**w[b]**	**$2.4**	**w[b]**

[a] Combination CWSs are costed as if they were once-through CWSs.

[b] Data withheld because of confidentiality reasons.

Source: U.S. EPA analysis for this report.

D1-4 PHASE II FACILITIES IN THE MID-ATLANTIC REGIONAL STUDY

Table D1-3 presents economic and operating characteristics of the Mid-Atlantic Study facilities.

Table D1-3: Phase II Facilities in the Mid-Atlantic Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
Estuary/Tidal River							
593	Edge Moor	DE	MAAC	O/G Steam	710	2,608,911	N
594	Indian River	DE	MAAC	Coal Steam	799	1,677,540	Y
1552	C P Crane	MD	MAAC	Coal Steam	416	2,236,071	N
1553	Gould Street	MD	MAAC	O/G Steam	104	188,570	N
1554	Herbert A Wagner	MD	MAAC	O/G Steam	1,059	3,413,594	N
1559	Riverside	MD	MAAC	O/G Steam	244	61,764	N
1571	Chalk Point	MD	MAAC	O/G Steam	2,647	4,670,004	Y
1573	Morgantown	MD	MAAC	Coal Steam	1,548	6,582,466	Y
6011	Calvert Cliffs	MD	MAAC	Nuclear	1,829	12,379,806	Y
10485	Sparrows Point	MD	MAAC	Other Steam	120	916,057	N
10629	Baltimore Refuse Energy Systems Co LP	MD	MAAC	Other Steam	65	260,248	N
2378	B L England	NJ	MAAC	Coal Steam	484	1,158,457	N
2384	Deepwater	NJ	MAAC	O/G Steam	227	512,222	N
2388	Oyster Creek	NJ	MAAC	Nuclear	641	5,215,005	N
2390	Sayreville	NJ	MAAC	O/G Steam	462	50,051	N
2403	Hudson	NJ	MAAC	Coal Steam	1,230	2,764,485	N
2404	Kearny	NJ	MAAC	O/G Steam	867	142,470	N
2406	Linden	NJ	MAAC	O/G Steam	922	327,796	N
2408	Mercer	NJ	MAAC	Coal Steam	768	2,802,612	N
2410	Salem	NJ	MAAC	Nuclear	2,386	17,205,046	Y
2411	Sewaren	NJ	MAAC	O/G Steam	577	319,518	N
6118	Hope Creek	NJ	MAAC	Nuclear	1,170	8,052,021	N
2480	Danskammer	NY	NPCC	Coal Steam	537	2,104,233	N
2491	Poletti	NY	NPCC	O/G Steam	883	2,562,092	N
2497	Indian Point	NY	NPCC	Nuclear	1,299	7,752,031	Y
2500	Ravenswood	NY	NPCC	O/G Steam	2,375	4,912,761	N
2511	Barrett	NY	NPCC	O/G Steam	687	1,711,962	N
2513	Far Rockaway	NY	NPCC	O/G Steam	100	295,490	N
2514	Glenwood	NY	NPCC	O/G Steam	338	816,686	N

Table D1-3: Phase II Facilities in the Mid-Atlantic Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
2516	Northport	NY	NPCC	O/G Steam	1,564	7,269,527	N
2625	Bowline	NY	NPCC	O/G Steam	1,155	1,715,931	N
2629	Lovett	NY	NPCC	Coal Steam	449	1,249,288	N
8006	Roseton	NY	NPCC	O/G Steam	1,242	1,960,925	N
8906	Astoria	NY	NPCC	O/G Steam	1,345	3,369,193	N
8907	Indian Point 3	NY	NPCC	Nuclear	1,012	8,006,454	N
50882	Westchester Resco	NY	NPCC	Other steam	75	37,777	N
54914	Brooklyn Navy Yard Cogeneration Partners L P	NY	NPCC	Combined Cycle	322	1,874,826	N
54785	Grays Ferry Cogeneration Partnership	PA	MAAC	Combined Cycle	193	677,311	N
3788	Potomac River	VA	MAAC	Coal Steam	514	2,006,566	N
3797	Chesterfield	VA	SERC	Coal Steam	1,800	9,908,478	N
3803	Chesapeake	VA	SERC	Coal Steam	812	4,229,965	N
3804	Possum Point	VA	SERC	O/G Steam	1,469	3,560,634	N
3806	Surry	VA	SERC	Nuclear	1,695	12,662,376	N
3809	Yorktown	VA	SERC	O/G Steam	1,257	5,014,009	N

Source: U.S. EPA analysis for this report.

Chapter D2: Evaluation of Impingement and Entrainment in the Mid-Atlantic Region

BACKGROUND: MID-ATLANTIC MARINE FISHERIES

CHAPTER CONTENTS

The Mid-Atlantic Fishery Management Council (MAFMC) manages fisheries in Federal waters off the Mid-Atlantic coast. States with voting representation on the MAFMC include New York, Pennsylvania, New Jersey, Delaware, Maryland, Virginia, and North Carolina. North Carolina is represented on both the MAFMC and the South Atlantic Fishery Management Council.

The MAFMC has fishery management plans in place for Atlantic mackerel (*Scomber scombrus*), squid (*Loligo pealeii* and *Illex illecebrosus*), butterfish (*Peprilus triacanthus*), Atlantic surf clam (*Spisula solidissima*), ocean quahog (*Arctica islandica*), Atlantic bluefish (*Pomatomus saltatrix*), summer flounder (*Paralichthys dentatus*), scup (*Stenotomus chrysops*), black sea bass (*Centropristis striata*), and monkfish (*Lophius americanus*). Mid-Atlantic groundfish fisheries are primarily for summer flounder, scup, goosefish (*Lophius americanus*), and black seabass (NMFS, 1999b). Summer flounder is one of the most valuable groundfish species in the region, and is targeted by both recreational and commercial fishermen (NMFS, 1999b).

D2-1 FISHERY SPECIES IMPINGED AND ENTRAINED

Table D2-1 shows the status of stocks in the Mid-Atlantic region that are managed by the MAFMC, indicating in bold the stocks subject to impingement and entrainment (I&E). In this table, overfishing refers to the situation in which fishing mortality is above a management threshold, jeopardizing the long-term capacity of the stock to produce the potential maximum sustainable yield on a continuing basis. A stock is considered overfished when biomass falls below a given threshold. In some cases, heavy fishing in the past may have reduced a stock to low abundance, so that it is now considered overfished even though the stock is not currently subject to overfishing.

As indicated in Table D2-1, 6 of the 14 managed stocks are classified as overfished, including the stock of monkfish in the southern portion of the region, spiny dogfish, scup, black seabass, bluefish, and golden tilefish (*Lopholatilus chamaeleonticeps*). Other stocks are in the process of being rebuilt from levels below the maximum sustainable yield, including the northern stock of monkfish and summer flounder. The status of two other stocks, surfclam and squid (*Illex*), is unknown or undefined. As indicated in the table, some of the stocks requiring management are also subject to I&E.

Table D2-1: Summary of Stock Status for Harvested Species of the Mid-Atlantic Region Included in Federal Fishery Management Plans

Stock (species in bold are subject to I&E)	Overfishing? (fishing mortality above threshold)	Overfished? (biomass below threshold)	Approaching Overfished Condition?
Monkfish (north)	Yes	No-rebuilding	No
Monkfish (south)	Yes	Yes	N/A
Spiny dogfish	Yes	Yes	N/A
Summer flounder	Yes	No-rebuilding	No
Scup	Yes	Yes	N/A
Black seabass	Yes	Yes	N/A
Bluefish	No	Yes	N/A
Surfclam	No	Undefined	Unknown
Ocean quahog	No	No	No
Squid (*Illex*)	No	Unknown	Unknown
Squid (*Loligo*)	No	No	No
Atlantic mackerel	No	No	No
Butterfish	No	No	No
Golden tilefish	Yes	Yes	N/A

Source: Table 4 in NMFS, 2002a.

D2-2 I&E SPECIES AND SPECIES GROUPS EVALUATED

Table D2-2 provides a list of species in the Mid-Atlantic region that are subject to I&E and the species groups that were evaluated in EPA's analysis of regional I&E.

Table D2-2: Species Evaluated by EPA that are Subject to I&E in the Mid-Atlantic Region

Species Group	Species	Recreational	Commercial	Forage
Alewife	Alewife		X	
American shad	American shad		X	
Atlantic croaker	Atlantic croaker	X	X	
Atlantic menhaden	Atlantic menhaden		X	
Atlantic tomcod	Atlantic tomcod			X
Bay anchovy	Bay anchovy			X
Blue crab	Blue crab		X	
Blueback herring	Blueback herring			X
Hogchoker	Hogchoker			X
Other (commercial)	American butterfish		X	
	American eel		X	
	Brown bullhead		X	
	Channel catfish		X	
	Conger eel		X	
	Gizzard shad		X	
	Harvestfish		X	
	Silver hake		X	

Table D2-2: Species Evaluated by EPA that are Subject to I&E in the Mid-Atlantic Region

Species Group	Species	Recreational	Commercial	Forage
	White catfish		X	
	Yellow perch		X	
Other (forage)	Atlantic herring			X
	Atlantic needlefish			X
	Atlantic silverside			X
	Banded killifish			X
	Blackcheek tonguefish			X
	Bluegill			X
	Chain pickerel			X
	Fourspine stickleback			X
	Golden shiner			X
	Inland silverside			X
	Inshore lizardfish			X
	Lined seahorse			X
	Mississippi silvery minnow			X
	Mud minnow			X
	Mummichog			X
	Northern pipefish			X
	Northern stargazer			X
	Pumpkinseed			X
	River herring			X
	Sheepshead minnow			X
	Skilletfish			X
	Spottail shiner			X
	Spotted codling			X
	Striped anchovy			X
	Striped blenny			X
	Striped killifish			X
	Threespine stickleback			X
Other (recreational)	Black drum	X		
	Black sea bass	X		
	Bluefish	X		
	Northern puffer	X		
	Northern searobin	X		
	Orange filefish	X		
	Oyster toadfish	X		
	Sea lamprey	X		
	Spotted hake	X		
	Spotted seatrout	X		
Naked goby	Naked goby			X
Spot	Spot	X	X	
Striped bass	Striped bass	X	X	
Summer flounder	Summer flounder	X	X	
Weakfish	Weakfish	X	X	

Table D2-2: Species Evaluated by EPA that are Subject to I&E in the Mid-Atlantic Region

Species Group	Species	Recreational	Commercial	Forage
White perch	White perch	X	X	
Windowpane	Windowpane		X	
Winter flounder	Winter flounder	X	X	

Life histories of the species with the highest losses are summarized in the following section. The life history data used in EPA's analysis and associated data sources are provided in Appendix D1 of this report.

D2-3 LIFE HISTORIES OF PRIMARY SPECIES IMPINGED AND ENTRAINED IN THE MID-ATLANTIC REGION

Life history characteristics of the primary species impinged or entrained at the Salem facility are summarized in the following sections. The species described are those with the highest I&E rates at Salem (presented in sections D2-4 and D2-4).

Alewife *(Alosa pseudoharengus)*

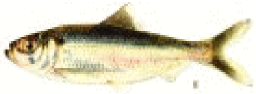
Alewife is a member of the herring family, Clupeidae, and ranges along the Atlantic coast from Newfoundland to North Carolina (Scott and Crossman, 1998). Alewife tend to be more abundant in the mid-Atlantic and along the northeastern coast. They are anadromous, migrating inland from coastal waters in the spring to spawn. Adult alewife overwinter along the northern continental shelf, settling at the bottom in depths of 56 to 110 m (184 ft to 361 ft) (Able and Fahay, 1998). Adults feed on a wide variety of food items, while juveniles feed mainly on plankton (Waterfield, 1995).

Alewife has been introduced to a number of lakes to provide forage for sport fish (Jude et al., 1987b). Ecologically, alewife is an important prey item for many fish, and commercial landings of river herring along the Atlantic coast have ranged from a high of 33,974 metric tons (74.9 million pounds) in 1958 to a low of less than 2,268 metric tons (5 million pounds) in recent years (Atlantic States Marine Fisheries Commission, 2000b).

Spawning is temperature-driven, beginning in the spring as water temperatures reach 13 to 15 °C, and ending when they exceed 27 °C (Able and Fahay, 1998). Spawning takes place in the upper reaches of coastal rivers, in slow-flowing sections of slightly brackish or freshwater.

Females lay demersal eggs in shallow water less than 2 m (6.6 ft) deep (Wang and Kernehan, 1979). They may lay from 60,000 to 300,000 eggs at a time (Kocik, 2000). The demersal eggs are 0.8 to 1.27 mm (0.03 to 0.05 in) in diameter. Larvae hatch at a size of approximately 2.5 to 5.0 mm (0.1 to 0.2 in) total length (Able and Fahay, 1998). Larvae remain in the upstream spawning area for some time before drifting downstream to natal estuarine waters. Juveniles table a diurnal vertical migration in the water column, remaining near the bottom during the day and rising to the surface at night (Fay et al., 1983c). In the fall, juveniles move offshore to nursery areas (Able and Fahay, 1998).

Maturity is reached at an age of 3 to 4 years for males, and 4 to 5 years for females (Able and Fahay, 1998). The average size at maturity is 265 to 278 mm (10.4 to 10.9 in) for males and 284 to 308 mm (11.2 to 12.1 in) for females (Able and Fahay, 1998). Alewife can live up to 8 years, but the average age of the spawning population tends to be 4 to 5 years (Waterfield, 1995; PSEG, 1999).



ALEWIFE
(Alosa pseudoharengus)

Family: Clupeidae (herrings).

Common names: River herring, sawbelly, kyak, branch herring, freshwater herring, bigeye herring, gray herring, grayback, white herring.

Similar species: Blueback herring.

Geographic range: Along the western Atlantic coast from Newfoundland to North Carolina.[a]

Habitat: Wide-ranging, tolerates fresh to saline waters, travels in schools.

Lifespan: May live up to 8 years.[b,c]

Fecundity: Females may lay from 60,000 to 300,000 eggs at a time.[d]

Food source: Small fish, zooplankton, fish eggs, amphipods, mysids.[c]

Prey for: Striped bass, weakfish, rainbow trout.

Life stage information:

***Eggs:** demersal*
- Found in waters less than 2 m (6.6 ft) deep.[d]
- Are 0.8 to 1.27 mm (0.03 to 0.05 in) in diameter.[f]

Larvae:
- Approximately 2.5 to 5.0 mm (0.1 to 0.2 in) at hatching.[f]
- Remain in upstream spawning area for some time before drifting downstream to natal estuarine waters.

Juveniles:
- Stay on the bottom during the day and rise to the surface at night.[g]
- Emigrate to ocean in summer and fall.[f]

***Adults:** anadromous*
- Reach maturity at 3-4 years for males and 4-5 years for females.[f]
- Average size at maturity is 265-278 mm (10.4-10.9 in) for males and 284-308 mm (11.2-12.1 in) for females.[f]
- Overwinter along the northern continental shelf.[f]

Location:
- Range along the western Atlantic coast from Newfoundland to North Carolina.
- Some landlocked populations exist in the Great Lakes and smaller lakes.

[a] Scott and Crossman, 1998.
[b] PSEG, 1999.
[c] Waterfield, 1995.
[d] Kocik, 2000.
[e] Wang and Kernehan, 1979.
[f] Able and Fahay, 1998.
[g] Fay et al., 1983c.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

American shad (*Alosa sapidissima*)

American shad is a member of the herring family, Clupeidae. American shad ranges from the Gulf of St. Lawrence, Canada, south to Florida, and are most abundant from Connecticut to North Carolina (Able and Fahay, 1998). An anadromous species, American shad migrate inland to spawn in natal rivers. Suitable American shad spawning habitat has declined over the years because of degradation in water quality and the construction of dams blocking natal spawning grounds (Atlantic States Marine Fisheries Commission, 2000b). Though still commercially and recreationally an important species, the economic importance of American shad has declined in the last century with its decreased abundance (Wang and Kernehan, 1979).

Spawning generally takes place from mid-April through early June, when water temperatures reach 12 ˚C (Able and Fahay, 1998). The slightly demersal eggs may hatch in 12 to 15 days at 12 ˚C (54 ˚F) and in 6 to 8 days at 17 ˚C (63 ˚F) (Wang and Kernehan, 1979; Able and Fahay, 1998). Larvae hatch at 5 to 10 mm (0.2 to 0.4 in) , and are pelagic for 2 to 3 weeks. At 25 to 28 mm, shad become juveniles (Able and Fahay, 1998), and will remain in riverine habitats through the first summer, gradually dispersing downstream (Able and Fahay, 1998). Emigration from estuarine habitats to marine waters occurs in the fall, and is triggered by decreasing water temperatures. Young-of-year are approximately 75 to 125 mm (3.0 to 4.9 in) at this point (Able and Fahay, 1998).

At 1 year, juveniles reach approximately 120 mm (4.7 in). Males tend to mature at 3 to 5 years, while females mature at 4 to 6 years (Able and Fahay, 1998). Mortality rates vary according to spawning grounds. Over half of the American shad that spawn in the Hudson River survive spawning migration and return to spawn again the following year (Wang and Kernehan, 1979), compared to less than 5 percent in the Delaware River (Wang and Kernehan, 1979).

American shad have a potential lifespan of up to 11 years (Carlander, 1969), but generally do not live longer than 8 years (PSEG, 1999).

AMERICAN SHAD
(Alosa sapidissima)

Family: Clupeidae (herrings).

Common names: Shad, Atlantic shad, white shad.

Similar species: Atlantic herring, alewife, blueback herring, Atlantic menhaden.

Geographic range: Atlantic coast from the St. Lawrence River to Florida.[a] May migrate more than 12,000 miles during their average lifespan.

Habitat: Marine waters, returning to inland tributaries and streams to spawn.

Lifespan: Generally up to 8 years.[b]

Fecundity: Females can lay over 600,000 eggs, as several hovering males fertilize them.[c]

Food source: Primarily plankton feeders, while at sea they feed on plankton, small crustaceans, and small fishes.

Prey for: Sea lamprey, striped bass, bluefish.

Life stage information:

Eggs: *slightly demersal*
- Shad move far enough upstream for the eggs to drift downstream and hatch before reaching saltwater.
- The eggs mature rapidly and transform into young fish in 3 to 4 weeks.

Larvae: *pelagic*
- Larvae hatch out at 5 to 10 mm (0.2 to 0.4 in) and are pelagic for 2 to 3 weeks.[d]

Juveniles:
- The young-of-year remain in fresh to brackish water until early fall before entering the sea. Some juveniles do not enter the sea and instead overwinter in deep holes near the mouth of the bay.

Adults: *anadromous*
- American shad are anadromous and do not feed during their return migration.

Location:
- Inshore and offshore. Atlantic coast from the St. Lawrence River to Florida. Spends most of its life at sea in large schools. It only enters the freshwater river in which it was born to spawn.
- American shad may migrate more than 1,000 miles during their average lifespan of five years at sea. They enter the bay from January to June between the ages of 4 and 6 to spawn in the freshwater and low-salinity tributaries.

[a] Able and Fahay, 1998.
[b] PSEG, 1999.
[c] Walburg, 1960.
[d] Able and Fahay, 1998.
Fish graphic from State of Maine Department of Marine Resources, 2001a.

Atlantic croaker (*Micropogonias undulatus*)

The Atlantic croaker is a member of the drum family Sciaenidae. Its distribution ranges from Massachusetts to the Gulf of Mexico along the Atlantic coast, with the greatest abundance from Chesapeake Bay to Florida (Able and Fahay, 1998; Desfosse et al., 1999). Populations of Atlantic croaker fluctuated over the last century, showing high levels in the 1940's, then declining sharply in the 1950's and 1960's (Joseph, 1972). Numbers remained low until the mid-1970's and steadily increased since then (Wang and Kernehan, 1979). Commercial landings in Delaware were reported as low as 0.1 metric tons (220 lb) in 1988, increasing to 6.7 metric tons (14,770 lb) in 1999 (personal communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, Maryland, March 26, 2001).

As a bottom-feeding fish, the Atlantic croaker feeds mainly on worms, crustaceans, and fish (Atlantic States Marine Fisheries Commission, 2000a). It can tolerate a wide range of salinities ranging from freshwater to 70 ppt (Able and Fahay, 1998). Spawning occurs offshore from September through December along the continental shelf between Delaware Bay and Cape Hatteras (Morse, 1980; Able and Fahay, 1998).

Female fecundity along the mid-Atlantic coast ranges from 100,800 to 1,742,000 eggs in females from 196 to 390 mm (7.7 to 15.4 in) in total length (Morse, 1980). Atlantic croaker larvae enter Delaware Bay in fall and spend the winter over the continental shelf. Young croaker use the estuary as a nursery area in late winter, spring, and summer. Larvae are most abundant in September-October and juveniles are most abundant in October-January. Young-of-year leave the offshore shelf waters for inshore estuaries beginning in October, at lengths of 8 to 20 mm (0.3 to 0.8 in) (Able and Fahay, 1998). Young-of-year are often found over soft mud bottoms at water temperatures between 9.5 and 23.2 ˚C (49.1 and 73.8 ˚F), and tend to overwinter in deeper areas of the same habitats (Cowan and Birdsong, 1995). By age 1, individuals in the Delaware Bay have reached lengths of 135 to 140 mm (Able and Fahay, 1998). In the fall, age 1 individuals leave their overwintering estuaries to migrate offshore and south for their second winter (Able and Fahay, 1998).

Maturity begins at lengths of 140 to 170 mm (5.5 to 6.7 in), as Atlantic croaker approach 2 years (White and Chittenden, 1977). Atlantic croaker is a relatively short-lived species, living to a maximum age of 2 to 4 years in the Mid-Atlantic Bight (White and Chittenden, 1977). Adults tend to be less than 200 mm (7.9 in) long south of Cape Hatteras (North Carolina), although they can reach more than 350 mm (13.8 in). Individuals north of Cape Hatteras are generally larger (White and Chittenden, 1977).

ATLANTIC CROAKER
(Micropogonias undulatus)

Family: Sciaenidae (drums).

Common names: Corvina, hardhead, king billy, roncadina, and grumbler.

Similar species: Red drum, weakfish, spotted seatrout, spot.

Geographic range: From Massachusetts to the Gulf of Mexico along the western Atlantic coast, with the greatest abundance from Chesapeake Bay to Florida.[a,b]

Habitat: Usually found over mud and sandy mud bottoms in coastal waters and estuaries.[b]

Lifespan: Croaker generally live for 2-4 years.[c]

Fecundity: Females may lay between 100,800 to 1.74 million eggs.[d]

Food source: Croaker are opportunistic bottom-feeders that consume a variety of invertebrates (mysid shrimp, copepods, marine worms) and occasionally fish.

Prey for: Striped bass, flounder, shark, spotted seatrout, other croaker, bluefish, and weakfish.

Life stage information:

Eggs: *weakly demersal*
- Develop offshore.

Larvae:
- Larvae are most abundant in September-October.[e]

Juveniles:
- Young-of-year migrate to inshore estuaries in the fall, and tend to overwinter in relatively deep areas with soft mud bottoms.
- Juvenile croaker leave estuaries in the fall to spend their second winter offshore.

Adults:
- Maturity begins at approximately 140-170 mm (5.5 to 6.7 in).[c]
- May reach over 350 mm (13.8 in).[c]

Location:
- New Jersey to the Gulf of Mexico and the Western Atlantic Coast. Most abundant between the Chesapeake Bay and Florida.
- Adult croaker generally spend the spring and summer in estuaries and move offshore and south along the Atlantic coast in the fall.
- Prefer muddy bottoms and depths less than 120 m.
- Euryhaline species — able to tolerate a wide range of salinities.

[a] Desfosse et al., 1999.
[b] Froese and Pauly, 2001.
[c] White and Chittenden, 1977.
[d] Morse, 1980.
[e] Able and Fahay, 1998.
Fish graphic from South Carolina Department of Natural Resources, 2001.

Atlantic menhaden (*Brevoortia tyrannus*)

The Atlantic menhaden, a member of the Clupeidae (herring) family, is a euryhaline species, occupying coastal and estuarine habitats. It is found along the Atlantic coast of North America, from Maine to northern Florida (Hall, 1995). Adults congregate in large schools in coastal areas; these schools are especially abundant in and near major estuaries and bays. They consume plankton, primarily diatoms and dinoflagellates, which they filter from the water through elaborate gill rakers. In turn, menhaden are consumed by almost all commercially and recreationally important piscivorous fish, as well as by dolphins and birds (Hall, 1995).

The menhaden fishery, one of the most important and productive fisheries on the Atlantic coast, is a multimillion-dollar enterprise (Hall, 1995). Menhaden are considered an “industrial fish” and are used to produce products such as paints, cosmetics, margarine (in Europe and Canada), and feed, as well as bait for other fisheries. Landings in New England declined to their lowest level of approximately 2.7 metric tons (5,952 lb) in the 1960s because of overfishing. Since then, landings have varied, ranging from approximately 240 metric tons (529,100 lb) in 1989 to 1,069 metric tons in 1998 (personal communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, Maryland, March 19, 2001).

Atlantic menhaden spawn year round at sea and in larger bays (Scott and Scott, 1988). Spawning peaks during the southward fall migration and continues throughout the winter off the North Carolina coast. There is limited spawning during the northward migration and during summer months (Hall, 1995). The majority of spawning occurs over the inner continental shelf, with less activity in bays and estuaries (Able and Fahay, 1998).

Females mature just before age 3, and release buoyant, planktonic eggs during spawning (Hall, 1995). Atlantic menhaden annual egg production ranges from approximately 100,000 to 600,000 eggs for fish age 1 to age 5 (Dietrich, 1979). Eggs are spherical and between 1.3 to 1.9 mm (0.05 to 0.07 in) in diameter (Scott and Scott, 1988).

Larvae hatch after approximately 24 hours and remain in the plankton. Larvae hatched in offshore waters enter the Delaware Estuary 1 to 2 months later to mature (Hall, 1995). Juveniles then migrate south in the fall, joining adults off North Carolina in January (Hall, 1995). Water temperatures below 3 ˚C (37 ˚F) kill the larvae, and therefore larvae that fail to reach estuaries before the fall are more likely to die than those arriving in early spring (Able and Fahay, 1998). Larvae hatchout at 2.4 to 4.5 mm (0.09 to 0.18 in). The transition to the juvenile stage occurs between 30 and 38 mm (1.2 and 1.5 in) (Able and Fahay, 1998). The juvenile growth rate in some areas is estimated to be 1 mm (0.04 in) per day (Able and Fahay, 1998).

During the fall and early winter, most menhaden migrate south off of the North Carolina coast, where they remain until March and early April. They avoid waters below 3 ˚C, but can tolerate a wide range of salinities from less than 1 percent up to 33-37 percent (Hall, 1995). Sexual maturity begins at age 2, and all individuals are mature by age 3 (Scott and Scott, 1988).

Adult fish are commonly between 30 and 35 cm (11.8 and 13.8 in) in length. The maximum age of a menhaden is approximately 7 to 8 years (Hall, 1995), although individuals of 8-10 years have been recorded (Scott and Scott, 1988).

ATLANTIC MENHADEN
(*Brevoortia tyrannus*)

Family: Clupeidae (herrings).

Common names: menhaden, bunker, fatback, bugfish.

Similar species: Gulf menhaden, yellowfin menhaden.

Geographic range: From Maine to northern Florida along the Atlantic coast.[a]

Habitat: Open-sea, marine waters. Travels in schools.[b]

Lifespan:
- Approximately 7 to 8 years.[a]

Fecundity:
- Females may produce between 100,000 to 600,000 eggs.[c]

Food Source: Phytoplankton, zooplankton, annelid worms, detritus[b]

Prey for: Sharks, cod, pollock, hakes, bluefish, tuna, swordfish, seabirds, whales, porpoises.[b]

Life Stage Information

Eggs: *pelagic*
- Spawning takes place along the inner continental shelf, in open marine waters.[d]
- Eggs hatch after approximately 24 hours.

Larvae: *pelagic*
- Larvae hatch out at sea, and enter estuarine waters 1 to 2 months later.[a]
- Remain in estuaries through the summer, emigrating to ocean waters as juveniles in September or October.[d]

Adults
- Congregate in large schools in coastal areas.
- Spawn year round.[b]

[a] Hall, 1995.
[b] Scott and Scott, 1988.
[c] Dietrich, 1979.
[d] Able and Fahay, 1998.
Fish graphic from South Carolina Department of Natural Resources, 2001.

Atlantic silverside (*Menidia menidia*)

The Atlantic silverside is a member of the silverside family, Atherinidae. Its geographic range extends from coastal waters of New Brunswick to northern Florida (Fay et al., 1983c), but it is most abundant between Cape Cod and South Carolina (Able and Fahay, 1998). Atlantic silversides inhabit sandy seashores and the mouths of inlets (Froese and Pauly, 2001). Silversides are an important species of forage fish, eaten by valuable fishery species such as striped bass (*Morone saxatilis*), bluefish (*Pomatomus salatrix*), weakfish (*Cynoscion regalis*), and Atlantic mackerel (*Scomber scombrus*) (Fay et al., 1983c; McBride, 1995).

Atlantic silversides spawn in the upper intertidal zone during spring and summer. Spawning appears to be stimulated by new and full moons, in association with spring tides. On average, females produce 4,500 to 5,000 demersal eggs per spawning season, which may include four to five separate spawning bouts (Fay et al., 1983c). The eggs are 0.9 to 1.2 mm (0.04 to 0.05 in) in diameter. Larvae range in size from 5.5 to 15.0 mm (0.2 to 0.6 in) (Fay et al., 1983c). The sex of Atlantic silversides is determined during the larval stage, at approximately 32 to 46 days after hatching. Water temperatures between 11 and 19 ˚C (52 and 66 ˚F) produce significantly more females, whereas temperatures between 17 and 25 ˚C (63 and 77 ˚F) produce significantly more males (Fay et al., 1983c).

Juveniles occur in estuaries during the summer months, occupying intertidal creeks, marshes, and shore zones of bays and estuaries. Silversides typically migrate offshore in the winter (McBride, 1995). In studies of seasonal distribution in Massachusetts, all individuals left inshore waters during winter months (Able and Fahay, 1998).

The diet of juveniles and adults consists of copepods, mysids, amphipods, cladocerans, fish eggs, squid, worms, molluscs, insects, algae, and detritus (Fay et al., 1983c). Atlantic silversides feed in large schools, preferring gravel and sand bars, open beaches, tidal creeks, river mouths, and marshes (Fay et al., 1983c).

Silversides live for only 1 or 2 years, usually dying after completing their first spawning (Fay et al., 1983c). Adults can reach sizes of up to 15 cm (5.9 in) in total length (Froese and Pauly, 2001).

ATLANTIC SILVERSIDE
(*Menidia menidia*)

Family: Atherinidae (silversides).

Common names: Spearing, sperling, green smelt, sand smelt, white bait, capelin, shiner.[a]

Similar species: Inland silverside (*Menidia beryllina*).[a]

Geographic range: New Brunswick to northern Florida[a]

Habitat: Sandy seashores and the mouths of inlets.[b]

Lifespan: One or 2 years. Often die after their first spawning.[a]

Fecundity: Females produce an average of 4,500 to 5,000 eggs per spawning season.[a]

Food Source: Zooplankton, fish eggs, squid, worms, molluscs, insects, algae, and detritus.[a]

Prey for: Striped bass, bluefish, weakfish, and Atlantic mackerel.[a,c]

Life Stage Information

Eggs: *demersal*
- Found in shallow waters of estuarine intertidal zones.[a]
- Can be found adhering to submerged vegetation.[a]

Larvae:
- Range from 5.5 to 15.0 mm (0.2 to 0.6 in) in size.[a]
- Sex is determined during the larval stage by the temperature regime. Colder temperatures tend to produce more females, and warmer temperatures produce more males.[a]

Adults:
- Overwinter in offshore marine waters.[d]
- Can reach sizes of up to 15 cm (5.9 in) total length.[d]

[a] Fay et al., 1983c.
[b] Froese and Pauly, 2001.
[c] McBride, 1995.
[d] Able and Fahay, 1998.
Fish graphic from Government of Canada, 2001.

Bay anchovy *(Anchoa mitchilli)*

Bay anchovy is a member of the anchovy family, Engraulidae, and is one of the most abundant species in estuaries along the Atlantic and Gulf coasts of the United States (Vouglitois et al., 1987). In Delaware Bay, bay anchovy shares the status of most abundant species with the Atlantic silverside (de Sylva et al., 1962). Because of its widespread distribution and overall abundance, bay anchovy are an important component of the food chain for recreational and commercial fish, and as such have indirect economic importance (Morton, 1989).

Bay anchovy is commonly found in shallow tidal areas, feeding mainly on copepods and other zooplankton. It tends to appear in higher densities in vegetated areas such as eelgrass beds (Castro and Cowen, 1991).

The spawning period of bay anchovy is long, with records ranging from April to November (Vouglitois et al., 1987). In the Delaware Estuary, the spawning season usually occurs from early April through mid-June (Wang and Kernehan, 1979). Spawning within the Delaware Estuary primarily occurs in the western part of the C & D Canal, and in the Elk River (Wang and Kernehan, 1979) (see Figure B1-1), and has been correlated with areas of high zooplankton abundance (Dorsey et al., 1996). In Chesapeake Bay, a minimum of 50 spawning events per female was estimated, with spawning events occurring every 4 days in June and every 1.3 days in July. Spawning generally occurs nocturnally, and during peak spawning periods females may spawn nightly. Fecundity estimates for bay anchovy in mid-Chesapeake Bay were reported at 643 eggs in July 1986 and 731 eggs in July 1987 (Zastrow et al., 1991). The pelagic eggs are 0.8 to 1.3 mm (0.03 to 0.05 in) in diameter (Able and Fahay, 1998). Size of the eggs varies with increased water salinity.

Eggs hatch in approximately 24 hours at average summer temperatures (Monteleone, 1992). The yolk sac larvae are 1.8 to 2.0 mm (0.07 to 0.08 in) long, with nonfunctioning eyes and mouth parts (Able and Fahay, 1998). Mortality during these stages is high. In a study conducted in the Chesapeake Bay, 73 percent of the eggs died before hatching, and mortality for surviving larvae was 72 percent within the first 24 hours of hatching (Dorsey et al., 1996).

Growth estimates for larval bay anchovy have been estimated at 0.53 to 0.56 mm (0.021 to 0.022 in) per day in Great South Bay, New York (Castro and Cowen, 1991), and young-of-year growth rates averaged 0.47 mm (0.02 in) per day in Chesapeake Bay (Zastrow et al., 1991). Sexual maturity occurs at a length of 40 to 45 mm (1.6 to 1.8 in) in Chesapeake Bay (Zastrow et al., 1991). Individuals hatched early in the season may become sexually mature by their first summer (Morton, 1989).

Most young-of-year migrate out of the estuaries at the end of the summer in schools, and can be found in large numbers on the inner continental shelf in the fall (Vouglitois et al., 1987). The average size for adults is 75 mm (2.95 in) (Morton, 1989). Bay anchovy live for only 1 or 2 years (Zastrow et al., 1991).

Near the Salem station, bay anchovy eggs are present from May to November and are most abundant from May to August. Larvae are present from May to October, with greatest abundance from June to August. Juveniles are present throughout the year but are most abundant from July to October. Adults are also present year-round and are most abundant from April to November.

BAY ANCHOVY
(Anchoa mitchilli)

Family: Engraulidae (anchovies).

Common names: Anchovy.

Similar species: Atlantic silverside.

Geographic range: From Maine, south to the Gulf of Mexico.[a]

Habitat: Commonly found in shallow tidal areas with muddy bottoms and brackish waters; often appears in higher densities in vegetated areas such as eelgrass beds.[b]

Lifespan: 1-2 years.[c]

Fecundity: Females spawn a minimum of 50 times over the spawning season in the Chesapeake Bay. Fecundity per spawning event is about 700 eggs.[c]

Food source: Primarily feed on copepods and other zooplankton, as well as small fishes and gastropods.[b]

Prey for: Striped bass, weakfish, jellyfish.

Life stage information:

Eggs: *pelagic*
- Eggs are 0.8-1.3 mm (0.03 to 0.05 in) in diameter.[a]
- Eggs experience an average mortality of 73 percent.[d]

Larvae:
- Yolk-sac larvae are 1.8 to 2.0 mm (0.7 to 0.8 in) on hatching.[a]
- Daily mortality for yolk-sac larvae is as high as 88 percent.[b]
- Daily mortality for 3-15 day old larvae is approximately 28 percent.[b]

Juveniles:
- Young-of-year migrate out of estuaries at the end of summer, and can be found in large numbers on the inner continental shelf in fall.[e]

Adults:
- Adults reach sexual maturity at 40 to 45 mm (1.6 to 1.8 in) in Chesapeake Bay.[c]
- The average adult is 75 mm (2.95 in) long.[f]

Location:
- Ranges from Cape Cod, Massachusetts, south to the Gulf of Mexico. Spawns in the Delaware Estuary in the Elk River and C&D Canal.[g]
- Most commonly found in shallow tidal areas with muddy bottoms and brackish waters, but can be found in a wide range of habitats.
- Tolerates a wide range of salinities.

[a] Able and Fahay, 1998.
[b] Castro and Cowen, 1991.
[c] Zastrow et al., 1991.
[d] Dorsey et al., 1996.
[e] Vouglitois et al., 1987.
[f] Morton, 1989.
[g] Wang and Kernehan, 1979.
Fish graphic from NOAA, 2001a.

Blue crab (*Callinectes sapidus*)

The Atlantic blue crab can be found in Atlantic coastal waters from Long Island to the Gulf of Mexico. Blue crab supports the most economically important inshore commercial fishery in the mid-Atlantic (Epifanio, 1995); Chesapeake Bay provides over 50 percent of the commercial landings of Atlantic blue crab nationwide (Epifanio, 1995).

Females typically mate only once within their lifetime. Spawning in the Delaware Bay peaks from late July to early August. After an elaborate courtship ritual, females lay two to three broods of eggs, each containing over 1 million eggs. Mating occurs in areas of low salinity. The eggs hatch near high tide and the larvae are carried out to sea by the current (Epifanio, 1995). This stage of the lifecycle is called the zoeal stage. The zoea go through seven molts before entering the next stage, the megalops stage, and are carried back to estuarine waters (Epifanio, 1995). The zoea stages last approximately 35 days, and the megalops stage may vary from several days to a few weeks (Epifanio, 1995).

While in the zoeal stage along the continental shelf, larvae are vulnerable to predators, starvation, and transport to unsuitable habitats. Larvae are especially vulnerable to predators while molting. Dispersal of young Atlantic blue crabs is primarily controlled by wind patterns, and they do not necessarily return to their parent estuaries (Epifanio, 1995). In the Delaware Estuary, maturity is reached at approximately 18 months (Epifanio, 1995).

Atlantic blue crabs inhabit all regions of the Delaware Estuary. Males prefer areas of low salinity, while females prefer the mouth of the estuary. In the warmer months, crabs occupy shallower areas in depths of less than 4.0 m (13 ft). They can tolerate water temperatures exceeding 35 ˚C (95 ˚F), but do not fare as well in cold water (Epifanio, 1995). In winter months, adults burrow into the bottom of deep channels and remain inactive (Epifanio, 1995). Extremely cold weather has resulted in high mortality of overwintering crabs (Epifanio, 1995).

Atlantic blue crabs are omnivorous, foraging on molluscs, mysid shrimp, small crabs, worms, and plant material (Epifanio, 1995). Adults prey heavily on juvenile Atlantic blue crab (Epifanio, 1995).

Atlantic blue crab can live up to 3 years (Epifanio, 1995).

Impingeable sizes of blue crab are present throughout the year near Salem, but are most abundant from April to November.

ATLANTIC BLUE CRAB
(*Callinectes sapidus*)

Family: Portunidae (swimming crabs).

Common names: Blue crab.

Similar species: Lesser blue crab (*Callinectes similis*).

Lifespan: Up to 3 years. Maturity is reached at 18 months.[a]

Geographic range: Atlantic coast from Long Island to the Gulf of Mexico.[a]

Habitat: Inhabit all areas of the Delaware Estuary. In warmer weather they occupy shallow areas less than 4 m (13 ft) deep. They burrow into the bottom of deep channels and remain inactive in winter.[a]

Fecundity: Typically mate once in their lifetime. Mating occurs in low salinity areas. Females lay two to three broods of 1 million eggs each.[a]

Food Source: Atlantic blue crabs are omnivores, foraging on molluscs, mysids, shrimp, small crabs, worms, and plant material.[a]

Prey for: Juveniles are preyed upon by a variety of fish (eels, striped bass, weakfish) and are heavily preyed upon by adult blue crabs.[a]

Life Stage Information

Eggs:
- Hatch near high tide.[a]

Larvae:
- Carried out to sea by the current, where they remain for seven molts before returning to estuaries.[a]

***Adults*:**
- Males prefer lower salinity while females prefer the mouth of the bay.[a]

[a] Epifanio, 1995.
Graphic from U.S. FDA, 2001.

Blueback herring (*Alosa aestivalis*)

Blueback herring is a member of the herring family, Clupeidae. It is closely related to the alewife; together they are commonly referred to as river herring. The range of blueback herring extends from Nova Scotia south to northern Florida, though they are more abundant in the southern portion of their range (Scott and Scott, 1988). Within the Delaware Estuary, blueback herring tend to be more abundant in the upper region of the estuary than do the closely related alewife (Waterfield, 1995). Economically, blueback herring are an important bait species for the blue crab industry of the Delaware and Chesapeake bays. They are also a significant prey item for many estuarine fish species.

Adults spawn from spring to early summer in upstream brackish or freshwater areas of rivers and tributaries. Spawning occurs at night in fast currents over a hard substrate (Loesch and Lund, 1977). Spawning groups have been observed diving to the bottom and releasing the semi-adhesive eggs over the substrate, but many eggs are dislodged by the current and enter the water column. Loesch and Lund (1977) reported fecundity estimates of 45,800 to 349,700 eggs per female, and noted that fecundity was positively correlated with total fish length up to approximately 300 mm. After spawning, adults move downstream and return to the ocean.

Eggs float near the bottom for 2 to 4 days until hatching, depending on temperature. At hatching, larvae are 3.1 to 5.0 mm (0.12 to 0.20 in) (Jones et al., 1978). Larvae become juveniles at approximately 20 mm (0.79 in), or at 25 to 35 days (Able and Fahay, 1998). Juveniles are distributed high in the water column and avoid bottom depths (Able and Fahay, 1998). In the early juvenile stages, fish are swept downstream by the tide. Some juveniles will move upstream until late summer before migrating downstream in late summer to early fall. Juveniles are sensitive to sudden water temperature changes, and emigrate downstream in response to a decline in temperature (Able and Fahay, 1998). By late fall, most young-of-year emigrate to ocean waters to overwinter (Wang and Kernehan, 1979).

Male blueback herring mature at ages 3 to 4, and females mature at ages 4 to 5. Over half of the adults are repeat spawners, returning to natal spawning grounds every year (Scherer, 1972). Females tend to grow larger than males and dominate the older age groups. Blueback herring can live to 8 years (Froese and Pauly, 2001).

Near Salem, blueback herring juveniles are present from winter through late spring and again in fall.

BLUEBACK HERRING
(*Alosa aestivalis*)

Family: Clupeidae (herrings).

Common names: River herring, glut herring, summer herring, kyak, blackbelly.

Similar species: alewife, American shad, Atlantic menhaden.

Geographic range: From Nova Scotia south to northern Florida.[a]

Habitat: Euryhaline, marine. Adults form schools and overwinter near the bottom out from the coast.[b]

Lifespan: May live up to 8 years.[b]

Fecundity: Fecundity ranges from 45,800 to 349,700 eggs per female.[c] Over half of adults are repeat spawners and return to natal spawning grounds every year.[d]

Food source: Shrimp, zooplankton, finfish.

Prey for: Striped bass, weakfish, bluefish.

Life stage information:

Eggs: *pelagic*
- Eggs float near the bottom for 2-4 days.[e]

Larvae:
- Larvae are 3.1-5.0 mm at hatching.[e]
- The larval stage duration is 25-35 days.[f]

Juveniles:
- Blueback herring reach the juvenile stage at 20 mm (0.79 in), or at an age of 25-35 days.[f]
- Juveniles are distributed high in the water column and avoid bottom depths.
- Juveniles tend to move upstream until late summer before migrating downstream in late summer in response to a decline in temperature.

Adults:
- Males mature at ages 3-4, females at ages 4-5.
- Adults overwinter near the bottom and out from the coast, then return to shore in late spring to spawn.

Location:
- Range from Nova Scotia south to northern Florida.
- More common in upper region of Delaware estuary than the closely related alewife.

[a] Scott and Scott, 1988.
[b] Froese and Pauly, 2001.
[c] Loesch and Lund, 1977.
[d] Scherer, 1972.
[e] Jones et al., 1978.
[f] Able and Fahay, 1998.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Spot (*Leiostomus xanthurus*)

Spot is a member of the drum family, Sciaenidae. Its range extends along the Atlantic coast from Massachusetts Bay to Campeche Bay, Mexico, and it is most abundant from Chesapeake Bay to South Carolina (Hildebrand and Schroeder, 1928; Mercer, 1987). Spot are occasionally harvested for food, but because of their small size, are typically used as bait and in pet food and fish meal (Hales and Van Den Avyle, 1989). Spot are often caught by anglers because they take the bait easily and are often found near piers and bridges (Hales and Van Den Avyle, 1989).

Ecologically they are an important species because of their high abundance and their status on the food chain as both predator and prey for many species. Because of their short lifespan, annual landings tend to consist of a single year class and fluctuate greatly from year to year, yet show no long-term trends (Atlantic States Marine Fisheries Commission, 2000c).

Spawning occurs in deeper waters along the continental shelf from late fall through early spring (Mercer, 1987). Females produce 30,000 to 60,000 eggs (Phillips et al., 1989), and eggs are 0.72-0.87 mm (0.028 to 0.034 in) in diameter (Able and Fahay, 1998). Larvae hatch out at 1.5 to 1.7 mm (0.06 to 0.07 in) in length and begin migrating to inshore estuaries, reaching the nursery estuarine waters in early to late spring. Young larvae show a preference for low salinity waters (Wang and Kernehan, 1979), and continue to migrate to the upper areas of estuaries to spend the summer. By the fall, young-of-year reach 10 to 11 cm (3.9 to 4.3 in) (Able and Fahay, 1998). First year growth rates for spot in Chesapeake Bay have been recorded from 10.5 mm (0.4 in) per month to 19.1 mm (0.8 in) per month (Hildebrand and Schroeder, 1928; McCambridge and Alden, 1984).

As water temperatures decrease in the fall, juveniles emigrate to the ocean in October and November. Larger individuals tend to leave the estuaries earliest. In the Chesapeake Bay, some young-of-year spot have remained in the estuaries throughout the first winter.

Spot are able to avoid heavy competition with Atlantic croaker by occupying different spatial and temporal niches. While Atlantic croaker spawn from October through February in the Delaware Estuary, spot spawn from December through March (Wang and Kernehan, 1979). They share a similar diet, consisting mostly of mysid shrimp, copepods, and marine worms, but spot feed more on burrowing worm species while Atlantic croaker show a preference for worms on the bottom surface (Chao and Musick, 1977).

Spot mature at 2 to 3 years (Atlantic States Marine Fisheries Commission, 2000c). The maximum recorded age for spot is 5 years (Mercer, 1987). The largest recorded spot was 35.6 cm (14.0 in) long, although most mature adults are 17.8 to 20.3 cm (7.0 to 8.0 in) (Atlantic States Marine Fisheries Commission, 2000c).

Spot may be particularly vulnerable to I&E in intake structures because of their slow swimming speeds and low endurance (Hales and Van Den Avyle, 1989). Young spot have significantly lower swimming speeds than most estuarine fishes and cannot maintain their orientation in currents exceeding 15 cm/s. Larger spot have increased swimming capabilities, but may also be vulnerable to I&E because they tend to drift with the currents (Hales and Van Den Avyle, 1989).

SPOT
(Leiostomus xanthurus)

Family: Sciaenidae (drums).

Common names: Spot croaker.

Similar species: Red drum, weakfish, spotted seatrout, Atlantic croaker.

Geographic range: Along the Atlantic coast from Massachusetts Bay to Campeche Bay, Mexico, and most abundant from Chesapeake Bay to South Carolina.[a,b]

Habitat: Often found near piers and bridges.[c] Occurs over sandy or muddy bottoms in coastal waters up to 60 m (197 ft) in depth.[d]

Lifespan: Up to 5 years.[b]

Fecundity: Females produce 30,000 to 60,000 eggs.[e]

Food source: Worms, mysid shrimp, copepods.[f]

Prey for: Striped bass, weakfish, bluefish, flounder, bonito, sandbar shark.

Life stage information:

Eggs: *pelagic*
- Eggs are 0.72-0.87 mm (0.028 to 0.034 in) in diameter.[f]

Larvae:
- Larvae are 1.5-1.7 mm (0.06 to 0.07 in) long at hatching.[e]
- Larvae migrate to inshore estuary waters, arriving in early to late spring.
- Young larvae prefer low salinity waters and are found in upper estuary waters.

Juveniles:
- As water temperature decreases in the fall, most young-of-year spot migrate out to the ocean.
- Larger individuals tend to leave the estuary earlier.

Adults:
- Spot mature at 2-3 years.[h]
- The largest recorded spot was 35.6 cm (14.0 in) long, although most mature adults are 17.8-20.3 cm (7.0 to 8.0 in).[h]

Location:
- Range along the western Atlantic coast from Massachusetts Bay to Campeche Bay, Mexico.
- Found over sandy or muddy bottoms in coastal waters to about 60 m depth.
- Found in nursery and feeding grounds in river estuaries in summer and fall.

[a] Hildebrand and Schroeder, 1928.
[b] Mercer, 1987.
[c] Hales and Van Den Avyle, 1989.
[d] Froese and Pauly, 2000.
[e] Phillips et al., 1989.
[f] Chao and Musick, 1977.
[g] Able and Fahay, 1998.
[h] Atlantic States Marine Fisheries Commission, 2000c.
Fish graphic from South Carolina Department of Natural Resources, 2001.

Striped bass (*Morone saxatilis*)

Striped bass is a member of the temperate bass family, Moronidae. Both migratory and nonmigratory populations span the Atlantic coast, from the St. Lawrence River, Canada, to the St. John's River in Florida (Scott and Scott, 1988). Striped bass has long been an important commercial and recreational species. The perceived decline in striped bass populations was the reason behind the creation of the Atlantic States Marine Fisheries Commission in 1942 (Miller, R.W., 1995). Spawning populations of striped bass were nearly eliminated from the Delaware River in the mid-1900's, because of poor water quality. Pollution in the lower portions of the Delaware River caused a decline in striped bass reproduction due to a decrease in dissolved oxygen for several years, but cleanup efforts in the 1980's and 1990's resulted in improved water quality and increased striped bass reproduction (Chittenden, 1971; Weisberg and Burton, 1993; Miller, R.W., 1995). A moratorium was declared on striped bass fishing in the State of Delaware from 1985 through 1989 (Miller, R.W., 1995). While populations of striped bass have rebounded, the fishery is still managed closely and tight restrictions on size limits and the length of the fishing season are kept to maintain the goals established under Amendment 5 of the Striped Bass Fishery Management Plan of 1995 (Atlantic States Marine Fisheries Commission, 2000g).

Striped bass are a popular catch among recreational anglers; however, consumption advisories are currently in place for striped bass from the Delaware River and Bay as a result of bioaccumulation of PCBs (PSEG, 1999). These advisories recommend limiting the consumption of striped bass to less than five 267 g (8-oz.) meals per year. A 1997 landings report estimated the yearly catch by recreational and commercial fisheries to be 4.094 million striped bass (Atlantic States Marine Fisheries Commission, 2000d). Angling efforts are typically centered on the C&D canal, from Port Penn to Augustine Beach, Delaware, and in the mouths of tributaries south of the canal (PSEG, 1999). In the Delaware Bay, there are currently no directed commercial fishing efforts for striped bass, although historically commercial harvesting of striped bass was an important resource (PSEG, 1999).

Striped bass are common along mid-Atlantic coastal waters. They are an anadromous fish that spend most of the year in saltwater but use the upper fresh and brackish water reaches of estuaries as spawning and nursery areas in spring and summer (Setzler et al., 1980). The principal spawning areas for striped bass along the Atlantic coast are the major tributaries of Chesapeake Bay, and the Delaware and Hudson rivers (NOAA, 2001c). The timing of spawning may be triggered by an increase in water temperature, and generally occurs from April to June (Fay et al., 1983c). Spawning behavior consists of a female surrounded by up to 50 males at or near the surface (Setzler et al., 1980). Eggs are broadcast loosely in the water and fertilized by the males. Females may release an estimated 14,000 to 40.5 million eggs, depending on the size of the female (Jackson and Tiller, 1952). A 23 kg (50 pound) female may produce approximately 5 million eggs (Mansueti and Hollis, 1963).

Striped bass eggs are semibuoyant, and require minimum water velocities to remain buoyant. Eggs that settle to the bottom may become smothered by sediment (Hill et al., 1989). The duration of larval development is influenced by water temperature; temperatures ranging from 24 to 15 ˚C (75 to 59 ˚F) correspond to larval durations of 23 to 68 days, respectively (Rogers et al., 1977). Saila and Lorda (1977) reported a 6 percent probability of survival for egg and yolk-sac stages of development, and a 4 percent probability of survival for the post yolk-sac stage.

At 30 mm (1.2 in), most striped bass enter the juvenile stage. Juveniles begin schooling in larger groups after age 2 (Bigelow and Schroeder, 1953). Migratory patterns of juveniles vary with locality (Setzler et al., 1980). In both the Delaware and the Hudson rivers, young-of-year migrate downstream from their spawning grounds to the tidal portions of the rivers to spend their first summer (Able and Fahay, 1998). In the Delaware River, young-of-year may spend 2 or more years within the estuary before joining the offshore migratory population (Miller, R.W., 1995). Similar trends were found in the Hudson River, where individuals were found to stay up to 3 years in estuaries before migrating offshore (Able and Fahay, 1998). Results of tagging studies reported by the Delaware Department of Natural Resources and Environmental Control (DDNREC, 2000) and Public Service Electric and Gas Company (PSEG, 1999) showed that striped bass tagged in the Delaware Estuary were recaptured from North Carolina to Maine. However, the majority of tagged fish were recovered between Maryland and Massachusetts.

Adult striped bass feed in intervals while schooling (Fay et al., 1983c). They primarily eat smaller fish species such as herring, silversides, and anchovies (Miller, R.W, 1995). Larvae feed primarily on copepods (Miller, R.W, 1995), and stomach contents of juveniles from the Delaware Estuary show mysid shrimp as a favored food item (Bason, 1971).

Adults may live up to 30 years (Atlantic States Marine Fisheries Commission, 2000d), and have been reported at sizes up to 200 cm (79 in) (Froese and Pauly, 2001).

STRIPED BASS
(Morone saxatilis)

Family: Moronidae (temperate basses).

Common names: Striper, rockfish, linesider, and sea bass.[g]

Similar species: White perch.

Geographic range: St. Lawrence River in Canada to the St. Johns River in Florida, and from the Suwannee River in western Florida to Lake Pontchartrain, Louisiana.[a]

Habitat: Juveniles prefer shallow rocky to sandy areas. Adults in inshore areas use a variety of substrates, including rock, boulder, gravel, sand, detritus, grass, moss, and mussel beds.[a]

Lifespan: Adults may reach 30 years.[b]

Fecundity: Females release 14,000 to 40.5 million eggs, depending on the size of the female.[c]

Food sources:
- Larvae feed primarily on mobile planktonic invertebrates (beetle larvae, copepodids *Daphnia* spp.).[a]
- Juveniles eat larger aquatic invertebrates and small fishes.[a]
- Adults are piscivorous. Clupeid fish are the dominant prey and adults prefer soft-rayed fishes.[a]

Prey for: Any sympatric piscivorous fish.[a]

Life stage information:

***Eggs:** pelagic*
- Eggs and newly hatched larvae require sufficient turbulence to remain suspended in the water column; otherwise, they can settle to the bottom and be smothered.[d]

***Larvae:** pelagic*
- Larvae range from 5 to 30 mm (0.2 to 1.2 in).[a]

Juveniles:
- Most striped bass enter the juvenile stage at 30 mm (1.2 in) total length.[d]
- Juveniles school in larger groups after 2 years of age.[d]
- Juveniles in the Delaware River generally remain in estuarine areas for 2 or more years before joining the offshore migratory population.[e]

***Adults*:** Anadromous
- Adults school offshore, but swim upstream to spawn.[f]
- May grow as large as 200 cm (79 in).[g]

Location:
- Estuaries are spawning grounds and nurseries and thus critically important to their life cycle.
- Mature striped bass are found in and around a variety of inshore habitats, including areas off sandy beaches and along rocky shorelines, in shallow water or deep trenches, and in rivers and the open bay.
- St. Lawrence River in Canada to the St. Johns River in Florida, and from the Suwannee River in western Florida to Lake Pontchartrain, Louisiana.
- Migratory behavior is more complex than that of most other anadromous fish. Seasonal movements depend on their age, sex, degree of maturity, and the river in which they were born.
- Mature striped bass move from the ocean into tidal freshwater to spawn in late winter and spring. Spawning generally occurs in April, May, and early June. Shortly after spawning, mature fish return to the coast. Most spend summer and early fall months in middle New England near-shore waters. In late fall and early winter they migrate south off the North Carolina and Virginia capes.

[a] Hill et al., 1989.
[b] Atlantic States Marine Fisheries Commission, 2000d.
[c] Jackson and Tiller, 1952.
[d] Bigelow and Schroeder, 1953.
[e] Miller, R.W, 1995.
[f] Setzler et al., 1980.
[g] Froese and Pauly, 2001.
Fish graphic from NOAA, 2001b.

Weakfish (*Cynoscion regalis*)

Weakfish is a member of the family Sciaenidae (drums), which is considered an important recreational and commercial resource along the Atlantic coast (Seagraves, 1995). Weakfish are found along the eastern seaboard, primarily from Massachusetts Bay to southern Florida (Seagraves, 1995). Adults travel in schools, following a seasonal migratory pattern from offshore wintering grounds in the spring to northern inland estuarine spawning grounds with warming of coastal waters in the spring (Seagraves, 1995). Weakfish spawn in the Delaware Estuary in spring and usually move north as far as Massachusetts for the summer (Shepherd and Grimes, 1984). These same fish over-winter as far south as Cape Hatteras, North Carolina. Weakfish favor shallow waters and sandy bottoms. They typically feed throughout the water column on fish, shrimp, and other small invertebrates (Seagraves, 1995).

Steady declines in weakfish landings since 1980 caused enough concern to prompt the Atlantic States Marine Fisheries Commission to develop a management plan for the species in 1985. In addition, the commission developed three amendments in an attempt to strengthen the management plan; the third amendment called for a 5-year restoration period to bring the weakfish population back to its historical age and size structure. Since 1993, annual landings have steadily increased (Atlantic States Marine Fisheries Commission, 2000f). Weakfish are very popular as a recreational fishing target in Delaware Bay and surrounding coastline. In a survey of Delaware anglers, weakfish was consistently one of the top three species targeted by anglers from 1982 to 1996 (PSEG, 1999). Recreational catches of weakfish in Delaware and New Jersey comprised greater than 70 percent the coastal recreational weakfish catch since 1995 (PSEG, 1999).

Spawning occurs shortly after the inshore migration, peaking from late April to June, with some geographic variation in timing. In the fall, an offshore and southerly migration of adults coincides with declining water temperatures (Atlantic States Marine Fisheries Commission, 2000f). Specific spawning time is correlated with the size of the individual; larger fish tend to spawn earlier (Shepherd and Grimes, 1984), often resulting in a bimodal distribution of size in larvae (Able and Fahay, 1998).

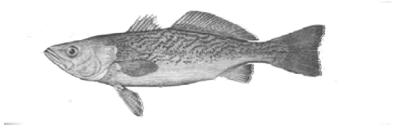
Fecundity of female weakfish varies with locality. A 50 cm (20 in) female weakfish from the New York Bight produced about 306,000 ova, while southern weakfish of the same size produced 2.05 million ova. Southern weakfish reproduce until approximately age 5, while northern weakfish can reproduce longer, meaning that lifetime fecundity would be similar (Shepherd and Grimes, 1984). Shepherd and Grimes (1984) found that females may not release all ova during spawning, and fertility may only be 60-75 percent of the estimated potential fecundity.

Weakfish eggs hatch approximately 50 hours after fertilization. The pelagic larvae hatch at 1.5 to 1.7 mm (0.6 to 0.7 in) in length, and move further upstream during the summer months. Though young-of-year are most abundant in estuarine waters, they have been found in coastal ocean waters and as far upstream as freshwater nurseries. Scales begin to form when larvae are approximately 14.3 mm (5.6 in) or 26 days old. Growth rates vary considerably depending on locality, salinity, and water temperature. Weakfish in the Delaware Bay tableed growth rates from 0.29 mm (0.1 in) per day at 20 ˚C (68 ˚F) to 1.49 mm (0.6 in) per day at 28 ˚C (82 ˚F) (Able and Fahay, 1998).

In the fall, weakfish less than 4 years of age tend to stay inshore and move southward to inner shelf waters, while older weakfish move southward to offshore areas until the spring (Seagraves, 1995).

As with most fish, size upon maturity for weakfish varies with locality. In northern weakfish, females mature at 25.4 cm (10 in), and males at 22.9 cm (9 in); in southern weakfish, both sexes mature at 17.8 cm (7 in). By age 2, all individuals are fully mature (Atlantic States Marine Fisheries Commission, 2000f). Weakfish may obtain a maximum size and age of approximately 80 cm (31.5 in) and 11 years in the northern part of their range (Shepherd and Grimes, 1983).

Weakfish larvae are most abundant near Salem from June to August (PSEG, 1999). Juveniles occur in summer and early fall. Eggs are present in some years, primarily in June and July.



WEAKFISH
(Cynoscion regalis)

Family: Sciaenidae (drums).

Common names: Gray/bastard/saltwater trout, silver seatrout, grey/bastard/common/silver weakfish, chickwick, gray/silver, silver seatrout.[a]

Similar species: Red drum, spot, spotted seatrout, Atlantic croaker.

Geographic Range: Along the Atlantic coast from Florida to Massachusetts, in shallow coastal and estuarine waters.[b] Estuaries provide feeding areas and spawning grounds for adult weakfish and are as important as nursery areas are for juveniles.[c]

Habitat: Occurs over sand and sandy mud bottoms in shallow coastal waters.[c]

Lifespan: Can live up to 11 years.[d]

Fecundity: Reach maturity at approximately 1 year. Fecundity for fish in the New York Bight is about 306,000. Females may not release all ova during spawning, meaning that fertility may be only 60-75 percent of total fecundity.[e]

Food source: Juveniles feed primarily on shrimp and other small invertebrates. Adults consume species such as butterfish, herrings, silversides, anchovies, young weakfish, Atlantic croaker, spot, scup, and killifishes.[f]

Prey for: Bluefish, striped bass, summer flounder, and larger weakfish.[f]

Life stage information:

Eggs:
- Hatch approximately 50 hours after fertilization.[c]

Larvae: *pelagic*
- Larvae are approximately 1.5-1.7 mm (0.6 to 0.7 in) long at hatching.[c]
- Larvae utilize tidal stream transport to move through the water column.[c]

Juveniles:
- Growth rates in the Delaware Bay range from 0.29 mm (0.1 in) per day at 20 ˚C (68 ˚F) to 1.49 mm (0.6 in) per day at 28 ˚C (82 ˚F).[c]
- Juveniles begin to migrate offshore and southward for overwintering in the fall.[c]

Adults:
- Travel in schools, and migrate seasonally from offshore wintering grounds to northern inland estuarine spawning grounds in the spring.[b]
- Adults can reach a maximum total length of 80 cm (31.5 in).[d]

Location:
- The young use the shore margins of the spawning area as nursery grounds.
- From spring through autumn, white perch are present on flats and in channels, retreating to deep channels in the winter.
- They move into waters with low salinity to freshwaters of large rivers in April through June.
- Located in estuaries and freshwater from Nova Scotia to South Carolina.
- Frequent areas with level bottoms of compact silt, mud, sand, or clay and show little preference for vegetation, structures, or other shelter.
- Able to live in salinities from zero to full strength seawater; they prefer waters < 18 percent salinity.

[a] Froese and Pauly, 2001.
[b] Seagraves, 1995.
[c] Able and Fahay, 1998.
[d] Shephard and Grimes, 1983.
[e] Shephard and Grimes, 1984.
[f] Seagraves, 1995.
Fish graphic from NOAA, 2001b.

White perch (*Morone americana*)

White perch is a member of the temperate bass family, Moronidae. Its geographic range extends from the upper St. Lawrence to South Carolina (Able and Fahay, 1998; Scott and Scott, 1988). Adults can be found in a wide range of habitats, but they prefer shallow water during warmer months (Stanley and Danie, 1983). In the winter months, adults can be found in deeper, saline waters (Beck, 1995). At the larval stage, white perch feed mainly on plankton. Adults feed on a variety of prey, including shrimp, fish, and crab. Their diet composition changes with seasonal and spatial food availability (Beck, 1995).

Unlike most other species, white perch has not suffered a drastic population decline in the past century. Because of their abundance, white perch are valuable for commercial fisheries and the recreational fishing industry. Their heartiness and abundance is due to their proliferation, early maturation, ability to utilize a large spawning and nursery ground, and tolerance of poor water quality (Beck, 1995).

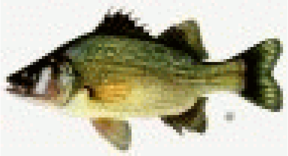
White perch are semi-anadromous, overwintering in deeper estuarine waters and migrating seasonally in the spring to spawn. Spawning occurs from April through early June in shallow waters of upstream brackish and freshwater tributaries. Fecundity estimates are higher for white perch than for other species of similar size, with estimates of 20,000 to 300,000 eggs per female (Stanley and Danie, 1983).

Depending on temperature, larvae hatch out between 2 to 6 days (Able and Fahay, 1998). Larvae are pelagic, remaining slightly below the surface of the water. They enter the juvenile stage in 6 weeks, at 20 to 30 mm (0.8 to 1.2 in) (Able and Fahay, 1998). Juveniles become increasingly demersal with size (Wang and Kernehan, 1979), and school in shallow, inshore waters through the summer. During the fall, juveniles tend to move offshore into more brackish, deeper waters to overwinter (Able and Fahay, 1998).

By age 1, white perch range from 72 to 93 mm (2.8 to 3.7 in). Rates of growth are positively correlated with water temperature during the first year (Able and Fahay, 1998). Most males and females reach maturity at age 2 to 3. Males were reported to mature at 72 mm (2.8 in) and females at 98 mm (3.9 in) (Stanley and Danie, 1983).

Average annual mortality rates for white perch in the Delaware River are 49 to 59 percent for males and 53 to 65 percent for females (Stanley and Danie, 1983). Mortality rates appear to be higher for females because females have higher growth rates and therefore reach a desirable harvest size earlier (Stanley and Danie, 1983). White perch up to 9 years of age have been caught in Delaware Bay (Wallace, 1971).

White perch larvae occur near Salem from April to July, with greatest abundance in April and May (PSEG, 1999). Juveniles occur from October to May. Adults are present throughout the year.



WHITE PERCH
(Morone americana)

Family: Moronidae, temperate bass.

Common names: White perch.[a]

Similar species: Striped bass.

Geographic range: Estuaries and freshwater from the upper St. Lawrence to South Carolina.[b,c]

Habitat: Occurs in fresh, brackish, and coastal waters, but prefers brackish, quieter waters.[a]

Lifespan: To 17 years (to 9 years in Delaware Bay).

Fecundity: Semi-anadromous spawners. Spawning occurs from April to early June in shallow waters of upstream brackish and freshwater tributaries. Females produce 20,000 to 300,000 eggs.[d]

Food source: White perch feed on zooplankton as larvae and juveniles. Adults primarily consume aquatic insects, but also crustaceans and fish, including their own young.[d]

Prey for: Striped bass, bluefish, weakfish, walleye.[a]

Life stage information:

Eggs: *demersal, semipelagic*
- Hatch out between 2 and 6 days.[b]

Larvae: *pelagic*
- Larvae float slightly below the surface of the water.[b]

Juveniles:
- White perch enter the juvenile stage in 6 weeks, at 20 to 30 mm (0.8 to 1.2 in).[b]
- School in shallow, inshore waters through the summer.[b]
- Move offshore to brackish, deeper waters to overwinter.[b]
- Growth rates are positively correlated with temperature during the first year.[b]

Adults:
- Reach maturity at 2 to 3 years of age, and lengths of 72 mm (2.8 in) for most males and 98 mm (3.9 in) for most females.[d]

[a] Froese and Pauly, 2001.
[b] Able and Fahay, 1998.
[c] Scott and Scott, 1988.
[d] Stanley and Danie, 1983.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

D2-4 I&E DATA EVALUATED

Table D2-3 lists Mid-Atlantic facilities in scope of the Phase II rule and the facility I&E data evaluated by EPA to estimate current I&E rates for the region. See Chapter A5 of Part A for a discussion of extrapolation methods.

Table D2-3: I&E Data Evaluated to Estimate Current I&E in the Mid-Atlantic Region

In Scope Facilities	I&E Data?	Years of Data
Astoria (NY)	No - extrapolated	
B L England (NJ)	No - extrapolated	
Baltimore Resco (MD)	No - extrapolated	
E F Barrett (NY)	No - extrapolated	
Bowline (NY)	No - extrapolated	
Brooklyn Navy Yard Cogeneration Partners, L.P. (NY)	No - extrapolated	
C P Crane (MD)	No - extrapolated	
Calvert Cliffs Nuclear (MD)	Yes	1975 - 1995
Chalk Point (MD)	Yes	1976, 1978, 1979
Chesapeake (VA)	No - extrapolated	
Chesterfield (VA)	No - extrapolated	
Danskammer (NY)	No - extrapolated	
Deepwater (NJ)	No - extrapolated	
Edge Moor (DE)	No - extrapolated	
Far Rockaway (NY)	No - extrapolated	
Glenwood (NY)	No - extrapolated	
Gould Street (MD)	No - extrapolated	
Grays Ferry Cogeneration Partnership (PA)	No - extrapolated	
Herbert A Wagner (MD)	No - extrapolated	
Hope Creek Nuclear (NJ)	No - extrapolated	
Hudson (NJ)	No - extrapolated	
Indian Point Nuclear (NY)	Yes	1981 - 1990
Indian Point 3 Nuclear (NY)	No - extrapolated	
Indian River (DE)	Yes	1975 - 1976
Kearny (NJ)	No - extrapolated	
Linden (NJ)	No - extrapolated	
Lovett (NY)	No - extrapolated	
Mercer (NJ)	No - extrapolated	
Morgantown (MD)	Yes	1976
Northport (NY)	No - extrapolated	
Oyster Creek Nuclear (NJ)	No - extrapolated	
Charles Poletti (NY)	No - extrapolated	
Possum Point (VA)	No - extrapolated	
Potomac River (VA)	No - extrapolated	
Ravenswood (NY)	No - extrapolated	
Riverside (MD)	No - extrapolated	
Roseton (NY)	No - extrapolated	
Salem Nuclear (NJ)	Yes	1978 - 1998
Sayreville (NJ)	No - extrapolated	

Table D2-3: I&E Data Evaluated to Estimate Current I&E in the Mid-Atlantic Region

In Scope Facilities	I&E Data?	Years of Data
Sewaren (NJ)	No - extrapolated	
Sparrows Point Div Bethlehem Steel Corp (MD)	No - extrapolated	
Surry Nuclear (VA)	No - extrapolated	
Westchester Resco Co., L.P. (NY)	No - extrapolated	
Yorktown (VA)	No - extrapolated	

D2-5 EPA'S ESTIMATE OF CURRENT I&E IN THE MID-ATLANTIC REGION EXPRESSED AS AGE 1 EQUIVALENTS, FOREGONE YIELD, AND PRODUCTION FOREGONE

Table D2-4 provides EPA's estimate of the annual age 1 equivalents, foregone fishery yield, and production foregone resulting from the impingement of aquatic species at facilities located in the Mid-Atlantic region. Table D2-5 displays this information for entrainment. Note that in these tables, "total yield" includes direct losses of harvested species and the yield of harvested species that is lost due to losses of forage species. As discussed in detail in Chapter A5 of Part A of the section 316(b) Phase II Regional Study Document, the conversion of forage to yield contributes only a very small fraction to total yield.

Table D2-4: Current Annual Impingement in the Mid-Atlantic Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species	Age 1 Equivalents (#s)	Total Yield (lbs)	Production Foregone
Alewife	36,730	328	6,357
American shad	61	15	37
Atlantic croaker	1,548,681	315,292	222,691
Atlantic menhaden	167,155,354	32,499,546	21,439,964
Atlantic tomcod	7	0	1
Bay anchovy	37,370,733	0	50,156
Blue crab	12,883,412	93,769	888,043
Blueback herring	123,460	0	32,122
Hogchoker	1,215,841	0	549
Naked goby	19,768	0	4
Other (commercial)	2,921,928	568,102	374,777
Other (forage)	12,141,704	0	18,004
Other (recreational and commercial)	1,736,708	337,663	338,614
Other (recreational)	195,864	38,081	25,122
Spot	18,299,940	2,049,584	1,235,941
Striped bass	199,780	277,288	311,016
Summer flounder	126,268	177,517	7,984
Weakfish	827,030	650,200	537,233
White perch	23,360,666	10,280	1,472,639
Windowpane	657	61	30
Winter flounder	116,962	12,594	7,557

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Table D2-5: Current Annual Entrainment in the Mid-Atlantic Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone.

Species	Age 1 Equivalents (#s)	Total Yield (lb)	Production Foregone
Alewife	4,562	41	7,022
American shad	14,018	3,431	75,968
Atlantic croaker	41,156,879	8,379,019	15,509,049
Atlantic menhaden	6,411,986	1,246,665	356,167
Bay anchovy	937,050,082	0	4,579,187
Blue crab	219,544,794	1,597,900	14,179,364
Blueback herring	19,029	0	21,796
Hogchoker	6,779,081	0	17,520,451
Naked goby	102,950,816	0	1,845,772
Other (commercial)	30,744	5,977	70,610
Other (forage)	17,891,263	0	161,470
Other (recreational and commercial)	20,811,436	4,046,309	5,128,817
Spot	70,646,917	7,912,419	10,755,819
Striped bass	1,579,532	2,192,332	7,460,609
Weakfish	2,993,309	2,353,300	2,813,383
White perch	24,541,655	10,799	1,918,290
Winter flounder	431,307	46,442	1,530,530

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D2-6 ASSUMPTIONS USED IN CALCULATING RECREATIONAL AND COMMERCIAL LOSSES

The lost yield estimates presented in Tables D2-4 and D2-5 are expressed as total pounds and include losses to both commercial and recreational catch. To estimate the economic value of these losses, total yield was partitioned between commercial and recreational fisheries based on the landings in each fishery. Table D2-6 presents the percentage impacts assumed for each species and the value per pound for commercially harvested species.

Age-1 equivalent fish that are spared from I&E are not necessarily old enough or large enough to be attractive to anglers. It may take one or more years for these fish to reach a harvestable age. For this reason, EPA discounts commercial and recreational benefits so that the cost and benefits estimates will be comparable. Tables D2-7 and D2-8 present the multiplicative discounting factors used in discounting benefits assuming a 3 percent real discount rate and a 7 percent real discount rate. For details on how these factors are developed, see Chapter A14.

Table D2-6: Percentage of Total Impacts Occurring to the Commercial and Recreational Fisheries and Commercial Value per Pound for Species Impinged and Entrained at Mid-Atlantic Facilities

Species Group	Percent Impact to Recreational Fishery[a,b]	Percent Impact to Commercial Fishery[a,b]	Commercial Value per Pound (2002$)[c]
Alewife	0.0%	100.0%	$0.11
American shad	0.0%	100.0%	$0.61
Atlantic croaker	66.4%	33.6%	$0.33
Atlantic herring	19.0%	81.0%	$0.08
Atlantic menhaden	0.0%	100.0%	$0.07
Blue crab	0.0%	100.0%	$0.76
Other (commercial)	0.0%	100.0%	$0.53
Other (recreational)	100.0%	0.0%	na
Other (recreational and commercial)	50.0%	50.0%	$0.53
Spot	52.4%	47.6%	$0.43
Striped bass	95.5%	4.5%	$1.69
Summer flounder	88.0%	12.0%	$1.55
Weakfish	77.2%	22.8%	$0.66
White perch	66.0%	34.0%	$0.60
Windowpane	0.0%	100.0%	$0.37
Winter flounder	63.0%	37.0%	$1.20
Other (forage)[d]	50.0%	50.0%	$0.39

[a] Based on landings from 1993 to 2001.

[b] Calculated using recreational landings data from NMFS (2003a, http://www.st.nmfs.gov/recreational/queries/catch/snapshot.html) and commercial landings data from NMFS (2003b, http://www.st.nmfs.gov/commercial/landings/annual_landings.html).

[c] Calculated using commercial landings data from NMFS (2003b).

[d] Assumed equally likely to be caught by recreational or commercial fishermen. Commercial value calculated as overall average for region based on data from NMFS (2003b).

Table D2-7: Factors Applied to Recreational Benefits to Implement Discounting in the Mid-Atlantic

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Atlantic croaker	0.934	0.858	0.962	0.918
Other (recreational)	na	na	0.950	0.889
Other (recreational and commercial)	0.922	0.831	0.950	0.889
Spot	0.949	0.888	0.977	0.950
Striped bass	0.864	0.717	0.879	0.749
Summer flounder	na	na	0.941	0.874
Weakfish	0.950	0.890	0.979	0.953
White perch	0.900	0.786	0.904	0.796
Windowpane	0.884	0.759	na	na
Winter flounder	na	na	0.911	0.812
Other (forage)	0.919	0.829	0.919	0.829

Table D2-8: Factors Applied to Commercial Benefits to Implement Discounting in the Mid-Atlantic

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Alewife	0.872	0.730	0.898	0.782
American shad	0.867	0.723	0.893	0.773
Atlantic croaker	0.899	0.788	0.926	0.843
Atlantic menhaden	0.930	0.847	0.958	0.906
Blue crab	0.949	0.888	0.978	0.950
Other (commercial)	0.913	0.813	0.940	0.870
Other (recreational and commercial)	0.913	0.813	0.940	0.870
Spot	0.921	0.831	0.949	0.889
Striped bass	0.841	0.675	0.848	0.692
Summer flounder	na	na	0.890	0.773
Weakfish	0.924	0.836	0.951	0.895
White perch	0.895	0.777	0.899	0.785
Windowpane	na	na	0.883	0.756
Winter flounder	0.859	0.711	0.885	0.761
Other (forage)	0.901	0.793	0.901	0.793

Chapter D3: Commercial Fishing Valuation

INTRODUCTION

This chapter presents the results of the commercial fishing benefits analysis for the Mid-Atlantic region. Section D3-1 details the estimated losses under current, or baseline, conditions. Section D3-2 presents the expected benefits in the region attributable to the rule. Chapter A10 details the methods used in this analysis.

CHAPTER CONTENTS

Note that all results have been sample weighted in this version. In the final revision results will be reported unweighted.

D3-1 BASELINE LOSSES

Table D3-1 provides EPA's estimate of the value of gross revenues lost in commercial fisheries resulting from the impingement of aquatic species at facilities in the Mid-Atlantic region. Table D3-2 displays this information for entrainment. Total annual revenue losses are approximately $8.4 million, assuming a 3 percent discount rate.

Table D3-1: Annual Commercial Fishing Gross Revenues Lost Due to Impingement at Facilities in the Mid-Atlantic Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002 dollars)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
Alewife	328	36	32	28
American shad	15	9	8	7
Atlantic croaker	106,026	33,921	31,426	28,585
Atlantic menhaden	32,499,546	2,106,126	2,016,725	1,908,528
Blue crab	93,769	69,777	68,209	66,264
Other (commercial)	568,102	296,446	278,800	257,851
Other (rec. and com.)	168,832	88,099	82,855	76,629
Spot	976,498	411,804	390,726	366,202
Striped bass	12,591	20,911	17,743	14,461
Summer flounder	21,279	32,232	28,672	24,904
Weakfish	148,021	95,423	90,774	85,387
White perch	3,494	2,067	1,858	1,622
Windowpane	61	22	20	17
Winter flounder	4,663	5,466	4,835	4,158
Other unidentified species (from forage losses)	5,699	2,182	1,965	1,730
TOTAL	34,608,925	3,164,522	3,014,650	2,836,373

Table D3-2: Annual Commercial Fishing Gross Revenues Lost Due to Entrainment at Facilities in the Mid-Atlantic Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002 dollars)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
Alewife	41	4	4	3
American shad	3,431	2,042	1,771	1,476
Atlantic croaker	2,817,684	901,465	810,842	709,973
Atlantic menhaden	1,246,665	80,790	75,107	68,421
Blue crab	1,597,900	1,189,060	1,128,495	1,055,323
Other (commercial)	5,977	3,119	2,848	2,536
Other (rec. and com.)	2,023,155	1,055,717	963,959	858,198
Spot	3,769,772	1,589,771	1,464,464	1,321,236
Striped bass	99,549	165,330	139,056	111,601
Weakfish	535,741	345,368	318,975	288,828
White perch	3,671	2,172	1,944	1,687
Winter flounder	17,197	20,156	17,311	14,330
Other unidentified species (from forage losses) (secondary)	1,963,709	751,707	676,967	595,959
TOTAL	14,084,491	6,106,702	5,601,742	5,029,570

D3-2 BENEFITS

As described in Chapter A10, EPA estimates that 0 to 40 percent of the gross revenue losses represent surplus losses to producers, assuming no change in prices or fishing costs. The 0 percent estimate, of course, results in loss estimates of $0. The 40 percent estimates, as presented in the Table D3-3, total approximately $3.3 million when a 3 percent discount rate is assumed.

The expected reductions in I&E attributable to changes at facilities required by the rule are 53.5 percent for impingement and 47.9 percent for entrainment. Total annual benefits are estimated by applying these estimated reductions to the annual producer surplus loss. As presented in Table D3-3, this results in total annual benefits of $1.7 million, assuming a 3 percent discount rate.

Table D3-3: Annual Commercial Fishing Benefits Attributable to Phase II Rule at Facilities in the Mid-Atlantic Region (million 2002$), Assumes Compliance in 2005

	Impingement	Entrainment	Total
Baseline loss - gross revenue			
Undiscounted	$3.2	$6.1	$9.3
3% discount rate	$2.9	$5.4	$8.4
7% discount rate	$2.6	$4.7	$7.3
Producer surplus lost - low	**$0.0**	**$0.0**	**$0.0**
Producer surplus lost - high (gross revenue * 0.4)			
Undiscounted	$1.3	$2.4	$3.7
3% discount rate	$1.2	$2.2	$3.3
7% discount rate	$1.1	$1.9	$2.9
Expected reduction due to rule[a]	53.5%	47.9%	---
Benefits attributable to rule - low	**$0.0**	**$0.0**	**$0.0**
Benefits attributable to rule - high			
Undiscounted	$0.7	$1.2	$1.8
3% discount rate	$0.6	$1.0	$1.7
7% discount rate	$0.6	$0.9	$1.5

[a] Estimated based on EPA's assumptions. EPA's assumption about the amount of electricity that will be produced in the future differs very slightly from DOE's. For the Mid-Atlantic region the EPA and DOE estimates are the same.

Chapter D4: RUM Analysis

INTRODUCTION

This case study uses a random utility model (RUM) approach to estimate the effects of improved fishing opportunities due to reduced impingement and entrainment (I&E) in the Mid-Atlantic region. The Mid-Atlantic region, as defined by the National Marine Fisheries Service (NMFS), includes NMFS fishing intercept sites along the Atlantic coasts of New York, New Jersey, Delaware, Maryland and Virginia; Chesapeake Bay sites in Delaware, Virginia, and Maryland; and Delaware Bay sites in Delaware and New Jersey. The RUM includes anglers from Virginia, Maryland, Delaware, New Jersey, New York, the District of Columbia, and Pennsylvania.

Cooling Water Intake Structures (CWIS) withdrawing water in the Mid-Atlantic region impinge and entrain many of the species sought by recreational anglers. EPA included the following species and species groups in the model: striped bass, bluefish, flatfish, weakfish, small game fish, big game fish, bottom fish. Some of these species (e.g., weakfish, flatfish, striped bass) inhabit a wide range of coastal waters spanning several states (e.g., striped bass range from North Carolina to Maine). Therefore, increased fish mortality from I&E in the Mid-Atlantic region may affect recreational fishing from North Carolina to Maine.

CHAPTER CONTENTS

The study's main assumption is that, all else being equal, anglers will get greater satisfaction, and thus greater economic value, from sites with a higher catch rate. This benefit may occur in two ways: first, an angler may get greater enjoyment from a given fishing trip with higher catch rates, yielding a greater value per trip; second, anglers may take more fishing trips when catch rates are higher, resulting in greater overall value for fishing in the region.

The following sections focus on the data set used in the Mid-Atlantic analysis and analytic results. Chapter A11 of this report provides a detailed description of the RUM methodology used in this analysis.

D4-1 DATA SUMMARY

EPA's analysis of improvements in recreational fishing opportunities in the Mid-Atlantic region relies on the NMFS Marine Recreational Fishery Statistics Survey (MRFSS), combined with the 1994 Add-on MRFSS Economic Survey (NMFS, 2003b; QuanTech, 1998).[1] The model of recreational fishing behavior relies on the subset that includes only single-day trips for boat and shore anglers. In addition, the sample excludes respondents missing data on key variables (e.g., home town). The Agency did not include charter boat anglers in the model. As explained further below, the welfare gain to charter boat anglers from improved catch rates is approximated based on the regression coefficients developed for the boat anglers. Additionally, values for single-day trips were used to value each day of a multi-day trip. The final sample used to estimate the RUM model includes 12,102 boat and shore anglers.

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[1] For general discussion of the MRFSS, see Chapter A11 of the Regional Study Report or Marine Recreational Fisheries Statistics: Data User's Manual, http://www.st.nmfs.gov/st1/recreational/pubs/data_users/index.html (NMFS, 1999a).

D4-1.1 Summary of Anglers' Characteristics

a. Fishing modes and targeted species

A majority of the interviewed anglers (56 percent) fish from either a private or a rental boat (see Table D4-1). Approximately 23 percent fish from the shore; the remaining 21 percent fish from a party or charter boat. In addition to the mode of fishing, the MRFSS contains information on the specific species targeted on the current trip. Approximately 19 percent of anglers did not have a designated target species. The most popular species, targeted by 31 percent of anglers, is flatfish, which includes summer and winter flounder. The second most popular species, targeted by 14 percent of anglers, is striped bass. Of the remaining anglers, thirteen, eleven, six, four, and two percent target bottom fish, bluefish, other small game fish, weakfish, and big game fish, respectively.[2]

Table D4-1: Species Group Choice by Mode of Fishing

Species	All Modes		Private/Rental Boat		Party/Charter Boat		Shore	
	Frequency	Percent	Frequency	Percent by Mode	Frequency	Percent by Mode	Frequency	Percent by Mode
No Target	2,894	19.00%	1,423	16.58%	455	14.56%	1,016	28.89%
Striped Bass	2,066	13.57%	1,316	15.33%	291	9.31%	459	13.05%
Bluefish	1,634	10.73%	654	7.62%	488	15.61%	492	13.99%
Flatfish	4,786	31.43%	3,183	37.08%	665	21.27%	938	26.67%
Weakfish	561	3.68%	434	5.06%	47	1.50%	80	2.27%
Big Game Fish	296	1.94%	139	1.62%	157	5.02%	0	0.00%
Bottom Fish	2001	13.14%	1002	11.67%	629	20.12%	370	10.52%
Other Small Game Fish	988	6.49%	434	5.06%	394	12.60%	160	4.55%
All Species	15,228	100.00%	8,585	56.38%	3,126	20.53%	3,517	23.10%

Source: NMFS, 2003b.

The distribution of target species is not uniform by fishing mode. Flatfish is the most popular species group for all modes, targeted by 37 percent of private/rental boat anglers, 27 percent of shore anglers, and 21 percent of charter/party boat anglers. While 29 percent of shore anglers do not target a particular species, 17 percent of private/rental boat anglers did not target, and 15 percent of charter boat anglers did not target. The second most popular species for private/rental boat anglers is striped bass (targeted by 15 percent), followed by bottom fish (12 percent), bluefish (8 percent), other small game fish (5 percent), weakfish (5 percent), and big game fish (2 percent). Shore anglers' second favorite target species is bluefish (targeted by 14 percent), followed by striped bass (13 percent), bottom fish (11 percent), other small game fish (5 percent), and weakfish (2 percent). Twenty percent of charter boat anglers target bottom fish, followed by bluefish (16 percent), other small game fish (13 percent), striped bass (9 percent), big game fish (5 percent), and weakfish (2 percent).

b. Anglers' characteristics

This section presents a summary of angler characteristics for the Mid-Atlantic region, as defined above. For this data comparison, the study uses both the observations valid for the site choice model and those valid for the trip participation model. Those valid for the trip participation model include only anglers who responded to the economic add-on survey. The following trip profile information relies on the 12,102 site choice observations for boat and shore anglers, of which 3,779 responded to key questions in the economic add-on survey, and therefore are also valid for the trip participation model. Table

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[2] Bottom fish includes dogfish sharks, catfish, white perch, white bass, black sea basses, scup, drums, spot, northern kingfish, Atlantic croaker, tautog, and codfish. Big game fish includes mako and blue sharks, dolphin, billfish, and tuna. Other small game fish include jacks, snappers, seatrout, mackerels, basses, and Atlantic bonito.

D4-2 summarizes characteristics of the sample of private/rental boat and shore anglers fishing at NMFS sites in the Mid-Atlantic region.

The average income of the respondent anglers was $47,992, with 88 percent having reported their household income. Ninety percent of the anglers are white, with an average age of about 46 years. Educational attainment information indicates that only 16 percent have a college degree. The average household size was 2.97 individuals. Twenty percent of the anglers are retired, while 73 percent are employed. Sixty-three percent of the anglers indicated that they had flexible time when setting their work schedule.

Table D4-2 shows that on average anglers spent 34 days fishing during the past year. The average duration of a fishing trip was 4.3 hours per day. Anglers made an average of 6.2 trips to the intercept site. The average round trip travel cost was $19.51 (1994$),[3] and the average travel time to and from the visited site was 1.6 hours. Fifty-nine percent of Mid-Atlantic anglers own their own boat. Finally, the average number of years of fishing experience was 24. This analysis does not include anglers under the age of 16, which may result in overestimation of the average age of recreational anglers and years of experience.

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[3] All costs are in 1994$ because that was the MRFSS survey year. All costs and benefits will be updated to 2002$ later in this analysis (i.e., for welfare estimation).

Table D4-2: Data Summary for the Mid-Atlantic Coast Anglers

Variable	All Modes					Private/Rental Boat					Shore				
	N	Mean[a]	Std Dev	Min	Max	N	Mean[a]	Std Dev	Min	Max	N	Mean[a]	Std Dev	Min	Max
Trip Cost	12,102	$19.51	$22.23	$0.29	$544.69	8,585	$19.49	$22.55	$0.29	$544.69	3,517	$19.56	$21.63	$0.29	$231.07
Travel Time	12,102	1.59	1.68	0	19.92	8,585	1.58	1.66	0	14.99	3,517	1.61	1.73	0	19.92
Visits	3,186	6.24	8.71	0	62	2,397	6.00	8.05	0	62	789	6.99	10.42	0	62
Hours Fished	12,093	4.30	2.08	0.5	24	8,577	4.52	1.92	0.5	20	4	3.76	2.34	0.5	24
Own a Boat	3,830	0.59	0.49	0	1	2,824	0.73	0.44	0	1	1,006	0.21	0.40	0	1
College Degree	3,800	0.16	0.37	0	1	2,801	0.16	0.37	0	1	999	0.16	0.37	0	1
Retired	3,817	0.20	0.40	0	1	2,817	0.19	0.39	0	1	1,000	0.22	0.41	0	1
Employed	3,817	0.73	0.44	0	1	2,817	0.75	0.43	0	1	1,000	0.67	0.47	0	1
Age	3,788	45.64	14.34	16	91	2,796	45.86	13.92	16	91	992	45.02	15.48	16	85
Years Fishing	3,925	23.96	15.78	1	99	2,900	24.63	15.53	1	88	1,025	22.07	16.32	1	99
Household Size	3,810	2.97	1.37	1	20	2,812	2.98	1.31	1	17	998	45.02	15.48	1	20
Flexible Time	2,749	0.63	0.48	0	1	2,090	0.64	0.48	0	1	659	0.62	0.49	0	1
Male	3,832	0.89	0.32	0	1	2,826	0.90	0.30	0	1	1,006	0.86	0.35	0	1
White	3,781	0.90	0.30	0	1	2,797	0.93	0.25	0	1	984	0.81	0.39	0	1
Household Income	3,391	$47,992	$27,169	$7,500	$165,000	2,488	$50,532	$27,358	$7,500	$165,000	903	$40,994	$25,372	$7,500	$165,000
Annual trips	12,102	34.30	45	1	365	8,585	32.16	37.58	0	301	3,517	39.53	58.34	0	365

[a] For dummy variables such as “Own a Boat” that take the value of 0 or 1, the reported value represents a portion of the survey respondents possessing the relevant characteristic. For example, 59 percent of the surveyed anglers own a boat.

Source: NMFS, 2003b.

D4-1.2 Recreational Fishing Choice Sets

The NMFS survey intercept sites included in the analysis are depicted in Chapter D1 of this report (see Figure D1-1). Table D4-3 summarizes the 790 NMFS intercept sites in the Mid-Atlantic region. For the RUM model, each angler's choice set included up to 74 sites: 37 boat sites and 37 shore sites.[4] Boat and shore sites were determined by whether boat or shore anglers had been intercepted at a particular site. Each angler's choice set included his chosen site, plus a randomly selected set of up to 73 additional sites within 120 miles of his home zip code. Distances from unique zip codes to each of the NMFS sites were estimated using ArcView 3.2a software. Anglers' complete choice sets were determined based on their geographical location, using the following criteria:[5]

- New York and New Jersey anglers were assumed to fish at sites in New York or New Jersey.
- Pennsylvania anglers were assumed to fish at any location in the region.
- Northern and central Delaware anglers were assumed to fish only in Delaware.
- Sussex County, Delaware anglers were assumed to fish in Delaware, the three southeastern Maryland counties, and the northern Virginia peninsula.
- Anglers from the eastern shore area of Maryland were assumed to fish at locations in the eastern shore region, Delaware, and the northern Virginia peninsula.
- Cecil County, Maryland anglers were assumed to fish at all sites except New York and New Jersey sites.
- Anglers from the three western Maryland shore counties, nine northern Virginia counties, and Washington, D.C. were assumed to fish along the western shore of the Chesapeake, two counties on the eastern shore in proximity to the Chesapeake Bay Bridge, Sussex County, Delaware, Worcester County Maryland, and anywhere in Virginia.
- Anglers from Maryland counties on the western shore of the Chesapeake were assumed to fish either in those Maryland counties or at sites in Virginia (excluding the northern peninsula).
- Anglers from the Virginia peninsula were assumed to fish at sites on the peninsula.
- Anglers from the 26 southeastern Virginia counties were assumed to fish anywhere in Virginia.
- Anglers from the remaining Virginia counties were assumed to fish only at mainland Virginia sites (excluding the peninsula).

The above criteria were developed based on the analysis of visited sites.

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[4] The total number of sites per angler was restricted to 74 to be compatible with LIMDEP's model specifications.

[5] These criteria were developed based on where anglers in the data set actually fished and geographical restrictions (e.g., we assumed that anglers would not cross large water bodies such as Delaware Bay to fish).

Table D4-3: Number and Description of Sites (by State)

State of Intercept	County of Intercept	Waterbody[a]	Number of Sites	Number of Observations	Percent of Sample
New York	Kings County	Atlantic Coast	12	161	1.33
New York	Nassau County	Atlantic Coast	61	1,330	10.99
New York	Queens County	Atlantic Coast	7	76	0.63
New York	Richmond County	Atlantic Coast	12	131	1.08
New York	Suffolk County	Atlantic Coast	220	2,286	18.89
New York	Westchester County	Atlantic Coast	20	103	0.85
New Jersey	Atlantic County	Atlantic Coast	33	306	3.42
New Jersey	Cape May County	Atlantic Coast, Delaware Bay	48	503	5.63
New Jersey	Cumberland County	Delaware Bay	8	81	0.91
New Jersey	Hudson County	Hudson River, East River	2	24	0.27
New Jersey	Middlesex County	Chesapeake Bay	4	34	0.38
New Jersey	Monmouth County	Atlantic Coast	30	1026	11.48
New Jersey	Ocean County	Atlantic Coast	45	531	5.94
Delaware	Kent County	Atlantic Coast, Delaware Bay	7	364	4.07
Delaware	New Castle County	Delaware Bay	8	180	2.01
Delaware	Sussex County	Atlantic Coast, Delaware Bay	26	1051	11.75
Maryland	Anne Arundel County	Chesapeake Bay	7	368	4.12
Maryland	Baltimore County	Chesapeake Bay	11	364	4.07
Maryland	Calvert County	Chesapeake Bay	7	127	1.42
Maryland	Cecil County	Chesapeake Bay	7	16	0.18
Maryland	Charles County	Chesapeake Bay	5	2	0.02
Maryland	Dorchester County	Chesapeake Bay	5	38	0.43
Maryland	Harford County	Chesapeake Bay	11	32	0.36
Maryland	Queen Annes County	Chesapeake Bay	5	24	0.27
Maryland	Somerset County	Chesapeake Bay	8	75	0.84
Maryland	St Marys County	Chesapeake Bay	6	76	0.85
Maryland	Talbot County	Chesapeake Bay	10	54	0.6
Maryland	Wicomico County	Chesapeake Bay	3	30	0.34
Maryland	Worcester County	Atlantic Coast	18	181	2.02
Virginia	Accomack County	Atlantic Coast, Chesapeake Bay	30	235	2.63
Virginia	Essex County	Chesapeake Bay	3	27	0.3
Virginia	Gloucester County	Chesapeake Bay	4	205	2.29

Table D4-3: Number and Description of Sites (by State)

State of Intercept	County of Intercept	Waterbody[a]	Number of Sites	Number of Observations	Percent of Sample
Virginia	Isle of Wight County	Chesapeake Bay	2	10	0.11
Virginia	James City County	Chesapeake Bay	3	14	0.16
Virginia	Lancaster County	Chesapeake Bay	2	3	0.03
Virginia	Mathews County	Chesapeake Bay	4	37	0.41
Virginia	Middlesex County	Chesapeake Bay	10	59	0.66
Virginia	Northampton County	Atlantic Coast, Chesapeake Bay	10	147	1.64
Virginia	Northumberland County	Chesapeake Bay	7	21	0.23
Virginia	Richmond County	Chesapeake Bay	3	12	0.13
Virginia	Suffolk City	Chesapeake Bay	4	20	0.22
Virginia	Surry County	Chesapeake Bay	5	17	0.19
Virginia	Virginia Beach City	Chesapeake Bay	6	967	10.82
Virginia	Westmoreland County	Chesapeake Bay	10	18	0.2
Virginia	York County	Chesapeake Bay	6	243	2.72
Virginia	Hampton City	Chesapeake Bay	10	374	4.18
Virginia	Newport News City	Chesapeake Bay	2	530	5.93
Virginia	Norfolk City	Chesapeake Bay	2	514	5.75
Virginia	Poquoson City	Chesapeake Bay	21	1	0.01

[a] Waterbody represents location of the sites included in each county: Atlantic Coast, Delaware Bay, or Chesapeake Bay. Some counties have sites at more than one waterbody.

Sources: NMFS, 2003b; and U.S. EPA analysis for this report.

D4-1.3 Site Attributes

This analysis assumes that the angler chooses between site alternatives based on catch rates at the sites. Catch rate is the most important attribute of a fishing site from the angler's perspective (McConnell and Strand, 1994; Haab et al., 2000). This attribute is also a policy variable of concern because catch rate is a function of fish abundance, which is affected by fish mortality due to I&E. The catch variable in the RUM therefore provides the means to measure baseline losses in I&E and changes in anglers' welfare attributed to changes from I&E due to the final section 316(b) rule.

To specify the fishing quality of the case study sites, EPA calculated historic catch rate based on the NMFS catch rates for the years 1990 to 1994 for recreationally important species: flatfish, striped bass, bluefish, and weakfish (McConnell and Strand, 1994). Other species of interest (e.g., white perch, Atlantic croaker, American shad, and spot) did not produce enough observations to permit a RUM analysis. EPA therefore bundled all other species into three aggregate groups — big game fish, bottom fish, and other small game fish — and calculated group-specific catch rates. No sample anglers targeted species in the "other fish" category (i.e., eel). The bottom fish, big game, and other small game groups include the following species:

- ***Bottom fish***: codfish, dogfish sharks, catfish, white perch, black sea basses, scup, drums, northern kingfish, tautog, Atlantic croaker, and spot;
- ***Big game***: mako shark, blue shark, bluefin and yellowfin tuna, billfish, and dolphin; and
- ***Other small game fish***: jacks, snappers, seatrout, mackerels, basses.

The catch rates represent the number of fish caught on a fishing trip divided by the number of hours spent fishing (i.e., the number of fish caught per hour per angler). The estimated catch rates are averages across all anglers in a given year over the five-year period.

The catch rate variables include total catch, including fish caught and kept and fish released. Some NMFS studies use the catch-and-keep measure as the relevant catch rate. Although a greater error may be associated with measured number of fish not kept, the total catch measure is most appropriate because a large number of anglers catch and release fish. The total catch rate variables include both targeted fish catch and incidental catch. For example, striped bass catch rates include fish caught by striped bass anglers and anglers who don't target any particular species. This method may underestimate the average historic catch rate for a given site because anglers not targeting particular fish species are usually less experienced and may not have the appropriate fishing gear. EPA considered using targeted species catch rates for this analysis, but discovered that this approach did not provide a sufficient number of observations per fishing zone to allow estimation of catch rates for all fishing sites included in the analysis.

For anglers who don't target any species, EPA used average catch rates for each site, for all species caught by no-target anglers, by mode, to characterize fishing quality. The MRFSS provided information on species caught for 3,820 no-target anglers. Of those, 56 percent caught bottom fish; 20 percent caught small game fish (i.e., striped bass, weakfish, bluefish, or other small game); 10 percent caught flatfish; and 1 percent caught big game fish. The remaining 13 percent caught other fish species.

Anglers who target particular species generally catch more fish in the targeted category because of specialized equipment and skills than anglers who don't target these species. Of the boat anglers who target particular species, bottom fish anglers catch the largest number of fish per hour, followed by anglers who catch flounder, bluefish, weakfish, striped bass, other small game fish, and big game fish. Of the shore anglers who target particular species, bottom fish anglers catch the largest number of fish per hour, followed by anglers who catch bluefish, striped bass, flounder or weakfish, other small game fish, and big game fish. Table D4-4 summarizes average catch rates by species for all sites in the study area.

Table D4-4: Average Catch Rate by Species/Species Group for the Mid-Atlantic Coast Sites by Mode of Fishing

Species/Species Group	Average Catch Rate (fish per angler per hour)			
	All Sites		Sites with Non Zero Catch Rates	
	Private/Rental Boat	Shore	Private/Rental Boat	Shore
Striped Bass	0.12	0.10	0.63	0.75
Weakfish	0.09	0.04	0.65	0.70
Flounder	0.27	0.12	0.84	0.70
Bluefish	0.20	0.25	0.75	1.30
Bottom Fish	0.41	0.32	1.15	1.31
Big Game Fish	0.04	N/A	0.39	N/A
Small Game Fish	0.07	0.04	0.58	0.59

Source: NMFS, 2002e.

Some RUM studies have used predicted, rather than actual, catch rates (Haab et al., 2000; Hicks et al., 1999; McConnell and Strand, 1994). This practice allows for individual characteristics to affect catch rates; for example, anglers with different levels of experience may have different catch rates. Haab et al. (2000) compared historic catch-and-keep rates to predicted catch-and-keep rates and found that historic catch-and-keep rates were a better measure of site quality. The authors also found that the choice of catch rate had little effect on the travel cost parameters. Hicks et al. (1999) found that using historic catch rates resulted in more conservative welfare estimates than predicted catch rate models. Consequently, EPA favored this more conservative approach.

D4-1.4 Travel Cost

EPA used ArcView 3.2a software to estimate distances from the household zip code to each NMFS fishing site in the individual opportunity sets. The Agency obtained fishing site locations from the Master Site Register supplied by NMFS. The Master Site Register includes both a unique identifier that corresponds to the visited site identifier used in the angler survey, and latitude and longitude coordinates. For some sites the latitude and longitude coordinates were missing or demonstrably incorrect, in which case the town point, as identified in the U.S. Geological Survey (USGS) Geographic Names Information System, was used as the site location if a town was reported in the site address. The program measured the distance in miles of the shortest route, using state and U.S. highways, from the household zip code to each fishing site, then added the distances from the zip code location to the closest highway and from the site location to the closest highway. The average one way distance to the visited site for boat and shore anglers is 32.4 miles. Private/rental boat anglers traveled an average of 32.2 miles to the chosen site, while shore anglers traveled an average of 32.8 miles.

EPA estimated trip "price" as the sum of travel costs plus the opportunity cost of time following the procedure described in Haab et al. (2000). Based on Parsons and Kealy (1992), this study assumed that time spent "on-site" is constant across sites and can be ignored in the price calculation. To estimate consumers' travel costs, EPA multiplied round trip distance by average motor vehicle cost per mile ($0.29, 1994 dollars).[6] To estimate the opportunity cost of travel time, EPA first divided round trip distance by 40 miles per hour to estimate trip time, and used the household's wage to yield the opportunity cost of time. EPA estimated household wage by dividing household income by 2,080 (i.e., the number of full time hours potentially worked).

Only those respondents who reported that they lost income during the trip (*LOSEINC*=1) are assigned a time cost in the trip cost variable. Information on the *LOSEINC* variable was available only for a subset of survey respondents who participated in the follow-up telephone interviews. Only 191 respondents reported that they lost income. Given that only a small number of survey respondents reported lost income, EPA assumed that the remaining 11,911 anglers did not lose income during the trip. EPA calculated visit price as:

$$Visit\ Price = \begin{cases} Round\ Trip\ Distance \times \$.29 + \dfrac{Round\ Trip\ Distance}{40\ mph} \times (Wage) & If\ LOSEINC = 1 \\ Round\ Trip\ Distance \times \$.29 & If\ LOSEINC = 0 \end{cases} \tag{D4-1}$$

For those respondents who do not lose income, the time cost is accounted for in an additional variable equal to the amount of time spent on travel. EPA therefore estimated time cost as the round trip distance divided by 40 mph:

$$Travel\ Time = \begin{cases} Round\ Trip\ Distance/40 & If\ LOSEINC = 0 \\ 0 & If\ LOSEINC = 1 \end{cases} \tag{D4-2}$$

EPA used a log-linear ordinary least square regression model to estimate wage rates for anglers who did not report their income. The estimated regression equation used in wage calculation is :

$$\begin{aligned} Ln(Income) &= 0.132 \times male + 0.179 \times white + 0.037 \times age - 0.0004 \times age^2 + 0.317 \times employed \\ &+ 0.177 \times boatown - 0.222 \times low\text{-}ed + 0.263 \times high\text{-}ed + 0.883 \log\ (stinc) \end{aligned} \tag{D4-3}$$

where:

Income = the reported household income;
Male = 1 for males;
White = 1 for white;
Age = age in years;

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[6] EPA used the 1994 government rate ($0.29) for travel reimbursement to estimate travel costs per mile traveled. This estimate includes vehicle operating cost only.

Employed = 1 if the respondent is currently employed and 0 otherwise;
Boatown = 1 if the respondent owns a boat;
Low-ed = 1 if the respondent had a high school education or less;
High-ed = 1 if the respondent graduated from college, or had a post-graduate degree; and
Stinc = the average income of residents in the corresponding states.

All variables in the estimated income regression are statistically significant at better than the 99th percentile.

D4-2 SITE CHOICE MODEL

The nature of the MRFSS data leads to the RUM as a means of examining anglers' preferences (Haab et al., 2000). Anglers arrive at each NMFS site by choosing among a set of feasible sites. Interviewers intercept individual anglers at marine fishing sites along the Mid-Atlantic coast, including Delaware Bay and Chesapeake Bay, and collect data on the anglers' origins and catch (including number and weight of species caught).

The RUM assumes that the individual angler makes a choice among mutually exclusive site alternatives based on the attributes of those alternatives (McFadden, 1981). The total number of sites in the study area is 790. Each angler's choice set was restricted, as described above, to a large set of feasible sites within 120 miles of the angler's home zip code.[7] This set of feasible sites was further restricted to up to 37 boat sites and 37 shore sites, for a total of up to 74 feasible choices (J).[8]
An angler's choice of mode and site is assumed to be based on utility maximization. An angler will choose mode k and site j if the utility (u_{jk}) from visiting site j and fishing with mode k is greater than that from visiting other sites (h) and fishing other modes (m), such that:

$$u_{jk} > u_{hm} \quad for\ h = 1,\ ....\ ,\ J\ and\ h \neq j,\ for\ m = 1,\ ....\ ,\ K\ and\ m \neq k \qquad \text{(D4-4)}$$

In addition to choosing a fishing mode and site, anglers choose the species to target. Available fishing modes include shore fishing, fishing from charter boats, or fishing from private or rental boats. EPA estimated the Mid-Atlantic RUM model using a nested logit, including boat and shore modes. Boat and shore sites were defined based on NMFS site descriptions, combined with availability of boat or shore catch rates for each site. EPA used values for boat anglers to value recreational benefits to charter anglers. EPA included the following species in the model: striped bass, bluefish, flounders, and weakfish. Additional species were grouped into the following categories: small game, big game, and bottom fish. Anglers may also choose not to target any particular species.

Recreational fishing models generally assume that anglers first choose a mode and species, and then a site. The nested logit model generally avoids the independence of relevant alternatives (IIA) problem, in which sites with similar characteristics that are not included in the model have correlated error terms. The nested structure based on mode/species and then site choice therefore assumes that sites selected for certain modes and/or species have similar characteristics.[9]

EPA used the following general model to specify the deterministic part of the utility function:[10]

$$v\ (site\ j,\ mode\ k) = f\ (TC_j,\ TT_j,\ SQRT(Q_{jks}) \times Flag(s)) \qquad \text{(D4-5)}$$

where:

v = the expected utility for site j and mode k (j=1,...,37; k=1,2);
TC_j = travel cost to site j;
TT_j = travel time to site j for survey respondents who cannot value the extra time according to the wage rate;

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[7] Based on the 99th percentile for the distance traveled to a fishing site.

[8] The actual site fished was included, along with other sites that were randomly drawn from each angler's feasible choice set.

[9] See Chapter A11 of this report for greater detail.

[10] See Chapter A11 of this report for detail on model specification.

$SQRT(Q_{jks})$ = square root of the historic catch rate for species *s* and mode *k*, at site *j*;[11] and
$Flag(s)$ = 1 if an angler is targeting this species; 0 otherwise;

The analysis assumes that each angler in the estimated model considers site quality based only on the catch rate for the targeted species. Theoretically, an angler may catch any of the available species at a given site (McFadden, 1981). If, however, an angler truly has a species preference, then including the catch variable for all species available at the site would inappropriately attribute utility to the angler for a species not pursued (Haab et al., 2000). To avoid this problem, the Agency used an interaction variable $SQRT\ (Q_{jks}) \times Flag(s)$, such that the catch rate variable for a given species is turned on only if the angler targets a particular species [$Flag\ (s) = 1$]. Because no-target anglers catch all of the modeled species, EPA used average catch rates for all species caught by no-target anglers at a particular site to characterize a site's fishing quality for the no-target angler group.

The analysis tested various alternative model specifications, but the model presented here was the most successful at explaining the probability of selecting a site. For example, models that allowed for differences in value by waterbody (e.g., Chesapeake Bay and Atlantic Coast) did not produce significantly different results from those presented here.

The final model presented here is a site choice model that includes all fish species. The analysis therefore assumes that each angler has chosen a species followed by choosing a mode (boat or shore) and then a site based on the catch rates for that site, species, and mode. The model also allows for different coefficients on travel time for private/rental boat anglers and shore anglers, thus allowing the value of time spent traveling to vary by fishing mode.[12] Table D4-5 gives the parameter estimates for the RUM model.

Table D4-5: Estimated Coefficients for the Nested Logit Site Choice Model

Variable	Estimated Coefficient	t-statistic
TRIPCST	-0.020	-15.11
TIMECST-SHORE	-0.806	-42.58
TIMECST-BOAT	-0.699	-40.42
$SQRT\ (Q_{weakfish})$	2.448	19.93
$SQRT\ (Q_{striped\ bass})$	2.202	26.40
$SQRT\ (Q_{bluefish})$	0.991	10.28
$SQRT\ (Q_{flounder})$	1.210	22.44
$SQRT\ (Q_{bottom})$	0.736	13.20
$SQRT\ (Q_{big\ game})$	3.852	16.20
$SQRT\ (Q_{small\ game})$	1.013	13.83
$SQRT\ (Q_{notarget})$	1.038	19.71
IV-SHORE	0.840	19.56
IV-BOAT	1.112	26.41

Source: EPA analysis for this report.

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[11] The analysis used the square root of the catch rate to allow for decreasing marginal utility of catching fish (McConnell and Strand, 1994).

[12] EPA estimated all RUM and Poisson models with LIMDEP™ software (Greene, 1995).

One disadvantage of the specified model is that the model looks at site and mode choice without regard to species. Once an angler chooses a target species, no substitution is allowed across species (i.e., the value of catching, or potentially catching, a different species is not included in the calculation). Therefore, improvements in fishing circumstances related to other species will have no effect on anglers' choices. This limitation, however, is unlikely to have a significant effect on welfare estimates, because most anglers tend to fish for the same target species on most of their trips (Haab et al., 2000).

Table D4-5 shows that all coefficients have the expected signs and are statistically significant at the 95th percentile. Travel cost and travel time have a negative effect on the probability of selecting a site, indicating that anglers prefer to visit sites closer to their homes (other things being equal). Boat anglers have a smaller negative value for travel time than shore anglers, indicating that, on average, boat anglers are willing to travel farther than shore anglers. The probability of a site visit increases as the historic catch rate for fish species increases.

Generally, the coefficient on the inclusive value is expected to fall between 0 and 1. As shown in Table D4-5, the coefficient on the inclusive value for the boat mode is greater than one in the estimated model. Kling and Herriges (1995) show that it is possible to have a coefficient greater than one that is still consistent with utility theory. The necessary condition for consistency is satisfied if the following inequality holds:

$$\theta_k \le \frac{1}{1 - Q_k(v)} \tag{D4-6}$$

where:

θ_k = the coefficient on the inclusive value for mode *k*; and
$Q_k(v)$ = the probability of selecting mode *k*.

EPA conducted this test for each angler in the model, and found that the test condition held for all anglers. Therefore, the inclusive value coefficient for boat mode is consistent with utility maximization.

D4-3 TRIP FREQUENCY MODEL

EPA also examined effects of changes in fishing circumstances on an individual's choice concerning the number of trips to take during a recreation season. EPA used the negative binomial form of the Poisson regression model to estimate the number of fishing trips per recreational season. The participation model relies on socio-economic data and estimates of individual utility (the inclusive value) derived from the site choice model (Parsons et al., 1999; Feather et al., 1995). EPA estimated a combined participation model for the North Atlantic and Mid-Atlantic regions.[13] This section discusses results from the Poisson model of recreational fishing participation, including statistical and theoretical implications of the model. A detailed discussion of the Poisson model is presented in Chapter A11 of this report.

The dependent variable, the number of recreational trips within the past 12 months, is an integer value ranging from 1 to 365. To avoid over-prediction of the number of fishing trips, EPA set the number of trips for anglers reporting over 125 trips per year to 125 in the model estimation.[14] The Agency first tested the data on the number of fishing trips for overdispersion to determine whether to use the Poisson model or the negative binomial model. If the dispersion parameter is equal to zero, then the Poisson model is appropriate; otherwise the negative binomial is more appropriate. The analysis found that the overdispersion parameter is significantly different from zero and therefore the negative binomial model is the most appropriate for this analysis.

Independent variables of importance include gender, ethnicity, education, household size, hourly wage, whether the angler targets a species, whether the angler fishes from shore or from a boat, whether the angler is employed, whether the angler is self-employed, and whether the angler owns a boat. The model also includes a dummy variable to indicate whether the angler is from the North Atlantic region. Variable definitions for the trip participation model are:

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[13] EPA combined data for the North and Mid-Atlantic regions, as these regions are part of a single NMFS data set, to estimate the model. The Agency calculated separate estimates of participation and changes in participation for each region, based on average values of variables for that region.

[14] The number of trips was truncated at the 95th percentile, 125 trips per year.

- Constant: a constant term;
- IVBASE: the inclusive value estimated using the coefficients from the site choice model;
- HIGH_ED: equals 1 if the individual completed college or an advanced degree, 0 otherwise;
- HH_SIZE: household size;
- EMPLYED: equals 1 if the individual is employed; 0 otherwise;
- SELFEMP: equals 1 if the individual is self-employed; 0 otherwise;
- MALE: equals 1 if the individual is male; 0 if female;
- WHITE: equals 1 if the individual is white; 0 otherwise;
- OWNBT: equals 1 if individual owns a boat, 0 otherwise;
- NOTARG: equals 1 if the individual did not target a particular species; 0 otherwise;
- SHORE: equals 1 if the individual fished from shore; 0 if the individual fished from a boat;
- WAGE: household hourly wage (household income divided by 2,080);
- N_ATL: equals 1 if the individual fished in the North Atlantic region; and
- α (alpha): overdispersion parameter estimated by the negative binomial model.

Table D4-6 presents the results of the trip participation model. Where a particular sign is expected, all estimated parameters have the expected signs. The model shows that the most significant determinants of the number of fishing trips taken by an angler are region (N_ATL), whether the angler fishes from shore (SHORE), whether the angler targets a species (NOTARG), boat ownership (OWNBT), whether the angler is male (MALE), whether the angler is employed (EMPLOYED), and the perceived quality of fishing sites (IVBASE).

Table D4-6: Trip Participation Model (Negative Binomial Model)

Variable	Coefficient	t-statistic
Constant	2.428	32.48
IVBASE	0.167	18.26
HIGH_ED	-0.146	-3.96
HH_SIZE	-0.033	-3.27
EMPLYD	-0.210	-5.84
SELFEMP	0.137	3.44
MALE	0.221	5.46
WHITE	0.124	2.64
OWNBT	0.379	11.78
NOTARG	-0.391	-11.43
SHORE	0.400	11.23
WAGE	0.003	2.40
N_ATL	-0.685	-18.29
α (alpha)	1.034	38.02

Source: U.S. EPA analysis for this report.

The positive coefficient on the inclusive value index (IVBASE) indicates that the quality of recreational fishing sites has a positive effect on the number of fishing trips per recreational season. EPA therefore expects improvements in recreational fishing opportunities, such as an increase in fish abundance and catch rate, to result in an increase in the number fishing trips to the affected sites.

The model shows that anglers in the North Atlantic region take less fishing trips than those in the Mid-Atlantic region. Anglers who completed college or an advanced degree tend to take less fishing trips than those with less education. Anglers with larger households take fewer trips than those with smaller households, and those who are employed take fewer trips than those who are retired or otherwise not employed. However, self-employed anglers take more trips than those who are not self-employed. Male anglers fish more frequently than female anglers, and white anglers take more trips than non-white anglers. Anglers who own boats, those who target a specific species, those with higher incomes, and those who fish from shore take more trips each year.

D4-4 WELFARE ESTIMATES

This section presents estimates of welfare losses to recreational anglers from fish mortality due to I&E, and potential welfare gains from improvements in fishing opportunities due to reduced fish mortality stemming from the final section 316(b) rule.

D4-4.1 Estimating Changes in the Quality of Fishing Sites

To estimate changes in the quality of fishing sites under different policy scenarios, EPA relied on the recreational fishery landings data by state and the estimates of recreational losses from I&E corresponding to different technology options. The NMFS provided recreational fishery landings data for the Mid-Atlantic region. EPA estimated the losses to recreational fisheries using the physical impacts of I&E on the relevant fish species, and the percentage of total fishery landings attributed to recreational fishing, as described in Chapter D2 of this document. I&E affects recreational species in two ways: by directly killing recreational species, and by killing forage species, thus indirectly affecting recreational species through the food chain. The indirect effects on recreational species were calculated in two steps. First, EPA estimated the total number of fish lost due to forage fish losses. Second, EPA allocated this total number of fish among recreational species according to each species' percent of total recreational landings.

The Agency estimated changes in the quality of recreational fishing sites under different policy scenarios in terms of the percentage change in the historic catch rate. EPA assumed that catch rates will change uniformly across all marine fishing sites in the Mid-Atlantic region, because species considered in this analysis (i.e., weakfish, striped bass, bottom fish, and flatfish) inhabit a wide range of states (e.g., from North Carolina to Massachusetts).[15] EPA used five-year recreational landing data (1997 through 2001) for state waters to calculate average landings per year for striped bass, weakfish, bottom fish, flatfish, and all species combined.[16,17] EPA then divided losses to the recreational fishery from I&E by the total recreational landings for the region to calculate the percent change in historic catch rate from eliminating I&E completely. Table D4-7 presents results of this analysis. EPA estimated that compliance with the Phase II rule would reduce impingement by 53.5 percent, and entrainment by 47.9 percent. Table D4-7 also presents the reductions in I&E effects that would occur with installation of the CWIS technology due to the final section 316(b) rule.

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[15] Fish lost to I&E are most often very small fish, which are too small to catch. Because of the migratory nature of most affected species, by the time these fish have grown to catchable size, they may have traveled some distance from the facility where I&E occurs. Without collecting extensive data on migratory patterns of all affected fish, it is not possible to evaluate whether catch rates will change uniformly or in some other pattern. Thus, EPA assumed that catch rates will change uniformly across the entire region.

[16] State waters include sounds, inlets, tidal portions of rivers, bay, estuaries, and other areas of salt or brackish water, plus ocean waters to three nautical miles from shore (NMFS, 2003b).

[17] EPA used average landings for all species to calculate changes in catch rates for no-target anglers.

Table D4-7: Estimated Changes in Historical Catch Rates From Eliminating and Reducing I&E in the Mid-Atlantic Region

Species	Total Recreational Landings 5 States (fish per year)[a]	Baseline		Final Section 316(b) Rule	
		Total Recreational Fishery Losses From I&E (number of fish)	Percent Increase in Recreational Catch From Eliminating I&E	Estimated Reduction in I&E (number of fish)	Percent Increase in Recreational Catch
Striped Bass	7,024,788	540,816	7.70%	262,141	3.73%
Flatfish	20,734,405	1,024,608	4.94%	497,762	2.40%
Bottom Fish	39,234,599	17,910,330	45.65%	8,746,693	22.29%
Weakfish	4,798,238	648,727	13.52%	317,158	6.61%
Small Game	7,335,013	344,059	4.69%	166,580	2.27%
No Target[b]	79,198,440	20,468,540	25.87%	9,990,333	12.63%

[a] Total recreational landings are calculated as a five year average (1997-2001) for sites in state waters.
[b] All species were summed to calculate percent change in catch rates for no-target anglers.

Sources: NMFS, 2002e; and U.S. EPA analysis for this report.

D4-4.2 Estimating Losses from I&E in the Mid-Atlantic Region

The recreational behavior model described in the preceding sections provides a means for estimating the economic effects of changes in recreational fishery losses from I&E in the Mid-Atlantic region. First, EPA estimated welfare gain to recreational anglers from eliminating fishery losses due to I&E. This estimate represents economic damages to recreational anglers from I&E of recreational fish species in the region under the baseline scenario. EPA then estimated benefits to recreational anglers from installing the CWIS technology due to the final section 316(b) rule.

EPA estimated anglers' willingness-to-pay (WTP) for improvements in the quality of recreational fishing by first calculating an average per-day welfare gain based on the expected changes in catch rates from eliminating I&E, and from reducing I&E by installing the CWIS technology due to the final section 316(b) rule. Table D4-8 presents the compensating variation per day (averaged over all anglers in the sample) associated with reduced fish mortality from eliminating and reducing I&E for each fish species of concern.[18,19]

Table D4-8 also reports the willingness-to-pay for a one-unit increase in historic catch rate by fishing mode and species for anglers targeting these species. The estimated values are consistent with those available from previous studies (McConnell and Strand, 1994).[20] In general, boat and shore anglers have similar values, and target anglers have higher values than no-target anglers. No-target anglers have higher values than anglers who target bottom fish, and shore anglers who target small game fish. Because no-target anglers catch a variety of species, including some of the higher-valued species, it makes sense that their value, on average, is higher than the values for the lowest-valued targeted species. Target anglers who fish from boats value an additional big game fish the most, followed by striped bass, weakfish, flatfish, other small game fish, bluefish, and bottom fish. Target anglers who fish from shore value an additional striped bass the most, followed by weakfish, bluefish, bottom fish and other small game fish.

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[18] A compensating variation equates the expected value of realized utility under the baseline and post-compliance conditions. For more detail, see Chapter A11 of this report.

[19] As the RUM model estimated values for single-day trips, the per-day value is equal to a per-trip value.

[20] Note that WTP for a one-unit increase in historical catch rates reported in Hicks et al. (1999) is lower compared to the values presented in Table D4-8. However, the values presented in the Hicks et al. study are not directly comparable with the values presented in Table D4-8. The values from the Hicks et al. study represent an average WTP for a one-unit increase in historical catch rates over all anglers while the values presented in Table D4-8 represent an average WTP for a one-unit increase in historical catch rates over anglers targeting a given species/species group.

Table D4-8: Per-Day Welfare Gain from Eliminating and Reducing I&E in the Mid-Atlantic Region, and Willingness-to-Pay per Additional Fish (2002$)

Targeted Species	Per-Day Welfare Gain (2000$)				WTP for an Additional Fish per Trip (2002$)	
	Baseline I&E		Reduced I&E		Boat Mode	Shore Mode
	Boat Mode	Shore Mode	Boat Mode	Shore Mode		
Striped Bass	$5.03	$4.59	$2.44	$2.23	$15.23	$15.19
Bottom Fish	$12.17	$13.46	$6.09	$6.67	$4.60	$4.66
Flatfish	$1.65	$1.72	$0.80	$0.84	$8.37	$8.57
Weakfish	$7.43	$8.21	$3.63	$4.02	$14.01	$14.58
Small Game Fish[a]	$1.46	$1.40	$0.71	$0.68	$6.50	$4.58
No Target	$7.86	$7.52	$3.88	$3.71	$5.71	$5.58
Big Game Fish[b]	N/A	N/A	N/A	N/A	$20.53	N/A
Bluefish[a]	N/A	N/A	N/A	N/A	$6.19	$6.28

[a] I&E welfare estimates for bluefish are included with small game fish.
[b] Shore anglers do not target big game fish.

Source: U.S. EPA analysis for this report.

The per-day values for changes in I&E are based on both the value of the species to anglers, and the expected percent change in catch. Bottom fish species have the highest per-day welfare gain, due to the large estimated change in catch rate from elimination of I&E (45.6 percent). No-target anglers receive the second highest per-day gain, mainly driven by the large expected change in catch rates (25.9 percent). Weakfish has the third highest change in per-day value, and striped bass has the fourth highest change. Both species are relatively valuable to anglers, and catch rates are expected to increase by significant amounts for both (13.5 percent for weakfish and 7.7 percent for striped bass). Flatfish, which are moderately valuable and have a moderate change in catch rates, have the fifth highest welfare gain. Finally, small game fish anglers have the lowest welfare gain, primarily due to the relatively low expected change in catch rates.

EPA calculated the total economic value of eliminating I&E in the Mid-Atlantic region by combining the estimated per-day welfare gain with the total number of fishing days at Mid-Atlantic sites. The Agency assumed that the welfare gain per day of fishing is independent of the number of days fished per trip and therefore equivalent for both single- and multiple-day trips.[21] Each day of a multiple-day trip is valued the same as a single-day trip. NMFS provided information on the total number of fishing trips by fishing mode; this total number of fishing days includes both single- and multiple-day trips. Table D4-9 presents the NMFS number of fishing days by fishing mode. Per-day welfare gain differs across recreational species and fishing mode.[22,23] EPA therefore estimated the number of fishing trips associated with each species of concern and the number of trips taken by no-target anglers. EPA used the MRFSS sample to calculate the proportion of recreational fishing trips taken by no-target anglers and anglers targeting each species of concern, and applied these percentages to the total number of trips to estimate species-specific participation. Table D4-9 shows the calculation results.

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[21] See section D4-5.1 for limitations and uncertainties associated with ths assumption.

[22] EPA used the per-day values for private/rental boat anglers to estimate welfare gains for charter boat anglers.

[23] NMFS reports the total days of fishing, including days fished on both single- and multiple-day trips. The Agency assumed that the welfare gain per day of fishing is independent of the number of days fished per trip and therefore equivalent for both single- and multiple-day trips.

Table D4-9: Recreational Fishing Participation by Species and Fishing Mode

Species	Mode: Private Rental Boats Number of Fishing Days	Mode: Shore Number of Fishing Days	Mode: Charter Boat Number of Fishing Days	Total for all Modes [a]
No Target	1,864,425	2,282,545	117,321	4,264,291
Striped Bass	1,723,862	1,031,056	75,018	2,829,936
Flatfish	4,169,655	2,107,147	171,389	6,448,191
Weakfish	568,998	179,349	12,087	760,434
Small Game Fish[a]	1,461,853	1,469,552	227,310	3,158,715
Big Game Fish	172,049	N/A	40,450	212,499
Bottom Fish	1,286,431	826,425	162,123	2,274,979
Total[b]	11,247,273	7,896,075	805,698	19,949,046

[a] Includes bluefish.
[b] Sum of individual values may not add up to totals due to the rounding error.

Sources: NMFS, 2002d; and U.S. EPA analysis for this report.

Anglers targeting flatfish account for the largest number of fishing days at Mid-Atlantic NMFS sites (6.4 million). No-target anglers, small game anglers, and anglers targeting striped bass rank second, third, and fourth, fishing 4.3 million, 3.2 million, and 2.8 million days per year, respectively. Anglers targeting big game species fish the least days per year (about 212,000).

The estimated number of trips represents the baseline level of participation. Anglers may take more fishing trips as recreational fishing circumstances change. EPA used the trip participation model to estimate the percentage increase in the number of trips due to the elimination and reduction of I&E. These changes are reported in Table D4-10. For baseline I&E, the estimated percentage increase ranges from 0.4 percent for anglers who target small game fish to 3.6 percent for anglers targeting bottom fish. EPA calculated the number of recreational fishing trips under each I&E scenario by applying the estimated percentage increase to the baseline number of trips. The estimated increase in the total number of recreational fishing days ranges from 12,678 days for anglers who target small game fish to 80,720 days for anglers who target bottom fish. The estimated aggregate increase in the number of fishing days is 271,104.

Tables D4-11 and D4-12 provide total welfare estimates for two policy scenarios. Table D4-11 presents losses to recreational anglers from baseline I&E. Table D4-12 presents the welfare gains that would result from installing the CWIS technology at all plants subject to final section 316(b) rule in the Mid-Atlantic region. EPA calculated the total welfare estimates by multiplying the estimated values per day (Table D4-8) by the number of fishing days (Tables D4-9 and D4-10).[24] These values were discounted, to reflect the fact that fish must grow to a certain size before they will be caught by recreational anglers. EPA calculated discount factors separately for I&E of each species (see Chapter D2 for details). To estimate discounted total benefits for the Mid-Atlantic, EPA calculated weighted averages of these discount factors, and applied them to estimated willingness-to-pay values. Discount factors were calculated for both a 3 percent discount rate and a 7 percent discount rate. For the final rule policy scenario, an additional discount factor was applied to account for the one-year lag between the date when costs are incurred and the installation of the required cooling water technology is completed.

Table D4-11 presents annual losses to recreational anglers from baseline I&E effects in the Mid-Atlantic region. Total recreational losses (2002$) to Mid-Atlantic anglers, before discounting, from I&E of striped bass, bottom fish, flatfish, weakfish, small game fish, and to no-target anglers, are $95.7 million per year. Total discounted baseline losses are $89.6 million, discounted using a 3 percent discount rate; and $82.5 million, discounted using a 7 percent discount rate.

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[24] EPA averaged the initial number of days (Table D4-9) and the predicted increased number of days (Table D4-10) to estimate total welfare (Bockstael, et al., 1987).

Table D4-10: Increased Recreational Fishing Participation by Species and Fishing Mode from Eliminating or Reducing I&E in the Mid-Atlantic Region

Species	Predicted Percent Change in Annual Fishing Trips		Private/Rental Mode		Shore Mode		Party/Charter Mode	
	Baseline I&E	Reduced I&E	Baseline	Reduced	Baseline	Reduced	Baseline	Reduced
Striped Bass	1.38%	0.67%	1,747,618	1,735,352	1,045,265	1,037,928	76,052	75,518
Bottom Fish	3.55%	1.75%	1,332,076	1,309,000	855,748	840,924	167,875	164,967
Flatfish	0.46%	0.23%	4,188,977	4,179,061	2,116,912	2,111,901	172,183	171,776
Weakfish	2.13%	1.03%	581,091	574,879	183,160	181,202	12,344	12,212
Small Game Fish	0.40%	0.19%	1,464,833	1,463,293	1,472,547	1,470,999	227,774	227,534
No Target	2.17%	1.07%	1,904,940	1,884,290	2,332,146	2,306,866	119,871	118,571
Totals			11,219,535	11,145,875	8,005,778	7,949,820	776,099	770,578

Source: U.S. EPA analysis for this report.

Table D4-11: Total Estimated Annual Baseline Losses from I&E for the Mid-Atlantic Region (2002$)

Species	Total Losses Before Discounting	Total Losses with 3% Discounting	Total Losses with 7% Discounting
Striped Bass	$13,864,218	$12,494,295	$10,965,862
Bottom Fish	$29,263,408	$27,729,976	$25,929,253
Flatfish	$10,783,335	$9,962,389	$9,010,383
Weakfish	$5,850,688	$5,529,514	$5,150,443
Small Game Fish	$2,815,749	$2,602,073	$2,353,597
No Target	$33,093,917	$31,264,188	$29,122,581
Total Recreational Use	$95,671,315	$89,582,435	$82,532,119

Source: U.S. EPA analysis for this report.

Table D4-12 presents the annual reduction in losses resulting from installation of the CWIS technology for each facility subject to final section 316(b) rule in the region. Total undiscounted recreational losses are reduced by $47.7 million under the final section 316(b) rule. Using a 3 percent discount rate, total losses are reduced by $43.4 million. Using a 7 percent discount rate, total losses are reduced by $38.5 million.

Table D4-12: Total Estimated Annual Welfare Gain from Reducing I&E Losses Under the Final Section 316(b) Rule in the Mid-Atlantic Region (2002$)

Species	Total Losses Before Discounting	Total Losses with 3% Discounting	Total Losses with 7% Discounting
Striped Bass	$6,711,814	$5,873,610	$4,963,735
Bottom fish	$14,458,662	$13,308,866	$11,987,589
Flatfish	$5,252,221	$4,712,489	$4,104,589
Weakfish	$2,845,927	$2,612,885	$2,344,593
Small Game	$2,195,124	$1,969,986	$1,715,870
No target	$16,227,901	$14,891,846	$13,362,426
Total recreational use losses	$47,691,649	$43,369,682	$38,478,802

Source: U.S. EPA analysis for this report.

D4-5 LIMITATIONS AND UNCERTAINTIES

D4-5.1 Extrapolating Single-Day Trip Results to Estimate Benefits from Multiple-Day Trips

Use of per-day welfare gain estimated for single-day trips to estimate per-day welfare gain associated with multiple-day trips can either understate or overstate benefits to anglers taking multiple-day trips. Inclusion of multi-day trips in the model of recreational anglers' behavior can be problematic because multi-day trips are frequently multi-activity trips. An individual might travel a substantial distance and participate in several recreational activities such as shopping and sightseeing, all as part of one trip. Recreational benefits from improved recreational opportunities for the primary activity are overstated if all travel costs are treated as though they apply to the one recreational activity of interest. EPA therefore limited the recreational behavior model to single-day trips only and then extrapolated single-day trip results to estimate benefits to anglers taking multiple-day trips.

There is evidence that multi-day trips are more valuable than single-day trips. McConnell and Strand (1994) estimated a random utility model (RUM) using the NMFS data for New England and the Mid-Atlantic. Their study was intended to supplement the RUM study of single-day trips for the same region conducted by Hicks et al. (1999). The reported values for a catch rate increase of one fish are consistently higher for overnight trips than for single-day trips. Lupi and Hoehn (1998) compared values for single- and multi-day fishing trips. Their comparison is based on a RUM for the Great Lakes, with single- and multiple-day trips treated as distinct alternatives in the choice set, with separate parameters for different length trips. They found that multiple-day trips are less responsive to changes in travel cost, and thus relatively more valuable than single-day trips. Their case study results found that "over half the value of an across the board marginal change in catch rates was due to multiple-day trips even though multiple-day trips represent less than one fourth of the trips in the sample (p. 45)."

D4-5.2 Considering Only Recreational Values

This study understates the total benefits of improvements in fishing site quality because estimates are limited to recreational use benefits. Many other forms of benefits, such as habitat values for a variety of species (in addition to recreational fish), non-use values, etc., are also likely to be important.

D4-5.3 Species Substitution

EPA's estimated RUM model does not allow for anglers to substitute between species. The analysis therefore assumes that each angler has chosen a species before choosing a mode followed by a site based on the catch rates for that site and species. Once an angler chooses a target species and mode, no substitution is allowed across species (i.e., the value of catching, or potentially catching, a different species is not included in the calculation). Therefore, improvements in fishing circumstances related to other species will have no effect on anglers' choices, and thus will not be accounted for in the welfare estimates.

D4-5.4 Charter Anglers

EPA's model does not include charter boat anglers. Instead, the Agency used values for private/rental boat anglers to estimate values for charter anglers. It is not clear whether this will result in an overestimate or underestimate of per-day values for charter boat anglers.

D4-5.5 Potential Sources of Survey Bias

The survey results could suffer from bias, such as recall bias and sampling effects.

a. Recall bias

Recall bias can occur when respondents are asked, such as in the MRFSS, the number of their recreation days over the previous season. Some researchers believe that recall bias tends to lead to an overstatement of the number of recreation days, particularly by more avid participants. Avid participants tend to overstate the number of recreation days because they count days in a "typical" week and then multiply them by the number of weeks in the recreation season. They often neglect to consider days missed due to bad weather, illness, travel, or when fulfilling "atypical" obligations. Some studies also found that the more salient the activity, the more "optimistic" the respondent tends to be in estimating the number of recreation days.

Individuals also have a tendency to overstate the number of days they participate in activities that they enjoy and value. Taken together, these sources of recall bias may result in an overstatement of the actual number of recreation days.

b. Sampling effects

Recreational demand studies frequently face observations that do not fit general recreation patterns, such as observations of avid participants. These participants can be problematic because they claim to participate in an activity an inordinate number of times. This reported level of activity is sometimes correct but often overstated, perhaps due to recall bias. Even where the reports are correct, these observations tend to be overly influential (Thomson, 1991). EPA set the upper limit of the number of fishing trips per year to 180 days to correct for potential bias caused by these observations when estimating trip participation models. Instead of dropping four survey observations with the number of annual trips reported as greater than 180, the Agency set the number of annual trips to the upper bound (i.e., 180 trips).

Chapter D5: Non-Use Benefits

INTRODUCTION

CHAPTER CONTENTS

Aquatic species without any direct uses account for the majority of losses due to impingement and entrainment (I&E) at cooling water intake structures (CWIS). However, EPA's analysis of direct use benefits includes values only for organisms with direct uses, which comprise a very small percentage of total losses (approximately two percent). Because the other 98 percent of losses, consisting of organisms without direct uses, are not without value, the potential exists for significant non-use values that have not been addressed under EPA's estimation of use benefits. For this reason it is important to consider non-use benefits to the human population, produced by the increased numbers of organisms without direct use values, under the final section 316(b) rule.

One way to consider the impact of the section 316(b) rule is to estimate the non-use value of baseline I&E losses and I&E reductions due to the final rule for each case study region using the non-use meta-analysis results. The non-use meta-analysis is presented in detail in Chapter A12, Non-Use Meta-Analysis Methodology, which includes discussions of the literature review process, the estimated regression models and results, and the general methodology used to estimate household and aggregate non-use benefits based on regression results. Total regional non-use benefits can be estimated using the following three steps:

1. Estimate annual changes in non-use value of the affected fishery resources per household due to the baseline impingement and entrainment (I&E) losses and the post-compliance reduction in impingement and entrainment;

2. Estimate the population of households in the Mid-Atlantic region holding non-use value for the affected resources; and

3. Estimate the total non-use value to the affected Mid-Atlantic populations for completely eliminating baseline I&E losses, and for reducing I&E losses from the baseline to post-compliance levels.

EPA explored this approach for the Mid-Atlantic region. However, EPA did not include the results of this approach in the benefit analysis because of limitations and uncertainties associated with estimation of non-use benefits on a regional scale. For further discussion of the limitations and uncertainties of this method, refer to Chapter A12.

D5-1 QUALITATIVE ASSESSMENT OF ECOLOGICAL BENEFITS FOR THE MID-ATLANTIC REGION

Changes in CWIS design or operations resulting from the section 316(b) regulations for existing facilities are expected to reduce I&E losses of fish, shellfish, and other aquatic organisms and, as a result, are expected to increase the numbers of individuals present, increase local and regional fishery populations, and ultimately contribute to the enhanced environmental functioning of affected waterbodies (rivers, lakes, estuaries, and oceans) and associated ecosystems. The economic welfare of human populations is expected to increase as a consequence of the improvements in fisheries and associated aquatic ecosystem functioning.

The aquatic resources affected by cooling water intake structures provide a wide range of services. Ecosystem services are the physical, chemical, and biological functions performed by natural resources and the human benefits derived from those functions, including both ecological and human use services (Daily, 1997; Daily et al., 1997). Scientific and public interest in protecting ecosystem services is increasing with the recognition that these services are vulnerable to a wide range of human activities and are difficult, if not impossible, to replace with human technologies (Meffe, 1992).

In addition to their importance in providing food and other goods of direct use to humans, the organisms lost to I&E are critical to the continued functioning of the ecosystems of which they are a part. Fish are essential for energy transfer in aquatic food webs, regulation of food web structure, nutrient cycling, maintenance of sediment processes, redistribution of bottom substrates, the regulation of carbon fluxes from water to the atmosphere, and the maintenance of aquatic biodiversity (Peterson and Lubchenco, 1997; Postel and Carpenter, 1997; Holmund and Hammer, 1999; Wilson and Carpenter, 1999). Examples of ecological and public services disrupted by I&E include:

- decreased numbers of ecological keystone, rare, or sensitive species;
- decreased numbers of popular species that are not fished, perhaps because the fishery is closed;
- decreased numbers of special status (e.g., threatened or endangered) species;
- increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E;
- disruption of ecological niches and ecological strategies used by aquatic species;
- disruption of organic carbon and nutrient transfer through the food web;
- disruption of energy transfer through the food web;
- decreased local biodiversity;
- disruption of predator-prey relationships;
- disruption of age class structures of species;
- disruption of natural succession processes;
- disruption of public uses other than fishing, such as diving, boating, and nature viewing; and
- disruption of public satisfaction with a healthy ecosystem.

Many of these services can only be maintained by the continued presence of all life stages of fish and other aquatic species in their natural habitats.

The traditional approach of EPA and other natural resource agencies to quantifying the environmental benefits of proposed regulations has focused on active use values, particularly direct use values such as recreational or commercial fishing. Nonconsumptive uses (such as the importance of fish for aquatic food webs), and passive use or non-use values (including the value of protecting a resource for its own sake), are seldom considered because they are difficult to monetize with available economic methods. However, even though economists debate methods for indirect and non-use valuation, there is general agreement that these values exist and can be important. The potential magnitude of non-use values remains an empirical matter. EPA believes that non-use values are applicable for the section 316(b)-related I&E and that these values are likely to be appreciable for the Mid-Atlantic region.

Chapter D6: Habitat Based Analysis

INTRODUCTION

Aquatic species without primary or direct uses account for the majority of losses at cooling water intake structures (CWIS). These species are not, however, without value to society. It is important to consider the non-use benefits to the human population produced by the increased number of these fish under the final section 316(b) rulemaking.

An alternative way to consider impingement and entrainment (I&E) losses is to value the habitat necessary to replace the lost organisms. The value of fish habitat can then provide an indirect basis for valuing the fish that are supported by the habitat. Existing wetland valuation studies found that members of the general public are aware of the fish production services provided by eelgrass (submerged aquatic vegetation, SAV) and wetlands, and that they express support for steps that include increasing SAV and wetland areas to restore reduced fish and shellfish populations (Opaluch et al., 1995, 1998; Mazzotta, 1996).

CHAPTER CONTENTS

EPA explored this approach for the Mid-Atlantic region. However, EPA did not include the results of this approach in the benefit analysis because of certain limitations and uncertainties regarding the application of this methodology to the national level. These limitations and uncertainties are discussed in Chapter A15. Thus, this chapter outlines the approach explored by EPA, but does not present benefit estimates.

The approach discussed here uses values that survey respondents indicated for preservation/restoration of habitat to evaluate losses of fishery resources in the Mid-Atlantic region. This analysis is not intended to value directly benefits provided by the lost fish, but to provide another perspective on the I&E losses by looking at values of habitat necessary to replace them. The method first estimates the quantity of wetland and eelgrass habitat required to replace fish and shellfish lost to I&E, and then assesses respondents' values for these habitats. These data would then be combined to yield an estimate of household values for improvements in fish and shellfish habitat, which provides an indirect estimate of the benefits of reducing or eliminating I&E. However, EPA does not present benefit estimates.

This benefit transfer approach involves four general steps, described in detail in Chapter A15:

1. Estimate the amount of restored wetlands needed to produce organisms at a level necessary to offset I&E losses for the subset of species for which potential production information is available.
2. Develop willingness-to-pay (WTP) values for fish production services of wetlands ecosystems.
3. Estimate the total value of baseline I&E losses by multiplying the WTP values for fish services of restored wetlands by the number of acres needed to offset I&E losses.
4. Estimate the total benefits of the final section 316(b) rule, in terms of the value of decreased I&E losses, by multiplying the WTP values for fish and shellfish services of restored habitat by the number of acres of each habitat type needed to offset decreased I&E losses.

The rest of this chapter describes EPA's exploratory application of this method to the Mid-Atlantic region.

D6-1 DATA SUMMARY

To estimate public WTP, EPA used information from two studies of public values for wetlands: a study of the Peconic Estuary, located on the East End of Long Island, New York (Johnston et al., 2001a, 2001b; Opaluch et al., 1995, 1998; Mazzotta, 1996); and a stated preference study from Narragansett Bay, Rhode Island (Johnston et al., 2002). These studies are discussed in detail in Chapter A15.

D6-2 BENEFIT TRANSFER FOR THE MID-ATLANTIC REGION

D6-2.1 Estimating the Amount of Habitat Needed to Offset Losses for Specific Species

For the Mid-Atlantic region, the only data available to estimate habitat requirements is an estimate of wetland acreage developed by the Public Service Electric and Gas Company (PSEG) and the New Jersey Department of Environmental Protection (NJDEP) for Salem's 1999 Permit Renewal Application (PSEG, 1999, Appendix G; NJDEP, 2000). The scaling method involved estimating wetland production using an aggregated food chain model and then relating production directly to the estimated biomass of fish lost at Salem (PSEG, 1999, Appendix G; NJDEP, 2000). The food chain model estimated the production of fish biomass per acre based on the biological conversion of wetland plant productivity through the food chain to I&E fish species. The amount of acreage required to offset I&E losses was based primarily on estimates for bay anchovy (*Anchoa mitchilli*), the species requiring the maximum acreage (NJDEP, 2000). PSEG and NJDEP estimated that approximately 7,400 acres of restored tidal wetlands are required to offset I&E of fish species at the Salem facility (NJDEP, 2000).

D6-2.2 Developing WTP Values for Fish Production Services Provided by Wetlands

Because coastal wetlands provide a number of services (e.g., habitat, water purification, storm buffering, and aesthetics), EPA attempted to separate values for fish habitat from values for other wetland services. Given survey data available from the Peconic Study, however, there is no direct means to estimate the proportion of total wetland value associated with fish habitat services alone. EPA therefore used the stated preference study from Narragansett Bay, Rhode Island, described in detail in Chapter A15, to adjust wetland values to reflect fish habitat services (Johnston et al., 2002). Based on the Agency's calculations, 25.64 percent of total wetland restoration value is attributable to gains in fish habitat services, given representative, mean values for other wetland services. Therefore, values per acre of wetlands were multiplied by 25.64 percent to estimate the value per acre attributable to fish habitat services.

Chapter C6 provides estimates of value per acre for fish habitat services of wetlands and eelgrass.

D6-2.3 Applicability of Study Area to Policy Area

In the Peconic study, corrections were made to WTP values to account for differences in demographics between survey respondents and the general population of the East End of Long Island. EPA compared demographics of the affected population for one Mid-Atlantic facility — the Salem Station — to demographics of the East End of Long Island. Demographics of the affected population in the Salem region (New Castle County, DE, and Salem County, NJ) are quite similar to those of the general population of the East End. Table D6-1 compares survey respondent demographics to residents of the East End and residents of the Salem region, based on education and income categories used to estimate WTP. The Salem region has very similar education levels, and slightly lower income levels, on average, than the Peconic region. While values presented in the analysis were adjusted to the Peconic levels, they could be easily re-adjusted to reflect Salem levels. However, based on the small differences in demographics between the regions, the effect is likely to be negligible.

Table D6-1: Comparison of the Demographics of the Salem Area with the Peconic Area

Population	% of Population, by Highest Level Educational Achievement Attained				% of Population, by Household Income (in 2000$)			
	Did Not Complete High School	High School	Some College	College Graduate	< $25,000	$25,000 - $49,999	$50,000 - $149,999	> $150,000
Population in abutting counties (Salem)[a]	15%	31%	19%	35%	21%	27%	47%	5%
Population in 32.4 mile radius (Salem)[b]	16%	32%	19%	33%	21%	27%	46%	6%
Population in Peconic region[c]	14%	31%	19%	35%	15%	21%	54%	9%

[a] Includes populations in the following counties: New Castle (DE); and Salem (NJ).
[b] Includes populations in the following counties: New Castle and Kent (DE); Atlantic, Cumberland, Gloucester, and Salem (NJ); Caroline, Cecil, Harford, Kent, and Queen Anne's (MD); and Chester and Delaware (PA).
[c] Includes population in Suffolk County (NY).

Source: U.S. Census Bureau, 2000.

D6-2.4 Determining the Affected Population

Evaluating the total value per acre of wetlands for the coastal population of the region requires a definition of the geographical extent of the affected population. The Peconic study defined the affected population as the total number of households in the towns bordering the Peconic Estuary. Similarly, as described in Chapter A15, EPA defines the affected population as households residing in the counties that abut the affected water bodies. These households are likely to value gains of fish in the affected water body, due to their very close proximity to the affected resource. As discussed further in Chapter A15, households in counties that do not directly abut the affected water body will also likely value the water body's resources.

D6-2.5 Habitat Values per Acre for the Affected Population

The total value per acre for the affected population is calculated by multiplying the value per acre per household by the total number of affected households.

D6-2.6 Estimating the Value of Habitat Needed to Offset I&E Losses for the Region

Due to limitations and uncertainties that make this valuation approach difficult to implement on a regional scale, EPA does not present aggregate values for I&E losses. These values would be calculated by multiplying the total number of acres of each habitat required to offset losses by the value per acre for the affected population.

D6-3 LIMITATIONS AND UNCERTAINTY

A number of issues are common to all benefit transfers. Benefit transfer involves adapting research conducted for another purpose in the available literature to address the policy questions at hand. Because benefits analysis of environmental regulations rarely affords enough time to develop original stated preference surveys that are specific to the policy effects, benefit transfer is often the only option to inform a policy decision. Specific issues associated with this approach are discussed in Chapter A15.

Appendix D1: Life History Parameter Values Used to Evaluate I&E in the Mid-Atlantic Region

The tables in this appendix present the life history parameter values used by EPA to calculate age 1 equivalents, fishery yields, and production foregone from I&E data for the Mid-Atlantic Region. Because of differences in the number of life stages represented in the loss data, there are cases where more than one life stage sequence was needed for a given species or species group. Alternative parameter sets were developed for this purpose and are indicated with a number following the species or species group name (i.e., Alewife 1, Alewife 2).

Table D1-1: Alewife Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.554	0	0	0.000000716
Yolksac larvae	1.81	0	0	0.000000728
Post-yolksac larvae	1.72	0	0	0.00000335
Juvenile 1	3.11	0	0	0.000746
Juvenile 2	3.11	0	0	0.0155
Age 1+	0.300	0	0	0.0303
Age 2+	0.300	0	0	0.125
Age 3+	0.300	0	0	0.254
Age 4+	0.900	0.1	0.45	0.379
Age 5+	1.50	0.1	0.9	0.485
Age 6+	1.50	0.1	1	0.565
Age 7+	1.50	0.1	1	0.625
Age 8+	1.50	0.1	1	0.666

[a] Life history parameters applied to losses from Salem.

Source: PSE&G, 1999.

Table D1-2: Alewife Life History Parameters 2[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.554	0	0	0.000000716
Larvae	3.53	0	0	0.00000204
Juvenile	6.21	0	0	0.000746
Age 1+	0.300	0	0	0.0303
Age 2+	0.300	0	0	0.125
Age 3+	0.300	0	0	0.254
Age 4+	0.900	0.1	0.45	0.379
Age 5+	1.50	0.1	0.9	0.485
Age 6+	1.50	0.1	1.0	0.565
Age 7+	1.50	0.1	1.0	0.625
Age 8+	1.50	0.1	1.0	0.666

[a] Life history parameters applied to losses from Calvert Cliffs, Chalk Point, Indian Point, and Morgantown.

Source: PSE&G, 1999.

Table D1-3: American Shad Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.496	0	0	0.000000716
Yolksac larvae	0.496	0	0	0.000000728
Post-yolksac larvae	2.52	0	0	0.00000335
Juvenile	7.4	0	0	0.000746
Age 1+	0.3	0	0	0.309
Age 2+	0.3	0	0	1.17
Age 3+	0.3	0	0	2.32
Age 4+	0.54	0.21	0.45	3.51
Age 5+	1.02	0.21	0.90	4.56
Age 6+	1.5	0.21	1.0	5.47
Age 7+	1.5	0.21	1.0	6.20
Age 8+	1.5	0.21	1.0	6.77

Sources: Able and Fahay, 1998; Froese and Pauly, 2001; PSE&G, 1999; and U.S. Fish and Wildlife Service, 1978.

Table D1-4: Atlantic Croaker Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.817	0	0	0.0000000128
Yolksac larvae	3.27	0	0	0.0000000441
Post-yolksac larvae	4.90	0	0	0.000000246
Juvenile 1	1.18	0	0	0.0000120
Juvenile 2	2.20	0	0	0.000113
Age 1+	1.09	0.3	0.50	0.220
Age 2+	0.300	0.3	1.0	0.672
Age 3+	0.300	0.3	1.0	1.24
Age 4+	0.300	0.3	1.0	1.88
Age 5+	0.300	0.3	1.0	2.43
Age 6+	0.300	0.3	1.0	3.26
Age 7+	0.300	0.3	1.0	3.26
Age 8+	0.300	0.3	1.0	3.26

[a] Life history parameters applied to losses from Salem.

Source: PSE&G, 1999.

Table D1-5: Atlantic Croaker Life History Parameters 2[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.817	0	0	0.0000000128
Larvae	8.10	0	0	0.000000145
Juvenile	3.38	0	0	0.0000624
Age 1+	1.09	0.3	0.50	0.220
Age 2+	0.300	0.3	1.0	0.672
Age 3+	0.300	0.3	1.0	1.24
Age 4+	0.300	0.3	1.0	1.88
Age 5+	0.300	0.3	1.0	2.43
Age 6+	0.300	0.3	1.0	3.26
Age 7+	0.300	0.3	1.0	3.26
Age 8+	0.300	0.3	1.0	3.26

[a] Life history parameters applied to losses from Calvert Cliffs, Chalk Point, Indian River, and Morgantown.

Source: PSE&G, 1999.

Table D1-6: Atlantic Menhaden Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Yolksac larvae	2.85	0	0	0.000000728
Post-yolksac larvae	2.85	0	0	0.00000335
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.8	0.50	0.356
Age 3+	0.450	0.8	1.0	0.679
Age 4+	0.450	0.8	1.0	0.974
Age 5+	0.450	0.8	1.0	1.21
Age 6+	0.450	0.8	1.0	1.38

[a] Life history parameters applied to losses from Salem.

Sources: ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; Froese and Pauly, 2001; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table D1-7: Atlantic Menhaden Life History Parameters 2[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.07	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile	2.85	0	0	0.000746
Age 1+	0.45	0	0	0.0937
Age 2+	0.45	0.8	0.50	0.356
Age 3+	0.45	0.8	1.0	0.679
Age 4+	0.45	0.8	1.0	0.974
Age 5+	0.45	0.8	1.0	1.21
Age 6+	0.45	0.8	1.0	1.38

[a] Life history parameters applied to losses from Calvert Cliffs, Chalk Point, Indian River, and Morgantown.

Sources: ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; Froese and Pauly, 2001; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table D1-8: Atlantic Tomcod Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	8.46	0	0	0.00000126
Larvae	8.46	0	0	0.0000185
Juvenile	8.46	0	0	0.0145
Age 1+	8.46	0	0	0.080
Age 2+	2.83	0	0	0.270
Age 3+	2.83	0	0	0.486

Sources: McLaren et al., 1988; NMFS, 2003a; Stewart and Auster, 1987; and Virginia Tech, 1998.

Table D1-9: Bay Anchovy Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000186
Yolksac larvae	1.57	0	0	0.0000000441
Post-yolksac larvae 1	2.11	0	0	0.0000000929
Post-yolksac larvae 2	4.02	0	0	0.00000461
Juvenile 1	0.0822	0	0	0.0000495
Juvenile 2	0.0861	0	0	0.000199
Juvenile 3	0.129	0	0	0.000532
Juvenile 4	0.994	0	0	0.00114
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] Life history parameters applied to losses from Salem.

Sources: Derickson and Price, 1973; NMFS, 2003a; and PSE&G, 1999.

Table D1-10: Bay Anchovy Life History Parameters 2[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000186
Larvae	7.70	0	0	0.00000158
Juvenile	1.29	0	0	0.000481
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] Life history parameters applied to losses from Calvert Cliffs, Chalk Point, Indian River, and Morgantown.

Sources: Derickson and Price, 1973; NMFS, 2003a; and PSE&G, 1999.

Table D1-11: Bay Anchovy Life History Parameters 3[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000186
Yolksac larvae	1.57	0	0	0.0000000441
Post-yolksac larvae	6.12	0	0	0.00000235
Juvenile	1.29	0	0	0.000481
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] Life history parameters applied to losses from Indian Point.

Sources: Derickson and Price, 1973; NMFS, 2003a; and PSE&G, 1999.

Table D1-12: Blue Crab Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Megalops	1.30	0	0	0.00000291
Juvenile	1.73	0.48	0.5	0.00000293
Age 1+	1.10	0.48	1	0.007
Age 2+	1.38	0.48	1	0.113
Age 3+	1.27	0.48	1	0.326

Sources: Hartman, 1993; and PSE&G, 1999.

Table D1-13: Blueback Herring Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.558	0	0	0.000000716
Yolksac larvae	1.83	0	0	0.000000728
Post-yolksac larvae	1.74	0	0	0.00000335
Juvenile 1	3.13	0	0	0.000746
Juvenile 2	3.13	0	0	0.00836
Age 1+	0.300	0	0	0.0160
Age 2+	0.300	0	0	0.0905
Age 3+	0.300	0	0	0.204
Age 4+	0.900	0	0	0.318
Age 5+	1.50	0	0	0.414
Age 6+	1.50	0	0	0.488
Age 7+	1.50	0	0	0.540
Age 8+	1.50	0	0	0.576

[a] Life history parameters applied to losses from Salem.

Sources: NMFS, 2003a; and PSE&G, 1999.

Table D1-14: Blueback Herring Life History Parameters 2[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.558	0	0	0.000000716
Larvae	3.18	0	0	0.00000204
Juvenile	6.26	0	0	0.000746
Age 1+	0.300	0	0	0.0160
Age 2+	0.300	0	0	0.0905
Age 3+	0.300	0	0	0.204
Age 4+	0.900	0	0	0.318
Age 5+	1.50	0	0	0.414
Age 6+	1.50	0	0	0.488
Age 7+	1.50	0	0	0.540
Age 8+	1.50	0	0	0.576

[a] Life history parameters applied to losses from Calvert Cliffs, Chalk Point, and Indian Point.

Sources: NMFS, 2003a; and PSE&G, 1999.

Table D1-15: Hogchoker Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.000000487
Larvae	5.20	0	0	0.00110
Juvenile	2.31	0	0	0.00207
Age 1+	2.56	0	0	0.0113
Age 2+	0.705	0	0	0.0313
Age 3+	0.705	0	0	0.0610
Age 4+	0.705	0	0	0.0976
Age 5+	0.705	0	0	0.138
Age 6+	0.705	0	0	0.178

Sources: Froese and Pauly, 2003; NMFS, 2003a; and PG&E National Energy Group, 2001.

Table D1-16: Naked Goby Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.288	0	0	0.0000370
Larvae	4.09	0	0	0.000221
Juvenile	2.30	0	0	0.000485
Age 1+	2.55	0	0	0.00205

Sources: Froese and Pauly, 2003; and PG&E National Energy Group, 2001.

Table D1-17: Spot Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.825	0	0	0.000000131
Yolksac larvae	3.30	0	0	0.000000154
Post-yolksac larvae	4.12	0	0	0.000000854
Juvenile 1	1.58	0	0	0.0000226
Juvenile 2	0.99	0.247	0.30	0.000220
Age 1+	0.463	0.40	1.0	0.0791
Age 2+	0.400	0.40	1.0	0.299
Age 3+	0.400	0.40	1.0	0.507
Age 4+	0.400	0.40	1.0	0.648
Age 5+	0.400	0.40	1.0	0.732
Age 6+	0.400	0.40	1.0	0.779
Age 7+	0.400	0.40	1.0	0.779
Age 8+	0.400	0.40	1.0	0.779
Age 9+	0.400	0.40	1.0	0.779
Age 10+	0.400	0.40	1.0	0.779
Age 11+	0.400	0.40	1.0	0.779
Age 12+	0.400	0.40	1.0	0.779
Age 13+	0.400	0.40	1.0	0.779
Age 14+	0.400	0.40	1.0	0.779
Age 15+	0.400	0.40	1.0	0.779

[a] Life history parameters applied to losses from Salem.

Sources: PSE&G, 1984b, 1999; and Schwartz et al., 1979.

Table D1-18: Spot Life History Parameters 2[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.825	0	0	0.000000131
Larvae	7.40	0	0	0.000000504
Juvenile	2.57	0	0	0.000121
Age 1+	0.463	0.40	1.0	0.0791
Age 2+	0.400	0.40	1.0	0.299
Age 3+	0.400	0.40	1.0	0.507
Age 4+	0.400	0.40	1.0	0.648
Age 5+	0.400	0.40	1.0	0.732
Age 6+	0.400	0.40	1.0	0.779
Age 7+	0.400	0.40	1.0	0.779
Age 8+	0.400	0.40	1.0	0.779
Age 9+	0.400	0.40	1.0	0.779
Age 10+	0.400	0.40	1.0	0.779
Age 11+	0.400	0.40	1.0	0.779
Age 12+	0.400	0.40	1.0	0.779
Age 13+	0.400	0.40	1.0	0.779
Age 14+	0.400	0.40	1.0	0.779
Age 15+	0.400	0.40	1.0	0.779

[a] Life history parameters applied to losses from Calvert Cliffs, Chalk Point, Indian River, and Morgantown.

Sources: PSE&G, 1984b, 1999; and Schwartz et al., 1979.

Table D1-19: Striped Bass Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.39	0	0	0.000000224
Yolksac larvae	2.22	0	0	0.000000243
Post-yolksac larvae	5.11	0	0	0.0000119
Juvenile 1	2.28	0	0	0.000154
Juvenile 2	1.00	0	0	0.0216
Age 1+	1.10	0	0	0.485
Age 2+	0.150	0.31	0.06	2.06
Age 3+	0.150	0.31	0.20	3.31
Age 4+	0.150	0.31	0.63	4.93
Age 5+	0.150	0.31	0.94	6.50
Age 6+	0.150	0.31	1.0	8.58
Age 7+	0.150	0.31	0.90	12.3
Age 8+	0.150	0.31	0.90	14.3
Age 9+	0.150	0.31	0.90	16.1
Age 10+	0.150	0.31	0.90	18.8
Age 11+	0.150	0.31	0.90	19.6
Age 12+	0.150	0.31	0.90	22.4
Age 13+	0.150	0.31	0.90	27.0
Age 14+	0.150	0.31	0.90	34.6
Age 15+	0.150	0.31	0.90	41.5

[a] Life history parameters applied to losses from Salem.

Sources: Bason, 1971; and PSE&G, 1999.

Table D1-20: Striped Bass Life History Parameters 2[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.39	0	0	0.000000224
Larvae	7.32	0	0	0.00000606
Juvenile	3.29	0	0	0.0109
Age 1+	1.10	0	0	0.485
Age 2+	0.150	0.31	0.06	2.06
Age 3+	0.150	0.31	0.20	3.31
Age 4+	0.150	0.31	0.63	4.93
Age 5+	0.150	0.31	0.94	6.5
Age 6+	0.150	0.31	1.0	8.58
Age 7+	0.150	0.31	0.90	12.3
Age 8+	0.150	0.31	0.90	14.3
Age 9+	0.150	0.31	0.90	16.1
Age 10+	0.150	0.31	0.90	18.8
Age 11+	0.150	0.31	0.90	19.6
Age 12+	0.150	0.31	0.90	22.4
Age 13+	0.150	0.31	0.90	27
Age 14+	0.150	0.31	0.90	34.6
Age 15+	0.150	0.31	0.90	41.5

[a] Life history parameters applied to losses from Calvert Cliffs, Chalk Point, and Morgantown.

Sources: Bason, 1971; and PSE&G, 1999.

Table D1-21: Striped Bass Life History Parameters 3[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.39	0	0	0.000000224
Yolksac larvae	2.22	0	0	0.000000243
Post-yolksac larvae	5.11	0	0	0.0000119
Juvenile	3.29	0	0	0.248
Age 1+	1.10	0	0	0.485
Age 2+	0.150	0.31	0.06	2.06
Age 3+	0.150	0.31	0.20	3.31
Age 4+	0.150	0.31	0.63	4.93
Age 5+	0.150	0.31	0.94	6.50
Age 6+	0.150	0.31	1.0	8.58
Age 7+	0.150	0.31	0.90	12.3
Age 8+	0.150	0.31	0.90	14.3
Age 9+	0.150	0.31	0.90	16.1
Age 10+	0.150	0.31	0.90	18.8
Age 11+	0.150	0.31	0.90	19.6
Age 12+	0.150	0.31	0.90	22.4
Age 13+	0.150	0.31	0.90	27
Age 14+	0.150	0.31	0.90	34.6
Age 15+	0.150	0.31	0.90	41.5

[a] Life history parameters applied to losses from Indian Point.

Sources: Bason, 1971; and PSE&G, 1999.

Table D1-22: Summer Flounder Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.288	0	0	0.00000109
Larvae	4.37	0	0	0.00000532
Juvenile	2.38	0	0	0.208
Age 1+	0.200	0.26	0.50	0.919
Age 2+	0.200	0.26	1.0	1.02
Age 3+	0.200	0.26	1.0	2.50
Age 4+	0.200	0.26	1.0	3.56
Age 5+	0.200	0.26	1.0	5.09
Age 6+	0.200	0.26	1.0	5.83
Age 7+	0.200	0.26	1.0	6.64
Age 8+	0.200	0.26	1.0	8.16
Age 9+	0.200	0.26	1.0	9.90
Age 10+	0.200	0.26	1.0	11.9
Age 11+	0.200	0.26	1.0	14.1
Age 12+	0.200	0.26	1.0	16.6
Age 13+	0.200	0.26	1.0	19.4
Age 14+	0.200	0.26	1.0	22.5

Sources: Bolz et al., 1999; Froese and Pauly, 2003; Grimes et al., 1989; NOAA, 2001c; PG&E National Energy Group, 2001; Packer et al., 1999; and Wang and Kernehan, 1979.

Table D1-23: Weakfish Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000787
Yolksac larvae	1.34	0	0	0.0000000882
Post-yolksac larvae	6.33	0	0	0.000000382
Juvenile 1	2.44	0	0	0.0000184
Juvenile 2	1.48	0	0	0.0502
Age 1+	0.349	0.25	0.10	0.260
Age 2+	0.250	0.25	0.50	0.680
Age 3+	0.250	0.25	1.0	1.12
Age 4+	0.250	0.25	1.0	1.79
Age 5+	0.250	0.25	1.0	2.91
Age 6+	0.250	0.25	1.0	6.21
Age 7+	0.250	0.25	1.0	7.14
Age 8+	0.250	0.25	1.0	9.16
Age 9+	0.250	0.25	1.0	10.8
Age 10+	0.250	0.25	1.0	12.5
Age 11+	0.250	0.25	1.0	12.5
Age12+	0.250	0.25	1.0	12.5
Age 13+	0.250	0.25	1.0	12.5
Age 14+	0.250	0.25	1.0	12.5
Age 15+	0.250	0.25	1.0	12.5

[a] Life history parameters applied to losses from Salem.

Sources: PSE&G, 1999; and Thomas, 1971.

Table D1-24: Weakfish Life History Parameters 2[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000787
Larvae	7.70	0	0	0.000000235
Juvenile	3.92	0	0	0.0251
Age 1+	0.349	0.25	0.10	0.260
Age 2+	0.250	0.25	0.50	0.680
Age 3+	0.250	0.25	1.0	1.12
Age 4+	0.250	0.25	1.0	1.79
Age 5+	0.250	0.25	1.0	2.91
Age 6+	0.250	0.25	1.0	6.21
Age 7+	0.250	0.25	1.0	7.14
Age 8+	0.250	0.25	1.0	9.16
Age 9+	0.250	0.25	1.0	10.8
Age 10+	0.250	0.25	1.0	12.5
Age 11+	0.250	0.25	1.0	12.5
Age12+	0.250	0.25	1.0	12.5
Age 13+	0.250	0.25	1.0	12.5
Age 14+	0.250	0.25	1.0	12.5
Age 15+	0.250	0.25	1.0	12.5

[a] Life history parameters applied to losses from Calvert Cliffs, Chalk Point, and Indian River.

Sources: PSE&G, 1999; and Thomas, 1971.

Table D1-25: White Perch Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.75	0	0	0.000000330
Yolksac larvae	2.10	0	0	0.000000353
Post-yolksac larvae	3.27	0	0	0.00000507
Juvenile 1	0.947	0	0	0.000317
Juvenile 2	0.759	0	0	0.00486
Age 1+	0.693	0	0	0.0198
Age 2+	0.693	0	0	0.0567
Age 3+	0.693	0.15	0.00080	0.103
Age 4+	0.689	0.15	0.027	0.150
Age 5+	1.58	0.15	0.21	0.214
Age 6+	1.54	0.15	0.48	0.265
Age 7+	1.48	0.15	0.84	0.356
Age 8+	1.46	0.15	1.0	0.387
Age 9+	1.46	0.15	1.0	0.516
Age 10+	1.46	0.15	1.0	0.619

[a] Life history parameters applied to losses from Salem.

Sources: Horseman and Shirey, 1974; and PSE&G, 1999.

Table D1-26: White Perch Life History Parameters 2[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.75	0	0	0.000000330
Larvae	5.37	0	0	0.00000271
Juvenile	1.71	0	0	0.00259
Age 1+	0.693	0	0	0.0198
Age 2+	0.693	0	0	0.0567
Age 3+	0.693	0.15	0.00080	0.103
Age 4+	0.689	0.15	0.027	0.150
Age 5+	1.58	0.15	0.21	0.214
Age 6+	1.54	0.15	0.48	0.265
Age 7+	1.48	0.15	0.84	0.356
Age 8+	1.46	0.15	1.0	0.387
Age 9+	1.46	0.15	1.0	0.516
Age 10+	1.46	0.15	1.0	0.619

[a] Life history parameters applied to losses from Calvert Cliffs, Chalk Point, and Morgantown.

Sources: Horseman and Shirey, 1974; and PSE&G, 1999.

Table D1-27: White Perch Life History Parameters 3[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.75	0	0	0.000000330
Yolksac larvae	2.10	0	0	0.000000353
Post-yolksac larvae	3.27	0	0	0.00000507
Juvenile	1.71	0	0	0.00259
Age 1+	0.693	0	0	0.0198
Age 2+	0.693	0	0	0.0567
Age 3+	0.693	0.15	0.00080	0.103
Age 4+	0.689	0.15	0.027	0.150
Age 5+	1.58	0.15	0.21	0.214
Age 6+	1.54	0.15	0.48	0.265
Age 7+	1.48	0.15	0.84	0.356
Age 8+	1.46	0.15	1.0	0.387
Age 9+	1.46	0.15	1.0	0.516
Age 10+	1.46	0.15	1.0	0.619

[a] Life history parameters applied to losses from Indian Point.

Sources: Horseman and Shirey, 1974; and PSE&G, 1999.

Table D1-28: Windowpane Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.41	0	0	0.00000154
Larvae	6.99	0	0	0.00165
Juvenile	2.98	0	0	0.00223
Age 1+	0.420	0	0	0.0325
Age 2+	0.420	1.6	0.25	0.122
Age 3+	0.420	1.6	0.61	0.265
Age 4+	0.420	1.6	1.0	0.433
Age 5+	0.420	1.6	1.0	0.603
Age 6+	0.420	1.6	1.0	0.761
Age 7+	0.420	1.6	1.0	0.899
Age 8+	0.420	1.6	1.0	1.02
Age 9+	0.420	1.6	1.0	1.11
Age 10+	0.420	1.6	1.0	1.19

Sources: Froese and Pauly, 2003; Hendrickson, 2000; PG&E National Energy Group, 2001; and USGen New England, 2001.

Table D1-29: Winter Flounder Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.288	0	0	0.00000115
Larvae	4.37	0	0	0.0138
Juvenile	2.38	0	0	0.0330
Age 1+	1.10	0.24	0.01	0.208
Age 2+	0.924	0.24	0.29	0.562
Age 3+	0.200	0.24	0.80	0.997
Age 4+	0.200	0.24	0.92	1.42
Age 5+	0.200	0.24	0.83	1.78
Age 6+	0.200	0.24	0.89	2.07
Age 7+	0.200	0.24	0.89	2.29
Age 8+	0.200	0.24	0.89	2.45
Age 9+	0.200	0.24	0.89	2.57
Age 10+	0.200	0.24	0.89	2.65
Age 11+	0.200	0.24	0.89	2.71
Age 12+	0.200	0.24	0.89	2.75
Age 13+	0.200	0.24	0.89	2.78
Age 14+	0.200	0.24	0.89	2.80
Age 15+	0.200	0.24	0.89	2.82
Age 16+	0.200	0.24	0.89	2.83

Sources: Able and Fahay, 1998; Colarusso, 2000; Nitschke et al., 2000; and PG&E National Energy Group, 2001.

Table D1-30: Other Commercial Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.5	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] Includes American butterfish, American eel, brown bullhead, channel catfish, conger eel, gizzard shad, harvestfish, silver hake, white catfish, and yellow perch.

Sources: Able and Fahay, 1998; Durbin et al., 1983; PSE&G, 1999.

Table D1-31: Other Recreational Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.5	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] Includes black drum, black sea bass, bluefish, northern puffer, northern searobin, orange filefish, oyster toadfish, sea lamprey, spotted hake, and spotted seatrout.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table D1-32: Other Recreational/Commercial Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Yolksac larvae	2.85	0	0	0.000000728
Post-yolksac larvae	2.85	0	0	0.00000335
Juvenile 1	1.43	0	0	0.000746
Juvenile 2	1.43	0	0	0.0472
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.5	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] Includes species designated as other commercial from Salem.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table D1-33: Other Forage Species Life History Parameters 1[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000186
Yolksac larvae	1.57	0	0	0.0000000441
Post-yolksac larvae 1	2.11	0	0	0.0000000929
Post-yolksac larvae 2	4.02	0	0	0.00000461
Juvenile 1	0.0822	0	0	0.0000495
Juvenile 2	0.0861	0	0	0.000199
Juvenile 3	0.129	0	0	0.000532
Juvenile 4	0.994	0	0	0.001161
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] Life history parameters applied to losses from Salem.
[b] Includes species designated as other forage from Salem.

Sources: Derickson and Price, 1973; and PSE&G, 1999.

Table D1-34: Other Forage Species Life History Parameters 2[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000186
Larvae	7.70	0	0	0.00000158
Juvenile	1.29	0	0	0.000481
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] Life history parameters applied to losses from Calvert Cliffs, Chalk Point, Indian Point, Indian River, and Morgantown.

[b] Includes Atlantic herring, Atlantic needlefish, Atlantic silverside, banded killifish, blackcheek tonguefish, bluegill, chain pickerel, fourspine stickleback, golden shiner, inland silverside, inshore lizardfish, lined seahorse, mississippi silvery minnow, mud minnow, mummichog, northern pipefish, northern stargazer, pumpkinseed, sheepshead minnow, skilletfish, spottail shiner, spotted codling, striped anchovy, striped blenny, striped killifish, threespine stickleback, and other organisms not identified to species.

Sources: Derickson and Price, 1973; and PSE&G, 1999.

Table D1-35: Other Forage Species Life History Parameters 3[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000186
Yolksac larvae	1.57	0	0	0.0000000441
Post-yolksac larvae	6.10	0	0	0.00000662
Juvenile	1.29	0	0	0.000481
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] Life history parameters applied to losses from Calvert Cliffs, Indian Point, and Salem.

[b] Includes inland silverside, river herring, and silversides not identified to species.

Sources: Derickson and Price, 1973; and PSE&G, 1999.

Part E

South Atlantic

Chapter E1: Background

INTRODUCTION

CHAPTER CONTENTS

This chapter presents an overview of the Phase II facilities in the South Atlantic study region and summarizes their key operating, economic, technical, and compliance characteristics. For further discussion of operating and economic characteristics of Phase II facilities, refer to Chapter A3 of the *Economic and Benefits Analysis for the Final Section 316(b) Phase II Existing Facilities Rule*; for further discussion of the technical and compliance characteristics of Phase II facilities, refer to the *Technical Development Document for the Final Section 316(b) Phase II Existing Facilities Rule* (U.S. EPA, 2004a,b).

E1-1 OVERVIEW

The South Atlantic Study includes 16 facilities that are in scope for the final Phase II regulation. Fifteen of the 16 facilities withdraw cooling water from an estuary or tidal river and one withdraws water from the Atlantic Ocean. Figure E1-1 presents a map of the 16 in-scope Phase II facilities located in the South Atlantic study region.

Figure E1-1: In-Scope Phase II Facilities in the South Atlantic Regional Study

Source: U.S. EPA analysis for this report.

E1-2 OPERATING AND ECONOMIC CHARACTERISTICS

Most of the 16 South Atlantic Study facilities (10) are oil/gas facilities; three are coal steam facilities; two are nuclear facilities; and one is a combined-cycle facility. In 2001, these 16 facilities accounted for 14 gigawatts of generating capacity, 65,000 gigawatt hours of generation, and $2.8 billion in revenues.

The operating and economic characteristics of the South Atlantic Study facilities are summarized in Table E1-1. Section E1-4 provides further information on each facility [including facility subregion, North American Electric Reliability Council (NERC) region, plant type, capacity, 2001 generation, and impingement and entrainment estimates were developed for the facility].

Table E1-1: Operating and Economic Characteristics of Phase II Facilities

Waterbody Type	Number of Facilities by Plant Type[a]					Total Capacity (MW)[b]	Total Generation (MWh)[b]	Electric Revenue (millions)
	Coal Steam	**Combined Cycle**	**Nuclear**	**Oil/Gas Steam**	**Total**			
Estuary/Tidal								
FL	1	1	-	8	10	8,361	32,039,494	$1,301
GA	-	-	-	2	2	750	97,088	$15
NC	-	-	1	-	1	1,790	13,843,547	$552
SC	2	-	-	-	2	1,265	5,921,762	$182
Subtotal	*3*	*1*	*1*	*10*	*15*	*12,166*	*51,901,891*	*$2,180*
Ocean								
FL	-	-	1	-	1	1,700	13,437,086	$637
TOTAL	**3**	**1**	**2**	**10**	**16**	**13,866**	**65,338,977**	**$2,817**

[a] Based on largest steam-electric capacity at facilities.

[b] MW is an abbreviation for megawatt; MWh is an abbreviation for megawatt hour.

Sources: Plant type (IPM Analysis, U.S. EPA, 2002; Form EIA-860, U.S. DOE, 2001a); capacity (Form EIA-860, U.S. DOE, 2001a); generation (Form EIA-906, U.S. DOE, 2001c); revenue (Form EIA-861, U.S. DOE, 2001b; Form EIA-906, U.S. DOE, 2001c).

E1-3 TECHNICAL AND COMPLIANCE CHARACTERISTICS

Twelve of the 16 South Atlantic Study facilities employ a once-through cooling system in the baseline; two facilities employ a combination cooling system; one facility employs a recirculating cooling system; and one facility employs an other type of cooling system. These 16 facilities incur a combined pre-tax compliance cost of $9 million. Table E1-2 summarizes the flow, compliance responses, and compliance costs for these 16 facilities.

Table E1-2: Technical and Compliance Characteristics of Phase II Facilities

	Cooling Water System (CWS) Type[a]				
	Once-Through	**Recirculating**	**Combination**	**Other**	**All**
Design Flow (MGD)	**10,730**	**99**	**819**	**824**	**12,471**
Number of Facilities by Compliance Response					
Fish H&R	3	-	-	-	3
Fine Mesh Traveling Screens w/ Fish H&R	1	-	1	-	2
New Larger Intake Structure with Fine Mesh and Fish H&R	1	-	-	-	1
Fish Barrier Net/Gunderboom	1	-	-	-	1
Relocate Intake to Submerged Offshore with Passive Screen	1	-	-	-	1
Velocity Cap	1	-	-	-	1
Double-Entry, Single-Exit with Fine Mesh and Fish H&R	-	-	-	1	1
None	4	1	1	-	6
Total	**12**	**1**	**2**	**1**	**16**
Compliance Cost (millions, 2002$)[b]	**$7.7**	**w[b]**	**w[b]**	**w[b]**	**$9.0**

[a] Combination and "other" CWSs are costed as if they were once-through CWSs.
[b] Data withheld because of confidentiality reasons.

Source: U.S. EPA analysis for this report.

E1-4 PHASE II FACILITIES IN THE SOUTH ATLANTIC REGIONAL STUDY

Table E1-3 presents economic and operating characteristics of the South Atlantic Study facilities.

Table E1-3: Phase II Facilities in the South Atlantic Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
Estuary/Tidal River							
207	St Johns River Power	FL	FRCC	Coal Steam	1,358	10,216,337	N
609	Cape Canaveral	FL	FRCC	O/G Steam	804	3,833,694	N
613	Lauderdale	FL	FRCC	Combined Cycle	1,863	6,164,232	N
617	Port Everglades	FL	FRCC	O/G Steam	1,665	5,199,333	N
619	Riviera	FL	FRCC	O/G Steam	621	3,055,683	N
658	Henry D King	FL	FRCC	O/G Steam	142	58,332	N
667	Northside Generating	FL	FRCC	O/G Steam	1,407	2,686,013	N
668	Southside Generating	FL	FRCC	O/G Steam	0	523,577	N
683	Indian River Plant	FL	FRCC	O/G Steam	343	67,733	N
693	Vero Beach Municipal	FL	FRCC	O/G Steam	158	234,560	N
715	McManus	GA	SERC	O/G Steam	644	96,889	N
734	Riverside	GA	SERC	O/G Steam	106	199	N
6014	Brunswick	NC	SERC	Nuclear	1,790	13,843,547	N
3298	Williams	SC	SERC	Coal Steam	687	4,193,258	N
3319	Jefferies	SC	SERC	Coal Steam	578	1,728,504	N
Ocean							
6045	St Lucie	FL	FRCC	Nuclear	1,700	13,437,086	N

Source: U.S. EPA analysis for this report.

Chapter E2: Evaluation of Impingement and Entrainment in the South Atlantic Region

BACKGROUND: SOUTH ATLANTIC MARINE FISHERIES

CHAPTER CONTENTS

Species of the family Sciaenidae, including Atlantic croaker, spot, red drum, black drum, weakfish, and spotted sea trout, contribute to some of the most important commercial and recreational fisheries in the South Atlantic region (NMFS, 1999b). The popularity of blackened redfish in U.S. restaurants beginning in the mid-1980's led to rapid increases in commercial landings of red drum, and eventual overexploitation of the offshore adult spawning stock. The Gulf of Mexico Fishery Management Council and The South Atlantic Fishery Management Fishery Management Council have now banned fishing red drum offshore until the adult stock recovers. There remains an inshore fishery for recreational anglers.

Atlantic menhaden is another important commercial and recreational species in Atlantic and Gulf of Mexico estuaries and coastal waters (NMFS, 1999b). In the Atlantic, the menhaden resource is fully utilized. Most menhaden harvest is for fish meal, fish oil, fish solubles, and bait fish. Menhaden is also an important forage species for marine birds and other fish species. Spawning stock biomass reached a peak in 1997, but the recruitment of juveniles in the past decade has reached historic lows. Another major management concern is overexploitation resulting from the harvesting too many fish before they reach adult size.

As in the Gulf of Mexico, important coastal pelagic species in the South Atlantic region include king and Spanish mackerels, cero, dolphinfish, and cobia (NMFS, 1999b). King and Spanish mackerel make up about 95 percent of the harvest of coastal pelagics. The east coast of Florida and the Florida keys is a major production area for the king mackerel commercial fishery.

Fisheries for snappers, groupers, amberjacks, grunts, seabasses, and other reef fishes are also important in the South Atlantic region (NMFS, 1999b). These fishes are vulnerable to overfishing because of their slow growth, delayed maturity, and ease of capture. Commercial quotas for snappers and groupers are in effect, as well as seasonal closures for some species.

Fisheries for invertebrate species such as shrimp, spiny lobster, and stone crab are also important in the South Atlantic region (NMFS, 1999b). The extensive shrimp fisheries are among the most valuable in the U.S.

E2-1 FISHERY SPECIES IMPINGED AND ENTRAINED

Table E2-1 shows the status of managed stocks in the South Atlantic region, indicating in bold the stocks subject to impingement and entrainment (I&E). Overfishing occurs when fishing mortality is above a management threshold, jeopardizing the long term capacity of the stock to produce the potential maximum sustainable yield on a continuing basis. A stock is considered overfished when biomass falls below a given threshold. In some cases, heavy fishing in the past may have reduced a stock to low abundance, so that it is now considered overfished even though the stock is not currently subject to overfishing.

As indicated in Table E2-1, 12 of the 32 managed stocks are classified as overfished, including vermilion snapper, red porgy, gag, red snapper, snowy grouper, warsaw grouper, golden tilefish, yellowtail snapper, red grouper, black grouper, black sea bass, and red drum. Other stocks are in the process of being rebuilt from levels below the maximum sustainable yield, including. The status of many other stocks is poorly known.

Table E2-1: Summary of Stock Status for Harvested Species of the South Atlantic Region Included in Federal Fishery Management Plans

Stock (species in bold are subject to I&E)	**Overfishing? (fishing mortality above threshold)**	**Overfished? (biomass below threshold)**	**Approaching Overfished Condition?**
Golden crab	No	Undefined	Unknown
White shrimp	No	Unknown	Unknown
Rock shrimp	No	Unknown	Unknown
Brown shrimp	No	Unknown	Unknown
Pink shrimp	No	Unknown	Unknown
Vermilion snapper	Yes	Yes	N/A
Red porgy	Yes	Yes	N/A
Gag	Yes	Yes	N/A
Red snapper	Yes	Yes	N/A
Snowy grouper	Yes	Yes	N/A
Warsaw grouper	Yes	Yes	N/A
Golden tilefish	Yes	Yes	N/A
Yellowtail snapper	Yes	Yes	N/A
Red grouper	Yes	Yes	N/A
Black grouper	Yes	Yes	N/A
Black sea bass	Yes	Yes	N/A
Goliath grouper (Jewfish)	No	Yes	N/A
Nassau grouper	No	Yes	N/A
Mutton snapper	No	No	No
Greater amberjack	No	No	No
Wreckfish	No	No	Unknown
Yellowedge grouper	No	No	Unknown
Red drum	Yes	Yes	N/A
Fire corals	No	Undefined	Unknown
Hydrocorals	No	Undefined	Unknown
Octocorals	No	Undefined	Unknown
Stony corals	No	Undefined	Unknown
Black corals	No	Undefined	Unknown
Spiny lobster	No	No	No
King mackerel	No	No	N/A
Spanish mackerel	No	No	No
Dolphin	No	No	No

E2-2 EPA'S ESTIMATES OF CURRENT I&E IN THE SOUTH ATLANTIC REGION EXPRESSED AS AGE 1 EQUIVALENTS, FOREGONE YIELD, AND PRODUCTION FOREGONE

Table E2-2 lists South Atlantic facilities in scope of the Phase II rule. Due to time, budget, and data limitations, EPA did not model I&E losses for the South Atlantic using the methods applied in the other regions. Rather, current loss and benefits estimates for the South Atlantic were extrapolated based on the total 3 year average operational intake flows at facilities in the Mid-Atlantic and Gulf of Mexico. The formula used is:

South Atlantic losses = (Gulf + Mid-Atlantic losses) * South Atlantic flow/(Gulf + Mid-Atlantic flow),

which is equivalent to

South Atlantic losses = (Gulf + Mid-Atlantic losses) * 0.178.

EPA applied this method *by species* to the estimated pounds of commercial and recreational harvest lost due to I&E (see Chapters E3 and E4). EPA only applied this method to the Mid-Atlantic and Gulf of Mexico regional totals for age 1 equivalents, total yield, and production foregone. The estimates are presented in Table E2-3.

Table E2-2: South Atlantic Facilities in Scope of the Section 316(b) Phase II Rule

In Scope Facilities
Brunswick Nuclear (NC)
Cape Canaveral (FL)
Henry D King (FL)
Indian River (FL)
Jefferies (SC)
Lauderdale (FL)
Mcmanus (GA)
Northside (FL)
Port Everglades (FL)
Riverside (GA)
Riviera (FL)
Southside (FL)
St Johns River Power (FL)
St Lucie Nuclear (FL)
Vero Beach (FL)
Williams (SC)

Table E2-3: Extrapolated Estimates of Current Annual I&E in the South Atlantic Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Loss Type	Age 1 Equivalents (millions)	Total Yield (million lbs)	Production Foregone (million lbs)
Impingement	58.2	12.4	5.3
Entrainment	206	11.1	4.8
Total	264	23.5	10.1

E2-3 ASSUMPTIONS USED IN CALCULATING RECREATIONAL AND COMMERCIAL LOSSES

As noted in the previous section, recreational and commercial I&E losses for the South Atlantic are estimated based on loss estimates for the Gulf of Mexico and Mid-Atlantic. Once these losses are estimated, the value of benefits is computed in a manner similar to the other regions. Table E2-4 presents the value per pound for commercially harvested species used in the commercial fishing analysis.

Age-1 equivalent fish that are spared from I&E are not necessarily old enough or large enough to be attractive to anglers. It may take one or more years for these fish to reach a harvestable age. For this reason, EPA discounts commercial and recreational benefits so that the cost and benefits estimates will be comparable. Tables E2-5 and E2-6 present the multiplicative discounting factors used in discounting benefits assuming a 3 percent real discount rate and a 7 percent real discount rate. For details on how these factors are developed, see Chapter A14.

Table E2-4: Commercial Value per Pound for Species Impinged and Entrained at South Atlantic Facilities

Species Group	Commercial Value per Pound (2002$)[a]
Alewife	$0.26
American shad	$0.75
Atlantic croaker	$0.33
Atlantic menhaden	$0.04
Black drum	$0.36
Blue crab	$0.65
Mackerels	$1.04
Other (commercial)	$0.55
Pink shrimp	$2.03
Sea basses	$1.45
Sheepshead	$0.67
Spot	$0.39
Stone crab	$1.34
Striped bass	$1.27
Striped mullet	$0.64
Summer flounder	$1.70
Weakfish	$0.55

[a] Calculated using 1993-2001 commercial landings data from NMFS (2003a).

Table E2-5: Factors Applied to Recreational Benefits to Implement Discounting in the South Atlantic

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Atlantic croaker	0.934	0.858	0.962	0.918
Black drum	0.884	0.764	0.910	0.818
Mackerels	na	na	0.928	0.845
Other (rec. and com.)	0.922	0.831	0.950	0.889
Other (recreational)	0.922	0.831	0.950	0.889
Pinfish	0.960	0.911	0.989	0.975
Red drum	0.884	0.764	0.910	0.818
Sea basses	na	na	0.850	0.691
Searobins	0.912	0.813	0.940	0.870
Sheepshead	0.909	0.804	0.936	0.861
Silver perch	0.943	0.873	0.971	0.935
Spot	0.949	0.888	0.977	0.950
Spotted seatrout	0.936	0.863	0.965	0.923
Striped bass	0.864	0.717	0.879	0.749
Striped mullet	0.930	0.848	0.957	0.907
Summer flounder	na	na	0.941	0.874
Weakfish	0.950	0.890	0.979	0.953
Other (forage)	0.919	0.829	0.919	0.829

Table E2-6: Factors Applied to Commercial Benefits to Implement Discounting in the South Atlantic

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Alewife	0.872	0.730	0.898	0.782
American shad	0.867	0.723	0.893	0.773
Atlantic croaker	0.899	0.788	0.926	0.843
Atlantic menhaden	0.930	0.847	0.958	0.906
Black drum	0.788	0.592	0.811	0.633
Blue crab	0.949	0.888	0.978	0.950
Leatherjacket	0.933	0.854	0.961	0.914
Mackerels			0.918	0.826
Menhadens	0.913	0.813	0.940	0.870
Other (commercial)	0.913	0.813	0.940	0.870
Other (rec. and com.)	0.913	0.813	0.940	0.870
Pink shrimp	0.971	0.935	0.898	0.788
Sea basses			0.836	0.666
Sheepshead	0.907	0.800	0.934	0.856
Spot	0.921	0.831	0.949	0.889
Stone crab	0.944	0.877	0.972	0.938
Striped bass	0.841	0.675	0.848	0.692
Striped mullet	0.890	0.768	0.916	0.821
Summer flounder			0.890	0.773
Weakfish	0.924	0.836	0.951	0.895
White perch			0.883	0.756
Other (forage)	0.901	0.793	0.901	0.793

Chapter E3: Commercial Fishing Valuation

INTRODUCTION

CHAPTER CONTENTS

This chapter presents the results of the commercial fishing benefits analysis for the South Atlantic region. Section E3.1 details the estimated losses under current, or baseline, conditions. Section E3.2 presents the expected benefits in the region attributable to the rule. Chapter A10 details the methods used in this analysis.

Note that, while results for other regions have been sample weighted, no weighting is needed in the South Atlantic.

E3-1 BASELINE LOSSES

Table E3-1 provides EPA's estimate of the value of gross revenues lost in commercial fisheries resulting from the impingement of aquatic species at facilities in the South Atlantic region. Table E3-2 displays this information for entrainment. Total annual revenue losses are approximately $1.9 million, assuming a 3 percent discount rate.

Table E3-1: Annual Commercial Fishing Gross Revenues Lost Due to Impingement at Facilities in the South Atlantic Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002$)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
Alewife	58	6	6	5
American shad	3	2	1	1
Atlantic croaker	35,152	9,805	9,084	8,262
Atlantic menhaden	5,784,919	374,891	358,977	339,718
Black drum	34	22	18	14
Blue crab	37,752	25,961	25,378	24,654
Leatherjacket	33,272	35,188	33,817	32,158
Mackerels	129	58	53	48
Menhadens	420,229	22,310	20,982	19,405
Other (commercial)	192,936	103,955	97,767	90,421
Other (rec. and com.)	30,052	15,682	14,748	13,640
Sea basses (com. and rec.)	9	5	4	3
Shrimp (commercial)	64,799	150,772	135,362	118,808
Spot	187,565	76,998	73,057	68,472
Stone crab	966	1,392	1,353	1,306
Striped bass	2,241	3,722	3,158	2,574
Striped mullet	58,353	38,631	35,404	31,727
Summer flounder	3,788	5,737	5,104	4,433

Table E3-1: Annual Commercial Fishing Gross Revenues Lost Due to Impingement at Facilities in the South Atlantic Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002$)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
Weakfish	26,348	16,985	16,158	15,199
Windowpane	11	4	4	3
Other (forage)	1,104	429	386	340
TOTAL	6,879,719	882,554	830,820	771,190

Table E3-2: Annual Commercial Fishing Gross Revenues Lost Due to Entrainment at Facilities in the South Atlantic Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002$)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
Alewife	7	1	1	1
American shad	611	363	315	263
Atlantic croaker	501,555	160,462	144,331	126,376
Atlantic menhaden	221,906	14,381	13,369	12,179
Black drum	6,239	4,093	3,224	2,422
Blue crab	316,777	232,452	220,612	206,307
Leatherjacket	658	696	649	594
Menhadens	1,677	89	81	72
Other (commercial)	2,186	1,181	1,078	960
Other (rec. and com.)	360,122	187,918	171,585	152,759
Sheepshead	6	2	2	2
Shrimp (commercial)	15,476	36,009	34,960	33,653
Spot	672,302	283,324	260,992	235,467
Stone crab	955	1,376	1,299	1,206
Striped bass	17,720	29,429	24,752	19,865
Striped mullet	167,925	111,172	98,915	85,329
Weakfish	95,362	61,476	56,777	51,411
Other (forage)	352,237	135,018	121,594	107,043
TOTAL	2,733,721	1,259,441	1,154,537	1,035,910

E3-2 BENEFITS

As described in Chapter A10, EPA estimates that 0 to 40 percent of the gross revenue losses represent surplus losses to producers, assuming no change in prices or fishing costs. The 0 percent estimate, of course, results in loss estimates of $0. The 40 percent estimates, as presented in the Table E3-3, total approximately $0.8 million when a 3 percent discount rate is assumed.

The expected reductions in I&E attributable to changes at facilities required by the rule are 33.7 percent for impingement and 17.1 percent for entrainment. Total annual benefits are estimated by applying these estimated reductions to the annual producer surplus loss. As presented in Table E3-3, this results in total annual benefits of $0.2 million, assuming a 3 percent discount rate.

Table E3-3: Annual Commercial Fishing Benefits Attributable to Phase II Rule at Facilities in the South Atlantic Region (million 2002$), Assumes Compliance in 2005

	Impingement	Entrainment	Total
Baseline loss — gross revenue			
Undiscounted	$0.9	$1.3	$2.1
3% discount rate	$0.8	$1.1	$1.9
7% discount rate	$0.7	$1.0	$1.7
Producer surplus lost — low	**$0.0**	**$0.0**	**$0.0**
Producer surplus lost — high (gross revenue * 0.4)			
Undiscounted	$0.4	$0.5	$0.9
3% discount rate	$0.3	$0.4	$0.8
7% discount rate	$0.3	$0.4	$0.7
Expected reduction due to rule[a]	**43.7%**	**17.1%**	---
Benefits attributable to rule — low	**$0.0**	**$0.0**	**$0.0**
Benefits attributable to rule — high			
Undiscounted	$0.2	$0.1	$0.2
3% discount rate	$0.1	$0.1	$0.2
7% discount rate	$0.1	$0.1	$0.2

[a] Estimated based on EPA's assumptions. EPA's assumption about the amount of electricity that will be produced in the future differs very slightly from DOE's. For the South Atlantic region the EPA and DOE estimates are the same.

Chapter E4: RUM Analysis

INTRODUCTION

This case study uses a random utility model (RUM) approach to estimate the effects of improved fishing opportunities due to reduced impingement and entrainment (I&E) in the South Atlantic region. The South Atlantic region, as defined by the National Marine Fisheries Service (NMFS), includes NMFS fishing intercept sites along the Atlantic coastal areas of North Carolina, South Carolina, Georgia, and East Florida.

Cooling Water Intake Structures (CWIS) withdrawing water from South Atlantic coastal waters impinge and entrain many of the species sought by recreational anglers. These species include black drum, Atlantic croaker, weakfish, spotted seatrout, spot, and others. Accordingly, EPA included the following species and species groups in the model: bottom fish, small game fish, snapper-grouper, big game fish, and flatfish. Some of these species inhabit a wide range of coastal waters spanning several states.

The main assumption of this analysis is that, all else being equal, anglers will get greater satisfaction, and thus greater economic value, from sites with a higher catch rate. This benefit may occur in two ways: first, an angler may get greater enjoyment from a given fishing trip with higher catch rates, yielding a greater value per trip; second, anglers may take more fishing trips when catch rates are higher, resulting in greater overall value for fishing in the region.

The following sections focus on the data used in the analysis and analytic results. Chapter A-11 provides a detailed description of the RUM methodology used in this analysis.

CHAPTER CONTENTS

E4-1 DATA SUMMARY

EPA's analysis of improvements in recreational fishing opportunities in the South Atlantic region relies on a subset of the NMFS Marine Recreational Fishery Statistics Survey (MRFSS), combined with the 1997 Add-On MRFSS Economic Survey (NMFS 2000, 2003b).[1] The model of recreational fishing behavior developed in the study relies on a subset of the survey respondents that includes only single-day trips to sites located along the Atlantic Coast from North Carolina to Florida. The Agency did not include charter boat anglers in the model. As explained further below, the welfare gain to charter boat anglers from improved catch rates is approximated based on the regression coefficients developed for the boat anglers. Additionally, values for single-day trips were used to value each day of a multi-day trip. This section provides a summary of characteristics of anglers who took one-day trips to fishing sites in the four South Atlantic states. This analysis is based a sample of 11,219 respondents to the MRFSS survey.

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[1] For general discussion of the MRFSS, see Chapter A11 of the Regional Study Report or Marine Recreational Fisheries Statistics: Data User's Manual, http://www.st.nmfs.gov/st1/recreational/pubs/data_users/index.html (NMFS, 1999a).

E4-1.1 Summary of Anglers' Characteristics

a. Fishing modes and targeted species

Table E4-1 presents information on anglers' choices of mode and species. Based on the data set used in developing the RUM, a majority of the interviewed anglers (65 percent) fish from either a private or a rental boat. Approximately 30 percent fish from the shore; the remaining 5 percent fish from a party or charter boat. In addition to the mode of fishing, the MRFSS contains information on the specific species targeted on the surveyed trip. A majority of the interviewed anglers (62 percent) do not have a targeted species. The most popular species group, targeted by 20 percent of all anglers, is small game. The second and the third most popular species groups are big game and bottom fish, targeted by 7 and 4 percent of the anglers, respectively.

Table E4-1: Species Group Choice by Mode of Fishing in the South Atlantic Region

Species	All Modes		Private/Rental Boat		Party/Charter Boat		Shore	
	Frequency	Percent	Frequency	Percent by Mode	Frequency	Percent by Mode	Frequency	Percent by Mode
Small Game	2,212	19.73%	1,752	23.99%	50	9.45%	410	12.11%
Bottom Fish	494	4.40%	290	3.97%	2	0.38%	202	5.97%
Snapper-Grouper	348	3.10%	263	3.60%	3	0.57%	82	2.42%
Flatfish	417	3.72%	334	4.57%	N/A	N/A	83	2.45%
Big Game	801	7.14%	694	9.50%	103	19.47%	4	0.12%
No Target	6,947	61.91%	3,971	54.37%	371	70.13%	2,605	76.93%
All Species	11,219	100.00%	7,304	100.00%	529	100.00%	3,386	100.00%

Source: NMFS, 2003b.

The distribution of target species is not uniform by fishing mode. For example, approximately 54 percent of the anglers fishing from private/rental boats do not target a particular species, while 70 percent of charter boat anglers and 77 percent of shore anglers do not target a particular species. The majority of the anglers fishing from private/rental boats target small game fish (24 percent), while only 9 percent of charter boat anglers and 12 percent of shore anglers target small game. Big game is the second and third most popular species group targeted by 20 and 10 percent of charter and private/rental boat anglers, respectively.

b. Anglers' characteristics

This section presents a summary of angler characteristics for the South Atlantic region as defined above. Table E4-2 summarizes characteristics of the sample anglers fishing the NMFS sites in the South Atlantic region.

The average income of the respondent anglers was $60,113 (1997$).[2,3] Ninety-one percent of the anglers are white, with an average age of about 44 years. Nearly 16 percent of the anglers are retired, and 77 percent are employed. Table E4-2 shows that on average anglers spent 47 days fishing during the past year. The average time spent fishing was about 4 hours per day. Anglers made an average of 5.1 trips to the current site, with an average trip cost of $62.86 (1997$). Average round trip travel time was about five hours. Sixty-three percent of the South Atlantic anglers own their own boat. Finally, the average number of years of fishing experience was 22. This analysis does not include anglers under the age of 16, which may result in overestimation of the average age of recreational anglers and years of experience.

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[2] Income was not reported by most survey respondents. Median household income data by zip code, from the U.S. Census Bureau, was used to provide income information for respondents not reporting income.

[3] All costs are in 1997$, which represent the MRFSS year. All costs/benefits will be updated to 2002$ later in this analysis (e.g., for welfare estimation).

Table E4-2: Data Summary for the South Atlantic Coast Anglers

Variable	All Modes			Private/Rental Boat			Party/Charter Boat			Shore		
	N	Mean[a]	Std Dev	N	Mean[a]	Std Dev	N	Mean[a]	Std Dev	N	Mean[a]	Std Dev
Trip Cost	9,600	62.86	39.42	6,371	61.30	39.07	411	74.82	50.48	2,818	64.70	37.98
Travel Time	9,600	4.89	2.58	6,371	4.74	2.56	411	5.61	2.33	2,818	5.11	2.62
Visits	3,018	5.10	7.30	2,086	4.69	5.60	125	1.66	2.25	807	6.71	10.63
Own a Boat	3,128	0.63	0.48	2,160	0.77	0.42	127	0.47	0.50	841	0.27	0.45
Retired	3,130	0.16	0.37	2,160	0.15	0.35	127	0.11	0.31	843	0.22	0.41
Employed	3,078	0.77	0.42	2,120	0.81	0.39	126	0.84	0.37	832	0.66	0.47
Age	3,060	43.96	13.85	2,108	43.67	13.23	126	43.56	12.80	826	44.77	15.43
Years Fishing	3,044	22.08	15.18	2,094	22.62	14.92	126	18.80	15.53	824	21.22	15.68
Hours Fished	3,126	4.34	1.99	2,157	4.44	1.86	127	6.19	1.70	842	3.85	2.13
Wage Lost	2,390	0.10	0.30	1,738	0.10	0.30	103	0.17	0.37	549	0.10	0.30
Male	3,129	0.89	0.31	2,159	0.92	0.28	127	0.91	0.29	843	0.82	0.38
White	3,055	0.91	0.29	2,101	0.94	0.23	125	0.91	0.28	829	0.83	0.38
Household Income	1,862	$60,113	$33,712	1,289	$63,993	$33,625	66	$73,788	$33,790	507	$48,466	$30,927
Average trip length in hours	9,600	5.00	2.49	9,600	4.85	2.47	411	5.77	2.18	2,818	5.20	2.55
Annual trips	3,056	47.21	57.51	2,105	46.45	52.14	124	9.76	19.05	827	54.74	70.60

[a] For dummy variables, such as “Own a Boat,” that take the value of 0 or 1, the reported value represents a portion of the survey respondents possessing the relevant characteristic. For example, 63 percent of the surveyed anglers own a boat.

Source: NMFS, 2003b.

E4-1.2 Recreational Fishing Choice Sets

There are 657 NMFS survey intercept sites (see Figure E1-1 in Chapter E1 for the survey intercept sites included in the analysis) in the South Atlantic region total choice set. Each angler's choice set included his/her chosen site, plus a randomly selected set of up to 73 additional sites within 150 miles of his/her home zip code.[4] EPA used ArcView 3.2a software to determine the distance from an angler's residence to each NMFS intercept site. Further discussion of distance estimation is presented in Section E4-1.4. EPA did not include sites on the Gulf coast of Florida, or anglers from western Florida, in the model, because the data indicated that Florida anglers do not generally cross to the opposite coast to fish.

E4-1.3 Site Attributes

Catch rate is the most important attribute of a fishing site from the angler's perspective (McConnell and Strand, 1994; Haab et al., 2000). This attribute is also a policy variable of concern as catch rate is a function of fish abundance, which is affected by fish mortality due to I&E. The catch rate variable in the model provides a means to measure baseline losses from I&E and changes in anglers' welfare attributed to changes from I&E due to the final section 316(b) rule.

To specify the fishing quality of the case study sites, EPA calculated historic catch rates based on the NMFS intercept survey data from 1992 to 1996 for recreationally important species, such as red drum, mackerel, spotted seatrout, striped bass, snook, spot, and left-eye flounder (McConnell and Strand, 1994; Hicks et al., 1999). EPA aggregated all species into 5 species groups — big game fish, bottom fish, snapper-grouper, flatfish, and small game fish — and calculated the average group-specific historic catch rates. The five specific groups include the following species:

- ***Big game:*** billfishes, blackfin tuna, blue marlin, cobia, dolphin, great hammerhead shark, sailfish, tuna, wahoo, yellowfin tuna.

- ***Bottom fish:*** Atlantic croaker, black drum, bonnetmouth, banded drum false pilchard, grunt, gulf kingfish, kingfish, mullet, pigfish, pinfish, sea catfish, southern kingfish, spot, spotted pinfish, tripletail, white mullet, crevalle jack.

- ***Snapper-grouper:*** Atlantic spadefish, black margate, black sea basses, blue runner, cubera snapper, gag, gray snapper, hind red, hogfish, lane snapper, mutton snapper, red snapper, sea basses, sheepshead, vermilion snapper, yellowtail snapper.

- ***Flatfish:*** gulf flounder, left-eye flounder, southern flounder.

- ***Small game:*** Atlantic bonito, Atlantic tarpon, Florida pompano, Spanish mackerel, amberjack, bluefish, bonefish, cero, crevalle jack, greater amberjack, Irish pompano, king mackerel, ladyfish, permit, pompano dolphin, red drum, seatrout, shad, snook, spotted seatrout, striped bass, tarpon snook, weakfish.

The catch rates represent the number of fish caught on a fishing trip per angler by aggregated species group. The estimated catch rates are averaged across all anglers by wave, mode, target species group, and site over the five-year period (1992-1996).[5] Catch rates for earlier years were not included in the analysis because of significant changes in species populations for recreational fisheries.

The catch rate variables include total catch, which includes both fish caught and kept and fish released. Several NMFS studies use only the catch-and-keep measure as the relevant catch rate. Although a greater error may be associated with the measured number of fish not kept, the total catch measure is more appropriate because a large number of anglers catch and release fish. The total catch rate variables include both targeted fish catch and incidental catch. For example, small game catch rates include fish caught by small game anglers and anglers who don't target any particular species. This method may underestimate the average historic catch rate for a given site because anglers not targeting particular fish species are usually less experienced and may not have the appropriate fishing gear. EPA considered using targeted species catch rates for this analysis, but discovered that this approach did not provide a sufficient number of observations per fishing site to allow estimation of catch rates for all fishing sites included in the analysis.

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[4] Based on the 99th percentile for the distance traveled to a fishing site.

[5] "Wave" is a two month period (e.g., May-June). Fishing conditions such as catch rates may differ significantly across six waves.

More than half of the anglers do not target any particular species, and therefore are treated in the analysis as 'no-target' anglers. For anglers who don't target any species, EPA used catch rates for all species caught by no-target anglers to characterize the fishing quality of a fishing site. EPA based its assessment on the analysis of fish species caught by no-target anglers. The MRFSS provided information on species caught for 5,799 no-target anglers. Of those, 56 percent caught bottom fish, 20 percent caught small game fish, 16 percent caught snapper-grouper, and 8 percent caught flatfish.

Anglers who target particular species generally catch more fish in the targeted category than anglers who do not target any species, mainly because of their skills and specialized equipment. Of the anglers who target particular species groups, bottom fish anglers catch the largest number of fish per hour, followed by anglers who catch snapper-grouper, and then followed by anglers who catch small game. Anglers who target big game fish catch fewer fish than anglers targeting any other species group. Table E4-3 summarizes average catch rates by species for all sites in the study area.

Table E4-3: Average Catch Rate by Species/Species Group for the South Atlantic Sites by Mode of Fishing

Species Group	Average Catch Rate (fish per angler per hour)			
	All Sites		Sites with Non Zero Catch Rates	
	Private/Rental Boat	Shore	Private/Rental Boat	Shore
Big Game	0.03	N/A	0.18	N/A
Bottom Fish	0.38	0.40	1.02	0.93
Flatfish	0.07	0.08	0.29	0.33
Small Game	0.16	0.16	0.43	0.43
Snapper-Grouper	0.20	0.15	0.72	0.51
No Target	0.16	0.17	0.50	0.40

Source: NMFS, 2002e.

E4-1.4 Travel Cost

EPA used ArcView 3.2a software to estimate distances from the household zip code to each NMFS fishing site in the individual opportunity sets. The Agency obtained fishing site locations from the Master Site Register supplied by the NMFS. The Master Site Register includes both a unique identifier that corresponds to the visited site used in the angler survey, and latitude and longitude coordinates. For some sites the latitude and longitude coordinates were missing or demonstrably incorrect, in which case the town point, as identified in the U.S. Geological Survey (USGS) Geographic Names Information System, was used as the site location if a town was reported in the site address. The ArcView program measured the distance in miles of the shortest route, using state and U.S. highways, from the household zip code to each fishing site, then added the distances from the zip code location to the closest highway and from the site location to the closest highway. The average one-way distance to the visited site is 29.3 miles.

EPA estimated trip "price" as the sum of travel costs plus the opportunity cost of time following the procedure described in Haab et al. (2000). Based on Parsons and Kealy (1992), this study assumed that time spent "on-site" is constant across sites and can be ignored in the price calculation. To estimate anglers' travel costs, EPA multiplied round-trip distance by average motor vehicle cost per mile ($0.31, 1997 dollars).[6] To estimate the opportunity cost of travel time, EPA divided round trip distance by 40 miles per hour to estimate trip time, and multiplied by the household's wage to yield the opportunity cost of time. EPA estimated household wage by dividing household income by 2,080 (i.e., the number of full time hours potentially worked).

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[6] EPA used the 1997 government rate ($0.31) for travel reimbursement to estimate travel costs per mile traveled. This estimate includes vehicle operating cost only.
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Only those respondents who reported that they lost income during the trip (*WAGELOST=1*) are assigned a time cost in the trip cost variable. Information on the *WAGELOST* variable was available only for a subset of survey respondents who participated in the follow-up telephone interviews. Only 350 out of 3,130 respondents reported that they lost income. Given that only a small number of survey respondents reported lost income, EPA assumed that the remaining 10,869 anglers did not lose income during the trip. EPA calculated visit price as:

$$Visit\ Price = \begin{cases} Round\ Trip\ Distance \times \$.31 + \dfrac{Round\ Trip\ Distance}{40\ mph} \times (Wage) & If\ WAGELOST = 1 \\ Round\ Trip\ Distance \times \$.31 & If\ WAGELOST = 0 \end{cases} \qquad \text{(E4-1)}$$

For those respondents who cannot work extra hours for extra pay, the time cost is accounted for in an additional variable equal to the amount of time spent on travel. EPA therefore estimated time cost as the round trip distance divided by 40 mph:

$$Travel\ Time = \begin{cases} Round\ Trip\ Distance/40 & If\ WAGELOST = 0 \\ 0 & If\ WAGELOST = 1 \end{cases} \qquad \text{(E4-2)}$$

EPA used a log-linear ordinary least square regression model to estimate wage rates for anglers who did not report their income. The estimated regression equation used in the wage calculation is :

$$\begin{aligned} Ln(Income) = {} & -0.64 + 0.28 \times white + 0.07 \times male + 0.11 \times age + 0.0018 \times age^2 \\ & + 0.0018 \times age^3 + 0.45 \times employed + 0.15 \times boatown + 0.81\ \ln\ (stinc) \end{aligned} \qquad \text{(E4-3)}$$

where:

Income = the reported household income;
Male = 1 for males;
Age = age in years;
Employed = 1 if the respondent is currently employed and 0 otherwise;
Boatown = 1 if the respondent owns a boat; and
Stinc = the average income of residents in the corresponding states.

All variables in the estimated income regression are statistically significant at better than the 99th percentile. The average imputed household income for anglers who do not report income is $45,775 per year and the corresponding hourly wage is $22.

E4-2 SITE CHOICE MODELS

The nature of the MRFSS data leads to the RUM as a means of examining anglers' preferences (Haab et al., 2000). Anglers arrive at each NMFS site by choosing among a set of feasible sites. Interviewers intercept individual anglers at marine fishing sites along the South Atlantic coast and collect data on the anglers' home location and catch (including number and weight of species caught).

The RUM assumes that the individual angler makes a choice among mutually exclusive site alternatives based on the attributes of those alternatives (McFadden, 1981). The number of feasible choices (J) in each angler's choice set was set to 74 sites within 150 miles of the angler's home.

An angler's choice of sites relies on utility maximization. An angler will choose site j if the utility (u_j) from visiting site j is greater than that from vising other sites (h), such that:

$$u_j > u_h \text{ for } h = 1, \dots , J \text{ and } h \neq j \tag{E4-4}$$

Anglers choose the species to seek and the mode of fishing in addition to choosing a fishing site. Available fishing modes include shore fishing, fishing from charter boats, or fishing from private or rental boats. The target species or group of species include big game, bottom fish, small game, snapper-grouper, and flatfish. Anglers may also choose not to target any particular species.

Recreational fishing models generally assume that anglers first choose a mode and species, and then a site. The nested logit model is generally used for recreational demand models, as it avoids the independence of relevant alternatives (IIA) problem, in which sites with similar characteristics that are not included in the model have correlated error terms. However, the nested model did not work well for the South Atlantic region, indicating that nesting may not be appropriate for the data. Consequently, EPA estimated separate logit models for boat and shore anglers. The Agency did not include the angler's choice of fishing mode and target species in the model, instead assuming that the mode/species choice is exogenous to the model and that the angler simply chooses the site. EPA used the following general model to specify the deterministic part of the utility function:[7]

$$v\ (site\ j) = f\,(TC_j,\ TT_j,\ SQRT(Q_{js}) \times Flag(s)) \tag{E4-5}$$

where:

v = the expected utility for site j (j=1,...37);
TC_j = travel cost for site j;
TT_j = travel time to site j;
$SQRT(Q_{js})$ = square root of the historic catch rate for species s at site j;[8] and
$Flag(s)$ = 1 if an angler is targeting this species; 0 otherwise.

The analysis assumes that each angler in the estimated model considers site quality based on the catch rate for the targeted species. Theoretically, an angler may catch any of the available species at a given site (McFadden, 1981). If, however, an angler truly has a species preference, then including the catch variable for all species available at the site would inappropriately attribute utility to the angler for a species not pursued (Haab et al., 2000). To avoid this problem, the Agency used an interaction variable $SQRT\ (Q_{js}) \times Flag(s)$, such that the catch rate variable for a given species is turned on only if the angler targets a particular species [$Flag\ (s) = 1$]. The Agency calculated a separate catch rate for no-target anglers, using the average of all species caught by no-target anglers. The analysis therefore assumes that each angler has chosen a mode/species combination followed by a site based on the catch rates for that site and species. EPA estimated all RUM models with LIMDEP^{TM} software (Greene, 1995). Table E4-4 gives the parameter estimates for this model.

One disadvantage of the specified model is that the model looks at site and mode choice without regard to species. Once an angler chooses a target species no substitution is allowed across species (i.e., the value of catching, or potentially catching, a different species is not included in the calculation). Therefore, improvements in fishing circumstances related to other modes or species will have no effect on anglers' choices.

Two variables present in the boat model were not included in the shore model: catch rates for big game and snapper grouper. EPA did not estimate a coefficient for big game based on the assumption that shore anglers would not target or catch big game species. The Agency combined species falling under snapper-grouper category with bottom fish species due to a small number of shore anglers targeting snapper-grouper fish.

All model coefficients have the expected signs and are statistically significant at the 99th percentile. Travel cost and travel time have a negative effect on the probability of selecting a site, indicating that anglers prefer to visit sites closer to their homes (other things being equal). The probability of a site visit increases as the historic catch rate for fish species increases.

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[7] See Chapter A-11 for detail on model specification.

[8] The analysis used the square root of the catch rate to allow for decreasing marginal utility of catching fish (McConnell and Strand, 1994).

Table E4-4: Estimated Coefficients for the Flat Logit Site Choice Model

Variable	Private/Rental Boat		Shore	
	Estimated Coefficient	t-statistic	Estimated Coefficient	t-statistic
TRAVCOST	-0.045	-12.646	-0.022	-5.821
TRAVTIME	-1.301	-25.839	-1.067	-19.938
SQRT ($Q_{\text{bottom fish}}$)	1.715	13.356	1.321	8.738
SQRT ($Q_{\text{small game}}$)	2.570	28.693	1.550	10.862
SQRT ($Q_{\text{snapper-grouper}}$)	1.841	8.53	N/A	N/A
SQRT ($Q_{\text{big game}}$)	6.950	25.239	N/A	N/A
SQRT (Q_{flatfish})	5.658	17.166	2.928	7.255
SQRT ($Q_{\text{no target}}$)	1.976	41.178	1.965	27.688

Source: U.S. EPA analysis for this report.

On average, no-target anglers place a lower value on the catch rate of particular species than anglers targeting a species. This result is not surprising. In general, species caught by no-target anglers are not as valuable as those caught by target anglers because of lack of special gear and skills. As discussed in Section E4-1.3, no-target anglers mostly catch bottom fish and therefore, the estimated coefficient for the no-target catch rate is close to the coefficient for the bottom fish catch rate.

E4-3 TRIP FREQUENCY MODEL

EPA also examined effects of changes in fishing circumstances on an individual's choice concerning the number of trips to take during a recreation season. EPA used the negative binomial form of the Poisson regression model to estimate the number of fishing trips per recreational season. The participation model relies on socio-economic data and estimates of individual utility (the inclusive value) derived from the site choice model (Parsons et al., 1999; Feather et al., 1995). EPA estimated a combined participation model for the South Atlantic and Gulf of Mexico regions.[9] This section discusses results from the Poisson model of recreational fishing participation, including statistical and theoretical implications of the model. A detailed discussion of the Poisson model is presented in Chapter A11 of this report.

The dependent variable, the number of recreational trips within the past 12 months, is an integer value ranging from 1 to 365. To avoid over-prediction of the number of fishing trips, EPA set the number of trips for anglers reporting over 151 trips per year to 151 in the model estimation.[10] The Agency first tested the data on the number of fishing trips for overdispersion to determine whether to use the Poisson model or the negative binomial model. If the dispersion parameter is equal to zero, then the Poisson model is appropriate; otherwise the negative binomial is more appropriate. The analysis found that the overdispersion parameter is significantly different from zero and therefore the negative binomial model is the most appropriate for this case study.

Independent variables of importance include gender, hourly wage, whether the angler targets a species, whether the angler fishes from shore or from a boat, whether the angler is retired, and whether the angler owns a boat. The model also includes a dummy variable to indicate whether the angler is from the Gulf of Mexico region. Variable definitions for the trip participation model are:

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[9] EPA combined data for the South Atlantic and Gulf of Mexico regions, as these regions are part of a single NMFS data set, to estimate the model. The Agency calculated separate estimates of participation and changes in participation for each region, based on average values of variables for that region.

[10] The number of trips was truncated at the 95th percentile, 151 trips per year.

- Constant: a constant term;
- IVBASE: the inclusive value estimated using the coefficients from the site choice model;
- RETIRED: equals 1 if the individual is retired; 0 otherwise;
- MALE: equals 1 if the individual is male; 0 if female;
- OWNBT: equals 1 if individual owns a boat, 0 otherwise;
- NOTARG: equals 1 if the individual did not target a particular species; 0 otherwise;
- SHORE: equals 1 if the individual fished from shore; 0 if the individual fished from a boat;
- WAGE: household hourly wage (household income divided by 2,080);
- GULF: equals 1 if the angler fishes in the Gulf of Mexico region; 0 if the angler fishes in the South Atlantic region; and
- α (alpha): overdispersion parameter estimated by the negative binomial model.

Table E4-5 presents the results of the trip participation model. Where a particular sign is expected, all estimated parameters have the expected signs. The model shows that the most significant determinants of the number of fishing trips taken by an angler are gender (MALE), region (GULF), boat ownership (OWNBT), whether the angler fishes from shore (SHORE), and whether the angler targets a species (NOTARG).

Table E4-5: Trip Participation Model (Negative Binomial Model)

Variable	Coefficient	t-statistic
Constant	3.284	49.69
IVBASE	0.106	16.48
RETIRED	0.102	2.24
MALE	0.266	5.33
OWNBT	0.191	5.15
NOTARG	-0.159	-4.71
SHORE	0.185	3.88
WAGE	-0.003	-2.13
GULF	-0.253	-7.16
α (alpha)	1.03	41.38

Source: U.S. EPA analysis for this report.

The positive coefficient on the inclusive value index (IVBASE) indicates that the quality of recreational fishing sites has a positive effect on the number of fishing trips per recreational season. EPA therefore expects improvements in recreational fishing opportunities, such as an increase in fish abundance and catch rate, to result in an increase in the number fishing trips to the affected sites.

The model shows that anglers in the Gulf region take less fishing trips than those in the South Atlantic region. Anglers who are retired take more trips than those who are not retired, and male anglers fish more frequently than female anglers. Anglers who own boats, those who target a specific species, and those who fish from shore take more trips each year, while those with higher incomes take less trips.

E4-4 Welfare Estimates

This section presents estimates of welfare losses to recreational anglers from fish mortality due to I&E, and potential welfare gains as a result of the final section 316(b) rule. These gains would result from improvements in fishing opportunities due to reduced fish mortality.

E4-4.1 Estimating Changes in the Quality of Fishing Sites

To estimate changes in the quality of fishing sites under different policy scenarios, EPA relied on the recreational fishery landings data by state and the estimates of recreational losses from I&E corresponding to different technology options. The NMFS provided recreational fishery landings data for the South Atlantic region. EPA estimated the losses to recreational fisheries using the physical impacts of I&E on the relevant fish species, and the percentage of total fishery landings attributed to recreational fishing, as described in Chapter E2 of this document. I&E affects recreational species in two ways: by directly killing recreational species, and by killing forage species, thus indirectly affecting recreational species through the food chain. The indirect effects on recreational species were calculated in two steps. First, EPA estimated the total number of fish lost due to forage fish losses. Second, EPA allocated this total number of fish among recreational species according to each species' percent of total recreational landings.

The Agency measured changes in the quality of recreational fishing sites in terms of a percentage change applied to the historic catch rate. EPA assumed that catch rates will change uniformly across all marine fishing sites along the South Atlantic coast because species considered in this analysis inhabit a wide range of states.[11] To estimate the expected change in catch rates, EPA used the most recent data on total recreational landings in the South Atlantic region. EPA used a five-year average of recreational landing data (1997 through 2001) for sites within state waters to calculate an average number of landings per year.[12] EPA then divided losses to the recreational fishery from I&E by the total recreational landings for the region to calculate the percent change in historic catch rate from eliminating I&E completely. EPA estimated that compliance with the Phase II rule would reduce impingement by 43.65 percent, and entrainment by 17.05 percent. EPA estimates the complete elimination of I&E losses to increase small game catch rates by 4 percent, bottom fish catch rates by 13 percent, snapper-grouper catch rates by 1 percent, flatfish catch rates by 2 percent, and no target catch rates by 7 percent.

EPA also estimated percentage changes to species group historic catch rates resulting from reduced I&E losses resulting from the final rule. Dividing the reduced I&E losses by the 5-year average recreational landings leads to an increase in small game catch rates of 1.1 percent, bottom fish catch rates of 2.8 percent, snapper-grouper catch rates by 0.3 percent, flatfish catch rates of 0.4 percent, and no target catch rates of 1.5 percent. Table E4-6 presents the recreational landings, I&E loss estimates, and percentage changes in historic catch rates.

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[11] Fish lost to I&E are most often very small fish, which are too small to catch. Because of the migratory nature of most affected species, by the time these fish have grown to catchable size, they may have traveled some distance from the facility where I&E occurs. Without collecting extensive data on migratory patterns of all affected fish, it is not possible to evaluate whether catch rates will change uniformly or in some other pattern. Thus, EPA assumed that catch rates will change uniformly across the entire region.

[12] State waters include sounds, inlets, tidal portions of rivers, bays, estuaries, and other areas of salt or brackish water; and ocean waters to three nautical miles offshore (NMFS, 2001a).

Table E4-6: Estimated Changes in Historic Catch Rates from Eliminating and Reducing I&E in the South-Atlantic Region

Species Group	Total Recreational Landings for Four States Combined (fish per year)[a]	Baseline Losses		Reduced Losses Under the Final Section 316(b) Rule	
		Total Recreational Losses from I&E	Percent Increase in Recreational Catch from Elimination of I&E	Combined I&E	Percent Increase in Recreational Catch from Reduction of I&E
Small game	14,642,212	526,377	3.59%	156,257	1.07%
Bottom fish	28,320,721	3,666,453	12.95%	802,529	2.83%
Snapper-Grouper	5,760,638	80,912	1.40%	17,075	0.30%
Flatfish	2,555,799	41,241	1.61%	9,908	0.39%
No target[b]	64,243,209	4,314,983	6.72%	985,769	1.53%

[a] Total recreational landings are calculated as a five-year average (1997-2001) for state waters.
[b] No target includes small game, bottom fish, snapper-grouper, and flatfish.

Source: NMFS, 2002e.

E4-4.2 Estimating Losses from I&E in the South Atlantic Region

The recreational behavior model described in the preceding sections provides a means for estimating the economic effects of changes in recreational fishery losses from I&E in the South Atlantic region. First, EPA estimated welfare gain to recreational anglers from eliminating fishery losses due to I&E. This estimate represents economic damages to recreational anglers from I&E of recreational fish species under the baseline scenario. EPA then estimated benefits to recreational anglers from the final section 316(b) rule.

EPA estimated anglers' willingness-to-pay (WTP) for improvements in the quality of recreational fishing due to changes in I&E by calculating an average per-day welfare gain based on the expected changes in catch rates from eliminating and reducing I&E. Table E4-7 presents the compensating variation per day (averaged over all anglers in the sample) associated with reduced fish mortality from changes in I&E for each fish species of concern.[13,14]

Table E4-7: Per-Day Welfare Gain from Eliminating and Reducing I&E in the South Atlantic Region (2002$)

Species Group	Baseline Per-Day Welfare Gain		Reduced Losses Under the Final Section 316(b) Rule Per-Day Welfare Gain		WTP for an Additional Fish per Day	
	Boat Anglers	Shore Anglers	Boat Anglers	Shore Anglers	Boat Anglers	Shore Anglers
Big Game	N/A	N/A	N/A	N/A	$37.09	N/A
Bottom Fish	$3.01	$4.40	$0.68	$0.83	$4.81	$9.19
Snapper-Grouper	$0.31	N/A	$0.07	N/A	$5.30	N/A
Flatfish	$0.61	$0.63	$0.15	$0.15	$27.05	$30.52
Small Game	$0.83	$1.09	$0.25	$0.33	$10.19	$13.43
No Target	$1.35	$2.14	$0.31	$0.49	$7.25	$19.31

Source: U.S. EPA analysis for this report.

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[13] A compensating variation equates the expected value of realized utility under the baseline and post-compliance conditions.

[14] As the RUM model estimated values for single-day trips, the per-day value is equal to a per-trip value.

Table E4-7 shows that shore anglers in the South Atlantic region targeting bottom fish have the largest per-day gain ($4.40) from eliminating I&E. Boat anglers targeting bottom fish also have a relatively high per-day welfare gain of $3.01. Table E4-7 also reports the willingness-to-pay for a one fish per trip increase in catch. The more desirable the fish, the greater the per-day welfare gain, as evidenced by the willingness-to-pay for catching one additional fish per trip. Of the species groups affected by I&E reductions, anglers value flatfish the most ($27.05 and $30.52 for an additional fish by boat and shore anglers, respectively), followed by small game ($10.19 and $13.43). Anglers targeting big game, not surprisingly, place the highest value on catching an additional fish ($37.09).

EPA calculated the total economic value of eliminating and reducing I&E in the South Atlantic region by combining the estimated per-day welfare gain with the total number of fishing days at coastal sites in the South Atlantic region. NMFS provided information on the total number of fishing trips by state and by fishing mode. The Agency assumed that the welfare gain per day of fishing is independent of the number of days fished per trip and therefore equivalent for both single- and multiple-day trips. Each day of a multiple-day trip is valued the same as a single-day trip.[15] Per-day welfare gain differs across recreational species and fishing mode.[16] EPA therefore estimated the number of fishing trips associated with each species of concern and the number of trips taken by no-target anglers. EPA used the MRFSS sample to calculate the proportion of recreational fishing trips taken by no-target anglers and anglers targeting each species of concern and applied these percentages to the total number of trips to estimate species-specific participation. Table E4-8 shows the calculation results for the South Atlantic states.

Table E4-8: Recreational Fishing Participation by Species and Fishing Mode

Species	Number of Fishing Days			
	Private/Rental Boat	Shore	Charter Boat	Total for all Modes[a]
Small Game	1,576,370	1,367,917	9,043	2,953,330
Bottom Fish	242,576	470,582	81	713,238
Snapper-Grouper	200,778	109,572	419	310,769
Flatfish	485,152	355,243	113	840,508
Big Game	683,691	N/A	86,349	770,040
No Target	4,275,306	9,230,555	65,185	13,571,045
Total[a]	7,463,872	11,533,868	161,190	19,158,930

[a] Sum of individual values may not add up to totals due to the rounding error.

Sources: NMFS,2002b; and U.S. EPA analysis for this report.

No-target anglers account for the largest number of fishing days at South Atlantic NMFS sites (13.6 million). Anglers targeting small game rank second, fishing almost 3 million days per year. Flatfish anglers, big game anglers, and bottom fish anglers rank third, fourth, and fifth, fishing 840 thousand, 770 thousand, and 713 thousand days per year, respectively. Anglers targeting snapper-grouper species have the lowest number of fishing days per year (311 thousand).

The estimated number of trips represents the baseline level of participation. Anglers may take more fishing trips as recreational fishing circumstances change. EPA used the trip participation model to estimate the percentage increase in the number of trips due to the elimination and reduction of I&E. These changes are reported in Table E4-9. For baseline I&E, the estimated percentage increase ranges from 0.13 percent for anglers who target snapper-grouper fish to 1.15 percent for anglers targeting bottom fish. EPA calculated the number of recreational fishing trips under each I&E scenario by applying the estimated percentage increase to the baseline number of trips.

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[15] See section E4-5.3 for limitations and uncertainties associated with ths assumption.

[16] EPA used the per-day values for private/rental boat anglers to estimate welfare gains for charter boat anglers.

Table E4-9: Increased Recreational Fishing Participation by Species and Fishing Mode From Eliminating or Reducing I&E in the South Atlantic Region

Species	Predicted Percent Change in Annual Fishing Trips		Number of Fishing Days					
			Private/Rental Boat		Shore		Charter Boat	
	Baseline I&E	Reduced I&E	Baseline I&E	Reduced I&E	Baseline I&E	Reduced I&E	Baseline I&E	Reduced I&E
Small Game	0.34%	0.10%	1,581,772	1,577,985	1,372,604	1,369,318	9,074	9,052
Bottom Fish	1.15%	0.26%	245,367	243,206	475,997	471,804	82	81
Snapper-Grouper	0.13%	0.03%	201,043	200,835	109,572	109,572	420	419
Flatfish	0.25%	0.06%	486,359	485,444	356,127	355,458	113	113
No Target	0.54%	0.12%	4,298,182	4,280,542	9,279,945	9,241,859	65,534	65,265
Total [a]			6,812,723	6,788,012	11,594,246	11,548,011	75,222	74,930

[a] Sum of individual values may not add up to totals due to the rounding error.

Source: U.S. EPA analysis for this report.

Table E4-10 provides total welfare estimates for two policy scenarios. It presents losses to recreational anglers from baseline I&E and the welfare gains that would result from installing the preferred CWIS technology at all plants in the South Atlantic region. EPA calculated the total welfare estimates by multiplying the estimated values per day (Table E4-7) by the number of fishing days (Tables E4-8 and E4-9).[17] These values were discounted to reflect the fact that fish must grow to a certain size before they will be caught by recreational anglers. EPA calculated discount factors separately for impingement and entrainment of each species. To estimate discounted total benefits for the South Atlantic, EPA calculated weighted averages of these discount factors, and applied them to estimated willingness-to-pay values. Discount factors were calculated for both a 3 percent discount rate and a 7 percent discount rate. For the final section 316(b) rule, an additional discount factor was applied to account for the one-year lag between the date when installation costs are incurred and the installation of the required cooling water technology is completed.

Table E4-10: Estimated Total Welfare Gain to Recreational Anglers From Eliminating and Reducing I&E in the South Atlantic Region (2002$)

Species Group	Eliminating Recreational Fishery Losses From I&E			Reduced Losses Under the the Final Section 316(b) Rule		
	Undiscounted	3% Discount Factor	7% Discount Factor	Undiscounted	3% Discount Factor	7% Discount Factor
Small Game	$2,806,549	$2,666,222	$2,497,829	$838,552	$773,418	$697,487
Bottom Fish	$2,818,284	$2,677,370	$2,480,090	$624,860	$576,325	$513,904
Snapper-Grouper	$62,432	$59,311	$54,941	$13,402	$12,361	$11,022
Flatfish	$520,244	$489,030	$452,613	$126,103	$115,084	$102,532
No Target	$25,673,146	$24,132,757	$22,592,369	$5,887,280	$5,372,837	$4,841,878
All Species	$31,880,656	$30,024,690	$28,077,841	$7,490,196	$6,850,024	$6,166,823

Source: U.S. EPA analysis for this report.

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[17] EPA averaged the initial number of days (Table E4-8) and the predicted increased number of days (Table E4-9) to estimate total welfare (Bockstael et al., 1987).

Table E4-10 presents annual losses to recreational anglers from baseline I&E effects in the South Atlantic region. The total value of recreational losses for all species impinged and entrained at the cooling water intake structures in the South Atlantic is $32 million per year (2002$), before discounting. The discounted recreational losses are $30 million and $28 million (2002$) per year, discounted at 3 and 7 percent, respectively.

Total welfare gain from reducing I&E from cooling water intake structures was also estimated. Multiplying the per-day welfare changes from reduced I&E under the final rule by the total number of fishing trips in 2001 yielded an undiscounted value of $7 million. Discounting the welfare gain by 3 and 7 percent results in total welfare gains of $7 million and $6 million, respectively.

E4-5 LIMITATIONS AND UNCERTAINTIES

E4-5.1 Considering Only Recreational Values

This study understates the total benefits of improvements in fishing site quality because estimates are limited to recreation benefits. Many other forms of benefits, such as habitat values for a variety of species (in addition to recreational fish), non-use values, etc., are also likely to be important.

E4-5.2 Including Welfare for Only Target Anglers

Due to the inability to estimate a statistically significant coefficient for no-target anglers, this study is likely to underestimate total welfare gains for the South Atlantic region.

E4-5.3 Extrapolating Single-Day Trip Results to Estimate Benefits from Multiple-Day Trips

Use of per-day welfare gain estimated for single-day trips to estimate per-day welfare gain associated with multiple-day trips can either understate or overstate benefits to anglers taking multiple-day trips. Inclusion of multi-day trips in the model of recreational anglers' behavior can be problematic because multi-day trips are frequently multi-activity trips. An individual might travel a substantial distance and participate in several recreational activities such as shopping and sightseeing, all as part of one trip. Recreational benefits from improved recreational opportunities for the primary activity are overstated if all travel costs are treated as though they apply to the one recreational activity of interest. EPA therefore limited the recreational behavior model to single-day trips only and then extrapolated single-day trip results to estimate benefits to anglers taking multiple-day trips.

There is evidence that multi-day trips are more valuable than single-day trips. McConnell and Strand (1994) estimated a RUM using the NMFS data for New England and the Mid-Atlantic. Their study was intended to supplement the RUM study of single-day trips for the same region conducted by Hicks et al. (1999). The reported values for a catch rate increase of one fish are consistently higher for overnight trips than for single-day trips. Lupi and Hoehn (1998) compared values for single- and multi-day fishing trips. Their comparison is based on a RUM for the Great Lakes, with single- and multiple-day trips treated as distinct alternatives in the choice set, with separate parameters for different length trips. They found that multiple-day trips are less responsive to changes in travel cost, and thus relatively more valuable than single-day trips. Their case study results found that "over half the value of an across the board marginal change in catch rates was due to multiple-day trips even though multiple-day trips represent less than one fourth of the trips in the sample (p. 45)."

E4-5.4 Potential Sources of Survey Bias

The survey results could suffer from bias, such as recall bias and sampling effects.

a. Recall bias

Recall bias can occur when respondents are asked, such as in the MRFSS, the number of their recreation days over the previous season. Some researchers believe that recall bias tends to lead to an overstatement of the number of recreation days, particularly by more avid participants. Avid participants tend to overstate the number of recreation days because they count days in a "typical" week and then multiply them by the number of weeks in the recreation season. They often neglect to consider days missed due to bad weather, illness, travel, or when fulfilling "atypical" obligations. Some studies also found that the more salient the activity, the more "optimistic" the respondent tends to be in estimating the number of recreation days. Individuals also have a tendency to overstate the number of days they participate in activities that they enjoy and value. Taken together, these sources of recall bias may result in an overstatement of the actual number of recreation days.

b. Sampling effects

Recreational demand studies frequently face observations that do not fit general recreation patterns, such as observations of avid participants. These participants can be problematic because they claim to participate in an activity an inordinate number of times. This reported level of activity is sometimes correct but often overstated, perhaps due to recall bias. Even where the reports are correct, these observations tend to be overly influential (Thomson, 1991).

Chapter E5: Non-Use Benefits

INTRODUCTION

CHAPTER CONTENTS

Aquatic species without any direct uses account for the majority of losses due to impingement and entrainment (I&E) at cooling water intake structures (CWIS). However, EPA's analysis of direct use benefits includes values only for organisms with direct uses, which comprise a very small percentage of total losses (approximately two percent). Because the other 98 percent of losses, consisting of organisms without direct uses, are not without value, the potential exists for significant non-use values that have not been addressed under EPA's estimation of use benefits. For this reason it is important to consider non-use benefits to the human population, produced by the increased numbers of organisms without direct use values, under the final section 316(b) rule.

One way to consider the impact of the section 316(b) rule is to estimate the non-use value of baseline I&E losses and I&E reductions due to the final rule for each case study region using the non-use meta-analysis results. The non-use meta-analysis is presented in detail in Chapter A12, Non-Use Meta-Analysis Methodology, which includes discussions of the literature review process, the estimated regression models and results, and the general methodology used to estimate household and aggregate non-use benefits based on regression results. Total regional non-use benefits can be estimated using the following three steps:

1. Estimate annual changes in non-use value of the affected fishery resources per household due to the baseline impingement and entrainment (I&E) losses and the post-compliance reduction in impingement and entrainment;

2. Estimate the population of households in the South Atlantic region holding non-use value for the affected resources; and

3. Estimate the total non-use value to the affected South Atlantic populations for completely eliminating baseline I&E losses, and for reducing I&E losses from the baseline to post-compliance levels.

EPA explored this approach for the South Atlantic region. However, EPA did not include the results of this approach in the benefit analysis because of limitations and uncertainties associated with estimation of non-use benefits on a regional scale. For further discussion of the limitations and uncertainties of this method, refer to Chapter A12.

E5-1 QUALITATIVE ASSESSMENT OF ECOLOGICAL BENEFITS FOR THE SOUTH ATLANTIC REGION

Changes in CWIS design or operations resulting from the section 316(b) regulations for existing facilities are expected to reduce I&E losses of fish, shellfish, and other aquatic organisms and, as a result, are expected to increase the numbers of individuals present, increase local and regional fishery populations, and ultimately contribute to the enhanced environmental functioning of affected waterbodies (rivers, lakes, estuaries, and oceans) and associated ecosystems. The economic welfare of human populations is expected to increase as a consequence of the improvements in fisheries and associated aquatic ecosystem functioning.

The aquatic resources affected by cooling water intake structures provide a wide range of services. Ecosystem services are the physical, chemical, and biological functions performed by natural resources and the human benefits derived from those functions, including both ecological and human use services (Daily, 1997; Daily et al., 1997). Scientific and public interest in protecting ecosystem services is increasing with the recognition that these services are vulnerable to a wide range of human activities and are difficult, if not impossible, to replace with human technologies (Meffe, 1992).

In addition to their importance in providing food and other goods of direct use to humans, the organisms lost to I&E are critical to the continued functioning of the ecosystems of which they are a part. Fish are essential for energy transfer in aquatic food webs, regulation of food web structure, nutrient cycling, maintenance of sediment processes, redistribution of bottom substrates, the regulation of carbon fluxes from water to the atmosphere, and the maintenance of aquatic biodiversity (Peterson and Lubchenco, 1997; Postel and Carpenter, 1997; Holmund and Hammer, 1999; Wilson and Carpenter, 1999). Examples of ecological and public services disrupted by I&E include:

- decreased numbers of ecological keystone, rare, or sensitive species;
- decreased numbers of popular species that are not fished, perhaps because the fishery is closed;
- decreased numbers of special status (e.g., threatened or endangered) species;
- increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E;
- disruption of ecological niches and ecological strategies used by aquatic species;
- disruption of organic carbon and nutrient transfer through the food web;
- disruption of energy transfer through the food web;
- decreased local biodiversity;
- disruption of predator-prey relationships;
- disruption of age class structures of species;
- disruption of natural succession processes;
- disruption of public uses other than fishing, such as diving, boating, and nature viewing; and
- disruption of public satisfaction with a healthy ecosystem.

Many of these services can only be maintained by the continued presence of all life stages of fish and other aquatic species in their natural habitats.

The traditional approach of EPA and other natural resource agencies to quantifying the environmental benefits of proposed regulations has focused on active use values, particularly direct use values such as recreational or commercial fishing. Nonconsumptive uses (such as the importance of fish for aquatic food webs), and passive use or non-use values (including the value of protecting a resource for its own sake), are seldom considered because they are difficult to monetize with available economic methods. However, even though economists debate methods for indirect and non-use valuation, there is general agreement that these values exist and can be important. The potential magnitude of non-use values remains an empirical matter. EPA believes that non-use values are applicable for the section 316(b)-related I&E and that these values are likely to be appreciable for the South Atlantic region.

Part F

Gulf of Mexico

Chapter F1: Background

INTRODUCTION

CHAPTER CONTENTS

This chapter presents an overview of the Phase II facilities in the Gulf of Mexico study region and summarizes their key operating, economic, technical, and compliance characteristics. For further discussion of operating and economic characteristics of Phase II facilities, refer to Chapter A3 of the *Economic and Benefits Analysis for the Final Section 316(b) Phase II Existing Facilities Rule*; for further discussion of the technical and compliance characteristics of Phase II facilities, refer to the *Technical Development Document for the Final Section 316(b) Phase II Existing Facilities Rule* (U.S. EPA, 2004a,b).

F1-1 OVERVIEW

The Gulf of Mexico Study includes 24 facilities that are in scope for the final Phase II regulation. Twenty-one of the 24 facilities withdraw cooling water from an estuary or tidal river, and three withdraw water from the Gulf of Mexico. Figure F1-1 presents a map of the 24 in-scope Phase II facilities located in the Gulf of Mexico study region.

Figure F1-1: In-Scope Phase II Facilities in the Gulf of Mexico Regional Study

Source: U.S. EPA analysis for this report.

F1-2 OPERATING AND ECONOMIC CHARACTERISTICS

Most of the 24 Gulf of Mexico Study facilities (17) are oil/gas facilities; five are coal steam facilities; one is a nuclear facility; and one is a combined-cycle facility. In 2001, these 24 facilities accounted for nearly 25 gigawatts of generating capacity, 102,000 gigawatt hours of generation, and $4.7 billion in revenues.

The operating and economic characteristics of the Gulf of Mexico Study facilities are summarized in Table F1-1. Section F1-4 provides further information on each facility [including facility state, North American Electric Reliability Council (NERC) region, plant type, capacity, 2001 generation, and whether impingement and entrainment estimates were developed for the facility].

Table F1-1: Operating and Economic Characteristics of Phase II Facilities

Waterbody Type	Number of Facilities by Plant Type[a]					Total Capacity (MW)[b]	Total Generation (MWh)[b]	Electric Revenue (millions)
	Coal Steam	Combined Cycle	Nuclear	Oil/Gas Steam	Total			
Estuary / Tidal								
FL	4	1	-	5	10	11,067	49,335,059	$2,327
LA	-	-	-	3	3	1,536	3,584,231	$223
MS	1	-	-	-	1	1,051	4,868,196	$203
TX	-	-	1	6	7	8,825	35,696,589	$1,515
Subtotal	*5*	*1*	*1*	*14*	*21*	*22,478*	*93,484,075*	*$4,268*
Ocean								
TX	-	-	-	2	2	1,267	4,835,268	$249
FL	-	-	-	1	1	1,112	4,124,241	$229
Subtotal	-	-	-	*3*	*3*	*2,379*	*8,959,509*	*$478*
TOTAL	**5**	**1**	**1**	**17**	**24**	**24,857**	**102,443,584**	**$4,746**

[a] Based on largest steam-electric capacity at facilities.

[b] MW is an abbreviation for megawatt; MWh is an abbreviation for megawatt hour.

Sources: Plant type (IPM Analysis, U.S. EPA, 2002; Form EIA-860, U.S. DOE, 2001a); capacity (Form EIA-860, U.S. DOE, 2001a); generation (Form EIA-906, U.S. DOE, 2001c); revenue (Form EIA-861, U.S. DOE, 2001b; Form EIA-906, U.S. DOE, 2001c).

F1-3 TECHNICAL AND COMPLIANCE CHARACTERISTICS

Twenty of the 24 Gulf of Mexico Study facilities employ a once-through cooling system in the baseline; three facilities employ a combination cooling system; and a single facility employs a recirculating cooling system. The 20 facilities with once-through systems incur a combined pre-tax compliance cost of $16.4 million, and the three facilities with combination cooling systems incur a combined pre-tax compliance cost of $0.6 million. Table F1-2 summarizes the flow, compliance responses, and compliance costs for these 24 facilities.

Table F1-2: Technical and Compliance Characteristics of Phase II Facilities

	Cooling Water System (CWS) Type[a]			
	Once-Through	**Recirculating**	**Combination**	**All**
Design Flow (MGD)	**18,114**	**776**	**3,879**	**22,770**
Number of Facilities by Compliance Response				
Fish H&R	6	-	-	6
Fine Mesh Traveling Screens w/Fish H&R	2	-	1	3
New Larger Intake Structure with Fine Mesh and Fish H&R	2	-	-	2
Passive Fine Mesh Screens	1	-	-	1
Fish Barrier Net/Gunderboom	1	-	-	1
Relocate Intake to Submerged Offshore with Passive Screen	1	-	-	1
Multiple	-	-	2	2
None	7	1	-	8
Total	**20**	**1**	**3**	**24**
Compliance Cost (2002$; millions)	**$16.4**	**w[b]**	**$0.6**	**w[b]**

[a] Combination CWSs are costed as if they were once-through CWSs.
[b] Data withheld because of confidentiality reasons.

Source: U.S. EPA analysis for this report.

F1-4 PHASE II FACILITIES IN THE GULF OF MEXICO REGIONAL STUDY

Table F1-3 presents economic and operating characteristics of the Gulf of Mexico Study facilities.

Table F1-3: Phase II Facilities in the Gulf of Mexico Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
Estuary/Tidal River							
610	Cutler	FL	FRCC	O/G Steam	237	245,846	N
612	Fort Myers	FL	FRCC	O/G Steam	1,302	3,499,471	N
628	Crystal River	FL	FRCC	Coal Steam	3,333	20,736,446	Y
634	P L Bartow	FL	FRCC	O/G Steam	717	2,141,129	Y
641	Crist	FL	FRCC	Coal Steam	1,229	4,488,205	N
643	Lansing Smith	FL	FRCC	Coal Steam	382	2,316,371	N
645	Big Bend	FL	FRCC	Coal Steam	1,998	9,259,719	Y
646	F J Gannon	FL	FRCC	Combined Cycle	1,302	5,083,474	N
647	Hookers Point	FL	FRCC	O/G Steam	233	(2,344)	N
689	S O Purdom	FL	FRCC	O/G Steam	335	1,566,742	N
1400	Teche	LA	SPP	O/G Steam	428	1,387,366	N
1407	A B Paterson	LA	SERC	O/G Steam	149	139,428	N
1409	Michoud	LA	SERC	O/G Steam	959	2,057,437	N
2049	Jack Watson	MS	SERC	Coal Steam	1,051	4,868,196	N
3436	E S Joslin	TX	ERCOT	O/G Steam	261	618,125	N
3459	Sabine	TX	SERC	O/G Steam	2,051	7,950,904	N
3461	Deepwater	TX	ERCOT	O/G Steam	188	83,471	N
3466	P H Robinson	TX	ERCOT	O/G Steam	2,315	5,703,777	N
3468	Sam Bertron	TX	ERCOT	O/G Steam	875	1,071,746	N
3471	Webster	TX	ERCOT	O/G Steam	426	427,968	Y
6251	South Texas	TX	ERCOT	Nuclear	2,709	19,840,598	N
Ocean							
3441	Nueces Bay	TX	ERCOT	O/G Steam	564	1,841,617	N
4939	Barney M Davis	TX	ERCOT	O/G Steam	703	2,993,651	N
8048	Anclote	FL	FRCC	O/G Steam	1,112	4,124,241	N

Source: U.S. EPA analysis for this report.

Chapter F2: Evaluation of Impingement and Entrainment in the Gulf of Mexico

CHAPTER CONTENTS

BACKGROUND: GULF OF MEXICO MARINE FISHERIES

Important marine fisheries of the Gulf of Mexico include both migratory pelagic species and reef fishes. Coastal pelagic fishes include king mackerel, Spanish mackerel, cero, dolphinfish, and cobia. These species range from the northeastern U.S. through the Gulf of Mexico and Caribbean Sea, and as far south as Brazil (NMFS, 1999b). They are managed under the Coastal Migratory Pelagic Resources Fishery Management Plan and regulations of the South Atlantic and Gulf of Mexico Fishery Management Councils, which are implemented by the National Marine Fisheries Service. King and Spanish mackerel make up nearly 95 percent of harvested coastal pelagic species, and are managed as two separate groups, the Gulf group and the Atlantic group (NMFS, 1999b). Most of the commercial catch of Spanish mackerel is landed in Florida. Up to 40 percent of the Gulf stock is also recreationally fished. Dolphinfish and cobia are also important recreational species, but the status of these stocks is uncertain (NMFS, 1999b).

Reef fishes include over 100 species ranging from North Carolina through the Gulf of Mexico and the Caribbean Sea that are important for commercial and recreational anglers.(NMFS, 1999b). Many reef fisheries are closely associated with other managed reef animals, including spiny lobster and stone crab. In the Gulf of Mexico, reef fisheries include snapper and grouper species as well as grunts, amberjacks, and seabasses. Although landings of individual species aren't large, collectively reef fisheries have significant landings and value (NMFS, 1999b). However, stock status of many of these species remains unknown. Red snapper, the most important Gulf reef fish, is considered overutilized, in part because it is caught incidentally by the shrimp fishery (NMFS, 1999b).

F2-1 FISHERY SPECIES IMPINGED AND ENTRAINED

Table F2-1 shows the status of managed stocks in the Gulf region, indicating in bold the stocks subject to impingement and entrainment (I&E). Overfishing occurs when fishing mortality is above a management threshold, jeopardizing the long term capacity of the stock to produce the potential maximum sustainable yield on a continuing basis. A stock is considered overfished when biomass falls below a given threshold. In some cases, heavy fishing in the past may have reduced a stock to low abundance, so that it is now considered overfished even though the stock is not currently subject to overfishing.

As indicated in Table F2-1, 4 of the 16 managed stocks are classified as overfished, including red snapper, red grouper, gag, and red drum. Gag and red drum are species subject to I&E.

Table F2-1: Summary of Stock Status for Harvested Species of the Gulf Region Included in Federal Fishery Management Plans

Stock (species in bold are subject to I&E)	Overfishing? (fishing mortality above threshold)	Overfished? (biomass below threshold)	Approaching Overfished Condition?
Stone crab	No	No	No
Brown shrimp	No	No	No
Pink shrimp	No	No	No
White shrimp	No	No	No
Royal red shrimp	No	Undefined	Unknown
Spiny lobster	No	No	No
King mackerel	No	Yes	N/A
Spanish mackerel	No	No	No
Dolphin	No	No	No
Red snapper	Yes	Yes	N/A
Red grouper	Yes	Yes	N/A
Nassau grouper	No	Yes	N/A
Goliath grouper (Jewfish)	No	Yes	N/A
Greater amberjack	No	Yes	Unknown
Gag	Yes	No	Yes
Red drum	Yes	Yes	N/A

F2-2 I&E SPECIES AND SPECIES GROUPS EVALUATED

Table F2-2 provides a list of species and associated species groups that were evaluated in EPA's analysis of I&E in the Gulf region.

Table F2-2: Species Groups Evaluated by EPA

Species Group	Species	Recreational	Commercial	Forage
Atlantic croaker	Atlantic croaker	X	X	
Bay anchovy	Bay anchovy			X
	Striped anchovy			X
Black drum	Black drum	X		
	Red drum	X	X	
Blue crab	Blue crab		X	
Chain pipefish	Chain pipefish			X
	Dusky pipefish			X
	Gulf pipefish			X
Goby species	Clown goby			X
	Code goby			X
	Frillfin goby			X
	Green goby			X

Table F2-2: Species Groups Evaluated by EPA

Species Group	Species	Recreational	Commercial	Forage
	Naked goby			X
	Sharptail goby			X
	Skilletfish			X
	Violet goby			X
Gulf killifish	Bayou killifish			X
	Gulf killifish			X
	Longnose killifish			X
Hogchoker	Hogchoker			X
	Lined sole			X
Leatherjacket	Atlantic bumper		X	
	Atlantic moonfish			X
	Bluntnose jack		X	
	Carangidae		X	
	Crevalle jack			X
	Leatherjacket		X	
	Lookdown			X
	Permit		X	
Mackerels	Spanish mackerel	X	X	
Menhaden species	Alabama shad		X	
	Atlantic thread herring		X	
	Finescale menhaden		X	
	Gizzard shad		X	
	Gulf menhaden		X	
	Skipjack herring		X	
	Yellowfin menhaden		X	
Other (commercial)	Atlantic cutlassfish		X	
	Black bullhead		X	
	Cobia		X	
	Grey snapper		X	
	Gulf butterfish		X	
	Ladyfish		X	
	Largehead hairtail		X	
	Silver jenny		X	
	Spotfin mojarra		X	
	Tripletail		X	
	Yellow bullhead		X	
Other (forage)	Atlantic midshipman			X
	Atlantic needlefish			X
	Atlantic spadefish			X
	Atlantic threadfin			X

Table F2-2: Species Groups Evaluated by EPA

Species Group	Species	Recreational	Commercial	Forage
	Barbfish			X
	Bay whiff			X
	Blackcheek tonguefish			X
	Blackwing flyingfish			X
	Bluegill			X
	Bridle cardinalfish			X
	Carp			X
	Common halfbeak			X
	Diamond lizardfish			X
	Dwarf seahorse			X
	Fat sleeper			X
	Feather blenny			X
	Florida blenny			X
	Freckled blenny			X
	Fringed filefish			X
	Fringed flounder			X
	Golden shiner			X
	Green sunfish			X
	Gulf flounder			X
	Gulf of Mexico ocellated flounder			X
	Halfbeak			X
	Harvestfish			X
	Inshore lizardfish			X
	Jawfish			X
	Lined seahorse			X
	Live sharksucker			X
	Longear sunfish			X
	Mottled jawfish			X
	Needlefish			X
	Orange filefish			X
	Planehead filefish			X
	Polka-dot batfish			X
	Redfin needlefish			X
	Roughback batfish			X
	Sailfin molly			X
	Scrawled cowfish			X
	Sheepshead minnow			X
	Snakefish			X
	Southern codling			X
	Southern hake			X

Table F2-2: Species Groups Evaluated by EPA

Species Group	Species	Recreational	Commercial	Forage
	Southern stargazer			X
	Spotted whiff			X
	Striped blenny			X
	Striped burrfish			X
	Warmouth			X
	Yellowhead jawfish			X
Other (recreational)	Atlantic sharpnose shark	X		
	Atlantic stingray	X		
	Bandtail puffer	X		
	Belted sandfish	X		
	Blackear bass	X		
	Bluefish	X		
	Bonnethead	X		
	Channel catfish	X		
	Dwarf sandperch	X		
	Gafftopsail catfish	X		
	Gag grouper	X		
	Gulf toadfish	X		
	Hardhead sea catfish	X		
	Least puffer	X		
	Pigfish	X		
	Puffer	X		
	Rock sea bass	X		
	Sand perch	X		
	Sea catfish	X		
	Smooth butterfly ray	X		
	Smooth puffer	X		
	Southern flounder	X		
	Southern puffer	X		
	Tomtate	X		
Pinfish	Spottail pinfish	X		
Pink shrimp	Pink shrimp		X	
	White shrimp		X	
Scaled sardine	Brazilian sardinella			X
	Scaled sardine			X
	Threadfin shad			X
Sea basses	Black sea bass	X		
Searobin	Bighead searobin	X		
Searobin	Leopard searobin	X		
Sheepshead	Sheepshead	X	X	

Table F2-2: Species Groups Evaluated by EPA

Species Group	Species	Recreational	Commercial	Forage
Silver perch	Banded drum	X		
	Northern kingfish	X		
	Silver perch	X		
	Silver seatrout	X		
	Southern kingfish	X		
	Star drum	X		
Spot	Spot		X	
Spotted seatrout	Kingcroaker species	X		
	Sand seatrout	X		
	Sand weakfish	X		
	Spotted seatrout	X		
Stone crab	Stone crab		X	
Striped mullet	Striped mullet	X		
	White mullet	X		
Tidewater silverside	California grunion			X
	Inland silverside			X
	Rough silverside			X
	Tidewater silverside			X

Life histories of the species with the highest losses are summarized in the following section. The life history data used in EPA's analysis and associated data sources are provided in Appendix F1 of this report.

F2-3 LIFE HISTORIES OF PRIMARY SPECIES IMPINGED AND ENTRAINED IN THE GULF REGION

Atlantic menhaden (*Brevoortia tyrannus*)

The Atlantic menhaden, a member of the Clupeidae (herring) family, is a euryhaline species, occupying coastal and estuarine habitats. It is found along the Atlantic coast of North America, from Maine to northern Florida (Hall, 1995). Adults congregate in large schools in coastal areas; these schools are especially abundant in and near major estuaries and bays. They consume plankton, primarily diatoms and dinoflagellates, which they filter from the water through elaborate gill rakers. In turn, menhaden are consumed by almost all commercially and recreationally important piscivorous fish, as well as by dolphins and birds (Hall, 1995).

The menhaden fishery, one of the most important and productive fisheries on the Atlantic coast, is a multimillion-dollar enterprise (Hall, 1995). Menhaden are considered an "industrial fish" and are used to produce products such as paints, cosmetics, margarine (in Europe and Canada), and feed, as well as bait for other fisheries. Landings in New England declined to their lowest level of approximately 2.7 metric tons (5,952 lb) in the 1960s because of overfishing. Since then, landings have varied, ranging from approximately 240 metric tons (529,100 lb) in 1989 to 1,069 metric tons in 1998 (personal communication, National Marine Fisheries Service, Fisheries Statistics and Economics Division, Silver Spring, Maryland, March 19, 2001).

Atlantic menhaden spawn year round at sea and in larger bays (Scott and Scott, 1988). Spawning peaks during the southward fall migration and continues throughout the winter off the North Carolina coast. There is limited spawning during the northward migration and during summer months (Hall, 1995). The majority of spawning occurs over the inner continental shelf, with less activity in bays and estuaries (Able and Fahay, 1998).

Females mature just before age 3, and release buoyant, planktonic eggs during spawning (Hall, 1995). Atlantic menhaden annual egg production ranges from approximately 100,000 to 600,000 eggs for fish age 1 to age 5 (Dietrich, 1979). Eggs are spherical and between 1.3 to 1.9 mm (0.05 to 0.07 in) in diameter (Scott and Scott, 1988).

Larvae hatch after approximately 24 hours and remain in the plankton. Larvae hatched in offshore waters enter the Delaware Estuary 1 to 2 months later to mature (Hall, 1995). Juveniles then migrate south in the fall, joining adults off North Carolina in January (Hall, 1995). Water temperatures below 3 ˚C (37 ˚F) kill the larvae, and therefore larvae that fail to reach estuaries before the fall are more likely to die than those arriving in early spring (Able and Fahay, 1998). Larvae hatchout at 2.4 to 4.5 mm (0.09 to 0.18 in). The transition to the juvenile stage occurs between 30 and 38 mm (1.2 and 1.5 in) (Able and Fahay, 1998). The juvenile growth rate in some areas is estimated to be 1 mm (0.04 in) per day (Able and Fahay, 1998).

During the fall and early winter, most menhaden migrate south off of the North Carolina coast, where they remain until March and early April. They avoid waters below 3 ˚C, but can tolerate a wide range of salinities from less than 1 percent up to 33-37 percent (Hall, 1995). Sexual maturity begins at age 2, and all individuals are mature by age 3 (Scott and Scott, 1988).

Adult fish are commonly between 30 and 35 cm (11.8 and 13.8 in) in length. The maximum age of a menhaden is approximately 7 to 8 years (Hall, 1995), although individuals of 8-10 years have been recorded (Scott and Scott, 1988).

ATLANTIC MENHADEN
(*Brevoortia tyrannus*)

Family: Clupeidae (herrings).

Common names: menhaden, bunker, fatback, bugfish.

Similar species: Gulf menhaden, yellowfin menhaden.

Geographic range: From Maine to northern Florida along the Atlantic coast.[a]

Habitat: Open-sea, marine waters. Travels in schools.[b]

Lifespan:
- Approximately 7 to 8 years.[a]

Fecundity:
- Females may produce between 100,000 to 600,000 eggs.[c]

Food Source: Phytoplankton, zooplankton, annelid worms, detritus[b]

Prey for: Sharks, cod, pollock, hakes, bluefish, tuna, swordfish, seabirds, whales, porpoises.[b]

Life Stage Information

Eggs: *pelagic*
- Spawning takes place along the inner continental shelf, in open marine waters.[d]
- Eggs hatch after approximately 24 hours.

Larvae: *pelagic*
- Larvae hatch out at sea, and enter estuarine waters 1 to 2 months later.[a]
- Remain in estuaries through the summer, emigrating to ocean waters as juveniles in September or October.[d]

Adults:
- Congregate in large schools in coastal areas.
- Spawn year round.[b]

[a] Hall, 1995.
[b] Scott and Scott, 1988.
[c] Dietrich, 1979.
[d] Able and Fahay, 1998.
Fish graphic from South Carolina Department of Natural Resources, 2001.

Bay anchovy (*Anchoa mitchilli*)

Bay anchovy is a member of the anchovy family, Engraulidae. It is one of the most common species in the Tampa Bay estuary (TBNEP, 1992), as well as one of the most abundant species in estuaries along the mid-Atlantic region and throughout the Gulf of Mexico (Wang and Kernehan, 1979). Bay anchovy range from Maine to the coastal Gulf of Mexico, and young life stages can be found in every estuary in the Middle Atlantic Bight (Able and Fahay, 1998).

Bay anchovy are present in a wide range of habitats along the western Atlantic coast, from hypersaline ocean waters to tidal fresh waters. They are more commonly found in shallow tidal areas and vegetated areas such as eelgrass beds, feeding on copepods and other zooplankton (Castro and Cowen, 1991). Eggs and larvae may be more common in the higher salinity regions of the Tampa Bay estuary, where salinity is greater than 18 ppt (TBNEP, 1992).

The spawning period of bay anchovy in Tampa Bay lasts from spring through fall, peaking between April and July (TBNEP, 1992). A study conducted in Tampa Bay found that spawning began when water temperatures reached 20 ˚C (68 ˚F) and ended by November (TBNEP, 1992). Spawning typically occurs in water less than 20 m deep (65.6 ft) (Robinette, 1983), and has been correlated with areas of high zooplankton abundance (Able and Fahay, 1998). Icthyoplankton collections conducted in and around Tampa Bay suggest that bay anchovy spawn within the Tampa Bay estuary (TBNEP, 1992). Spawning generally occurs at night, and during peak spawning periods females may spawn nightly. Fecundity estimates for bay anchovy in mid-Chesapeake Bay were reported at 643 eggs per spawning episode in July 1986 and 731 eggs per spawning episode in July 1987 (Zastrow et al., 1991).

The pelagic eggs are 0.8 to 1.3 mm (0.03 to 0.05 in.) in diameter (Able and Fahay, 1998). Size of the eggs varies with increased water salinity. Eggs hatch in approximately 24 hours at average summer water temperatures (Monteleone, 1992). The yolk sac larvae are 1.8 to 2.0 mm (0.07 to 0.08 in.) long, with nonfunctioning eyes and mouth parts (Able and Fahay, 1998). Mortality during these stages is high (Leak and Houde, 1987).

Early juvenile stages of bay anchovy in Tampa Bay are approximately 15 mm (0.6 in.) (TBNEP, 1992). Individuals hatched early in the season may become sexually mature by their first summer (Robinette, 1983). The average size for adults is approximately 75 mm (2.95 in.) (Morton, 1989). Bay anchovy live for only 1 or 2 years (Zastrow et al., 1991).

There was an important bait fishery for bay anchovy in Tampa Bay until 1993, when the fishery was closed because of a declining population. Bay anchovy remains an important component of the food chain for recreational and commercial fish (Morton, 1989).

BAY ANCHOVY
(*Anchoa mitchilli*)

Family: Engraulidae (anchovies).

Common names: Anchovy.

Similar species: Atlantic silverside.

Geographic range: From Maine, south to the Gulf of Mexico.[a]

Habitat: Commonly found in shallow tidal areas with muddy bottoms and brackish waters; often appears in higher densities in vegetated areas such as eelgrass beds.[b]

Lifespan: 1-2 years.[c]

Fecundity: Fecundity per spawning event is about 700 eggs. During peak spawning periods, females may spawn nightly [c]

Food source: Primarily feed on copepods and other zooplankton, as well as small fishes and gastropods.[b]

Prey for: Snook, spotted seatrout, white seatrout, gulf flounder, and lizard fish.[e]

Life stage information:

Eggs: *pelagic*
- Eggs are 0.8-1.3 mm (0.03 to 0.05 in.) in diameter.[a]

Larvae:
- Yolk-sac larvae are 1.8 to 2.0 mm (0.7 to 0.8 in.) on hatching.[a]
- Predation mortality ranges from 18 to 28 percent per day.[f]

Juveniles:
- Young-of-year migrate out of estuaries at the end of summer, and can be found in large numbers on the inner continental shelf in fall.[g]

Adults:
- The average adult is 75 mm (2.95 in.) long.[h]

[a] Able and Fahay, 1998.
[b] Castro and Cowen, 1991.
[c] Zastrow et al., 1991.
[d] Dorsey et al., 1996.
[e] TBNEP, 1992.
[f] Leak and Houde, 1987.
[g] Vouglitois et al., 1987.
[h] Morton, 1989.
Fish graphic from NOAA, 2001a.

Blue crab (*Callinectes sapidus*)

The Atlantic blue crab can be found in Atlantic coastal waters from Long Island to the Gulf of Mexico. Blue crab supports the most economically important inshore commercial fishery in the mid-Atlantic (Epifanio, 1995); Chesapeake Bay provides over 50 percent of the commercial landings of Atlantic blue crab nationwide (Epifanio, 1995).

Females typically mate only once within their lifetime. Spawning in the Delaware Bay peaks from late July to early August. After an elaborate courtship ritual, females lay two to three broods of eggs, each containing over 1 million eggs. Mating occurs in areas of low salinity. The eggs hatch near high tide and the larvae are carried out to sea by the current (Epifanio, 1995). This stage of the lifecycle is called the zoeal stage. The zoea go through seven molts before entering the next stage, the megalops stage, and are carried back to estuarine waters (Epifanio, 1995). The zoea stages last approximately 35 days, and the megalops stage may vary from several days to a few weeks (Epifanio, 1995).

While in the zoeal stage along the continental shelf, larvae are vulnerable to predators, starvation, and transport to unsuitable habitats. Larvae are especially vulnerable to predators while molting. Dispersal of young Atlantic blue crabs is primarily controlled by wind patterns, and they do not necessarily return to their parent estuaries (Epifanio, 1995). In the Delaware Estuary, maturity is reached at approximately 18 months (Epifanio, 1995).

Atlantic blue crabs inhabit all regions of the Delaware Estuary. Males prefer areas of low salinity, while females prefer the mouth of the estuary. In the warmer months, crabs occupy shallower areas in depths of less than 4.0 m (13 ft). They can tolerate water temperatures exceeding 35 ˚C (95 ˚F), but do not fare as well in cold water (Epifanio, 1995). In winter months, adults burrow into the bottom of deep channels and remain inactive (Epifanio, 1995). Extremely cold weather has resulted in high mortality of overwintering crabs (Epifanio, 1995).

Atlantic blue crabs are omnivorous, foraging on molluscs, mysid shrimp, small crabs, worms, and plant material (Epifanio, 1995). Adults prey heavily on juvenile Atlantic blue crab (Epifanio, 1995).

Atlantic blue crab can live up to 3 years (Epifanio, 1995).

Impingeable sizes of blue crab are present throughout the year near Salem, but are most abundant from April to November.

ATLANTIC BLUE CRAB
(*Callinectes sapidus*)

Family: Portunidae (swimming crabs).

Common names: Blue crab.

Similar species: Lesser blue crab (*Callinectes similis*).

Lifespan: Up to 3 years. Maturity is reached at 18 months.[a]

Geographic range: Atlantic coast from Long Island to the Gulf of Mexico.[a]

Habitat: Inhabit all areas of the Delaware Estuary. In warmer weather they occupy shallow areas less than 4 m (13 ft) deep. They burrow into the bottom of deep channels and remain inactive in winter.[a]

Fecundity: Typically mate once in their lifetime. Mating occurs in low salinity areas. Females lay two to three broods of 1 million eggs each.[a]

Food Source: Atlantic blue crabs are omnivores, foraging on molluscs, mysids, shrimp, small crabs, worms, and plant material.[a]

Prey for: Juveniles are preyed upon by a variety of fish (eels, striped bass, weakfish) and are heavily preyed upon by adult blue crabs.[a]

Life Stage Information

Eggs:
- Hatch near high tide.[a]

Larvae:
- Carried out to sea by the current, where they remain for seven molts before returning to estuaries.[a]

***Adults*:**
- Males prefer lower salinity while females prefer the mouth of the bay.[a]

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[a] Epifanio, 1995.
Graphic from U.S. FDA, 2001.

Pink shrimp *(Penaeus duorarum duorarum)*

Pink shrimp range from the lower portions of Chesapeake Bay to the Florida Keys and along the Gulf of Mexico (Pérez Farfante, 1969). Large populations are found off the southwestern coast of Florida and the southeast portion of the Gulf of Campeche. Pink shrimp are found in the highest densities at depths of 11 to 35 m (36 to 115 ft), but are abundant to 65 m (213 ft). Individuals have been found as deep as 330 m (1,082 ft) (Pérez Farfante, 1969).

Pink shrimp was separated into two subspecies by Pérez Farfante (Costello and Allen, 1970). *Penaeus duorarum duoarum* inhabits the northwestern Atlantic Ocean and the Gulf of Mexico, whereas *Penaeus duorarum notialis* is found in the Caribbean Sea, the Atlantic coast of South America, and the Atlantic coast of Africa.

Adult pink shrimp prefer firm or hard sandy or mixed substrate bottoms (Williams, 1958; Pérez Farfante, 1969). Juveniles and subadults are more commonly found in seagrass substrates (Ault et al., 1999). Adults can survive in waters ranging from 10 to 35.5 °C (50 to 96 °F) (Pattillo et al., 1997). Adults are primarily nocturnal, while postlarvae, juveniles, and subadults are active during the day (Pérez Farfante, 1969). Pink shrimp are bottom-feeders, ingesting algae, plants, crustaceans, and fish larvae as well as mud and sand (Pérez Farfante, 1969).

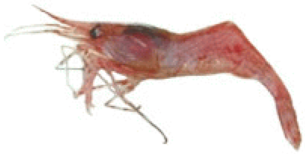
Females reach sexual maturity at approximately 69 to 89 mm (2.7 to 3.5 in.) total length, while males appear to be sexually mature at 65 mm (2.6 in.) total length (Pérez Farfante, 1969). Fecundity increases linearly with body weight, and fecundity for females weighing between 10.1 and 66.8 g (0.4 to 2.4 oz.) has been estimated at 44,000 to 534,000 eggs (Martosubroto, 1974). Pink shrimp move out of the estuary into deeper offshore waters to spawn, usually at depths of 3.5 to 50 m (11.5 to 164 ft) (Pérez Farfante, 1969). Spawning occurs throughout the year, although there is evidence that spawning is more intense during the spring and summer months (Cummings, 1961; Pérez Farfante, 1969). Eggs measure approximately 0.23 to 0.33 mm (0.009 to 0.013 in.) in diameter (Costello and Allen, 1970), and are opaque and yellow-brown.

Pink shrimp develop through several larval stages extending for 15 to 25 days in laboratory studies (Pérez Farfante, 1969). As larvae progress through their various life stages they range in size from nauplii, 0.35 to 0.61 mm (0.013 to 0.024 in.), to protozoeae, 0.86 to 2.7 mm (0.03 to 0.11 in.), to myses, 2.9 to 4.4 mm (0.11 to 0.17 in.) (Costello and Allen, 1970). Larvae are more sensitive to water temperature than adults, growing normally only between 21 and 26 ˚C (69.8 and 78.8 ˚F) (Pattillo et al., 1997).

Advanced larval pink shrimp enter estuaries when they are approximately 8 mm (0.31 in.) (Costello and Allen, 1970). They usually remain for 6-9 months before returning to open water as benthic juveniles, although some individuals may spend little or no time in an estuary (Costello and Allen, 1966; Beardsley, 1970; Allen et al., 1980). A study conducted in the Everglades National Park in Florida indicated that juvenile pink shrimp tend to rise into the surface waters during ebb tides to travel out of estuarine areas (Beardsley, 1970). Mark-recapture studies indicate that offshore adult populations are connected to specific nursery estuaries (Costello and Allen, 1966). Pink shrimp production is highly dependent on survival and growth in these nursery habitats (Sheridan, 1996). The average pink shrimp lives up to 83 weeks, but pink shrimp can potentially live for over 2 years (TBNEP, 1992).

Pink shrimp are one of the most valuable species of commercial shrimp in the Gulf of Mexico (Pérez Farfante, 1969; Beardsley, 1970; Sheridan, 1996). Annual landings in the gulf through the 1990's averaged about 8,200 metric tons (9,039 tons) (personal communication, NMFS, Fisheries Statistics and Economics Division, Silver Spring, Maryland, May 2001). The pink shrimp fishery off Florida is concentrated in the winter and spring months (Pérez Farfante, 1969). The Tortugas Grounds, off the southwestern coast of Florida, produced an average of 4,525 metric tons (4,988 tons) of shrimp tails between 1960 and 1980 (Sheridan, 1996). However, landings in Tortugas declined for unknown reasons in the 1980's, reaching a low of 2,000 metric tons (2,204 tons). Catches rebounded to over 4,000 metric tons (4,409 tons) by 1994 (Sheridan, 1996).

Ecologically, pink shrimp is an important food source for important gamefish, including the spotted seatrout, snook, mangrove snapper (*Lutjanus griseus*), red grouper (*Epinephelus morio*), black grouper (*Mycteroperca bonaci*), and king mackerel (*Scomberomorus cavalla*). Bottlenose dolphins and many species of wading and diving birds also prey on this organism (TBNEP, 1992).



PINK SHRIMP
(*Penaeus duorarum duorarum*)

Family: Palaemonidae.

Common names: Pink shrimp.

Similar species: Pink shrimp (*Penaeus duorarum notialis*).[a]

Lifespan: The average pink shrimp lives up to 83 weeks.[b]

Geographic range: From the lower portions of Chesapeake Bay to the Florida Keys and along the Gulf of Mexico.[a]

Habitat: Prefer firm or hard sandy or mixed substrate bottoms.[a,c]

Fecundity: Fecundity for females weighing between 10.1 and 66.8 g (0.4 to 2.4 oz.) has been estimated at 44,000 to 534,000 eggs.[d]

Food source: Algae, plants, crustaceans, and fish larvae as well as mud and sand.[a]

Prey for: Mangrove snapper, red grouper, black grouper, king mackerel, bottlenose dolphins, and many species of wading and diving birds.[b]

Life stage information:

Eggs:
- Eggs measure approximately 0.23 to 0.33 mm (0.009 to 0.013 in.) in diameter.[e]
- Eggs are opaque and yellow-brown.[e]

Larvae:
- Advanced larval pink shrimp enter estuaries as developmental nurseries when they are approximately 8 mm (0.31 in.).[e]

Adults:
- Pink shrimp are one of the most valuable species of commercial shrimp in the Gulf of Mexico.[a,f,g]

[a] Pérez Farfante, 1969.
[b] TBNEP, 1992.
[c] Williams, 1958.
[d] Martosubroto, 1974.
[e] Costello and Allen, 1970.
[f] Beardsley, 1970.
[g] Sheridan, 1996.
Graphic from NOAA, 2002.

Spotted seatrout (*Cynoscion nebulosus*)

Spotted seatrout is a member of the drum and croaker family Sciaenidae (Froese and Pauly, 2001). It is commonly found throughout the Gulf of Mexico and ranges along the Atlantic coast from Cape Cod to Florida. As a top carnivore within its ecosystem and a popular sport fish, it is both ecologically and economically important in Tampa Bay (Lassuy, 1983).

Spotted seatrout complete their entire life cycle in inshore waters (Lassuy, 1983), and there is little interestuary movement (Pattillo et al., 1997). Larvae are found in central Tampa Bay, while juveniles and adults are more commonly found in nearshore, vegetated seagrass areas (TBNEP, 1992). Juveniles may also be found in marshes and unvegetated backwater areas (McMichael and Peters, 1989). Historical seagrass bed loss, particularly in Hillsborough Bay and the upper half of Old Tampa Bay, partly accounts for seatrout decline in Tampa Bay. This population may not fully recover until seagrass beds repopulate most of their historical range (TBNEP, 1992).

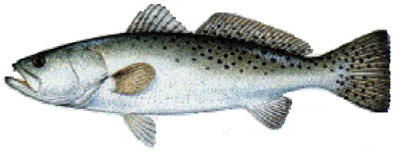
Spotted seatrout spawn in Tampa Bay from early April through October, with two major seasonal peaks in the spring and summer. Minor monthly peaks associated with the full moon also occur (McMichael and Peters, 1989). Based on the distribution of larvae within the Tampa Bay estuary, McMichael and Peters (1989) determined that spawning occurs in the middle and lower bay, and possibly in nearshore gulf waters.

Females may lay up to 0.75 million eggs per spawn, or up to 10 million eggs annually (Thomas, 2001). Eggs of the spotted seatrout are approximately 0.9 mm (0.036 in.) in diameter (Stone & Webster Engineering Corporation, 1980). Hatching occurs after 40 hours at a water temperature of 25 ˚C (77 ˚F). Larvae hatch out at approximately 1.3 mm (0.05 in.) standard length and become demersal after 4 to 7 days (Lassuy, 1983). Transformation to the juvenile stage occurs at 10 to 12 mm (0.39 to 0.47 in.) (Pattillo et al., 1997).

Most females reach maturity by 220-240 mm (8.7-9.4 in.), while all males are fully mature by 200 mm (7.9 in.) (Pattillo et al., 1997). Estimated maximum ages for spotted seatrout are 6 to 8 years for females and 5 to 9 years for males (Pattillo et al., 1997).

The diet of juvenile spotted seatrout in Tampa Bay consists mainly of copepods. Once the fish reach approximately 15-30 mm (0.6-1.2 in.), they also eat fish and shrimp (McMichael and Peters, 1989). As adults, spotted seatrout are top carnivores, and feed on several fish species in the Tampa Bay estuary, including bay anchovy, silversides, code goby, clown goby, silver perch, and mojarras (McMichael and Peters, 1989; TBNEP, 1992).

Spotted seatrout are a major component of both commercial and recreational fisheries in the Gulf of Mexico. In 1992, 637.8 billion kg (703.1 million tons) of spotted seatrout were landed in the Gulf of Mexico, of which 233.3 billion kg (257.2 million tons) were caught in Florida waters (Pattillo et al., 1997). Landings in Tampa Bay have decreased from approximately 408,000 kg (900,000 lb) in the early 1950's to approximately 91,000 kg (200,000 lb) in the early 1980's, which may be partially attributable to the loss of seagrass habitat in the bay (TBNEP, 1992).



SPOTTED SEATROUT
(*Cynoscion nebulosus*)

Family: Sciaenidae (drum family).

Common names: Spotted seatrout.

Similar species: Weakfish**.**

Lifespan: Up to 8 years for females and 9 years for males.[a]

Geographic range: Atlantic coast from Cape Cod to Florida.[b]

Habitat: Primarily shallow, vegetated seagrass beds within estuaries.[c]

Fecundity: Up to 0.75 million eggs per spawn, or up to 10 million eggs per female annually.[d]

Food source: Copepods, shrimp, and fish, including bay anchovy, silversides, clown goby, silver perch, and mojarras.[c,e]

Prey for: Snook, tarpon, barracuda, Spanish mackerel, king mackerel, bluefish.[c]

Life stage information:

Eggs:
- Eggs are approximately 0.9 mm (0.036 in.) in diameter.[f]

Larvae:
- Larvae are found in the deeper central areas of Tampa Bay.[c]

Adults:
- Decline of spotted seatrout can be attributed to the loss of historical seagrass habitat.[c]

[a] Murphy and Taylor, 1994.
[b] Froese and Pauly, 2001.
[c] TBNEP, 1992.
[d] Thomas, 2001.
[e] McMichael and Peters, 1989.
[f] Stone & Webster Engineering Corporation, 1980.
Graphic from U.S. EPA, 2002c.

F2-4 DATA EVALUATED

Table F2-3 lists Gulf facilities in scope of the Phase II rule and the facility I&E data evaluated by EPA to estimate current I&E rates for the region.

Table F2-3: California Facilities In Scope of the Section 316(b) Phase II Rule and Facility I&E Data Evaluated

In Scope Facilities	I&E Data?	Years of Data
A B Paterson (LA)	No - extrapolated	
Anclote (FL)	No - extrapolated	
Barney M Davis (TX)	No - extrapolated	
Big Bend (FL)	Yes	1976, 1979
Crist (FL)	No - extrapolated	
Crystal River (FL)	Yes	1984
Cutler (FL)	No - extrapolated	
Deepwater (TX)	No - extrapolated	
E S Joslin (TX)	No - extrapolated	
F J Gannon (FL)	No - extrapolated	
Fort Myers (FL)	No - extrapolated	
Hookers Point (FL)	No - extrapolated	
Jack Watson (MS)	No - extrapolated	
Lansing Smith (FL)	No - extrapolated	
Michoud (LA)	No - extrapolated	
Nueces Bay (TX)	No - extrapolated	
P H Robinson (TX)	No - extrapolated	
P L Bartow (FL)	Yes	1978
S O Purdom (FL)	No - extrapolated	
Sabine (TX)	No - extrapolated	
Sam Bertron (TX)	No - extrapolated	
South Texas Nuclear (TX)	No - extrapolated	
Teche (LA)	No - extrapolated	
Webster (TX)	Yes	1978

F2-5 EPA'S ESTIMATE OF CURRENT I&E IN THE GULF REGION EXPRESSED AS AGE 1 EQUIVALENTS, FOREGONE YIELD, AND PRODUCTION FOREGONE

Table F2-4 provides EPA's estimate of the annual age 1 equivalents, foregone fishery yield, and production foregone resulting from the impingement of aquatic species at facilities located in the Gulf region. Table F2-5 displays this information for entrainment.

Table F2-4: Current Annual Impingement in the Gulf Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species Group	Age 1 Equivalents (#s)	Yield (lbs)	Production Foregone
Atlantic croaker	3,809,400	775,545	257,421
Bay anchovy	7,288,096	0	787
Black drum	30,369	136,743	21,157
Blue crab	11,718,239	118,321	47,092
Chain pipefish	148,425	0	892
Gobies	54,758	0	11
Gulf killifish	86,514	0	533
Hogchoker	204,318	0	2,751
Leatherjacket	1,610,418	186,919	230,106
Mackerels	19,702	2,724	1,802
Menhadens	12,142,537	2,360,839	1,557,447
Other (commercial)	2,652,948	515,805	340,277
Other (forage)	4,290,717	0	463
Other (recreational)	985,538	191,615	126,409
Pinfish	67,031	1,764	4,290
Red drum	190,347	857,064	132,604
Scaled sardine	324,907	0	732
Sea basses (com. and rec.)	1,743	363	41
Searobin	2,212,666	88,968	122,541
Sheepshead	1,023	3	14
Shrimp (commercial)	51,222,033	364,041	336,693
Silver perch	676,308	74	470
Spot	906,538	101,532	51,256
Spotted seatrout	2,931,573	2,593,981	820,677
Stone crab	397,026	278,402	149,872
Striped mullet	860,443	364,724	93,431
Tidewater silverside	523,985	0	253

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Table F2-5: Current Annual Entrainment in the Gulf Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species Group	Age 1 Equivalents (#s)	Yield (lbs)	Production Foregone
Atlantic croaker	1,587	323	3,207
Bay anchovy	16,434,395	0	300,911
Black drum	5,545,684	24,970,270	14,168,078
Blue crab	17,999,496	181,744	243,944
Chain pipefish	67,188	0	3,068
Gobies	5,283,066	0	87,762
Hogchoker	50,267	0	27,224
Leatherjacket	31,851	3,697	21,620
Menhadens	48,462	9,422	111,301
Other (commercial)	32,410	6,301	21,765,577
Other (forage)	17,447,761	0	122,746
Other (recreational)	117,234	22,794	269,261
Pinfish	1,013,606	26,669	222,241
Red drum	13,685	61,619	34,828
Scaled sardine	567,076	0	37,370
Searobin	345,217	13,881	48,542
Sheepshead	32,908	110	14,268
Shrimp (commercial)	12,233,458	86,945	1,288,687
Silver perch	4,838,028	531	3,115,945
Spot	84,591	9,474	16,011
Spotted seatrout	138,776	122,795	352,834
Stone crab	392,534	275,252	1,073,087
Striped mullet	2,476,134	1,049,583	494,958
Tidewater silverside	675,206	0	939

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F2-6 ASSUMPTIONS USED IN CALCULATING RECREATIONAL AND COMMERCIAL LOSSES

The lost yield estimates presented in Tables F2-4 and F2-5 are expressed as total pounds and include losses to both commercial and recreational catch. To estimate the economic value of these losses, total yield was partitioned between commercial and recreational fisheries based on the landings in each fishery. Table F2-6 presents the percentage impacts assumed for each species, as well as the value per pound for commercially harvested species. Commercial and recreational fishing benefits are presented in Chapters F3 and F4.

Table F2-6: Percentage of Total Impacts Occurring to the Commercial and Recreational Fisheries and Commercial Value per Pound for Species Impinged and Entrained at Gulf of Mexico Facilities

Species Group	Percent Impact to Recreational Fishery[a,b]	Percent Impact to Commercial Fishery[a,b]	Commercial Value per Pound[c]
Atlantic croaker	88.2%	11.8%	$0.24
Black drum	93.0%	7.0%	$0.67
Blue crab	0.0%	100.0%	$0.66
Leatherjacket	0.0%	100.0%	$1.08
Mackerels	73.5%	26.5%	$0.46
Menhaden	0.0%	100.0%	$0.05
Other (commercial)	0.0%	100.0%	$0.57
Other (recreational)	100.0%	0.0%	na
Pinfish	100.0%	0.0%	$2.09
Pink shrimp	0.0%	100.0%	$2.37
Red drum	100.0%	0.0%	na
Sea basses	86.0%	14.0%	$0.54
Searobin	100.0%	0.0%	na
Sheepshead	67.0%	33.0%	$0.32
Silver perch	100.0%	0.0%	na
Spot	23.9%	76.1%	$0.27
Spotted seatrout	100.0%	0.0%	na
Stone crab	0.0%	100.0%	$1.47
Striped mullet	10.1%	89.9%	$0.68
Other (forage)[d]	50.0%	50.0%	$0.46

[a] Based on landings from 1993-2001 in Alabama, Florida (west coast), Louisiana, and Mississippi. Recreational landings data for Texas are not collected by NMFS.
[b] Calculated using recreational landings data from NMFS (2003b, http://www.st.nmfs.gov/recreational/queries/catch/snapshot.html) and commercial landings data from NMFS (2003a, http://www.st.nmfs.gov/commercial/landings/annual_landings.html).
[c] Calculated using commercial landings data from NMFS (2003a).
[d] Assumed equally likely to be caught by recreational or commercial fishermen. Commercial value calculated as overall average for region based on data from NMFS (2003a).

Age-1 equivalent fish that are spared from I&E are not necessarily old enough or large enough to be attractive to anglers. It may take one or more years for these fish to reach a harvestable age. For this reason, EPA discounts commercial and recreational benefits so that the cost and benefits estimates will be comparable. Tables F2-7 and F2-8 present the multiplicative discounting factors used in discounting benefits assuming a 3 percent real discount rate and a 7 percent real discount rate. For details on how these factors are developed, see Chapter A14.

Table F2-7: Factors Applied to Recreational Benefits to Implement Discounting in the Gulf of Mexico

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Atlantic croaker	0.934	0.858	0.962	0.918
Black drum	0.884	0.764	0.910	0.818
Mackerels	na	na	0.928	0.845
Other (recreational)	0.922	0.831	0.950	0.889
Pinfish	0.960	0.911	0.989	0.975
Red drum	0.884	0.764	0.910	0.818
Sea basses	na	na	0.850	0.691
Searobin	0.912	0.813	0.940	0.870
Sheepshead	0.909	0.804	0.936	0.861
Silver perch	0.943	0.873	0.971	0.935
Spot	0.949	0.888	0.977	0.950
Spotted seatrout	0.936	0.863	0.965	0.923
Striped mullet	0.930	0.848	0.957	0.907
Other (forage)	0.919	0.829	0.919	0.829

Table F2-8: Factors Applied to Commercial Benefits to Implement Discounting in the Gulf of Mexico

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Atlantic croaker	0.899	0.788	0.926	0.843
Black drum	0.788	0.592	0.811	0.633
Blue crab	0.949	0.888	0.978	0.950
Leatherjacket	0.933	0.854	0.961	0.914
Mackerels	na	na	0.918	0.826
Menhaden	0.913	0.813	0.940	0.870
Other (commercial)	0.913	0.813	0.940	0.870
Pink shrimp	0.971	0.935	0.898	0.788
Sea basses	na	na	0.836	0.666
Sheepshead	0.907	0.800	0.934	0.856
Spot	0.921	0.831	0.949	0.889
Stone crab	0.944	0.877	0.972	0.938
Striped mullet	0.890	0.768	0.916	0.821
Other (forage)	0.901	0.793	0.901	0.793

Chapter F3: Commercial Fishing Valuation

INTRODUCTION

CHAPTER CONTENTS

This chapter presents the results of the commercial fishing benefits analysis for the Gulf of Mexico region. Section F3.1 details the estimated losses under current, or baseline, conditions. Section F3.2 presents the expected benefits in the region attributable to the rule. Chapter A10 details the methods used in this analysis. All estimates for the South Atlantic are based on model results from the Mid-Atlantic and the Gulf of Mexico. The extrapolation is based on 3-year average daily flow.

Note that, while results for other regions have been sample weighted, no weighting is needed for the South Atlantic.

F3-1 BASELINE LOSSES

Table F3-1 provides EPA's estimate of the value of gross revenues lost in commercial fisheries resulting from the impingement of aquatic species at facilities in the Gulf of Mexico region. Table F3-2 displays this information for entrainment. Total annual revenue losses are approximately $4.1 million, assuming a 3 percent discount rate.

Table F3-1: Annual Commercial Fishing Gross Revenues Lost Due to Impingement at Facilities in the Gulf of Mexico Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002 dollars)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
Atlantic croaker	91,455	21,161	19,605	17,833
Black drum	9,667	6,342	5,146	4,015
Blue crab	118,321	76,073	74,364	72,243
Leatherjacket	186,919	197,683	189,984	180,663
Mackerels	722	324	297	267
Menhadens	2,360,839	125,336	117,875	109,018
Other (commercial)	515,805	287,569	270,452	250,130
Sea basses (com. and rec.)	51	27	23	18
Sheepshead	1	0	0	0
Shrimp (commercial)	364,041	847,034	760,460	667,458
Spot	77,236	20,771	19,707	18,470
Stone crab	278,402	401,031	389,903	376,249
Striped mullet	327,826	217,031	198,896	178,241
Other unidentified species (from forage losses)	503	227	204	180
TOTAL	4,331,790	2,200,608	2,046,918	1,874,786

Table F3-2: Annual Commercial Fishing Gross Revenues Lost Due to Entrainment at Facilities in the Gulf of Mexico Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002 dollars)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
Atlantic croaker	38	9	8	7
Black drum	1,760,386	1,154,817	909,755	683,310
Blue crab	181,744	116,850	110,898	103,708
Leatherjacket	3,697	3,910	3,648	3,339
Menhadens	9,422	500	457	407
Other (commercial)	6,301	3,513	3,208	2,856
Sheepshead	36	12	11	9
Shrimp (commercial)	86,945	202,299	196,407	189,064
Spot	7,207	1,938	1,785	1,611
Stone crab	275,252	396,493	374,264	347,656
Striped mullet	943,400	624,559	555,702	479,376
Other unidentified species (from forage losses)	15,153	6,823	6,144	5,409
TOTAL	3,289,582	2,511,723	2,162,286	1,816,751

F3-2 BENEFITS

As described in Chapter A10, EPA estimates that 0 to 40 percent of the gross revenue losses represent surplus losses to producers, assuming no change in prices or fishing costs. The 0 percent estimate, of course, results in loss estimates of $0. The 40 percent estimates, as presented in the Table F3-3, total approximately $1.6 million when a 3 percent discount rate is assumed.

The expected reductions in I&E attributable to changes at facilities required by the rule are 59.0 percent for impingement and 31.9 percent for entrainment. Total annual benefits are estimated by applying these estimated reductions to the annual producer surplus loss. As presented in Table F3-3, this results in total annual benefits of $0.7 million, assuming a 3 percent discount rate.

Table F3-3: Annual Commercial Fishing Benefits Attributable to Phase II Rule at Facilities in the Gulf of Mexico Region (million 2002$), Assumes Compliance in 2005

	Impingement	Entrainment	Total
Baseline loss — gross revenue			
Undiscounted	$2.2	$2.5	$4.7
3% discount rate	$2.0	$2.1	$4.1
7% discount rate	$1.7	$1.7	$3.4
Producer surplus lost — low	**$0.0**	**$0.0**	**$0.0**
Producer surplus lost — high (gross revenue * 0.4)			
Undiscounted	$0.9	$1.0	$1.9
3% discount rate	$0.8	$0.8	$1.6
7% discount rate	$0.7	$0.7	$1.4
Expected reduction due to rule[a]	**59.0%**	**31.9%**	---
Benefits attributable to rule — low	**$0.0**	**$0.0**	**$0.0**
Benefits attributable to rule — high			
Undiscounted	$0.5	$0.3	$0.8
3% discount rate	$0.5	$0.3	$0.7
7% discount rate	$0.4	$0.2	$0.6

[a] Estimated based on EPA's assumptions. EPA's assumption about the amount of electricity that will be produced in the future differs very slightly from DOE's. For the Gulf of Mexico region the EPA and DOE estimates are the same.

Chapter F4: RUM Analysis

INTRODUCTION

This case study uses a random utility model (RUM) approach to estimate the effects of improved fishing opportunities due to reduced impingement and entrainment (I&E) in the Gulf of Mexico region. The Gulf of Mexico region, as defined by the National Marine Fisheries Service (NMFS), includes NMFS fishing intercept sites along the Gulf of Mexico coasts of Florida, Alabama, Mississippi, and Louisiana. Because of data limitations for Texas, anglers from this state were not incorporated in the RUM analysis. Texas was included, however, in the benefits estimation.[1]

Cooling Water Intake Structures (CWIS) withdrawing water in the Gulf of Mexico region impinge and entrain many of species sought by recreational anglers, including seatrout, mackerel, sea bass, sheepshead, black drum, silver perch, spot, and striped mullet. Accordingly, EPA included the following six species groups in the model: seatrout, bottom fish, small game, snapper-grouper, big game, and flatfish. Some of these species inhabit a wide range of coastal waters, spanning several states.

CHAPTER CONTENTS

The study's main assumption is that, all else being equal, anglers will get greater satisfaction, and thus greater economic value, from sites with a higher catch rate. This benefit may occur in two ways: first, an angler may get greater enjoyment from a given fishing trip with higher catch rates, yielding a greater value per trip; second, anglers may take more fishing trips when catch rates are higher, resulting in greater overall value for fishing in the region.

The following sections focus on the data set used in the analysis and analytic results. Chapter A-11 provides a detailed description of the RUM methodology used in this analysis.

F4-1 DATA SUMMARY

EPA's analysis of improvements in recreational fishing opportunities in the Gulf of Mexico region relies on the NMFS Marine Recreational Fishery Statistics Survey (MRFSS), combined with the 1997 Add-on MRFSS Economic Survey (NMFS, 2000, 2003b).[2] The model of recreational fishing behavior relies on the subset of the data that includes only single-day trips for boat and shore anglers. The Agency did not include charter boat anglers in the model. As explained further below, the welfare gain to charter boat anglers from improved catch rates is approximated based on the regression coefficients developed for the boat anglers. Additionally, values for single-day trips were used to value each day of a multi-day trip. This analysis is based on a sample of 12,777 respondents to the MRFSS.

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[1] For more detail, see sections F4-4.1 and F4-5.6.

[2] For general discussion of the MRFSS, see Chapter A11 of the Regional Study Report or Marine Recreational Fisheries Statistics: Data User's Manual, http://www.st.nmfs.gov/st1/recreational/pubs/data_users/index.html (NMFS, 1999a).

F4-1.1 Summary of Anglers' Characteristics

a. Fishing modes and targeted species

A majority of the interviewed anglers (70 percent) fish from either a private or a rental boat. Approximately 25 percent fish from the shore; the remaining 5 percent fish from a party or charter boat. In addition to the mode of fishing, the MRFSS contains information on the specific species targeted on the current trip (see Table F4-1). Approximately 47 percent of anglers did not have a designated target species. The most popular species group, targeted by 25 percent of anglers, is small game. The second most popular species group, targeted by 16 percent of anglers, is seatrout. Of the remaining anglers, 7, 2, 1, and almost 1 percent target snapper-grouper, bottom fish, big game, and flatfish, respectively.

For private/rental boat and shore anglers, small game is the most popular species group, targeted by 28 percent of private/rental boat anglers and 20 percent of shore anglers. The second most popular species group for private/rental boat and shore anglers is seatrout, targeted by 20 percent and 7 percent of anglers, respectively. Snapper-grouper is the third most popular species group, targeted by 8 percent of private/rental boat anglers and 4 percent of shore anglers. Small game is the most popular target species group for charter/party boat anglers (17 percent), followed by snapper-grouper (15 percent) and big game (11 percent).

Table F4-1: Species Group Choice by Mode of Fishing

Species Group	All Modes		Private/Rental Boat		Party/Charter Boat		Shore	
	Frequency	Percent	Frequency	Percent by Mode	Frequency	Percent by Mode	Frequency	Percent by Mode
Big Game	182	1.42%	114	1.28%	68	11.04%	N/A	0.00%
Bottom Fish	224	1.75%	132	1.48%	N/A	0.00%	92	2.82%
Flatfish	88	0.69%	54	0.61%	N/A	0.00%	34	1.04%
Seatrout	2,049	16.04%	1,809	20.34%	19	3.08%	221	6.76%
Small Game	3,239	25.35%	2,491	28.01%	103	16.72%	645	19.74%
Snapper-Grouper	930	7.28%	708	7.96%	93	15.10%	129	3.95%
No Target	6,065	47.47%	3,585	40.31%	333	54.06%	2,147	65.70%
All Species	12,777	100.00%	8,893	100.00%	616	100.00%	3,268	100.00%

Source: National Marine Fisheries Service, 2003b.

b. Anglers' characteristics

This section presents a summary of angler characteristics for private/rental boat and shore anglers included in the Gulf of Mexico region RUM model. The Agency did not include charter anglers in the model. Table F4-2 summarizes angler characteristics.

The average income of respondent anglers is $58,337 (1997$).[3] Ninety one percent of the anglers are white, with an average age of about 43 years. Fifteen percent of the anglers are retired, while 77 percent are employed. Less than 1 percent of anglers indicated that they lost income by taking the fishing trip.

Table F4-2 shows that, on average, anglers spent 43 days fishing during the past year. The average duration of a fishing trip was 4.2 hours, and anglers made an average of 4.3 trips to the current site. The average round trip travel cost was $21.25 (1997$), and the average travel time to and from the visited site was 1.6 hours. Sixty three percent of Gulf of Mexico anglers own their own boat. Finally, the average number of years of fishing experience is 22. This analysis does not include anglers under the age of 16, which may result in an overestimation of the average age and years of experience of recreational anglers.

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[3] All costs are in 1997$, which represent the MRFSS year. All costs and benefits will be updated to 2002$ later in this analysis (e.g., for welfare estimation).

Table F4-2: Data Summary for the Gulf of Mexico Anglers

Variable	All Modes					Private/Rental Boat					Shore				
	N	Mean[a]	Std Dev	Min	Max	N	Mean[a]	Std Dev	Min	Max	N	Mean[a]	Std Dev	Min	Max
Trip Cost	12,812	$21.25	$27.17	$0.12	$537.16	8,911	$19.97	$25.33	$0.43	$537.16	3,283	$21.99	$27.99	$0.19	$471.45
Travel Time	12,812	1.64	2.00	0	38.02	8,911	1.53	1.83	0	19.72	3,283	1.73	2.13	0	38.02
Visits	2,903	4.27	6.31	1	60	2,139	4.13	5.30	1	60	643	5.28	9.13	1	60
Hours Fished	12,785	4.16	2.08	0.5	23.5	8,889	4.30	1.89	0.5	20	3,278	3.60	2.43	0.5	23.5
Own a Boat	3,007	0.63	0.48	0	1	2,211	0.76	0.43	0	1	671	0.28	0.44	0	1
Retired	3,011	0.15	0.36	0	1	2,214	0.14	0.35	0	1	671	0.18	0.38	0	1
Employed	2,963	0.77	0.42	0	1	2,178	0.79	0.41	0	1	661	0.69	0.46	0	1
Age	2,938	43.19	14.17	14	96	2,157	43.09	13.95	14	96	657	43.41	14.97	14	93
Years Fishing	2,921	22.36	14.99	0	85	2,146	23.18	14.82	0	85	651	20.19	15.28	0	70
Wage Lost	2,301	0.08	0.27	0	1	1,737	0.08	0.27	0	1	464	0.07	0.26	0	1
Male	3,008	0.90	0.3	0	1	2,211	0.91	0.28	0	1	671	0.87	0.33	0	1
White	2,934	0.91	0.29	0	1	2,157	0.93	0.25	0	1	655	0.82	0.38	0	1
Household Income	1,732	$58,337	$33,136	$7,500	$122,500	1,277	$60,789	$32,944	$7,500	$122,500	387	$47,642	$31,263	$7,500	$122,500
Annual trips	2,971	43.14	45	0	364	2,184	40.65	48.16	0	360	663	56.37	70.43	0	364

[a] For dummy variables, such as "Own a Boat," that take the value of 0 or 1, the reported value represents a portion of the survey respondents possessing the relevant characteristic. For example, 63 percent of the surveyed anglers own a boat.

Sources: NMFS, 2003b; and U.S. Census Bureau, 2002.

F4-1.2 Recreational Fishing Choice Sets

There are 514 NMFS survey intercept sites (see Figure F1-1 in Chapter F1 for the survey intercept sites included in the analysis) in the Gulf of Mexico region total choice set. Each angler's choice set included his/her chosen site, plus a randomly selected set of up to 73 additional sites within 150 miles of his/her home zip code. EPA used ArcView 3.2a software to determine the distance from an angler's residence to each NMFS intercept site. Further discussion of distance estimation is presented in section F4-1.4. EPA did not include sites on the Atlantic Coast of Florida or anglers from eastern Florida in the model, because the data indicated that Florida anglers do not generally cross to the opposite coast to fish.[4]

F4-1.3 Site Attributes

This analysis assumes that the angler chooses between site alternatives based on catch rates at the sites. Catch rates are the most important attribute of a fishing site from the angler's perspective (McConnell and Strand, 1994; Haab et al., 2000). This attribute is also a policy variable of concern because catch rate is a function of fish abundance, which is affected by fish mortality due to I&E. The catch variable in the RUM therefore provides the means to measure baseline losses from I&E, and changes in anglers' welfare due to reductions in I&E.

To specify the fishing quality of the case study sites, EPA calculated historical catch rates based on the NMFS catch rates for the years 1993 to 1997. EPA created six species groups: big game, bottom fish, small game, seatrout, snapper-grouper, and flatfish, and calculated group-specific catch rates. The six specific groups include the following species:

- ***Big game***: blackfin tuna, dolphin, sailfish, wahoo, bigeye tuna, billfish, blue shark, bluefin tuna, tiger shark, tuna, great hammerhead shark, smalleye hammerhead shark, skipjack tuna, blue marlin, and longbill spearfish.

- ***Bottom fish***: striped mullet, black drum, gulf kingfish, mullet, largemouth bass, pinfish, southern kingfish, kingfish, Atlantic croaker, tripletail, sea catfish, drums, white mullet, spotted pinfish, silver perch, grunt, gafftopsail catfish, grass porgy, mullet, striped mullet, sand tiger shark, lizardfish, toadfish, leopard toadfish, reef squirrelfish, ribbonfishes, searobin, leopard searobin, sunfish, mojarra, silver jenny, tomtate, caesar grunt, French grunt, bluestriped grunt, pigfish, porgy, sea bream, spotted pinfish, slippery dick, blackear wrasse, parrotfish, Atlantic cutlassfish, and barrelfishes.

- ***Small game***: red drum, snook, Spanish mackerel, king mackerel, cobia, Atlantic tarpon, Florida pompano, bonefish, blue runner, bluefish, mackerels and tunas, permit, leatherjacket, ladyfish, pompano dolphin, jack, swordspine snook, striped bass, African pompano, Atlantic bumper, amberjack, banded rudderfish, round scad, cottonmouth jack, and cero.

- ***Seatrout***: spotted seatrout, sand seatrout, silver seatrout, and weakfish.

- ***Snapper-grouper***: gag, sheepshead, red snapper, grey snapper, snapper, sea bass, red grouper, white grunt, crevalle jack, hogfish, black sea bass, greater amberjack, mutton snapper, yellowtail snapper, Atlantic spadefish, gray triggerfish, black grouper, wenchman, hind red, lane snapper, mutton snapper, orange filefish, jewfish, rock hind, speckled hind, Nassau grouper, scamp, dwarf sandperch, sand tilefish, cubera snapper, schoolmaster, vermilion snapper, sailors choice, ocean triggerfish, and sargassum triggerfish.

- ***Flatfish***: left-eye flounder, southern flounder, gulf flounder, summer flounder, and hogchoker.

The catch rates measure the number of fish caught on a fishing trip divided by the number of hours spent fishing (i.e., the number of fish caught per hour per angler). The estimated catch rates are averaged across all anglers in a given year over the five-year period. EPA used total catch, including fish caught and kept and fish released. Some NMFS studies use the catch-and-keep measure as the relevant catch rate. Although a greater error may be associated with the measured number of fish not kept, the total catch measure is most appropriate because a large number of anglers catch and release fish. The total catch rate variables include both targeted fish catch and incidental catch. For example, king mackerel catch rates include fish

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[4] According to the NMFS data, less than 0.01 percent of anglers from the Gulf Coast travel across Florida to fish at Atlantic coast sites.

caught by king mackerel anglers, and anglers who do not target any particular species or target something else. This method may underestimate the average historical catch rate for a given site because anglers not targeting particular fish species are usually less experienced and may not have the appropriate fishing gear. EPA considered using targeted species catch rates for this analysis, but discovered that this approach did not provide a sufficient number of observations per fishing site to allow estimation of catch rates for all fishing sites included in the analysis.

About half of the anglers do not target any particular species, and therefore are treated in the analysis as "no-target" anglers. For anglers who don't target any species, EPA used catch rates for all species and species groups caught by no-target anglers to characterize the fishing quality of a fishing site. The MRFSS provided information on species caught by 4,059 no-target anglers. Of those, 36 percent caught bottom fish; 32 percent caught snapper-grouper; 16 percent caught small game fish (i.e., king mackerel, Atlantic tarpon, Florida pompano, or other small game); 14 percent caught seatrout; and 2 percent caught flatfish.

Anglers who target particular species generally catch more fish in the targeted category than anglers who don't target any species mainly because of their skills and specialized equipment. Of the boat anglers who target particular species, bottom fish anglers catch the largest number of fish per hour, followed by anglers who target seatrout, snapper-grouper, small game, flatfish, and big game. Of the shore anglers who target particular species, bottom fish anglers catch the largest number of fish per hour, followed by anglers who target snapper-grouper, seatrout, flatfish, and small game. Table F4-3 summarizes average catch rates by species for all sites in the study area.

Table F4-3: Average Catch Rate by Species/Species Group for the Gulf of Mexico Sites by Mode of Fishing

Species Group	Average Catch Rate (fish per angler per hour)			
	All Sites		Sites with Zero Catch Rates	
	Private/Rental Boat	Shore	Private/Rental Boat	Shore
Big Game	0.02	N/A	0.27	N/A
Bottom Fish	0.25	0.28	0.98	1.27
Flatfish	0.05	0.04	0.38	0.42
Seatrout	0.18	0.07	0.82	0.45
Small Game	0.12	0.07	0.46	0.36
Snapper-Grouper	0.18	0.13	0.77	0.74
No Target	0.16	0.15	0.58	0.58

Source: National Marine Fisheries Service, 2002e.

Some RUM studies have used predicted, rather than actual, catch rates (Haab et al., 2000; Hicks et al., 1999; McConnell and Strand, 1994). This practice allows for individual characteristics to affect catch rates; for example, anglers with different levels of experience may have different catch rates. Haab et al. (2000) compared historical catch-and-keep rates to predicted catch-and-keep rates and found that historical catch-and-keep rates were a better measure of site quality. The authors also found that the choice of catch rate had little effect on the travel cost parameters. Hicks et al. (1999) found that using historical catch rates resulted in more conservative welfare estimates than predicted catch rate models. Consequently, EPA favored this more conservative approach.

F4-1.4 Travel Cost

EPA used ArcView 3.2a software to estimate distances from each angler's zip code to each NMFS fishing site in the angler's opportunity set. The Agency obtained fishing site locations from the Master Site Register supplied by NMFS. The Master Site Register includes both a unique identifier that corresponds to the visited site used in the angler survey, and latitude and longitude coordinates. For some sites, the latitude and longitude coordinates were missing or demonstrably incorrect, in which case the town point, as identified in the U.S. Geological Survey (USGS) Geographic Names Information System, was used as the site location if a town was reported in the site address. EPA measured the distance in miles of the shortest route, using state and U.S. highways, from the household zip code to each fishing site, then added the distances from the zip code location to the closest highway and from the site location to the closest highway. The average one-way distance to the visited site for boat and shore anglers is 33.4 miles. Private/rental boat anglers traveled an average of 31.2 miles to the chosen site, while shore anglers traveled an average of 35.0 miles.

EPA estimated trip "price" as the sum of travel costs plus the opportunity cost of time following the procedure described in Haab et al. (2000). Based on Parsons and Kealy (1992), this study assumed that time spent "on-site" is constant across sites and can be ignored in the price calculation. To estimate anglers' travel costs, EPA multiplied round trip distance by average motor vehicle cost per mile ($0.31, 1997$).[5] To estimate the opportunity cost of travel time, EPA divided round trip distance by 40 miles per hour to estimate trip time, and multiplied by the household's wage to yield the opportunity cost of time. EPA estimated household wage by dividing household income by 2,080 (i.e., the number of full-time hours potentially worked).

Only those respondents who reported that they lost income during the trip *(LOSEINC*=1) are assigned a time cost in the trip cost variable. Information on the *LOSEINC* variable was available only for a subset of survey respondents who participated in the follow-up telephone interviews. Only 181 out of the 2,731respondents reported that they lost income. Given that only a small number of survey respondents reported lost income, EPA assumed that the remaining 10,081 anglers did not lose income during the trip. EPA calculated visit price as:

$$Visit\ Price = \begin{cases} Round\ Trip\ Distance \times \$.29 + \dfrac{Round\ Trip\ Distance}{40\ mph} \times (Wage) & If\ LOSEINC = 1 \\ Round\ Trip\ Distance \times \$.29 & If\ LOSEINC = 0 \end{cases} \qquad \text{(F4-1)}$$

For those respondents who do not lose income, the time cost is accounted for in an additional variable equal to the amount of time spent traveling. EPA estimated time cost as the round trip distance divided by 40 mph:

$$Travel\ Time = \begin{cases} Round\ Trip\ Distance/40 & If\ LOSEINC = 0 \\ 0 & If\ LOSEINC = 1 \end{cases} \qquad \text{(F4-2)}$$

EPA used a log-linear ordinary least square regression model to estimate wage rates for anglers who did not report their income. The estimated regression equation used in the wage calculation is :

$$\begin{aligned} Ln(Income) = {} & 0.14 \times male + 0.10 \times age - 0.0017 \times age^2 + 0.32 \times employed \\ & + 0.147 \times boatown + 0.818 \log (stinc) \end{aligned} \qquad \text{(F4-3)}$$

where:

Income = the reported household income;
Male = 1 for males;
Age = age in years;
Employed = 1 if the respondent is currently employed and 0 otherwise;
Boatown = 1 if the respondent owns a boat; and
Stinc = the average income of residents in the corresponding states.

All variables in the estimated income regression are statistically significant at better than the 99th percentile. The average imputed household income for anglers who do not report income is $30,058 per year, and the corresponding hourly wage is $14.73.

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[5] EPA used the 1997 government rate ($0.31) for travel reimbursement to estimate travel costs per mile traveled. This estimate includes vehicle operating cost only.

F4-2 SITE CHOICE MODELS

The nature of the MRFSS data leads to the RUM as a means of examining anglers' preferences (Haab et al., 2000). Anglers arrive at each NMFS site by choosing among a set of feasible sites. Interviewers intercept individual anglers at marine fishing sites along the Gulf of Mexico Coast and collect data on the anglers' origins and catch (including number and weight of species caught).

The RUM assumes that the individual angler makes a choice among mutually exclusive site alternatives based on the attributes of those alternatives (McFadden, 1981). The number of feasible choices (J) in each angler's choice set was set to 74 sites within 150 miles of the angler's home.[6]

An angler's choice of sites relies on utility maximization. An angler will choose site j if the utility (u_j) from visiting site j is greater than that from vising other sites (h), such that:

$$u_j > u_h \text{ for } h = 1, \ldots, J \text{ and } h \neq j \qquad \text{(F4-4)}$$

Anglers choose the species to seek and the mode of fishing in addition to choosing a fishing site. Available fishing modes include shore fishing, fishing from charter boats, or fishing from private or rental boats. The target species or group of species include big game, bottom fish, small game, seatrout, snapper-grouper, and flatfish. Anglers may also choose not to target any particular species.

Recreational fishing models generally assume that anglers first choose a mode and species, and then a site. The nested logit model is generally used for recreational demand models, as it avoids the independence of relevant alternatives (IIA) problem, in which sites with similar characteristics that are not included in the model have correlated error terms. However, the nested model did not work well for the Gulf of Mexico region, indicating that nesting may not be appropriate for the data. Consequently, EPA estimated separate logit models for boat and shore anglers. The Agency did not include the angler's choice of fishing mode and target species in the model, instead assuming that the mode/species choice is exogenous to the model and that the angler simply chooses the site. EPA used the following general model to specify the deterministic part of the utility function:[7]

$$v\ (site\ j) = f\ (TC_j,\ TT_j,\ SQRT(Q_{js}) \times Flag(s)) \qquad \text{(F4-5)}$$

where:

v = the expected utility for site j (j=1,...37);
TC_j = travel cost for site j;
TT_j = travel time for site j;
$SQRT(Q_{js})$ = square root of the historical catch rate for species s at site j;[8] and
$Flag(s)$ = 1 if an angler is targeting this species; 0 otherwise.

The analysis assumes that each angler in the estimated model considers site quality based on the catch rate for the targeted species. Theoretically, an angler may catch any of the available species at a given site (McFadden, 1981). If, however, an angler truly has a species preference, then including the catch variable for all species available at the site would inappropriately attribute utility to the angler for a species not pursued (Haab et al., 2000). To avoid this problem, the Agency used an interaction variable $SQRT\ (Q_{js}) \times Flag(s)$, such that the catch rate variable for a given species is turned on only if the angler targets a particular species [$Flag\ (s)$=1]. The Agency calculated a separate catch rate for no-target anglers, using the average of all species caught by no-target anglers. The analysis therefore assumes that each angler has chosen a mode/species combination followed by a site based on the catch rates for that site and species. EPA estimated all RUM models with LIMDEPTM software (Greene, 1995). Table F4-4 gives the parameter estimates for this model.

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[6] Based on the 99th percentile for the distance traveled to a fishing site.

[7] See Chapter A-11 for detail on model specification.

[8] The analysis used the square root of the catch rate to allow for decreasing marginal utility of catching fish (McConnell and Strand, 1994).

Table F4-4: Estimated Coefficients for the Flat Logit Site Choice Model

Variable	Private/Rental Boat		Shore	
	Estimated Coefficient	T-statistic	Estimated Coefficient	T-statistic
TRAVCOST	-0.030	-10.315	-0.031	-4.690
TRAVTIME	-1.129	-28.906	-0.705	-8.466
SQRT (Q_{seatrout})	2.225	27.850	2.755	15.273
SQRT ($Q_{\text{bottom fish}}$)	1.662	6.690	0.595	6.046
SQRT ($Q_{\text{small game}}$)	2.660	32.797	2..117	21.944
SQRT ($Q_{\text{snapper-grouper}}$)	2.442	20.304	2.420	9.462
SQRT ($Q_{\text{big game}}$)	5.531	11.074	N/A	N/A
SQRT (Q_{flatfish})	3.159	4.683	2.006	4.105
SQRT ($Q_{\text{no target}}$)	1.417	34.045	1.149	28.564

Source: U.S. EPA analysis for this report.

One disadvantage of the specified model is that the model looks at site and mode choice without regard to species. Once an angler chooses a target species, no substitution is allowed across species (i.e., the value of catching, or potentially catching, a different species is not included in the calculation). Therefore, improvements in fishing circumstances related to other species will have no effect on anglers' choices.

All model coefficients have the expected signs and are statistically significant at the 99th percentile. Travel cost and travel time have a negative effect on the probability of selecting a site, indicating that anglers prefer to visit sites closer to their homes (other things being equal). The probability of a site visit increases as the historical catch rate for fish species increases.

On average, no-target anglers place a lower value on the catch rate of particular species than anglers targeting a species. This result is not surprising. In general, species caught by no-target anglers are not as valuable as those caught by target anglers, because of lack of special gear and skills. As discussed in section F4-1.3, no-target anglers mostly catch bottom fish and therefore, the estimated coefficient for the no-target catch rate is close to the coefficient for the bottom fish catch rate.

F4-3 TRIP FREQUENCY MODEL

EPA also examined effects of changes in fishing circumstances on an individual's choice concerning the number of trips to take during a recreation season. EPA used the negative binomial form of the Poisson regression model to estimate the number of fishing trips per recreational season. The participation model relies on socio-economic data and estimates of individual utility (the inclusive value) derived from the site choice model (Parsons et al., 1999; Feather et al., 1995). EPA estimated a combined participation model for the Gulf of Mexico and South Atlantic regions.[9] This section discusses results from the Poisson model of recreational fishing participation, including statistical and theoretical implications of the model. A detailed discussion of the Poisson model is presented in Chapter A11 of this report.

The dependent variable, the number of recreational trips within the past 12 months, is an integer value ranging from 1 to 365. To avoid over-prediction of the number of fishing trips, EPA set the number of trips for anglers reporting more than 151 trips per year to 151 in the model estimation.[10] The Agency first tested the data on the number of fishing trips for overdispersion to

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[9] EPA combined data for the Gulf of Mexico and South Atlantic regions to estimate the model. The Agency calculated separate estimates of participation and changes in participation for each region, based on average values of variables for that region.

[10] The number of trips was truncated at the 95th percentile, 151 trips per year.

determine whether to use the Poisson model or the negative binomial model. If the dispersion parameter is equal to zero, then the Poisson model is appropriate; otherwise the negative binomial is more appropriate. The analysis found that the overdispersion parameter is significantly different from zero and therefore the negative binomial model is the most appropriate for this case study.

Independent variables of importance include gender, hourly wage, whether the angler targets a species, whether the angler fishes from shore or from a boat, whether the angler is retired, and whether the angler owns a boat.[11] The model also includes a dummy variable to indicate whether the angler fishes in the Gulf of Mexico region. Variable definitions for the trip participation model are:

Constant:	a constant term;
IVBASE:	the inclusive value estimated using the coefficients from the site choice model;
RETIRED:	equals 1 if the individual is retired, 0 otherwise;
MALE:	equals 1 if the individual is male, 0 if female;
OWNBT:	equals 1 if individual owns a boat, 0 otherwise;
NOTARG:	equals 1 if the individual did not target a particular species, 0 otherwise;
SHORE:	equals 1 if the individual fished from shore, 0 if the individual fished from a boat;
WAGE:	household hourly wage (household income divided by 2,080);
GULF:	equals 1 if the angler fishes in the Gulf of Mexico region, 0 if the angler fishes in the South Atlantic region; and
α (alpha):	overdispersion parameter estimated by the negative binomial model.

Table F4-5 presents the results of the trip participation model. Where a particular sign is expected, all estimated parameters have the expected signs. The model shows that the most significant determinants of the number of fishing trips taken by an angler are gender (MALE), boat ownership (OWNBT), region (GULF), whether the angler targets a species (NOTARG), and whether the angler fishes from shore (SHORE).

Table F4-5: Trip Participation Model (Negative Binomial Model)

Variable	Coefficient	t-statistic
Constant	3.284	49.69
IVBASE	0.106	16.48
RETIRED	0.101	2.24
MALE	0.266	5.33
OWNBT	0.191	5.15
NOTARG	-0.159	-4.71
SHORE	0.185	3.88
WAGE	-0.003	-2.13
GULF	-0.254	-7.16
α (alpha)	1.03	41.38

Source: U.S. EPA analysis for this report.

The positive coefficient on the inclusive value index (IVBASE) indicates that the quality of recreational fishing sites has a positive effect on the number of fishing trips per recreational season. EPA therefore expects improvements in recreational fishing opportunities, such as an increase in fish abundance and catch rate, to result in an increase in the number fishing trips to the affected sites.

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[11] It would be desirable to include additional socio-economic variables such as age, education, and household size in the participation model. However, those data are not available in the MRFSS Economic Survey.

The model shows that anglers in the Gulf of Mexico region take less fishing trips than those in the South Atlantic region. Anglers who are retired take more trips than those who are not retired, and male anglers fish more frequently than female anglers. Anglers who own boats, those who target a specific species, and those who fish from shore take more trips each year, while those with higher incomes take less trips.

F4-4 WELFARE ESTIMATES

This section presents estimates of welfare losses to recreational anglers from fish mortality due to I&E, and potential welfare gains from improvements in fishing opportunities due to reduced fish mortality stemming from the final section 316(b) rule. While Texas was not included in the RUM because of data limitations, EPA estimated welfare effects for Texas.

F4-4.1 Estimating Changes in the Quality of Fishing Sites

To estimate changes in the quality of fishing sites under different policy scenarios, EPA relied on recreational fishery landings data by state and the estimates of recreational losses from I&E corresponding to different technology options. The NMFS provided the recreational fishery landings data for all the states in the Gulf of Mexico region except for Texas.[12] EPA estimated the losses to recreational fisheries using the physical impacts of I&E on the relevant fish species, and the percentage of total fishery landings attributed to recreational fishing, as described in Chapter F2 of this document.

The Agency estimated changes in the quality of recreational fishing sites under different policy scenarios in terms of the percentage change in the historical catch rate. EPA assumed that catch rates will change uniformly across all marine fishing sites in the Gulf of Mexico region, because species considered in this analysis (e.g., black drum, seatrout, sea bass) are found throughout waters of the Gulf. EPA used five-year recreational landing data (1997 through 2001) for state waters to calculate an average landing per year for all species groups.[13] Since landing data for Texas were limited, EPA assumed that Texas anglers have similar catch rates to those in the other Gulf states and therefore would have the same per-day welfare gain. EPA then divided losses to the recreational fishery from I&E by the total recreational landings for the region to calculate the percent change in historical catch rate from eliminating I&E completely. EPA estimated I&E losses for West Florida, Alabama, Mississippi, and Louisiana by applying an adjustment factor of 0.6683 to the I&E losses estimated for all five states in the Gulf of Mexico region. This adjustment factor reflects the fact that Texas facilities account for 33.17 percent of CWIS flow in the region. Table F4-6 presents the results of this analysis.

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[12] EPA obtained landing data for Texas from the Texas Parks and Wildlife Department, Marine Sport-Harvest Monitoring Program, but found that landing data for the shore mode were not available, and data for private/rental and charter boat modes were very limited (e.g., landing data for the bottom fish group included only 3 species, whereas NMFS data for other Gulf states included 20 species in this group) (TPWD, 2003).

[13] State waters include sounds, inlets, tidal portions of rivers, bay, estuaries, and other areas of salt or brackish water plus ocean waters to three nautical miles from shore (NMFS, 2003a).

Table F4-6: Estimated Changes in Historical Catch Rates from Eliminating and Reducing I&E in the Gulf of Mexico Region

Species Group[a]	Baseline Losses				Reduced Losses under Preferred Option		
						For Four States	
	Total Recreational Landings for Four States (fish per year)[b,c]	Baseline I&E for Five States[d]	Baseline I&E for Four States[c,e]	Percent Increase in Recreational Catch from Elimination of I&E, for Four States[b]	Reduced I&E for Five States[d]	Reduced I&E for Four States[c,e]	Percent Increase in Recreational Catch from Elimination of I&E, for Four States[b]
Bottom Fish	33,608,792	2,461,061	1,644,727	4.89%	997,789	666,822	1.98%
Seatrout	27,822,999	1,196,527	799,639	2.87%	689,698	460,925	1.66%
Small Game	15,004,373	108,072	72,225	0.48%	61,145	40,863	0.27%
Snapper-Grouper	17,132,522	55,421	37,038	0.22%	30,866	20,627	0.12%
Flatfish	1,077,195	3,465	2,316	0.22%	1,930	1,290	0.12%
No Target	104,064,982	3,854,850	2,576,196	2.48%	1,798,304	1,201,806	1.15%

[a] I&E losses to species that were not identified and those attributed to I&E forage fish were distributed to the species in the same proportions found in the MRFSS landing data.
[b] Includes Western Florida, Alabama, Mississippi, and Louisiana; does not include Texas.
[c] Total recreational landings are calculated as a five-year average (1997-2001) for state waters.
[d] Includes Western Florida, Alabama, Mississippi, Louisiana, and Texas.
[b] I&E losses for four states were calculated based on the intake flow in the region; the four states account for 66.83 percent of the region flow.

Sources: National Marine Fisheries Service, 2002e; and U.S. EPA analysis for this report.

F4-4.2 Estimating Losses from I&E in the Gulf of Mexico Region

The recreational behavior model described in the preceding sections provides a means for estimating the economic effects of changes in recreational fishery losses from I&E in the Gulf of Mexico region. The total welfare gain for the five Gulf states is calculated by estimating the per-day welfare gain for the four states included in the RUM, and then multiplying the per day welfare gain by the predicted total number of fishing days by residents of all five Gulf states. Welfare gains to recreational anglers are estimated under two scenarios. The baseline scenario represents economic damages from I&E to recreational anglers in the region. Under the second scenario, EPA estimated reduced damages to recreational anglers from implementing the CWIS technologies under the final section 316(b) rule.

EPA estimated anglers' willingness-to-pay (WTP) for improvements in the quality of recreational fishing due to I&E elimination by first calculating an average per-day welfare gain based on the expected changes in catch rates from eliminating I&E. Table F4-7 presents the compensating variation per day (averaged over all anglers in the sample) associated with reduced fish mortality from eliminating I&E for each fish species of concern.[14] Table F4-7 also shows the per-day welfare gain attributable to reduced I&E resulting from the final section 316(b) rule.[15]

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[14] A compensating variation equates the expected value of realized utility under the baseline and post-compliance conditions. For more detail, see Chapter A11 of this report.

[15] As the RUM model estimated values for single-day trips, the per-day value is equal to a per-trip value.

Table F4-7: Per-Trip Welfare Gain from Eliminating and Reducing I&E in the Gulf of Mexico Region (2002$)

Species Group	Baseline Per-Trip Welfare Gain		Reduced Losses Under the Proposed Rule Per-Trip Welfare Gain		WTP for an Additional Fish per Trip	
	Boat Anglers	Shore Anglers	Boat Anglers	Shore Anglers	Boat Anglers	Shore Anglers
Big Game[a]	N/A	N/A	N/A	N/A	$29.84	N/A
Bottom Fish	$1.53	$0.62	$0.62	$0.25	$7.08	$2.16
Flatfish	$0.09	$0.16	$0.05	$0.09	$16.27	$9.21
Seatrout	$1.13	$1.36	$0.66	$0.78	$9.93	$13.56
Small Game	$0.17	$0.13	$0.10	$0.07	$15.31	$12.57
Snapper-Grouper	$0.09	$0.08	$0.05	$0.04	$11.03	$11.23
No Target	$0.54	$0.40	$0.25	$0.19	$6.23	$5.24

[a] Shore anglers do not target Big Game.

Source: U.S. EPA analysis for this report.

Table F4-7 shows that boat anglers in the Gulf of Mexico region targeting bottom fish have the largest per-day gain ($1.53) from eliminating I&E. Seatrout anglers have the largest per-day gain ($1.36) of those who fish from the shore. Shore anglers targeting bottom fish also have a relatively high per-day welfare gain of $0.62. Table F4-7 also reports the WTP for a one fish per day increase in catch. The more desirable the fish, the greater the per-day welfare gain, as evidenced by the WTP for catching one additional fish per trip. Of the species groups affected by I&E reductions, boat anglers value flatfish the most ($16.27 for an additional fish) followed by small game ($15.31) and snapper-grouper ($11.03). Shore anglers value seatrout the most ($13.56) followed by small game ($12.57) and snapper-grouper ($11.23). Both boat and shore anglers place the lowest value on bottom fish, $7.08 and $2.16, respectively. Anglers targeting big game, not surprisingly, place the highest value on catching an additional fish ($29.84).

EPA calculated the total economic value of eliminating I&E in the Gulf of Mexico region by combining the estimated per-day welfare gain with the total number of fishing days at Gulf of Mexico sites. NMFS provided information on the total number of fishing trips by state and by fishing mode for West Florida, Alabama, Mississippi, and Louisiana. The Agency utilized data from the U.S. Department of the Interior's *2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation* (U.S. Fish and Wildlife Service, 2001) to estimate fishing days in Texas.[16]

The Agency assumed that the welfare gain per day of fishing is independent of the number of days fished per trip and therefore equivalent for both single- and multiple-day trips. Each day of a multiple-day trip is valued the same as a single-day trip.[17] Per-day welfare gain differs across recreational species and fishing mode.[18] EPA therefore estimated the number of fishing days associated with each species of concern and the number of days taken by no-target anglers. EPA used the MRFSS sample to calculate the proportion of recreational fishing days taken by no-target anglers and anglers targeting each species of concern and applied these percentages to the total number of days to estimate species-specific participation. Table F4-8 shows the calculation results for the Gulf states.

No-target anglers account for the largest number of fishing days at Gulf of Mexico NMFS sites (11 million). Anglers targeting small game and seatrout rank second and third, fishing 5 million and 2.9 million days per year, respectively. Anglers targeting other species have the lowest number of fishing days per year (59,110).

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[16] EPA assumed Texas anglers chose their mode of fishing and target species in the same proportions as in the other Gulf states.

[17] See section F4-5.1 for limitations and uncertainties associated with this assumption.

[18] EPA used the per-day values for private/rental boat anglers to estimate welfare gains for charter boat anglers.

Table F4-8: Recreational Fishing Participation by Species for the Gulf of Mexico Region

Species Group	Number of Fishing Days		
	Four States[a]	Texas	All Gulf States
Big Game	181,944	65,280	247,224
Bottom Fish	434,177	155,778	589,955
Flatfish	167,801	60,205	228,006
Seatrout	2,870,680	1,029,968	3,900,648
Small Game	5,016,475	1,799,854	6,816,329
Snapper-Grouper	1,305,131	468,266	1,773,397
Other	59,110	21,208	80,318
No Target	10,974,261	3,937,441	14,911,702
Total[b]	21,009,580	7,538,000	28,547,580

[a] Includes Western Florida, Alabama, Mississippi, and Louisiana.
[b] Sum of individual values may not add up to totals due to rounding.

Source: National Marine Fisheries Service, 2002d.

The estimated number of days presented in Table F4-8 represents the baseline level of participation. However, anglers may take more trips if recreational fishing conditions improve. EPA used the trip frequency model described in section F4-3 to estimate the predicted number of fishing days due to the elimination and reduction of I&E. These changes are reported in Table F4-9. For baseline I&E elimination, the estimated percentage increase ranges from 0.43 percent for boat anglers targeting bottom fish to 0.02 percent for shore anglers targeting snapper-grouper. For I&E reduction under the final section 316(b) rule, the increase ranges from 0.23 per cent for shore anglers targeting seatrout to 0.01 percent for boat anglers targeting flatfish and all anglers targeting snapper-grouper. The total increase for the region is 37,385 fishing days under the baseline elimination of I&E and 19,022 days under the final section 316(b) rule reduced I&E, an increase of 0.13 and 0.07 percent, respectively.

Table F4-9: Increased Recreational Fishing Participation by Species and Fishing Mode from Eliminating or Reducing I&E in the Gulf of Mexico Region

Species	Predicted Percent Change in Annual Fishing Trips				Boat Mode		Shore Mode		Party/Charter Mode	
	Boat Mode		Shore Mode		Baseline	Reduced	Baseline	Reduced	Baseline	Reduced
	Baseline	Reduced	Baseline	Reduced						
Bottom Fish	0.43%	0.18%	0.18%	0.07%	218,952	218,394	372,610	372,216	-	-
Flatfish	0.03%	0.01%	0.05%	0.03%	89,878	89,868	138,215	138,186	-	-
Seatrout	0.32%	0.18%	0.39%	0.23%	2,999,831	2,995,793	897,513	896,026	16,406	16,375
Small Game	0.05%	0.03%	0.04%	0.02%	4,119,123	4,118,268	2,611,203	2,610,793	88,942	88,918
Snapper-Grouper	0.03%	0.01%	0.02%	0.01%	1,171,379	1,171,241	522,165	522,115	80,289	80,277
No Target	0.15%	0.07%	0.11%	0.05%	5,935,061	5,930,261	8,708,202	8,702,878	287,665	287,450
Total					14,534,224	14,523,825	13,249,908	13,242,214	473,302	473,020

Source: U.S. EPA analysis for this report.

Table F4-10 provides welfare estimates for two policy scenarios: welfare losses to recreational anglers from baseline I&E and welfare gains that will result from installing the technology required under the final section 316(b) rule at the Gulf of Mexico region facilities. EPA calculated the total welfare estimates by multiplying the estimated values per day (Table F4-7) by the number of fishing days (Tables F4-8 and F4-9).[19] These values were discounted to reflect the fact that fish must grow to a certain size before they can be caught by recreational anglers. EPA calculated discount factors separately for I&E of each species(See Chapter F2 for details). To estimate discounted total benefits, EPA calculated weighted averages of these discount factors for each species group, and applied them to estimated WTP values. Discount factors were calculated for both a 3 percent discount rate and a 7 percent discount rate. For the welfare estimates of the final section 316(b) rule, an additional discount factor was applied to account for the 1-year lag between the date when installation costs are incurred and the installation of the required cooling water technology is completed.

Table F4-10: Total Estimated Annual Welfare Gain to Recreational Anglers from Eliminating and Reducing I&E Under the Final Section 316(b) Rule in the Gulf of Mexico Region (2002$)

Species Group	Eliminating Recreational Fishery Losses from I&E			Reduced I&E Losses Under the Final Section 316(b) Rule		
	Undiscounted	3% Discount Factor	7% Discount Factor	Undiscounted	3% Discount Factor	7% Discount Factor
Big Game	N/A	N/A	N/A	N/A	N/A	N/A
Bottom Fish	$565,039	$514,186	$463,332	$230,230	$203,407	$176,438
Flatfish	$30,064	$28,260	$26,156	$16,744	$15,281	$13,614
Seatrout	$4,631,381	$4,446,125	$4,260,870	$2,673,690	$2,491,974	$2,298,875
Small Game	$1,041,644	$947,896	$854,148	$589,764	$521,052	$451,969
Snapper-Grouper	$157,082	$135,090	$111,528	$89,703	$74,897	$59,523
No Target	$6,817,301	$6,340,090	$5,794,706	$3,186,871	$2,877,455	$2,531,628
All Species	$13,242,511	$12,411,647	$11,510,740	$6,787,002	$6,184,066	$5,532,047

Source: U.S. EPA analysis for this report.

The total value of recreational losses for all species impinged and entrained at the cooling water intake structures in the region is $13.2 million per year (2002$), for all anglers in all five Gulf states, before discounting. The discounted recreational losses are $12.4 million and $11.5 million (2002$) per year, discounted at 3 and 7 percent, respectively. The last three columns of Table F4-10 present the annual reduction in losses resulting from installation of the CWIS technology for each facility subject to the final section 316(b) regulation. Total recreational losses under the final section 316(b) rule are reduced by $6.8 million. Discounting the welfare gain by 3 and 7 percent results in total welfare gains of $6.2 million and $5.5 million, respectively.

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[19] EPA averaged the baseline number of days (Table F4-8) and predicted increased number of days (Table F4-9) to estimate total welfare (Bockstael et al., 1987).

F4-5 LIMITATIONS AND UNCERTAINTIES

F4-5.1 Extrapolating Single-Day Trip Results to Estimate Benefits from Multiple-Day Trips

Use of per-day welfare gain estimated for single-day trips to estimate per-day welfare gain associated with multiple-day trips can either understate or overstate benefits to anglers taking multiple-day trips. Inclusion of multi-day trips in the model of recreational anglers' behavior can be problematic because multi-day trips are frequently multi-activity trips. An individual might travel a substantial distance and participate in several recreational activities such as shopping and sightseeing, all as part of one trip. Recreational benefits from improved recreational opportunities for the primary activity are overstated if all travel costs are treated as though they apply to the one recreational activity of interest. EPA therefore limited the recreational behavior model to single-day trips only and then extrapolated single-day trip results to estimate benefits to anglers taking multiple-day trips.

There is evidence that multi-day trips are more valuable than single-day trips. McConnell and Strand (1999) estimated a RUM using the NMFS data for New England and the Mid-Atlantic. Their study was intended to supplement the RUM study of single-day trips for the same region conducted by Hicks et al. (1999). The reported values for a catch rate increase of one fish are consistently higher for overnight trips than for single-day trips. Lupi and Hoehn (1998) compared values for single- and multi-day fishing trips. Their comparison is based on a RUM for the Great Lakes, with single and multiple-day trips treated as distinct alternatives in the choice set, with separate parameters for different length trips. They found that multiple-day trips are less responsive to changes in travel cost, and thus relatively more valuable than single-day trips. Their case study results found that "over half the value of an across the board marginal change in catch rates was due to multiple-day trips even though multiple-day trips represent less than one fourth of the trips in the sample" (p. 45).

F4-5.2 Considering Only Recreational Values

This study understates the total benefits of improvements in fishing site quality because estimates are limited to recreational use benefits. Many other forms of benefits, such as habitat values for a variety of species (in addition to recreational fish), non-use values, etc., are also likely to be important.

F4-5.3 Species Substitution

EPA's estimated RUM model does not allow for anglers to substitute between modes or species. The analysis therefore assumes that each angler has chosen a mode/species combination followed by a site based on the catch rates for that site and species. One disadvantage of the specified model is that the model looks at site choice without regard to mode or species. Once an angler chooses a target species and mode, no substitution is allowed across species or mode (i.e., the value of catching, or potentially catching, a different species or fishing using a different mode is not included in the calculation). Therefore, improvements in fishing circumstances related to other species or modes will have no effect on anglers' choices, and thus will not be accounted for in the welfare estimates. This limitation, however, is unlikely to have a significant effect on welfare estimates, because most anglers tend to fish for the same target species on most of their trips (Haab et al., 2000).

F4-5.4 Charter Anglers

EPA's model does not include charter boat anglers. Instead, the Agency used values for private/rental boat anglers to estimate values for charter anglers. It is not clear whether this will result in an overestimate or underestimate of per-trip values for charter boat anglers.

F4-5.5 Potential Sources of Survey Bias

The survey results could suffer from bias, such as recall bias and sampling effects.

a. Recall bias

Recall bias can occur when respondents are asked, such as in the MRFSS, the number of their recreation days over the previous season. Some researchers believe that recall bias tends to lead to an overstatement of the number of recreation days, particularly by more avid participants. Avid participants tend to overstate the number of recreation days because they count days in a “typical” week and then multiply them by the number of weeks in the recreation season. They often neglect to consider days missed due to bad weather, illness, travel, or when fulfilling “atypical” obligations. Some studies also found that the more salient the activity, the more “optimistic” the respondent tends to be in estimating the number of recreation days. Individuals also have a tendency to overstate the number of days they participate in activities that they enjoy and value. Taken together, these sources of recall bias may result in an overstatement of the actual number of recreation days.

b. Sampling effects

Recreational demand studies frequently face observations that do not fit general recreation patterns, such as observations of avid participants. These participants can be problematic because they claim to participate in an activity an inordinate number of times. This reported level of activity is sometimes correct but often overstated, perhaps due to recall bias. Even where the reports are correct, these observations tend to be overly influential (Thomson, 1991).

F4-5.6 Extrapolation to Texas

The per-trip welfare calculations used angler data from the four Gulf states, excluding Texas. However, the I&E data pertained to all five states and was reduced by 33.17 percent to reflect Texas’ share of CWIS flow in the region. To estimate angling days by mode and target species for Texas from total angling days, EPA assumed Texas anglers chose their mode of fishing and target species in the same proportions as in the other Gulf states. EPA also assumed that per-trip welfare for Texas anglers would be the same as the other Gulf states anglers. This may introduce an unknown bias if the changes in fishing site quality in Texas differ from the changes estimated for other the Gulf states or if Texas anglers prefer different species and fishing modes than anglers in their neighboring states.

Chapter F5: Non-Use Benefits

CHAPTER CONTENTS

INTRODUCTION

Aquatic species without any direct uses account for the majority of losses due to impingement and entrainment (I&E) at cooling water intake structures (CWIS). However, EPA's analysis of direct use benefits includes values only for organisms with direct uses, which comprise a very small percentage of total losses (approximately two percent). Because the other 98 percent of losses, consisting of organisms without direct uses, are not without value, the potential exists for significant non-use values that have not been addressed under EPA's estimation of use benefits. For this reason it is important to consider non-use benefits to the human population, produced by the increased numbers of organisms without direct use values, under the final section 316(b) rule.

One way to consider the impact of the section 316(b) rule is to estimate the non-use value of baseline I&E losses and I&E reductions due to the final rule for each case study region using the non-use meta-analysis results. The non-use meta-analysis is presented in detail in Chapter A12, Non-Use Meta-Analysis Methodology, which includes discussions of the literature review process, the estimated regression models and results, and the general methodology used to estimate household and aggregate non-use benefits based on regression results. Total regional non-use benefits can be estimated using the following three steps:

1. Estimate annual changes in non-use value of the affected fishery resources per household due to the baseline impingement and entrainment (I&E) losses and the post-compliance reduction in impingement and entrainment;

2. Estimate the population of households in the Gulf of Mexico region holding non-use value for the affected resources; and

3. Estimate the total non-use value to the affected Gulf of Mexico populations for completely eliminating baseline I&E losses, and for reducing I&E losses from the baseline to post-compliance levels.

EPA explored this approach for the Gulf of Mexico region. However, EPA did not include the results of this approach in the benefit analysis because of limitations and uncertainties associated with estimation of non-use benefits on a regional scale. For further discussion of the limitations and uncertainties of this method, refer to Chapter A12.

F5-1 QUALITATIVE ASSESSMENT OF ECOLOGICAL BENEFITS FOR THE GULF OF MEXICO REGION

Changes in CWIS design or operations resulting from the section 316(b) regulations for existing facilities are expected to reduce I&E losses of fish, shellfish, and other aquatic organisms and, as a result, are expected to increase the numbers of individuals present, increase local and regional fishery populations, and ultimately contribute to the enhanced environmental functioning of affected waterbodies (rivers, lakes, estuaries, and oceans) and associated ecosystems. The economic welfare of human populations is expected to increase as a consequence of the improvements in fisheries and associated aquatic ecosystem functioning.

The aquatic resources affected by cooling water intake structures provide a wide range of services. Ecosystem services are the physical, chemical, and biological functions performed by natural resources and the human benefits derived from those functions, including both ecological and human use services (Daily, 1997; Daily et al., 1997). Scientific and public interest in protecting ecosystem services is increasing with the recognition that these services are vulnerable to a wide range of human activities and are difficult, if not impossible, to replace with human technologies (Meffe, 1992).

In addition to their importance in providing food and other goods of direct use to humans, the organisms lost to I&E are critical to the continued functioning of the ecosystems of which they are a part. Fish are essential for energy transfer in aquatic food webs, regulation of food web structure, nutrient cycling, maintenance of sediment processes, redistribution of bottom substrates, the regulation of carbon fluxes from water to the atmosphere, and the maintenance of aquatic biodiversity (Peterson and Lubchenco, 1997; Postel and Carpenter, 1997; Holmund and Hammer, 1999; Wilson and Carpenter, 1999). Examples of ecological and public services disrupted by I&E include:

- decreased numbers of ecological keystone, rare, or sensitive species;
- decreased numbers of popular species that are not fished, perhaps because the fishery is closed;
- decreased numbers of special status (e.g., threatened or endangered) species;
- increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E;
- disruption of ecological niches and ecological strategies used by aquatic species;
- disruption of organic carbon and nutrient transfer through the food web;
- disruption of energy transfer through the food web;
- decreased local biodiversity;
- disruption of predator-prey relationships;
- disruption of age class structures of species;
- disruption of natural succession processes;
- disruption of public uses other than fishing, such as diving, boating, and nature viewing; and
- disruption of public satisfaction with a healthy ecosystem.

Many of these services can only be maintained by the continued presence of all life stages of fish and other aquatic species in their natural habitats.

The traditional approach of EPA and other natural resource agencies to quantifying the environmental benefits of proposed regulations has focused on active use values, particularly direct use values such as recreational or commercial fishing. Nonconsumptive uses (such as the importance of fish for aquatic food webs), and passive use or non-use values (including the value of protecting a resource for its own sake), are seldom considered because they are difficult to monetize with available economic methods. However, even though economists debate methods for indirect and non-use valuation, there is general agreement that these values exist and can be important. The potential magnitude of non-use values remains an empirical matter. EPA believes that non-use values are applicable for the section 316(b)-related I&E and that these values are likely to be appreciable for the Gulf of Mexico region.

Appendix F1: Life History Parameter Values Used to Evaluate I&E in the Gulf of Mexico Region

The tables in this appendix are those life history parameter values used by EPA to calculate age 1 equivalents, fishery yield, and production foregone from I&E data for the Gulf of Mexico region. Because of differences in the number of life stages represented in the loss data, there are cases where more than one life stage sequence was needed for a given species or species group. Alternative parameter sets were developed for this purpose and are indicated with a number following the species or species group name (i.e., Anchovies 1, Anchovies 2).

Table F1-1: Atlantic Croaker Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.817	0	0	0.0000000128
Larvae	8.10	0	0	0.000000145
Juvenile	3.38	0	0	0.0000624
Age 1+	1.09	0.30	0.50	0.220
Age 2+	0.300	0.30	1.0	0.672
Age 3+	0.300	0.30	1.0	1.24
Age 4+	0.300	0.30	1.0	1.88
Age 5+	0.300	0.30	1.0	2.43
Age 6+	0.300	0.30	1.0	3.26
Age 7+	0.300	0.30	1.0	3.26
Age 8+	0.300	0.30	1.0	3.26

Source: PSE&G, 1999.

Table F1-2: Anchovies Parameters 1[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.94	0	0	0.0000000186
Prolarvae	1.57	0	0	0.0000000441
Post larvae	6.12	0	0	0.00000235
Juvenile	1.29	0	0	0.000481
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] Includes bay anchovy, striped anchovy, and other anchovies not identified to species.
[b] Life history parameters applied to losses from Big Bend, Crystal River, Robinson, and Webster.

Sources: Derickson and Price, 1973; Leak and Houde, 1987; NMFS, 2003a; and PSE&G, 1999.

Table F1-3: Anchovies Parameters 2[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.94	0	0	0.0000000186
Larvae	7.70	0	0	0.00000158
Juvenile 1	0.0822	0	0	0.0000495
Juvenile 2	0.0861	0	0	0.000199
Juvenile 3	0.129	0	0	0.000532
Juvenile 4	0.994	0	0	0.00114
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] Includes bay anchovy.
[b] Life history parameters applied to losses from Big Bend and Webster.

Sources: Derickson and Price, 1973; Leak and Houde, 1987; NMFS, 2003a; and PSE&G, 1999.

Table F1-4: Black Drum Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Egg	2.27	0	0	0.000000842
Prolarvae	3.06	0	0	0.000000926
Postlarvae	3.06	0	0	0.0000176
Juvenile	1.15	0.15	0.50	0.0327
Age 1+	0.0977	0.15	1.0	0.671
Age 2+	0.0977	0.15	1.0	1.70
Age 3+	0.0977	0.15	1.0	3.21
Age 4+	0.0977	0.15	1.0	5.15
Age 5+	0.0977	0.15	1.0	7.43
Age 6+	0.0977	0.15	1.0	9.93
Age 7+	0.0977	0.15	1.0	12.6
Age 8+	0.0977	0.15	1.0	15.3
Age 9+	0.0977	0.15	1.0	18.0
Age 10+	0.0977	0.15	1.0	20.7
Age 11+	0.0977	0.15	1.0	23.3
Age 12+	0.0977	0.15	1.0	25.7
Age 13+	0.0977	0.15	1.0	28.1
Age 14+	0.0977	0.15	1.0	30.2
Age 15+	0.0977	0.15	1.0	32.3
Age 16+	0.0977	0.15	1.0	34.1
Age 17+	0.0977	0.15	1.0	35.8
Age 18+	0.0977	0.15	1.0	37.4
Age 19+	0.0977	0.15	1.0	38.8
Age 20+	0.0977	0.15	1.0	40.1
Age 21+	0.0977	0.15	1.0	41.3
Age 22+	0.0977	0.15	1.0	42.4
Age 23+	0.0977	0.15	1.0	43.3
Age 24+	0.0977	0.15	1.0	44.2
Age 25+	0.0977	0.15	1.0	45.0
Age 26+	0.0977	0.15	1.0	45.7
Age 27+	0.0977	0.15	1.0	46.3
Age 28+	0.0977	0.15	1.0	46.8
Age 29+	0.0977	0.15	1.0	47.3
Age 30+	0.0977	0.15	1.0	47.8
Age 31+	0.0977	0.15	1.0	48.2
Age 32+	0.0977	0.15	1.0	48.5
Age 33+	0.0977	0.15	1.0	48.8
Age 34+	0.0977	0.15	1.0	49.1
Age 35+	0.0977	0.15	1.0	49.4
Age 36+	0.0977	0.15	1.0	49.6
Age 37+	0.0977	0.15	1.0	49.8
Age 38+	0.0977	0.15	1.0	50.0
Age 39+	0.0977	0.15	1.0	50.1
Age 40+	0.0977	0.15	1.0	50.3

[a] Life history parameters applied to losses from Big Bend, Crystal River, and Robinson.

Sources: Bartell and Campbell, 2000; Froese and Pauly, 2001; Leard et al., 1993; Murphy and Taylor, 1989; Scott and Scott, 1988; Sutter et al., 1986; and personal communication with Michael D. Murphy, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute, January 23, 2002.

Table F1-5: Black Drum Life History Parameters 2[a]				
Stage Name	**Natural Mortality (per stage)**	**Fishing Mortality (per stage)**	**Fraction Vulnerable to Fishery**	**Weight (lbs)**
Egg	2.27	0	0	0.000000842
Larvae	6.13	0	0	0.00000453
Juvenile	1.15	0.15	0.50	0.0327
Age 1+	0.0977	0.15	1.0	0.671
Age 2+	0.0977	0.15	1.0	1.70
Age 3+	0.0977	0.15	1.0	3.21
Age 4+	0.0977	0.15	1.0	5.15
Age 5+	0.0977	0.15	1.0	7.43
Age 6+	0.0977	0.15	1.0	9.93
Age 7+	0.0977	0.15	1.0	12.6
Age 8+	0.0977	0.15	1.0	15.3
Age 9+	0.0977	0.15	1.0	18.0
Age 10+	0.0977	0.15	1.0	20.7
Age 11+	0.0977	0.15	1.0	23.3
Age 12+	0.0977	0.15	1.0	25.7
Age 13+	0.0977	0.15	1.0	28.1
Age 14+	0.0977	0.15	1.0	30.2
Age 15+	0.0977	0.15	1.0	32.3
Age 16+	0.0977	0.15	1.0	34.1
Age 17+	0.0977	0.15	1.0	35.8
Age 18+	0.0977	0.15	1.0	37.4
Age 19+	0.0977	0.15	1.0	38.8
Age 20+	0.0977	0.15	1.0	40.1
Age 21+	0.0977	0.15	1.0	41.3
Age 22+	0.0977	0.15	1.0	42.4
Age 23+	0.0977	0.15	1.0	43.3
Age 24+	0.0977	0.15	1.0	44.2
Age 25+	0.0977	0.15	1.0	45.0
Age 26+	0.0977	0.15	1.0	45.7
Age 27+	0.0977	0.15	1.0	46.3
Age 28+	0.0977	0.15	1.0	46.8
Age 29+	0.0977	0.15	1.0	47.3
Age 30+	0.0977	0.15	1.0	47.8
Age 31+	0.0977	0.15	1.0	48.2
Age 32+	0.0977	0.15	1.0	48.5
Age 33+	0.0977	0.15	1.0	48.8
Age 34+	0.0977	0.15	1.0	49.1
Age 35+	0.0977	0.15	1.0	49.4
Age 36+	0.0977	0.15	1.0	49.6
Age 37+	0.0977	0.15	1.0	49.8
Age 38+	0.0977	0.15	1.0	50.0
Age 39+	0.0977	0.15	1.0	50.1
Age 40+	0.0977	0.15	1.0	50.3

[a] Life history parameters applied to losses from Big Bend and Webster.

Sources: Able and Fahay, 1998; Bartell and Campbell, 2000; Froese and Pauly, 2001; Leard et al., 1993; Murphy and Taylor, 1989; Scott and Scott, 1988; Sutter et al., 1986; and personal communication with Michael D. Murphy, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute, January 23, 2002.

Table F1-6: Blue Crab Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Zoeae	13.8	0	0	0.000000211
Megalops	1.30	0	0	0.00000291
Juvenile	1.73	0.48	0.50	0.00000293
Age 1+	1.00	1.0	1.0	0.00719
Age 2+	1.00	1.0	1.0	0.113
Age 3+	1.00	1.0	1.0	0.326

Sources: Hartman, 1993; Murphy and Nelson, 2000; and PSE&G, 1999.

Table F1-7: Commercial Shrimp Life History Parameters 1[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	3.22	0	0	0.0000000253
Prolarvae	1.70	0	0	0.00000274
Postlarvae	1.70	0	0	0.0000268
Juvenile	0.140	0.14	1.0	0.0473
Age 1+	0.140	0.14	1.0	0.0770

[a] Includes pink shrimp, brown shrimp, white shrimp, and other commercial shrimp not identified to species.
[b] Life history parameters applied to losses from Big Bend, Crystal River, Robinson, and Webster.

Sources: Bielsa et al., 1983; Costello and Allen, 1970; TBNEP, 1992b; and Stone & Webster Engineering Corporation, 1980.

Table F1-8: Commercial Shrimp Life History Parameters 2[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	3.22	0	0	0.0000000253
Larvae	3.40	0	0	0.00000274
Juvenile	0.140	0.14	1.0	0.0473
Age 1+	0.140	0.14	1.0	0.0770

[a] Includes pink shrimp.
[b] Life history parameters applied to losses from Big Bend.

Sources: Bielsa et al., 1983; Costello and Allen, 1970; TBNEP, 1992b; and Stone & Webster Engineering Corporation, 1980.

Table F1-9: Goby Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.288	0	0	0.00000200
Larvae	4.09	0	0	0.00000219
Juvenile	2.30	0	0	0.00049
Age 1+	2.55	0	0	0.00205

[a] Includes clown goby, code goby, frillfin goby, green goby, naked goby, sharptail goby, skilletfish, violet goby, and other goby species not identified to species.

Sources: Froese and Pauly, 2003; NMFS, 2003a; and PSE&G, 1999.

Table F1-10: Hogchoker Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.24	0	0	0.000000487
Larvae	6.73	0	0	0.00110
Juvenile	0.916	0	0	0.00207
Age 1+	0.250	0	0	0.0113
Age 2+	0.250	0	0	0.0313
Age 3+	0.250	0	0	0.0610
Age 4+	0.250	0	0	0.0976
Age 5+	0.250	0	0	0.138
Age 6+	0.250	0	0	0.178

Sources: Able and Fahay, 1998; New England Power Company and Marine Research Inc., 1995; NMFS, 2003a; and PG&E National Energy Group, 2001.

Table F1-11: Jack/Pompano Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.817	0	0	0.00000115
Larvae	8.61	0	0	0.00000127
Juvenile	0.916	0	0	0.0222
Age 1+	0.340	0.25	0.50	0.168
Age 2+	0.340	0.25	1.0	0.460
Age 3+	0.340	0.25	1.0	0.511
Age 4+	0.340	0.25	1.0	0.565

[a] Includes Atlantic bumper, Atlantic moonfish, bluntnose jack, crevalle jack, leatherjacket, lookdown, and permit.

Sources: Florida Fish and Wildlife Conservation Commission, 2001; Froese and Pauly, 2003; Overholtz, 2002b; and PSE&G, 1999.

Table F1-12: Killifish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.0000180
Larvae	3.00	0	0	0.0000182
Juvenile	0.916	0	0	0.000157
Age 1+	0.777	0	0	0.0121
Age 2+	0.777	0	0	0.0327
Age 3+	0.777	0	0	0.0551
Age 4+	0.777	0	0	0.0778
Age 5+	0.777	0	0	0.0967
Age 6+	0.777	0	0	0.113
Age 7+	0.777	0	0	0.158

[a] Includes gulf killifish, longnose killifish, bayou killifish, and other killifish species not identified to species.

Sources: Able and Fahay, 1998; Carlander, 1969; Meredith and Lortich, 1979; NMFS, 2003a; and Stone & Webster Engineering Corporation, 1977.

Table F1-13: Mackerel Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.39	0	0	0.00000176
Larvae	10.6	0	0	0.00000193
Juvenile	0.916	0	0	0.0000368
Age 1+	0.520	0	0	0.309
Age 2+	0.370	0.25	0.50	0.510
Age 3+	0.370	0.25	1.0	0.639
Age 4+	0.370	0.25	1.0	0.752
Age 5+	0.370	0.25	1.0	0.825
Age 6+	0.370	0.25	1.0	0.918
Age 7+	0.370	0.25	1.0	1.02
Age 8+	0.370	0.25	1.0	1.10
Age 9+	0.370	0.25	1.0	1.13
Age 10+	0.370	0.25	1.0	1.15
Age 11+	0.370	0.25	1.0	1.22
Age 12+	0.370	0.25	1.0	1.22
Age 13+	0.370	0.25	1.0	1.22
Age 14+	0.370	0.25	1.0	1.22

[a] Includes Spanish mackerel.

Sources: Entergy Nuclear Company, 2000; Froese and Pauly, 2001, 2003; Overholtz, 1991; Scott and Scott, 1988; and Studholme et al., 1999.

Table F1-14: Menhaden Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000203
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.8	0.50	0.356
Age 3+	0.450	0.8	1.0	0.679
Age 4+	0.450	0.8	1.0	0.974
Age 5+	0.450	0.8	1.0	1.21
Age 6+	0.450	0.8	1.0	1.38

[a] Includes Alabama shad, Atlantic thread herring, finescale menhaden, gizzard shad, gulf menhaden, skipjack herring, yellowfin menhaden, and other closely related herrings not identified to species.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; Froese and Pauly, 2001; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table F1-15: Pinfish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000107
Larvae	7.39	0	0	0.0000238
Juvenile	1.91	0	0	0.00669
Age 1+	0.340	0.34	0.50	0.0791
Age 2+	0.340	0.34	1.0	0.218

[a] Includes pinfish, spottail pinfish, and other porgies not identified to species.

Sources: Froese and Pauly, 2001; Muncy, 1984; and Nelson, 1998.

Table F1-16: Pipefish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.000000842
Larvae	2.40	0	0	0.0000122
Juvenile	0.916	0	0	0.00785
Age 1+	0.750	0	0	0.0195
Age 2+	0.750	0	0	0.0384
Age 3+	0.750	0	0	0.0658
Age 4+	0.750	0	0	0.103
Age 5+	0.750	0	0	0.151

[a] Includes chain pipefish, dusky pipefish, gulf pipefish, and other pipefish not identified to species.

Sources: Able and Fahay, 1998; Froese and Pauly, 2001, 2003; NMFS, 2003a; Scott and Scott, 1988; and Stone & Webster Engineering Corporation, 1977.

Table F1-17: Red Drum Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Egg	2.27	0	0	0.000000842
Prolarvae	3.06	0	0	0.000000926
Postlarvae	3.06	0	0	0.0000176
Juvenile	1.15	0.15	0.50	0.0327
Age 1+	0.0977	0.15	1.0	0.671
Age 2+	0.0977	0.15	1.0	1.70
Age 3+	0.0977	0.15	1.0	3.21
Age 4+	0.0977	0.15	1.0	5.15
Age 5+	0.0977	0.15	1.0	7.43
Age 6+	0.0977	0.15	1.0	9.93
Age 7+	0.0977	0.15	1.0	12.6
Age 8+	0.0977	0.15	1.0	15.3
Age 9+	0.0977	0.15	1.0	18.0
Age 10+	0.0977	0.15	1.0	20.7
Age 11+	0.0977	0.15	1.0	23.3
Age 12+	0.0977	0.15	1.0	25.7
Age 13+	0.0977	0.15	1.0	28.1
Age 14+	0.0977	0.15	1.0	30.2
Age 15+	0.0977	0.15	1.0	32.3
Age 16+	0.0977	0.15	1.0	34.1
Age 17+	0.0977	0.15	1.0	35.8
Age 18+	0.0977	0.15	1.0	37.4
Age 19+	0.0977	0.15	1.0	38.8
Age 20+	0.0977	0.15	1.0	40.1
Age 21+	0.0977	0.15	1.0	41.3
Age 22+	0.0977	0.15	1.0	42.4
Age 23+	0.0977	0.15	1.0	43.3
Age 24+	0.0977	0.15	1.0	44.2
Age 25+	0.0977	0.15	1.0	45.0
Age 26+	0.0977	0.15	1.0	45.7
Age 27+	0.0977	0.15	1.0	46.3
Age 28+	0.0977	0.15	1.0	46.8
Age 29+	0.0977	0.15	1.0	47.3
Age 30+	0.0977	0.15	1.0	47.8
Age 31+	0.0977	0.15	1.0	48.2
Age 32+	0.0977	0.15	1.0	48.5
Age 33+	0.0977	0.15	1.0	48.8
Age 34+	0.0977	0.15	1.0	49.1
Age 35+	0.0977	0.15	1.0	49.4
Age 36+	0.0977	0.15	1.0	49.6
Age 37+	0.0977	0.15	1.0	49.8
Age 38+	0.0977	0.15	1.0	50.0
Age 39+	0.0977	0.15	1.0	50.1
Age 40+	0.0977	0.15	1.0	50.3

Sources: Bartell and Campbell, 2000; Froese and Pauly, 2001; Leard et al., 1993; Murphy and Taylor, 1989; Scott and Scott, 1988; Sutter et al., 1986; and personal communication with Michael D. Murphy, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute, January 23, 2002.

Table F1-18: Scaled Sardine Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.12	0	0	0.00000533
Prolarvae	0.560	0	0	0.00000586
Postlarvae	6.53	0	0	0.0000247
Juvenile	0.916	0	0	0.000483
Age 1+	1.02	0	0	0.275

[a] Includes Brazilian sardinella, scaled sardine, threadfin shad, and other clupeids not identified to species.

Sources: Froese and Pauly, 2003; Houde et al., 1974; NMFS, 2003a; Pierce et al., 2001; and Stone & Webster Engineering Corporation, 1980.

Table F1-19: Sea Bass Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lb)
Egg	0.288	0	0	0.00000101
Larvae	6.00	0	0	0.00000111
Juvenile	0.190	0	0	0.000581
Age 1+	0.190	0	0	0.0313
Age 2+	0.190	0	0	0.0625
Age 3+	0.190	0	0	0.125
Age 4+	0.190	0	0	0.312
Age 5+	0.190	0.26	0.50	0.531
Age 6+	0.190	0.26	1.0	0.813
Age 7+	0.287	0.26	1.0	1.13
Age 8+	0.287	0.26	1.0	1.50
Age 9+	0.287	0.26	1.0	1.88
Age 10+	0.287	0.26	1.0	2.19

[a] Includes black sea bass.

Sources: Cailliet, 2000; California Department of Fish and Game, 2000b; Froese and Pauly, 2002; and Leet et al., 2001.

Table F1-20: Searobin Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000132
Larvae	3.66	0	0	0.00000145
Juvenile	0.916	0	0	0.000341
Age 1+	0.420	0.10	0.50	0.0602
Age 2+	0.420	0.10	1.0	0.176
Age 3+	0.420	0.10	1.0	0.267
Age 4+	0.420	0.10	1.0	0.386
Age 5+	0.420	0.10	1.0	0.537
Age 6+	0.420	0.10	1.0	0.721
Age 7+	0.420	0.10	1.0	0.944
Age 8+	0.420	0.10	1.0	1.21

[a] Includes bighead searobin, leopard searobin, and other searobins not identified to species.

Sources: Froese and Pauly, 2001, 2003; Saila et al., 1997; and Virginia Tech, 1998.

Table F1-21: Sheepshead Seabream Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.000000591
Larvae	7.39	0	0	0.0000241
Juvenile	1.91	0	0	0.00167
Age 1+	1.98	0	0	0.981
Age 2+	1.98	0	0	1.22
Age 3+	1.98	0.45	0.50	1.56
Age 4+	1.98	0.45	1.0	2.33
Age 5+	1.98	0.45	1.0	2.43
Age 6+	1.98	0.45	1.0	2.45
Age 7+	1.98	0.45	1.0	2.47
Age 8+	1.98	0.45	1.0	2.49
Age 9+	1.98	0.45	1.0	2.51
Age 10+	1.98	0.45	1.0	2.53
Age 11+	1.98	0.45	1.0	2.55
Age 12+	1.98	0.45	1.0	2.57
Age 13+	1.98	0.45	1.0	2.59
Age 14+	1.98	0.45	1.0	2.61
Age 15+	1.98	0.45	1.0	2.63
Age 16+	1.98	0.45	1.0	2.65

Sources: Froese and Pauly, 2002; Murphy and MacDonald, 2000; Murphy et al., 2000; Nelson, 1998; Pattillo et al., 1997; and personal communication with Michael D. Murphy, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute, January 23, 2002.

Table F1-22: Silver Perch Life History Parameters 1[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.75	0	0	0.000000527
Prolarvae	2.10	0	0	0.000000580
Postlarvae	3.27	0	0	0.0000379
Juvenile	1.71	0	0	0.0445
Age 1+	3.84	0	0	0.273
Age 2+	3.84	0.10	0.50	4.15
Age 3+	3.84	0.10	1.0	0.607

[a] Includes banded drum, silver perch, silver seatrout, southern kingfish, and star drum.
[b] Life history parameters applied to losses from Crystal River, Robinson, and Webster.

Sources: Able and Fahay, 1998; Florida Fish and Wildlife Conservation Commission, 2001; Froese and Pauly, 2001, 2003; PSE&G, 1999; and personal communication with Michael D. Murphy, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute, January 23, 2002.

Table F1-23: Silver Perch Life History Parameters 2[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.75	0	0	0.000000527
Larvae	5.37	0	0	0.00000771
Juvenile	1.71	0	0	0.0445
Age 1+	3.84	0	0	0.273
Age 2+	3.84	0.10	0.50	0.415
Age 3+	3.84	0.10	1.0	0.607

[a] Includes silver perch, northern kingfish, and southern kingfish.
[b] Life history parameters applied to losses from Big Bend.

Sources: Able and Fahay, 1998; Florida Fish and Wildlife Conservation Commission, 2001; Froese and Pauly, 2001, 2003; PSE&G, 1999; and personal communication with Michael D. Murphy, Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute, January 23, 2002.

Table F1-24: Silverside Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.000000487
Prolarvae	1.45	0	0	0.000000554
Postlarvae	1.45	0	0	0.00000554
Juvenile	0.916	0	0	0.0000292
Age 1+	2.10	0	0	0.0119
Age 2+	2.10	0	0	0.0224

[a] Includes California grunion, inland silverside, rough silverside, tidewater silverside, and other silversides not identified to the species.

Sources: Froese and Pauly, 2001; Garwood, 1968; Hildebrand, 1922; NMFS, 2003a; Scott and Scott, 1988; Stone & Webster Engineering Corporation, 1977, 1980.

Table F1-25: Spot Life History Parameters 1[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.825	0	0	0.000000131
Prolarvae	3.30	0	0	0.000000154
Postlarvae	4.12	0	0	0.000000854
Juvenile	2.57	0	0	0.000121
Age 1+	0.463	0.4	1.0	0.0791
Age 2+	0.400	0.4	1.0	0.299
Age 3+	0.400	0.4	1.0	0.507
Age 4+	0.400	0.4	1.0	0.648
Age 5+	0.400	0.4	1.0	0.732
Age 6+	0.400	0.4	1.0	0.779
Age 7+	0.400	0.4	1.0	0.779
Age 8+	0.400	0.4	1.0	0.779
Age 9+	0.400	0.4	1.0	0.779
Age 10+	0.400	0.4	1.0	0.779
Age 11+	0.400	0.4	1.0	0.779
Age 12+	0.400	0.4	1.0	0.779
Age 13+	0.400	0.4	1.0	0.779
Age 14+	0.400	0.4	1.0	0.779
Age 15+	0.400	0.4	1.0	0.779

[a] Life history parameters applied to losses from Crystal River and Robinson.

Sources: PSE&G, 1984b, 1999; and Warlen et al., 1980.

Table F1-26: Spot Life History Parameters 2[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.825	0	0	0.000000131
Larvae	7.42	0	0	0.000000504
Juvenile	2.57	0	0	0.000121
Age 1+	0.463	0.4	1.0	0.0791
Age 2+	0.400	0.4	1.0	0.299
Age 3+	0.400	0.4	1.0	0.507
Age 4+	0.400	0.4	1.0	0.648
Age 5+	0.400	0.4	1.0	0.732
Age 6+	0.400	0.4	1.0	0.779
Age 7+	0.400	0.4	1.0	0.779
Age 8+	0.400	0.4	1.0	0.779
Age 9+	0.400	0.4	1.0	0.779
Age 10+	0.400	0.4	1.0	0.779
Age 11+	0.400	0.4	1.0	0.779
Age 12+	0.400	0.4	1.0	0.779
Age 13+	0.400	0.4	1.0	0.779
Age 14+	0.400	0.4	1.0	0.779
Age 15+	0.400	0.4	1.0	0.779

[a] Life history parameters applied to losses from Webster.

Sources: PSE&G, 1984b, 1999; and Warlen et al., 1980.

Table F1-27: Spotted Seatrout Life History Parameters 1[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.000000842
Prolarvae	1.50	0	0	0.000000926
Postlarvae	6.92	0	0	0.00000568
Juvenile	0.272	0.27	0.50	0.571
Age 1+	0.272	0.27	1.0	0.914
Age 2+	0.272	0.27	1.0	1.55
Age 3+	0.272	0.27	1.0	2.50
Age 4+	0.272	0.27	1.0	3.15
Age 5+	0.272	0.27	1.0	3.54
Age 6+	0.272	0.27	1.0	4.41
Age 7+	0.272	0.27	1.0	4.97
Age 8+	0.272	0.27	1.0	4.99

[a] Includes sand seatrout, sand weakfish, spotted seatrout, and other drums not identified to species.
[b] Life history parameters applied to losses from Big Bend, Crystal River, and Robinson.

Sources: Johnson and Seaman, 1986; Murphy and Taylor, 1994; Stone & Webster Engineering Corporation, 1980; and Sutter et al., 1986.

Table F1-28: Spotted Seatrout Life History Parameters 2[a,b]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.000000842
Larvae	8.42	0	0	0.000000926
Juvenile	0.272	0.27	0.50	0.571
Age 1+	0.272	0.27	1.0	0.914
Age 2+	0.272	0.27	1.0	1.55
Age 3+	0.272	0.27	1.0	2.50
Age 4+	0.272	0.27	1.0	3.15
Age 5+	0.272	0.27	1.0	3.54
Age 6+	0.272	0.27	1.0	4.41
Age 7+	0.272	0.27	1.0	4.97
Age 8+	0.272	0.27	1.0	4.99

[a] Includes sand seatrout and spotted seatrout.

[b] Life history parameters applied to losses from Webster.

Sources: Johnson and Seaman, 1986; Murphy and Taylor, 1994; Stone & Webster Engineering Corporation, 1980; and Sutter et al., 1986.

Table F1-29: Stone Crab Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Stage 1	1.97	0	0	0.000000101
Stage 2	1.97	0	0	0.000000417
Stage 3	1.97	0	0	0.00000109
Stage 4	1.97	0	0	0.00000226
Stage 5	1.97	0	0	0.00000405
Megalops	1.97	0	0	0.00000662
Juvenile	1.97	0	0	0.0000182
Age 1+	0.939	0.75	0.50	1.02
Age 2+	0.939	0.75	1.0	3.63
Age 3+	0.939	0.75	1.0	7.12
Age 4+	0.939	0.75	1.0	10.0

Sources: Bert et al., 1978; Ehrhardt et al., 1990; Lindberg and Marshall, 1984; Sullivan, 1979; and Van Den Avyle and Fowler, 1984.

Table F1-30: Striped Mullet Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.000000537
Larvae	4.61	0	0	0.0000110
Juvenile	0.916	0	0	0.131
Age 1+	0.230	0.30	0.50	0.187
Age 2+	0.230	0.30	1.0	0.379
Age 3+	0.230	0.30	1.0	0.774
Age 4+	0.230	0.30	1.0	1.58
Age 5+	0.230	0.30	1.0	3.21
Age 6+	0.230	0.30	1.0	6.53

Sources: Collins, 1985; Froese and Pauly, 2003; PSE&G, 1999; and Wang, 1986.

Table F1-31: Other Commercial Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.50	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] Includes Atlantic cutlassfish, black bullhead, cobia, grey snapper, gulf butterfish, ladyfish, largehead hairtail, mojarra spp, silver jenny, spotfin mojarra, tripletail, and yellow bullhead.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table F1-32: Other Recreational Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.50	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] See Table F1-34 for a list of species.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table F1-33: Other Forage Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000186
Larvae	7.70	0	0	0.00000158
Juvenile	1.29	0	0	0.000481
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] See Table F1-35 for a list of species.

Sources: Derickson and Price, 1973; and PSE&G, 1999.

Table F1-34: Other Recreational Species[a]

Atlantic sharpnose shark	Bonnethead	Hardhead sea catfish	Smooth butterfly ray
Atlantic stingray	Channel catfish	Least puffer	Smooth puffer
Bandtail puffer	Dwarf sandperch	Pigfish	Southern flounder
Belted sandfish	Gafftopsail catfish	Rock sea bass	Southern puffer
Blackear bass	Gag grouper	Sand perch	Tomtate
Bluefish	Gulf toadfish	Sea catfish	

[a] Includes other organisms not identified to species.

Table F1-35: Other Forage Species[a]

- Atlantic midshipman
- Atlantic needlefish
- Atlantic spadefish
- Atlantic threadfin
- Barbfish
- Bay whiff
- Blackcheek tonguefish
- Blackwing flyingfish
- Bluegill
- Bridle cardinalfish
- Carp
- Common halfbeak
- Diamond lizardfish
- Dwarf seahorse
- Fat sleeper
- Feather blenny
- Florida blenny
- Freckled blenny
- Fringed filefish
- Fringed flounder
- Golden shiner
- Green sunfish
- Gulf of Mexico ocellated flounder
- Halfbeak
- Harvestfish
- Inshore lizardfish
- Jawfish
- Lined seahorse
- Live sharksucker
- Longear sunfish
- Mottled jawfish
- Needlefish
- Orange filefish
- Planehead filefish
- Polka dot batfish
- Redfin needlefish
- Roughback batfish
- Sailfin molly
- Scrawled cowfish
- Seahorse
- Sheepshead minnow
- Snakefish
- Southern codling
- Southern hake
- Southern stargazer
- Spotted whiff
- Striped blenny
- Striped burrfish
- Warmouth
- Yellowhead jawfish

[a] Includes other organisms not identified to species.

Part G

The Great Lakes

Chapter G1: Background

INTRODUCTION

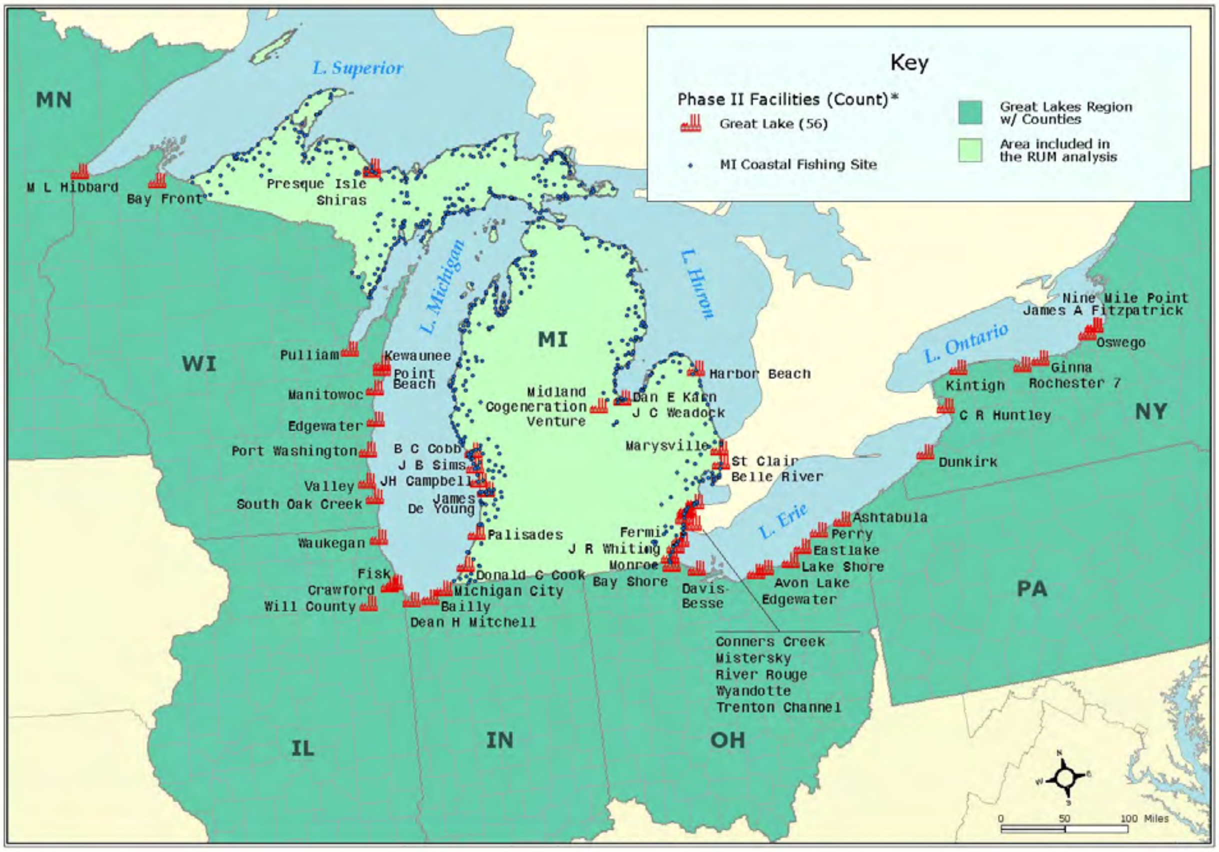
CHAPTER CONTENTS

This chapter presents an overview of the Phase II facilities in the Great Lakes study region and summarizes their key operating, economic, technical, and compliance characteristics. For further discussion of operating and economic characteristics of Phase II facilities, refer to Chapter A3 of the *Economic and Benefits Analysis for the Final Section 316(b) Phase II Existing Facilities Rule*; for further discussion of the technical and compliance characteristics of Phase II facilities, refer to the *Technical Development Document for the Final Section 316(b) Phase II Existing Facilities Rule* (U.S. EPA, 2004a,b).

G1-1 OVERVIEW

The Great Lakes Study includes 56 facilities that are in scope for the final Phase II regulation. All 56 facilities withdraw cooling water from the Great Lakes or their tributaries. Figure G1-1 presents a map of the 56 in-scope Phase II facilities located in the Great Lakes study region.

Figure G1-1: In-Scope Phase II Facilities in the Great Lakes Regional Study



Source: U.S. EPA analysis for this report.

G1-2 OPERATING AND ECONOMIC CHARACTERISTICS

Most of the 56 Great Lakes Study facilities (41) are coal steam facilities; 10 are nuclear facilities; 4 are oil/gas facilities; and 1 is a combined-cycle facility. In 2001, these 56 facilities accounted for 44.6 gigawatts of generating capacity, 215,000 gigawatt hours of generation, and $7.1 billion in revenues.

The operating and economic characteristics of the Great Lakes Study facilities are summarized in Table G1-1. Section G1-4 provides further information on each facility [including facility state, North American Electric Reliability Council (NERC) region, plant type, capacity, 2001 generation, and whether impingement and entrainment estimates were developed for the facility].

Table G1-1: Operating and Economic Characteristics of Phase II Facilities

Waterbody Type	Number of Facilities by Plant Type[a]					Total Capacity (MW)[b]	Total Generation (MWh)[b]	Electric Revenue (millions)
	Coal Steam	Combined Cycle	Nuclear	Oil/Gas Steam	Total			
Great Lake								
IL	4	-	-	-	4	3,651	12,478,209	$334
IN	3	-	-	-	3	1,880	6,843,217	$245
MI	17	1	3	2	23	20,881	101,784,212	$3,385
MN	1	-	-	-	1	123	-	$-
NY	4	-	3	1	8	7,460	37,887,228	$1,131
OH	5	-	2	1	8	5,863	29,033,765	$1,111
WI	7	-	2	-	9	4,771	27,147,465	$899
TOTAL	**41**	**1**	**10**	**4**	**56**	**44,629**	**215,174,096**	**$7,104**

[a] Based on largest steam-electric capacity at facilities.

[b] MW is an abbreviation for megawatt. MWh is an abbreviation for megawatt hour.

Sources: Plant type (IPM Analysis, U.S. EPA, 2002; Form EIA-860, U.S. DOE, 2001a); capacity (Form EIA-860, U.S. DOE, 2001a); generation (Form EIA-906, U.S. DOE, 2001c); revenue (Form EIA-861, U.S. DOE, 2001b; Form EIA-906, U.S. DOE, 2001c).

G1-3 TECHNICAL AND COMPLIANCE CHARACTERISTICS

The 56 Great Lakes Study facilities have a combined design intake flow of 35,500 million gallons per day (MGD). Forty-nine of the facilities employ a once-through cooling system in the baseline, four facilities employ a recirculating cooling system, and three facilities employ a combination cooling system. The 56 facilities incur a combined pre-tax compliance cost of $59 million. Table G1-2 below summarizes the flow, compliance responses, and compliance costs for these 56 facilities.

Table G1-2: Technical and Compliance Characteristics of Phase II Facilities

	Cooling Water System (CWS) Type[a]			
	Once-Through	**Recirculating**	**Combination**	**All**
Design Flow (MGD)	**33,939**	**548**	**1,058**	**35,545**
Number of Facilities by Compliance Response				
Fine Mesh Traveling Screens w/Fish H&R	6	-	-	6
New Larger Intake Structure with Fine Mesh and Fish H&R	5	-	-	5
Passive Fine Mesh Screens	6	-	1	7
Fish Barrier Net/Gunderboom	1	-	-	1
Relocate Intake to Submerged Offshore with Passive Screen	-	-	1	1
Double-Entry, Single-Exit with Fine Mesh and Fish H&R	7	-	-	7
Multiple	5	-	1	6
None	19	4	-	23
Total	**49**	**4**	**3**	**56**
Compliance Cost (2002$; millions)	**$53.6**	**$0.4**	**$4.7**	**$58.7**

[a] Combination CWSs are costed as if they were once-through CWSs.

Source: U.S. EPA analysis for this report.

G1-4 PHASE II FACILITIES IN THE GREAT LAKES REGIONAL STUDY

Table G1-3 presents economic and operating characteristics of the Great Lakes Study facilities.

Table G1-3: Phase II Facilities in the Great Lakes Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
Great Lake							
867	Crawford	IL	MAIN	Coal Steam	805	2,059,096	N
883	Waukegan	IL	MAIN	Coal Steam	915	4,703,658	N
884	Will County	IL	MAIN	Coal Steam	1,269	4,454,422	N
886	Fisk	IL	MAIN	Coal Steam	663	1,261,033	N
995	Bailly	IN	ECAR	Coal Steam	653	2,657,837	N
996	Dean H Mitchell	IN	ECAR	Coal Steam	547	1,770,841	N
997	Michigan City	IN	ECAR	Coal Steam	680	2,414,539	N
1695	B C Cobb	MI	ECAR	Coal Steam	378	2,087,331	N
1702	Dan E Karn	MI	ECAR	O/G Steam	1,761	4,541,738	N
1710	J H Campbell	MI	ECAR	Coal Steam	1,542	9,714,966	N
1715	Palisades	MI	ECAR	Nuclear	812	2,331,046	N
1720	J C Weadock	MI	ECAR	Coal Steam	333	2,176,183	N
1723	J R Whiting	MI	ECAR	Coal Steam	346	2,119,978	Y
1726	Conners Creek	MI	ECAR	Coal Steam	275	62,543	N
1729	Fermi	MI	ECAR	Nuclear	1,218	8,556,303	N
1731	Harbor Beach	MI	ECAR	Coal Steam	125	214,420	N
1732	Marysville	MI	ECAR	Coal Steam	200	108,778	N
1733	Monroe	MI	ECAR	Coal Steam	3,293	18,328,247	Y
1740	River Rouge	MI	ECAR	Coal Steam	944	2,612,562	N
1743	St Clair	MI	ECAR	Coal Steam	1,929	5,764,277	N
1745	Trenton Channel	MI	ECAR	Coal Steam	776	4,128,006	N
1769	Presque Isle	MI	MAIN	Coal Steam	625	3,305,693	N
1822	Mistersky	MI	ECAR	O/G Steam	189	413,834	N
1825	J B Sims	MI	ECAR	Coal Steam	75	407,456	N
1830	James De Young	MI	ECAR	Coal Steam	63	337,358	N
1843	Shiras	MI	MAIN	Coal Steam	78	278,646	N
1866	Wyandotte	MI	ECAR	Coal Steam	73	257,391	N
6000	Donald C Cook	MI	ECAR	Nuclear	2,285	15,824,307	Y
6034	Belle River	MI	ECAR	Coal Steam	1,709	9,268,439	N
10745	Midland Cogeneration Venture	MI	ECAR	Combined Cycle	1,854	8,944,710	N
1897	M L Hibbard	MN	MAPP	Coal Steam	123	0	N
2549	C R Huntley	NY	NPCC	Coal Steam	816	3,575,773	N

Table G1-3: Phase II Facilities in the Great Lakes Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
2554	Dunkirk	NY	NPCC	Coal Steam	560	3,437,101	N
2589	Nine Mile Point	NY	NPCC	Nuclear	1,901	11,762,527	N
2594	Oswego	NY	NPCC	O/G Steam	1,804	484,773	N
2642	Rochester 7	NY	NPCC	Coal Steam	253	1,727,793	N
6082	Kintigh	NY	NPCC	Coal Steam	728	5,492,573	N
6110	James A FitzPatrick	NY	NPCC	Nuclear	882	7,120,960	N
6122	Ginna	NY	NPCC	Nuclear	517	4,285,728	N
2835	Ashtabula	OH	ECAR	Coal Steam	440	1,192,438	N
2836	Avon Lake	OH	ECAR	Coal Steam	870	3,586,861	N
2837	Eastlake	OH	ECAR	Coal Steam	1,289	5,022,223	N
2838	Lake Shore	OH	ECAR	Coal Steam	260	554,150	N
2857	Edgewater	OH	ECAR	O/G Steam	171	35,465	N
2878	Bay Shore	OH	ECAR	Coal Steam	655	3,178,866	N
6020	Perry	OH	ECAR	Nuclear	1,253	7,779,444	N
6149	Davis-Besse	OH	ECAR	Nuclear	925	7,684,318	N
3982	Bay Front	WI	MAPP	Coal Steam	68	331,254	N
4040	Port Washington	WI	MAIN	Coal Steam	340	941,117	N
4041	South Oak Creek	WI	MAIN	Coal Steam	1,211	5,909,779	N
4042	Valley	WI	MAIN	Coal Steam	275	1,115,111	N
4046	Point Beach	WI	MAIN	Nuclear	1,073	8,045,696	N
4050	Edgewater	WI	MAIN	Coal Steam	770	4,844,573	N
4072	Pulliam	WI	MAIN	Coal Steam	410	2,235,357	N
4125	Manitowoc	WI	MAIN	Coal Steam	89	262,568	N
8024	Kewaunee	WI	MAIN	Nuclear	535	3,462,010	N

Source: U.S. EPA analysis for this report.

Chapter G2: Evaluation of Impingement and Entrainment in the Great Lakes Region

INTRODUCTION

CHAPTER CONTENTS

Great Lakes fisheries are among the most important in the world, providing $4 billion in landings and recreation for some 5 million recreational anglers (Great Lakes Fishery Commission, 2003). Historically, the top predators in the Great Lakes included lake trout (*Salvelinus namaycush*), sturgeon (*Acipenser fulvescens*), lake whitefish (*Coregonus clupeaformis*), northern pike (*Esox lucius*), walleye (*Sander vitreus*), and muskellunge (*Esox masquinongy*). Today, as a result of numerous stressors such as habitat destruction, damming, and the introduction of sea lamprey and other exotic species, dominant species are primarily non-native salmon sustained by hatcheries. Not all introductions have been harmful, however. For example, alewife was introduced to provide forage for sport fish (Jude et al., 1987b). Losses of alewife (*Alosa pseudoharengus*), emerald shiner (*Notropis atherinoides*), and other forage species to impingement and entrainment (I&E) at Great Lakes facilities are sometimes substantial. Impinged and entrained species of commercial and/or recreational importance include yellow perch (*Perca flavescens*), white bass (*Morone chrysops*), gizzard shad (*Dorosoma cepedianum*), and walleye.

G2-1 I&E SPECIES AND SPECIES GROUPS EVALUATED

Table G2-1 provides a list of species and associated species groups that were evaluated in EPA's analysis of I&E in the Great Lakes.

Table G2-1: Species Evaluated by EPA That are Subject to I&E in the Great Lakes Region

Species Group	Species	Recreational	Commercial	Forage
Alewife	Alewife			X
Black bullhead	Black bullhead			X
Black crappie	Black crappie	X		
Bluegill	Bluegill			X
Bluntnose minnow	Bluntnose minnow			X
	Fathead minnow			X
	Hornyhead chub			X
	Lake chub			X
	Longnose dace			X

Table G2-1: Species Evaluated by EPA That are Subject to I&E in the Great Lakes Region

Species Group	Species	Recreational	Commercial	Forage
Brown bullhead	Brown bullhead		X	
Bullhead species	Stonecat		X	
	Tadpole madtom		X	
	Yellow bullhead		X	
Burbot	Burbot			X
Carp	Bowfin			X
	Carp			X
	Common carp			X
	Goldfish			X
Channel catfish	Channel catfish		X	
	Flathead catfish	X	X	
Crappie	White crappie	X		
Emerald shiner	Emerald shiner			X
Freshwater drum	Freshwater drum		X	
Gizzard shad	Gizzard shad		X	
Golden redhorse	Golden redhorse			X
	Shorthead redhorse			X
	Silver redhorse			X
Logperch	Logperch			X
	Trout-perch			X
Muskellunge	Grass pickerel	X		
	Muskellunge	X		
	Northern pike	X		
Other (forage)	Central mudminnow			X
	Chestnut lamprey			X
	Johnny darter			X
	Lake sturgeon			X
	Longnose gar			X
	Ninespine stickleback			X
	Pirate perch			X
	Sea lamprey			X
	Silver lamprey			X
Other (recreational)	Deepwater sculpin	X		
	Mottled sculpin	X		
	Slimy sculpin	X		
Rainbow smelt	Rainbow smelt	X	X	
	Smelt	X	X	

Table G2-1: Species Evaluated by EPA That are Subject to I&E in the Great Lakes Region

Species Group	Species	Recreational	Commercial	Forage
Shiner species	Common shiner			X
	Golden shiner			X
	Spotfin shiner			X
	Spottail shiner			X
Smallmouth bass	Largemouth bass	X		
	Smallmouth bass	X		
Spotted sucker	Spotted sucker			X
Sucker species	Lake chubsucker			X
	Longnose sucker			X
	Northern hog sucker			X
	Quillback			X
	White sucker			X
Sunfish	Green sunfish			X
	Hybrid sunfish	X		
	Orangespotted sunfish	X		
	Pumpkinseed			X
	Rock bass	X		
	Warmouth	X		
Walleye	Walleye	X		
White bass	White bass	X	X	
White perch	White perch			X
Whitefish	Bloater	X	X	
	Brown trout	X	X	
	Chinook salmon	X	X	
	Coho salmon	X	X	
	Lake herring	X	X	
	Lake trout	X	X	
	Lake whitefish	X	X	
	Rainbow trout	X	X	
	Round whitefish	X	X	
Yellow perch	Yellow perch		X	

Life histories of the species with the highest losses are summarized in the following section. The life history data used in EPA’s analysis and associated data sources are provided in Appendix G1 of this report.

G2-2 LIFE HISTORIES OF PRIMARY SPECIES IMPINGED AND ENTRAINED IN THE GREAT LAKES REGION

Alewife *(Alosa pseudoharengus)*

Alewife is a member of the herring family, Clupeidae, and ranges along the Atlantic coast from Newfoundland to North Carolina (Scott and Crossman, 1998). Alewives entered the Great Lakes region through the Welland Canal which connects Lake Erie and Lake Ontario, and by 1949, they were present in Lake Michigan (University of Wisconsin Sea Grant Institute, 2001a). Because alewives are not a freshwater species, they are particularly susceptible to osmotic stress associated with freshwater. Freshwater fish have larger kidneys which they use to constantly pump water from their bodies. Since they lack this physiological adaptation, alewives are more susceptible to environmental disturbances.

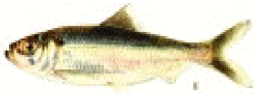
In the Great Lakes, alewives spend most of their time in deeper water. During spawning season, they move towards shallower inshore waters to spawn. Although alewives generally do not die after spawning, the fluctuating temperatures that the adults are exposed to when they move to inshore waters often results in mortality due to osmotic stress. In certain years, temperature changes caused by upwelling may result in a massive die-off of spawning alewives (University of Wisconsin Sea Grant Institute, 2001a).

Alewife has been introduced to a number of lakes to provide forage for sport fish (Jude et al., 1987b). Ecologically, alewife is an important prey item for many fish.

Spawning is temperature-driven, beginning in the spring as water temperatures reach 13 to 15 ˚C, and ending when they exceed 27 ˚C (Able and Fahay, 1998). In their native coastal habitats, alewives spawn in the upper reaches of coastal rivers, in slow-flowing sections of slightly brackish or freshwater. In the Great Lakes, alewives move inshore toward the outlets of rivers and streams to spawn (University of Wisconsin Sea Grant Institute, 2001a).

In coastal habitats, females lay demersal eggs in shallow water less than 2 m (6.6 ft) deep (Wang and Kernehan, 1979). They may lay from 60,000 to 300,000 eggs at a time (Kocik, 2000). The demersal eggs are 0.8 to 1.27 mm (0.03 to 0.05 in.) in diameter. Larvae hatch at a size of approximately 2.5 to 5.0 mm (0.1 to 0.2 in.) total length (Able and Fahay, 1998). Larvae remain in the upstream spawning area for some time before drifting downstream to natal estuarine waters. Juveniles table a diurnal vertical migration in the water column, remaining near the bottom during the day and rising to the surface at night (Fay et al., 1983a). In the fall, juveniles move offshore to nursery areas (Able and Fahay, 1998).

Maturity is reached at 3 to 4 years for males, and 4 to 5 years for females (Able and Fahay, 1998). The average size at maturity is 265 to 278 mm (10.4 to 10.9 in.) for males and 284 to 308 mm (11.2 to 12.1 in.) for females (Able and Fahay, 1998). Alewife can live up to 8 years, but the average age of the spawning population tends to be 4 to 5 years (Waterfield, 1995; PSEG, 1999).



ALEWIFE
(Alosa pseudoharengus)

Family: Clupeidae (herrings).

Common names: River herring, sawbelly, kyak, branch herring, freshwater herring, bigeye herring, gray herring, grayback, white herring.

Similar species: Blueback herring.

Geographic range: Along the western Atlantic coast from Newfoundland to North Carolina.[a] Arrived in the Great Lakes via the Welland Canal.[b]

Habitat: Wide-ranging, tolerates fresh to saline waters, travels in schools.

Lifespan: May live up to 8 years.[c,d]

Fecundity: Females may lay from 60,000 to 300,000 eggs at a time.[e]

Food source: Small fish, zooplankton, fish eggs, amphipods, mysids.[d]

Prey for: Striped bass, weakfish, rainbow trout.

Life stage information:

Eggs: *demersal*
- Found in waters less than 2 m (6.6 ft) deep.[e]
- Are 0.8 to 1.27 mm (0.03 to 0.05 in) in diameter.[f]

Larvae:
- Approximately 2.5 to 5.0 mm (0.1 to 0.2 in) at hatching.[f]
- Remain in upstream spawning area for some time before drifting downstream to natal estuarine waters.

Juveniles:
- Stay on the bottom during the day and rise to the surface at night.[g]
- Emigrate to ocean in summer and fall.[f]

Adults: *anadromous*
- Reach maturity at 3-4 years for males and 4-5 years for females.[f]
- Average size at maturity is 265-278 mm (10.4-10.9 in) for males and 284-308 mm (11.2-12.1 in) for females.[f]
- Overwinter along the northern continental shelf.[f]

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[a] Scott and Crossman, 1998.
[b] University of Wisconsin Sea Grant Institute, 2001a.
[c] PSEG, 1999.
[d] Waterfield, 1995.
[e] Kocik, 2000.
[f] Able and Fahay, 1998.
[g] Fay et al., 1983a.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

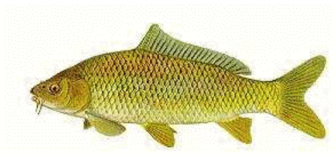
Carp (*Cyprinus carpio carpio*)

Carp is a member of the family of carps and minnows, Cyprinidae, and is abundant in Lake Erie. Carp were first introduced from Asia to the United States in the 1870's and 1880's, and by the 1890's were abundant in the Maumee River and in the west end of Lake Erie (Trautman, 1981). Carp are most abundant in low-gradient, warm streams and lakes with high levels or organic matter, but tolerate all types of bottom and clear to turbid waters (Trautman, 1981). Carp overwinter in deeper water and migrate to shallow water, preferably marshy environments with submerged aquatic vegetation in advance of the spawning season (McCrimmon, 1968). Adults feed on a wide variety of plants and animals, and juveniles feed primarily on plankton.

Carp are often considered a nuisance species because of their habit of uprooting vegetation and increase turbidity when feeding (McCrimmon, 1968; Scott and Crossman, 1973). Carp are not widely popular fishes for anglers, although carp fishing may be an important recreational activity in some parts of the United States (Scott and Crossman, 1973). They are occasionally harvested commercially and sold for food (Scott and Crossman, 1973).

Male carp reach sexual maturity between ages 3 and 4, and the females reach maturity between ages 4 and 5 (Swee and McCrimmon, 1966). Spawning can occur at temperatures between 16 and 28 ˚C (60.8 and 82.4 ˚F) with optimum activity between 19 and 23 ˚C (66.2 and 73.4 ˚F) (Swee and McCrimmon, 1966). Fecundity in carp can range from 36,000 eggs for a 39.4 cm (15.5 in.) fish to 2,208,000 in a 85.1 cm (33.5 in.) fish (Swee and McCrimmon, 1966) but individuals may spawn only about 500 eggs at a given time (Dames and Moore, 1977). Eggs are demersal and stick to submerged vegetation.

Eggs hatch 3 to 6 days after spawning and larvae tend to lie in shallow water among vegetation (Swee and McCrimmon, 1966). The lifespan of a typical carp in North America is less than 20 years (McCrimmon, 1968). Adult carp can reach 102-122 cm (40-48 in.) long, and weigh 18-27 kg (40-60 lb) (Trautman, 1981).



CARP
(*Cyprinus carpio carpio*)

Family: Cyprinidae (minnows or carp).

Common names: Carp.

Similar species: Goldfish, buffalofishes, carpsuckers.[a]

Geographic range: Wide-ranging throughout the United States.

Habitat: Low-gradient, warm streams and lakes with high levels or organic carbon. Tolerates relatively wide range of turbidity. Often associated with submerged aquatic vegetation.[b]

Lifespan: Less than 20 years.[b]

Fecundity: 36,000 to 2,208,000 eggs per season.[c]

Food source: Omnivorous; diet includes invertebrates, small molluscs, ostracods, and crustaceans as well as roots, leaves, and shoots of water plants.[b]

Prey for: Juveniles provide limited forage for northern pike, smallmouth bass, striped bass, and longnosed gar, as well as green frogs, bullfrogs, turtles, snakes, mink.[b]

Life stage information:

Eggs: *demersal*
- During spawning, eggs are released in shallow, vegetated water. Eggs are demersal and stick to submerged vegetation.
- Eggs hatch in 3-6 days.[c]

Larvae:
- Larvae are found in shallow, weedy, and muddy habitats.[d]

Adults:
- May reach lengths of 102-122 cm (40-48 in.).[a]

[a] Trautman, 1981.
[b] McCrimmon, 1968.
[c] Swee and McCrimmon, 1966.
[d] Wang, 1986.
Fish graphic from North Dakota Game and Fish Department (1986).

Channel catfish (*Ictalarus punctatus*)

Channel catfish is a member of the Ictaluridae (North American freshwater catfish) family. It is found from Manitoba to southern Quebec, and as far south as the Gulf of Mexico (Dames and Moore, 1977). Channel catfish can be found in freshwater streams, lakes, and ponds. They prefer deep water with clean gravel or boulder substrates and low to moderate currents (Ohio Department of Natural Resources, 2001).

Channel catfish reach sexual maturity at ages 5-8, and females will lay 4,000-35,000 eggs dependent on body weight (Scott and Crossman, 1998). Spawning begins when temperatures reach 24-29 ˚C (75-85 ˚F) in late spring or early summer. Spawning occurs in natural nests such as undercut banks, muskrat burrows, containers, or submerged logs. Eggs approximately 3.5 mm (0.1in) in diameter are deposited in a large, flat, gelatinous mass (Wang, 1986). After spawning, the male guards the nest and fans it to keep it aerated. Eggs hatch in 7-10 days at 24-26 ˚C (75-79 ˚F) and the newly hatched larvae remain near the nest for several days (Wang, 1986). Young fish prefer to inhabit riffles and turbulent areas. Channel catfish are very popular with anglers and are relatively prized as a sport fish (Dames and Moore, 1977).

CHANNEL CATFISH
(*Ictalarus punctatus*)

Family: Ictaluridae (North American freshwater catfish).

Common names: Channel catfish, graceful catfish.[a]

Similar species: Blue and white catfishes.[b]

Geographic range: South-central Canada, central United States, and northern Mexico.[a]

Habitat: Freshwater streams, lakes, and ponds. Prefer deep water with clean gravel or boulder substrates.[c]

Lifespan: Maximum reported age: 16 years.[a]

Fecundity: 4,000 to 35,000 eggs depending on body weight.[e]

Food source: Small fish, crustaceans, clams, snails.[a]

Prey for: Chestnut lamprey.[a]

Life stage information:

Eggs: *demersal*
- 3-4 mm in diameter.[d]
- Hatch in 7-10 days.[d]

Larvae:
- Remain near nest for a few days then disperse to shallow water.[d]
- Approx. 6.4 mm (0.25 in.) upon hatching.[d]

Adults: *demersal*
- Average length: 30-36 cm (12-14 in.).[c]
- Maximum length: up to 104 cm (41 in.).[c]

[a] Froese and Pauly, 2001.
[b] Trautman, 1981.
[c] Ohio Department of Natural Resources, 2001.
[d] Wang, 1986.
[e] Scott and Crossman, 1998.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Emerald shiner (*Notropis atherinoides*)

Emerald shiner is a member of the family Cyprinidae. It is found in large open lakes and rivers from Canada south throughout the Mississippi Valley to the Gulf Coast in Alabama (Scott and Crossman, 1973). Emerald shiner prefer clear waters in the mid to upper sections of the water column, and are most often found in deep, slow moving rivers and in Lake Erie (Trautman, 1981). The emerald shiner is one of the most prevalent fishes in Lake Erie (Trautman, 1981). Because of their small size, they are an important forage fish for many species.

Spawning occurs from July to August in Lake Erie (Scott and Crossman, 1973). Females lay anywhere from 870 to 8,700 eggs (Campbell and MacCrimmon, 1970), which hatch within 24 hours (Scott and Crossman, 1973). Young-of-year remain in large schools in inshore waters until the fall, when they move into deeper waters to overwinter (Scott and Crossman, 1973). Young-of-year average 5.1 to 7.6 cm (2 to 3 in.) in length (Scott and Crossman, 1973).

Emerald shiner are sexually mature by age 2, though some larger individuals may mature at age 1 (Campbell and MacCrimmon, 1970). Most do not live beyond 3 years of age (Fuchs, 1967). Adults typically range from 6.4 to 8.4 cm (2.5 to 3.3 in.) (Trautman, 1981). Populations may fluctuate dramatically from year to year (Trautman, 1981).

EMERALD SHINER
(*Notropis atherinoides*)

Family: Cyprinidae (herrings).

Common names: Emerald shiner.

Similar species: Silver shiner, rosyface shiner.[a]

Geographic range: From Canada south throughout the Mississippi valley to the Gulf Coast in Alabama.[b,c]

Habitat: Large open lakes and rivers.[b]

Lifespan: Emerald shiner live to 3 years.[a,d]

Fecundity: Mature by age 2. Females can lay anywhere from approximately 870-8,700 eggs.[3]

Food source: Microcrustaceans, midge larvae, zooplankton, algae.[d]

Prey for: Gulls, terns, mergansers, cormorants, smallmouth bass, yellow perch, and others.[d]

Life stage information:

Eggs: *demersal*
- Eggs hatch in less than 24 hours.[d]

Larvae: *pelagic*
- Individuals from different year classes can have varying body proportions and fin length, as can individuals from different localities.[a]

Adults:
- Typically range in size from 6.4 to 8.4 cm (2.5 to 3.3 in.).[a]

[a] Trautman, 1981.
[b] Froese and Pauly, 2000.
[c] Campbell and MacCrimmon, 1970.
[d] Scott and Crossman, 1973.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Freshwater drum (*Aplodinotus grunniens*)

Freshwater drum is a member of the drum family, Sciaenidae. Possibly tabling the greatest latitudinal range of any North American freshwater species, its distribution ranges from Manitoba, Canada, to Guatemala, and throughout the Mississippi River drainage basin (Scott and Crossman, 1973). The freshwater drum is found in deeper pools of rivers and in Lake Erie at depths between 1.5 and 18 m (5 and 60 ft) (Trautman, 1981). Drum is not a favored food item of either humans or other fish (Edsall, 1967; Trautman, 1981; Bur, 1982).

Based on studies in Lake Erie, the spawning season peaks in July (Daiber, 1953), although spent females have been found as late as September (Scott and Crossman, 1973). Females in Lake Erie produce anywhere from 43,000 to 508,000 eggs (Daiber, 1953). The eggs are buoyant, floating at the surface of the water (Daiber, 1953; Scott and Crossman, 1973). This unique quality may be one explanation for the freshwater drum's exceptional distribution (Scott and Crossman, 1973). Yolk-sac larvae are buoyant as well, floating inverted at the surface of the water with the posterior end of the yolk sac and tail touching the surface (Swedberg and Walburg, 1970).

Larvae develop rapidly over the course of their first year. Maturity appears to be reached earlier among freshwater drum females from the Mississippi River than females from Lake Erie. Daiber (1953) found Lake Erie females begin maturing at age 5, and 46 percent reach maturity by age 6. Lake Erie males begin maturing at age 4, and by age 5, 79 percent had reached maturity.

The maximum age for fish in western Lake Erie is 14 years for females and 8 years for males (Edsall, 1967). Adults tend to be between 30 to 76 cm (12 to 30 in.) long.

FRESHWATER DRUM
(*Aplodinotus grunniens*)

Family: Sciaenidae.

Common names: freshwater drum, white perch, sheepshead.[a]

Similar species: white bass, carpsuckers.[a]

Geographic range: From Manitoba, Canada, to Guatemala. They can be found throughout the Mississippi River drainage basin.

Habitat: Bottoms of medium- to large-sized rivers and lakes.[b]

Lifespan: The maximum age for fish in western Lake Erie is 14 years for females and 8 years for males.[c]

Fecundity: Females in Lake Erie produce from 43,000 to 508,000 eggs.[e]

Food sources: Juveniles: Cladocerans (plankton), copepods, dipterans.[d]

Adults: Dipterans, cladocerans,[d] darters, emerald shiner.[e]

Prey for: Very few species.

Life stage information:

Eggs: *pelagic*

- The buoyant eggs float at the surface of the water, possibly accounting for the species' high distribution.[e]

Larvae:

- Prolarvae float inverted at the surface of the water with the posterior end of the yolk sac and their tail touching the surface.[f]

Adults:

- The species owes its name to the audible "drumming" sound that it is often heard emitting during summer months.[e]
- Tend to be between 30 to 76 cm (12 to 30 in.) long.[a]

[a] Trautman, 1981
[b] Froese and Pauly, 2001.
[c] Edsall, 1967.
[d] Bur, 1982.
[e] Scott and Crossman, 1973.
[f] Swedberg and Walburg, 1970.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

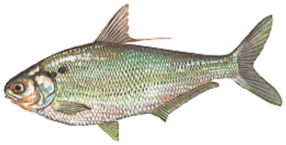
Gizzard shad (*Dorosoma cepedianum*)

Gizzard shad is a member of the family Clupeidae. Its distribution is widespread throughout the eastern United States and into southern Canada, with occurrences from the St. Lawrence River south to eastern Mexico (Miller, 1960; Scott and Crossman, 1973). Gizzard shad are found in a range of salinities from freshwater inland rivers to brackish estuaries and marine waters along the Atlantic Coast of the United States (Miller, 1960; Carlander, 1969). Gizzard shad often occur in schools (Miller, 1960). Young-of-year are considered an important forage fish (Miller, 1960), though their rapid growth rate limits the duration of their susceptibility to many predators (Bodola, 1966). In Lake Erie, gizzard shad are most populous in the shallow waters of western Lake Erie, around the Bass Islands, and in protected bays and mouths of tributaries (Bodola, 1966).

Spawning occurs from late winter or early spring to late summer, depending on temperature. Spawning has been observed in early June to July in Lake Erie (Bodola, 1966), and in May elsewhere in Ohio (Miller, 1960). The spawning period generally lasts 2 weeks (Miller, 1960). Males and females release sperm and eggs while swimming in schools near the surface of the water. Eggs sink slowly to the bottom or drift with the current, and adhere to any surface they encounter (Miller, 1960). Females release an average of 378,990 eggs annually (Bodola, 1966), which average 0.75 mm (0.03 in.) in diameter (Wallus et al., 1990).

Hatching time can be anywhere from 36 hours to 1 week, depending on water temperature (Bodola, 1966). Young shad may remain in upstream natal waters if conditions permit (Miller, 1960). By age 2 all gizzard shad are sexually mature, though some may mature as early as age 1 (Bodola, 1966). Unlike many other fish, fecundity in gizzard shad declines with age (Electric Power Research Institute, 1987).

Gizzard shad generally live up to 6 years in Lake Erie, but individuals up to 10 years have been reported in southern locations (Scott and Crossman, 1973). Mass mortalities have been documented in several locations during winter months, due to extreme temperature changes (Williamson and Nelson, 1985).



GIZZARD SHAD
(*Dorosoma cepedianum*)

Family: Clupeidae (herrings).

Common names: Gizzard shad.

Similar species: Threadfin shad.[a]

Geographic range: Eastern North America from the St. Lawrence River to Mexico.[b,c]

Habitat: Inhabits inland lakes, ponds, rivers, and reservoirs to brackish estuaries and ocean waters.[b,c]

Lifespan: Gizzard shad generally live 5 to 6 years, but have been reported up to 10 years.[b]

Fecundity: Maturity is reached by age 2; females produce average of 378,990 eggs.[b]

Food sources: Larvae consume protozoans, zooplankton, and small crustaceans.[c] Adults are mainly herbivorous, feeding on plants, phytoplankton, and algae. They are one of the few species able to feed solely on plant material.[b]

Prey for: Walleye, white bass, largemouth bass, crappie, among others (immature shad only).[b]

Life stage information:

Eggs: *demersal*

- During spawning, eggs are released near the surface and sink to the bottom, adhering to any surface they touch.

Larvae: *pelagic*

- Larvae serve as forage to many species.
- After hatching, larvae travel in schools for the first few months.

Adults

- May grow as large as 52.1 cm (20.5 in.).[a]
- May be considered a nuisance species because of sporadic mass winter die-offs.[3]

[a] Trautman, 1981.
[b] Miller, 1960.
[c] Scott and Crossman, 1973.
Fish graphic from Iowa Dept. of Natural Resources, 2001.

Walleye (*Stizostedion vitreum*)

Walleye is a member of the perch family, Percidae. It is found in freshwater from as far north as the Mackenzie River near the Arctic Coast to as far south as Georgia, and is common in the Great Lakes. Walleye are popular sport fish both in the summer and winter. They generally feed at night because their eyes are sensitive to bright daylight (Scott and Crossman, 1998).

Walleye spawn in spring or early summer, although the exact timing depends on latitude and water temperature. Spawning has been reported at temperatures of 5.6 to 11.1 ˚C (42 to 52 ˚F), in rocky areas in white water or shoals of lakes (Scott and Crossman, 1998). They do not fan nests like other similar species, but instead broadcast eggs over open ground, which reduces their ability to survive environmental stresses (Carlander, 1997). Females produce between 48,000 and 614,000 eggs in Lake Erie, and the eggs are 1.4 to 2.1 mm (0.06 to 0.08 in.) in diameter (Carlander, 1997). Eggs hatch in 12-18 days (Scott and Crossman, 1998). Larvae are approximately 6.0 to 8.6 mm (0.23 to 0.33 in.) at hatching (Carlander, 1997).

Walleye develop more slowly in the northern extent of their range; in Lake Erie they are 8.9 to 20.3 cm (3.5 to 8.0 in.) by the end of the first growing season. Males generally mature at 2-4 years and females at 3-6 years (Scott and Crossman, 1998), and females tend to grow faster than males (Carlander, 1997). Walleye may reach up to 78.7 cm (31 in.) long in Lake Erie (Scott and Crossman, 1998).

WALLEYE
(*Stizostedion vitreum*)

Family: Percidae (perch).

Common names: Blue pike, glass eye, gray pike, marble eye, yellow pike-perch.[a]

Similar species: Sauger.[b]

Geographic range: Canada to southern United States.[c]

Habitat: Large, shallow, turbid lakes; large streams or rivers.[c]

Lifespan: Maximum reported age: 12 years.[b]

Fecundity: 48,000 to 614,000 in Lake Erie.[b]

Food source: Insects, yellow perch, freshwater drum, crayfish, snails, frogs.[a]

Prey for: Sea lamprey, northern pike, muskellunge, sauger.[a]

Life stage information:

Eggs: *demersal*
- 1.4 - 2.1 mm (0.06 - 0.08 in.) in diameter.[b]
- Hatch in 12-18 days.[c]

Larvae: *pelagic*
- Approx. 6.2 - 7.3 mm (0.24 - 0.29 in.) upon hatching.[b]

Adults: *demersal*
- Maximum length: up to 78.7 cm (31 in.).[c]

[a] Froese and Pauly, 2001.
[b] Carlander, 1997.
[c] Scott and Crossman, 1998.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

White bass (*Morone chrysops*)

White bass is a member of the temperate bass family, Moronidae. It ranges from the St. Lawrence River south through the Mississippi valley to the Gulf of Mexico, though the species is most abundant in the Lake Erie drainage (Van Oosten, 1942). White bass has both commercial and recreational fishing value.

Spawning take place in May in Lake Erie and may extend into June, depending on temperatures. Spawning bouts can last from 5 to 10 days (Scott and Crossman, 1973). Adults typically spawn near the surface, and eggs are fertilized as they sink to the bottom. Fecundity increases directly with size in females; the average female lays approximately 565,000 eggs. Eggs hatch within 46 hours at a water temperature of 15.6 ˚C (60 ˚F) (Scott and Crossman, 1973).

Larvae grow rapidly, and young white bass reach lengths of 13 to 16 cm (5.1 to 6.3 in.) by the fall (Scott and Crossman, 1973). They feed on microscopic crustaceans, insect larvae, and small fish. As adults, the diet switches to fish. Yellow perch are an especially important prey species for white bass (Scott and Crossman, 1973).

Most white bass mature at age 3 (Van Oosten, 1942). Upon reaching sexual maturation, adults tend to form unisexual schools, traveling up to 11.1 km (6.9 mi) a day. Adults occupy the upper portion of the water column, maintaining depths of 6 m or less (Scott and Crossman, 1973). On average, adults are between 25.4 to 35.6 cm (10 to 14 in.) long (Ohio Department of Natural Resources, 2001). White bass rarely live beyond 7 years (Scott and Crossman, 1973).

WHITE BASS
(*Morone chrysops*)

Family: Moronidae.

Common names: White bass, silver bass.

Similar species: White perch, striped bass.[a]

Geographic range: St. Lawrence River south through the Mississippi valley to the Gulf of Mexico, highly abundant in the Lake Erie drainage.[b]

Habitat: Occurs in lakes, ponds, and rivers.[c]

Lifespan: White bass may live up to 7 years.[d]

Fecundity: The average female lays approximately 565,000 eggs.[b]

Food source: Juveniles consume microscopic crustaceans, insect larvae, and small fish.[b] Adults have been found to consume yellow perch, bluegill, white crappie,[b] and carp.[b,d]

Prey for: Other white bass.[a]

Life stage information:

Eggs: *demersal*
- Eggs are approximately 0.8 mm (0.03 in.) in diameter.[b]

Larvae: *pelagic*
- White bass experience their maximum growth in their first year.[b]

***Adults*:**
- Travel in schools, traveling up to 11.1 km (6.9 mi) a day.[b]
- Most mature at age 3.[e]
- Adults prefer clear waters with firm bottoms.[a]

[a] Trautman, 1981.
[b] Scott and Crossman, 1973.
[c] Froese and Pauly, 2000.
[d] Carlander, 1997.
[e] Van Oosten, 1942.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Yellow perch (*Perca flavescens*)

The yellow perch is a member of the Percidae family and is found in fresh waters in the northern and eastern United States and across eastern and central Canada. Yellow perch are also occasionally seen in brackish waters (Scott and Crossman, 1973). They are typically found in greatest numbers in clear waters with low gradients and abundant vegetation (Trautman, 1981). Perch feed during the day on immature insects, larger invertebrates, fishes, and fish eggs (Scott and Crossman, 1973).

Yellow perch are of major commercial and recreational value in Lake Erie, and the Great Lakes are a major source of yellow perch to the commercial fishing industry.

Sexual maturity is reached at age 1 for males and at ages 2 and 3 for females (Saila et al., 1987). Perch spawn in the spring in water temperatures ranging from 6.7 to 12.2 ˚C (44-54 ˚F) (Scott and Crossman, 1973). Adults move to shallower water to spawn, usually near rooted vegetation, fallen trees, or brush. Spawning takes place at night or in the early morning. Females lay all their eggs in a single transparent strand that is approximately 3 cm (1.2 in.) wide (Saila et al., 1987) and up to 2.1 m (7 ft) long (Scott and Crossman, 1973). These egg cases are semi-buoyant and attach to submerged vegetation or occasionally to the bottom and may contain 2,000-90,000 eggs (Scott and Crossman, 1973). In western Lake Erie, fecundities for yellow perch were reported to range from 8,618 to 78,741 eggs (Saila et al., 1987).

Yellow perch larvae hatch within about 8-10 days and are inactive for about 5 days until the yolk is absorbed (Scott and Crossman, 1973). Young perch are initially pelagic and found in schools, but become demersal after their first summer (Saila et al., 1987).

Adult perch are inactive at night and rest on the bottom (Scott and Crossman, 1973). Females generally grow faster than males and reach a greater final length (Scott and Crossman, 1973). In Lake Erie, perch may reach up to approximately 31 cm (12 in.) in total length and have been reported to live up to 11 years.

YELLOW PERCH
(*Perca flavescens*)

Family: Percidae (perches).

Common names: Yellow perch, perch, American perch, lake perch.[a]

Similar species: Dusky darter.[b]

Geographic range: Northern and eastern United States.[c]

Habitat: Lakes, ponds, creeks, rivers. Found in clear water near vegetation.[a,b]

Lifespan: Up to 11 years.[c]

Fecundity: 2,000-90,000 eggs.[c]

Food source: Immature insects, larger invertebrates, fishes, and fish eggs.[c]

Prey for: Almost all warm to cool water predatory fish including bass, sunfish, crappies, walleye, sauger, northernpike, muskellunge, and other perch, as well as a number of birds.[c]

Life stage information:

Eggs: *semi-buoyant*
- Eggs laid in long tubes containing 2,000-90,000 eggs.[c]
- Eggs usually hatch in 8-10 days.[c]

Larvae: *pelagic*
- Larvae are 4.1-5.5 mm (0.16-0.22 in.) upon hatching.[d]
- Found in schools with other species.[c]
- Become demersal during the first summer.[d]

Adults: *demersal*
- Reach up to 31 cm (12 in.) in Lake Erie.[c]
- Found in schools near the bottom.

[a] Froese and Pauly, 2001.
[b] Trautman, 1981.
[c] Scott and Crossman, 1973.
[d] Saila et al., 1987.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

G2-3 I&E DATA EVALUATED

Table G2-2 lists Great Lakes facilities in scope of the Phase II rule and the facility I&E data evaluated by EPA to estimate current I&E rates for the region.

Table G2-2: Great Lakes Facilities In Scope of the Section 316(b) Phase II Rule and Facility I&E Data Evaluated

In Scope Facilities	I&E Data?	Years of Data
AES Somerset (NY)	No - extrapolated	
Ashtabula (OH)	No - extrapolated	
Avon Lake (OH)	No - extrapolated	
B C Cobb (MI)	No - extrapolated	
Bailly (IN)	No - extrapolated	
Bay Front (WI)	No - extrapolated	
Bay Shore (OH)	No - extrapolated	
Belle River (MI)	No - extrapolated	
C R Huntley (NY)	No - extrapolated	
Conners Creek (MI)	No - extrapolated	
Crawford (IL)	No - extrapolated	
Dan E Karn (MI)	No - extrapolated	

Table G2-2: Great Lakes Facilities In Scope of the Section 316(b) Phase II Rule and Facility I&E Data Evaluated

In Scope Facilities	I&E Data?	Years of Data
Davis-Besse (OH)	No - extrapolated	
Dean H Mitchell (IN)	No - extrapolated	
Donald C Cook Nuclear (MI)	Yes	1975-1982
Dunkirk (NY)	No - extrapolated	
Eastlake (OH)	No - extrapolated	
Edgewater (OH)	No - extrapolated	
Edgewater (WI)	No - extrapolated	
Fermi Nuclear (MI)	No - extrapolated	
Fisk (IL)	No - extrapolated	
Ginna (NY)	No - extrapolated	
Harbor Beach (MI)	No - extrapolated	
J B Sims (MI)	No - extrapolated	
J C Weadock (MI)	No - extrapolated	
J H Campbell (MI)	No - extrapolated	
J R Whiting (MI)	Yes	1978-1983, 1987, 1991
James A Fitzpatrick (NY)	No - extrapolated	
James De Young (MI)	No - extrapolated	
Kewaunee Nuclear (WI)	No - extrapolated	
Lake Shore (OH)	No - extrapolated	
M L Hibbard (MN)	No - extrapolated	
Manitowoc (WI)	No - extrapolated	
Marysville (MI)	No - extrapolated	
Michigan City (IN)	No - extrapolated	
Midland Cogeneration Venture (MI)	No - extrapolated	
Mistersky (MI)	No - extrapolated	
Monroe (MI)	Yes	1974, 1975, 1982, 1985
Nine Mile Point Nuclear (NY)	No - extrapolated	
Oswego (NY)	No - extrapolated	
Palisades Nuclear (MI)	No - extrapolated	
Perry Nuclear (OH)	No - extrapolated	
Point Beach Nuclear (WI)	No - extrapolated	
Port Washington (WI)	No - extrapolated	
Presque Isle (MI)	No - extrapolated	
Pulliam (WI)	No - extrapolated	
River Rouge (MI)	No - extrapolated	
Rochester 7 (NY)	No - extrapolated	
Shiras (MI)	No - extrapolated	
South Oak Creek (WI)	No - extrapolated	
St Clair (MI)	No - extrapolated	

Table G2-2: Great Lakes Facilities In Scope of the Section 316(b) Phase II Rule and Facility I&E Data Evaluated

In Scope Facilities	I&E Data?	Years of Data
Trenton Channel (MI)	No - extrapolated	
Valley (WI)	No - extrapolated	
Waukegan (IL)	No - extrapolated	
Will County (IL)	No - extrapolated	
Wyandotte (MI)	No - extrapolated	

G2-4 EPA'S ESTIMATE OF CURRENT I&E IN THE GREAT LAKES REGION EXPRESSED AS AGE 1 EQUIVALENTS, FOREGONE YIELD, AND PRODUCTION FOREGONE

Table G2-3 provides EPA's estimate of the annual age 1 equivalents, foregone fishery yield, and production foregone resulting from the impingement of aquatic species at facilities located in the Great Lakes region. Table G2-4 displays this information for entrainment.

Table G2-3: Current Annual Impingement in the Great Lakes Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species Group	Age 1 Equivalents (#s)	Yield (lbs)	Production Foregone
Alewife	41,459	0	652
Bass (Micropterus sp.)	4,132	167	347
Black crappie	507	84	21
Bluegill	150	3	2
Bullheads	6,426	499	175
Burbot	3,614	0	568
Carp minnow	54,947	0	18,709
Crappie	1,676	279	70
Freshwater catfish	20,103	4,162	1,786
Freshwater drum	451,661	107,628	42,954
Gizzard shad	167,951,902	0	6,072,918
Logperch	326,715	0	1,339
Other (forage)	56,022	0	6
Other (recreational)	16,390	3,187	2,102
Pikes	19	71	11
Rainbow smelt	377,860	1,313	5,625
Redhorse	33	0	2
Salmonids (other)	128,267	115,041	27,994
Shiners	102,907,376	0	172,221
Spotted sucker	1	0	0
Suckers	7,813	0	1,258
Sunfish	150,023	108	253
Walleye	47,025	41,167	13,864

Table G2-3: Current Annual Impingement in the Great Lakes Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species Group	Age 1 Equivalents (#s)	Yield (lbs)	Production Foregone
White bass	1,777,091	541,636	166,314
White perch	1,603,562	0	20,055
Yellow perch	1,516,297	20,202	16,554

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Table G2-4: Current Annual Entrainment in the Great Lakes Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species Group	Age 1 Equivalents (#s)	Yield (lbs)	Production Foregone
Alewife	5,839	0	85,563
Bass (Micropterus sp.)	304,131	12,299	53,051
Burbot	3,218	0	1,749
Carp minnow	2,334,006	0	3,621,033
Crappie	48,623	8,106	49,604
Freshwater catfish	293,443	60,756	183,668
Freshwater drum	207,784	49,514	305,024
Gizzard shad	22,146,154	0	3,131,790
Logperch	448,198	0	37,182
Other (forage)	1,175,936	0	55,849
Other (recreational)	1,537	299	3,531
Rainbow smelt	160,820	559	38,249
Salmonids (other)	163	146	181
Shiners	1,586,308	0	75,338
Suckers	183,186	0	296,552
Sunfish	8,458,028	6,104	44,787
Walleye	31,500	27,576	78,999
White bass	2,344,707	714,638	3,597,786
Yellow perch	1,929,941	25,713	1,115,874

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G2-5 ASSUMPTIONS USED IN CALCULATING RECREATIONAL AND COMMERCIAL LOSSES

In order to estimate the economic value of these losses, total yield was partitioned between commercial and recreational fisheries based on the landings in each fishery. Table G2-5 presents the percentage impacts and commercial value per pound assumed for each species. Commercial and recreational fishing benefits are presented in Chapters G3 and G4.

Table G2-5: Percentage of Total Impacts Occurring to the Commercial and Recreational Fisheries and Commercial Value per Pound for Species Impinged and Entrained at Great Lakes Facilities

Species Group	Percent Impact to Recreational Fishery[a]	Percent Impact to Commercial Fishery[a]	Commercial Value per Pound (2002$)[b]
Black crappie	100.0%	0.0%	na
Bluegill	100.0%	0.0%	na
Bullhead species	0.0%	100.0%	$0.50
Channel catfish	50.0%	50.0%	$0.50
Crappie	100.0%	0.0%	na
Freshwater drum	0.0%	100.0%	$0.14
Muskellunge	100.0%	0.0%	na
Rainbow smelt	50.0%	50.0%	$0.61
Smallmouth bass	100.0%	0.0%	na
Sunfish	100.0%	0.0%	na
Walleye	100.0%	0.0%	na
White bass	50.0%	50.0%	$0.85
Whitefish	50.0%	50.0%	$0.84
Yellow perch	50.0%	50.0%	$2.12
Other (forage)[c]	50.0%	50.0%	$0.71

[a] Based on opinion of local experts and comments received at proposal. EPA collected recreational landings data by species from State fisheries experts. However, this data was limited to a few broad species groups and was not sufficient to calculate more accurate values.

[b] Calculated using 1993-2001 commercial landings data from NMFS (2003a, http://www.st.nmfs.gov/commercial/landings/annual_landings.html).

[c] Assumed equally likely to be caught by recreational or commercial fishermen. Commercial value calculated as overall average for region based on data from NMFS (2003a).

Age-1 equivalent fish that are spared from I&E are not necessarily old enough or large enough to be attractive to anglers. It may take one or more years for these fish to reach a harvestable age. For this reason, EPA discounts commercial and recreational benefits so that the cost and benefits estimates will be comparable. Tables G2-6 and G2-7 present the multiplicative discounting factors used in discounting benefits assuming a 3 percent real discount rate and a 7 percent real discount rate. For details on how these factors are developed, see Chapter A14.

Table G2-6: Factors Applied to Recreational Benefits to Implement Discounting in the Great Lakes

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Black crappie	na	na	0.928	0.845
Bluegill	na	na	0.925	0.838
Channel catfish	0.938	0.866	0.966	0.926
Crappie	0.901	0.789	0.928	0.845
Pikes	na	na	0.696	0.439
Rainbow smelt	0.904	0.796	0.931	0.851
Salmonids (other)	0.947	0.884	0.976	0.946
Smallmouth bass	0.926	0.839	0.953	0.897
Sunfish	0.908	0.803	0.936	0.859
Walleye	0.890	0.770	0.917	0.823
White bass	0.919	0.826	0.947	0.883
Yellow perch	0.899	0.783	0.925	0.838
Other (forage)	0.919	0.829	0.919	0.829

Table G2-7: Factors Applied to Commercial Benefits to Implement Discounting in the Great Lakes

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
Bullhead species	na	na	0.895	0.778
Channel catfish	0.899	0.786	0.925	0.841
Freshwater drum	0.837	0.672	0.862	0.719
Rainbow smelt	0.889	0.765	0.915	0.818
Salmonids (other)	0.934	0.858	0.962	0.918
White bass	0.913	0.813	0.941	0.870
Yellow perch	0.895	0.776	0.921	0.830
Other (forage)	0.901	0.793	0.901	0.793

Chapter G3: Commercial Fishing Valuation

INTRODUCTION

CHAPTER CONTENTS

This chapter presents the results of the commercial fishing benefits analysis for the Great Lakes region. Section G3.1 details the estimated losses under current, or baseline, conditions. Section G3.2 presents the expected benefits in the region attributable to the rule. Chapter A10 details the methods used in this analysis.

Note that all results have been sample weighted in this version. In the final revision results will be reported unweighted.

G3-1 BASELINE LOSSES

Table G3-1 provides EPA's estimate of the value of gross revenues lost in commercial fisheries resulting from the impingement of aquatic species at facilities in the Great Lakes region. Table G3-2 displays this information for entrainment. Total annual revenue losses are approximately $1.0 million, assuming a 3 percent discount rate.

Table G3-1: Annual Commercial Fishing Gross Revenues Lost Due to Impingement at Facilities in the Great Lakes Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002 dollars)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
Bullheads	499	243	217	188
Freshwater catfish	2,081	1,016	940	855
Freshwater drum	107,628	14,956	12,897	10,749
Rainbow smelt	657	391	358	320
Salmonids (other)	57,521	47,310	45,534	43,409
White bass	270,818	226,186	212,733	196,803
Yellow perch	10,101	21,016	19,366	17,442
Other unidentified species (from forage losses)	669,739	463,365	417,294	367,359
TOTAL	1,119,043	774,483	709,339	637,124

Table G3-2: Annual Commercial Fishing Gross Revenues Lost Due to Entrainment at Facilities in the Great Lakes Region

Species	Estimated Pounds of Harvest Lost	Estimated Value of Harvest Lost (in 2002 dollars)		
		Undiscounted	Discounted Using 3% Discount Rate	Discounted Using 7% Discount Rate
Freshwater catfish	30,378	14,827	13,322	11,657
Freshwater drum	49,514	6,880	5,760	4,621
Rainbow smelt	279	166	148	127
Salmonids (other)	73	60	56	51
White bass	357,319	298,432	272,506	242,676
Yellow perch	12,856	26,750	23,931	20,748
Other unidentified species (from forage losses)	38,717	26,786	24,123	21,236
TOTAL	489,137	373,901	339,847	301,117

G3-2 BENEFITS

As described in Chapter A10, EPA estimates that 0 to 40 percent of the gross revenue losses represent surplus losses to producers, assuming no change in prices or fishing costs. The 0 percent estimate, of course, results in loss estimates of $0. The 40 percent estimates, as presented in the Table G3-3, total approximately $0.4 million when a 3 percent discount rate is assumed.

The expected reductions in I&E attributable to changes at facilities required by the rule are 51.5 percent for impingement and 40.1 percent for entrainment. Total annual benefits are estimated by applying these estimated reductions to the annual producer surplus loss. As presented in Table G3-3, this results in total annual benefits of $0.2 million, assuming a 3 percent discount rate.

Table G3-3: Annual Commercial Fishing Benefits Attributable to Phase II Rule at Facilities in the Great Lakes Region (million 2002$), Assumes Compliance in 2005

	Impingement	Entrainment	Total
Baseline loss — gross revenue			
Undiscounted	$0.8	$0.4	$1.1
3% discount rate	$0.7	$0.3	$1.0
7% discount rate	$0.6	$0.3	$0.9
Producer surplus lost — low	**$0.0**	**$0.0**	**$0.0**
Producer surplus lost — high (gross revenue * 0.4)			
Undiscounted	$0.3	$0.1	$0.5
3% discount rate	$0.3	$0.1	$0.4
7% discount rate	$0.2	$0.1	$0.3
Expected reduction due to rule[a]	**51.5%**	**40.1%**	---
Benefits attributable to rule — low	**$0.0**	**$0.0**	**$0.0**
Benefits attributable to rule — high			
Undiscounted	$0.2	$0.1	$0.2
3% discount rate	$0.1	$0.1	$0.2
7% discount rate	$0.1	$0.0	$0.2

[a] Estimated based on EPA's assumptions. EPA's assumption about the amount of electricity that will be produced in the future differs very slightly from DOE's. For the Great Lakes region the EPA and DOE estimates are the same.

Chapter G4: RUM Analysis

CHAPTER CONTENTS

INTRODUCTION

This case study uses a random utility model (RUM) approach to estimate the effects of improved fishing opportunities due to reduced impingement and entrainment (I&E) in the Great Lakes region. The Great Lakes region includes all facilities in scope of the Phase II rule that withdraw water from Lakes Ontario, Erie, Michigan, Huron, and Superior or are located on a waterway with open fish passage to a Great Lake and within 30 miles of the lake. The case study uses data from the Michigan Department of Natural Resources (MDNR) recreational angler survey (MDNR, 2002) conducted in 2001, which surveyed anglers at fishing sites on Lakes Michigan, Huron, Superior, and Erie. EPA applied benefits estimated for Michigan anglers to anglers in other Great Lakes states.

Cooling Water Intake Structures (CWIS) withdrawing water from the Great Lakes and connecting tributaries impinge and entrain many species sought by recreational anglers, including bass, perch, walleye, salmon, and other species. Accordingly, EPA included the following species groups in the model: bass-perch, walleye-pike, salmon-trout, and general.[1]

The study's main assumption is that, all else being equal, anglers will get greater satisfaction and thus greater economic value from sites with a higher catch rate. This benefit may occur in two ways: first, an angler may get greater enjoyment from a given fishing trip with higher catch rates, yielding a greater value per trip; second, anglers may take more fishing trips when catch rates are higher, resulting in greater overall value for fishing in the region.[2]

The following sections describe the data set used in the analysis and present analytic results. Chapter A11 of this report provides a detailed description of the RUM methodology used in this analysis.

G4-1 DATA SUMMARY

EPA's analysis of improvements in recreational fishing opportunities in the Great Lakes region relies on the Michigan Department of Natural Resources study: *Measurement of Sportfishing Harvest in Lakes Michigan, Huron, Erie, and Superior* (MDNR, 2002).[3] The model of recreational fishing behavior relies on a subset of the 2001 MDNR data for boat, shore, and

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[1] Bass-perch includes largemouth bass, rock bass, smallmouth bass, white bass, white perch, and yellow perch; walleye-pike includes muskellunge, tiger muskellunge, northern pike, and walleye; salmon-trout includes Atlantic trout, brook trout, brown trout, lake trout, rainbow trout, chinook salmon, coho salmon, pink salmon, siscowet, splake, and other salmon and trout; and the general category includes all of these species, plus all other species (including catfish, crappie, herring, whitefish, and pumpkinseed).

[2] MDNR did not collect the information needed to estimate a participation model. Therefore, the welfare estimates presented in this chapter are based on the baseline level of participation. This approach will underestimate total welfare effects, to the extent that the number of trips would increase with improved fishing quality.

[3] The data required to calculate a RUM model for other Great Lakes states were not available.

ice-fishing anglers, which included 9,256 anglers.[4] Anglers who live outside of Michigan and anglers who travel more than 120 miles one way to the fishing site were excluded.[5] EPA then randomly selected 10,000 anglers from the resulting data set.[6] After additional data cleaning, EPA estimated the RUM model using data for 9,256 anglers.

The Agency included both single- and multiple-day trips in estimating the total economic gain from improvements in fishing site quality from reduced I&E. Details of this analysis are provided in Section G4-3 of this report.

G4-1.1 Summary of Anglers' Characteristics

a. Fishing modes and targeted species

Table G4-1 presents summary statistics on fishing mode and targeted species for the RUM sample of anglers. Almost 66 percent of anglers in the sample fished from boats; 23 percent fished from piers, docks, or shore; and 11 percent fished from open ice or shanty. EPA did not estimate values by mode in the RUM model for two reasons. First, in testing different models, EPA found that values were fairly consistent across modes. Second, data are not available on numbers of trips by mode, so welfare estimation relies only on the total number of trips. Almost 59 percent of anglers target either salmon or trout species; 20.5 percent target bass or perch; 13.5 percent target walleye or pike; and 7.4 percent do not target a particular species.

Table G4-1: Mode Choice and Targeted Species

Fishing Mode	Number of Anglers	Percent of Sample
Boat	6,088	65.77%
Pier/Dock	882	9.53%
Shore	1,231	13.30%
Open Ice	831	8.98%
Shanty	224	2.42%
Targeted Species	**Number of Anglers**	**Percent of Sample**
Bass-Perch	1,895	20.47%
Walleye-Pike	1,249	13.49%
Salmon-Trout	5,427	58.63%
No Target	685	7.40%

Source: MDNR, 2002.

b. Anglers' characteristics

This section presents a summary of angler characteristics, for anglers in the RUM sample. Table G4-2 summarizes this information. On average, anglers in the case study area traveled 30.6 miles, one way, to the visited fishing site. The average round trip travel cost, excluding opportunity cost of time, was $21; and the average travel cost, including opportunity cost of time, was $31.46. The average angler in the Michigan survey fished for 3.8 hours on the intercepted trip. The MDNR study did not collect socio-economic data. Therefore, EPA used median household income data by zip code, from the 2000 U.S. Census, to approximate income data for survey respondents.[7] The average annual census data income for the respondent anglers was $39,151.

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[4] MDNR also surveys charter boat anglers. EPA did not include charter anglers in the model, because the charter data are not exactly comparable to the data from surveys of boat, shore and ice anglers.

[5] The MDNR data did not distinguish between single-day and multiple-day trips. Anglers who traveled more than 120 miles one way were excluded from the model, based on the assumption that these longer trips are most likely multiple-day trips.

[6] EPA decreased the size of the data set to accommodate software and computer resource limitations.

[7] Census data for median income by zip code are from Census Summary File 3 (U.S. Census Bureau, 2002).

Table G4-2: Data Summary for Anglers in the RUM Sample (N=9,256)

Variable	Mean Value	Std Dev	Minimum	Maximum
One Way Distance to Visited Site (Miles)	30.57	30.82	0.40	119.9
Trip Cost[a,c]	$21.09	$21.27	$0.28	$82.73
Travel Cost[a,c]	$31.46	$32.65	$0.43	$155.22
Household Income[c]	$39,151	$8,800	$11,667	$112,809
Average Hours Fished (n=44,933)[d]	3.79	2.46	0	19

[a] Trip cost is the round trip cost to the visited site, excluding opportunity cost of time.
[b] Travel cost is the round trip cost to the visited site, including opportunity cost of time.
[c] Calculation of these values is described in Section G4-1.4, below.
[d] Calculated for entire Michigan sample.

Sources: MDNR, 2002 and U.S. Census Bureau, 2002.

G4-1.2 Recreational Fishing Choice Sets

Figure G1-1 in Chapter G1 shows both the entire Great Lakes region and the geographic area included in the RUM analysis. To analyze welfare effects from I&E in the Great Lakes region, the Agency first modeled recreational anglers' behavior in the state of Michigan. This analysis includes only Great Lakes sites and sites on tributaries up to 30 miles from the lakes in the state of Michigan. EPA did not include other river and lake sites in the model, because catch rate data were not available for these sites, and because the large size of the resulting data set would lead to estimation problems.

MDNR provided data on site locations, catch rates, and other site characteristics, such as fish stocking and presence of boat ramps. Each angler's choice set was drawn from 105 Great Lakes sites in Michigan for which catch rate data were available over a five-year period (1997-2001). EPA initially included all 331 Great Lakes fishing sites in Michigan that were included in the MDNR database, interpolating catch rate values for sites without catch data. Inclusion of the interpolated catch rates did not produce satisfactory model results for no-target anglers. The results for target anglers were similar with and without the interpolated catch rates, so in the model reported here EPA included only sites with measured catch rates.

EPA selected each angler's choice set by, first, eliminating all sites farther than 120 miles from the angler's home zip code,[8] and then randomly selecting up to 74 sites per angler: 37 warm-water species sites and 37 cold-water species sites. Each angler's choice set, by definition, includes the site actually visited. For the final RUM model, EPA did not distinguish between warm-water and cold-water species groups. Therefore, the average number of sites in each angler's choice set for the RUM was 12, and ranged from 6 to 23 sites.[9]

G4-1.3 Site Attributes

This analysis assumes that the angler chooses among site alternatives based on catch rates at each site, and whether fish are stocked at the site. Catch rate is the most important attribute of a fishing site from the anglers' perspective (McConnell and Strand, 1994; Haab et al., 2000). This attribute is also a policy variable of concern because catch rate is a function of fish abundance, which is affected by fish mortality due to I&E. The catch rate variable in the RUM therefore provides the means to measure baseline losses in I&E and changes in anglers' welfare attributed to changes in I&E due to the final section 316(b) rule.

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[8] Agency's assumption for single-day anglers based on the 99th percentile for the distance traveled by single-day anglers to a fishing site in other regions.

[9] Originally, following Lupi and Hoehn (1997), EPA attempted to estimate a nested logit model, with separate nests for warm-water species/sites and cold-water species/sites. However, the model results were not as good as those from a single logit model, most likely due to a large overlap in warm- and cold-water species fishing sites.

To specify the fishing quality of the case study sites, EPA calculated historic catch rate based on MDNR creel surveys for the years 1997 to 2007 for recreationally important species: bass and perch, walleye and pike, salmon and trout, and a "general" catch rate, which includes these species plus all other species. The catch rates represent the number of fish caught on a fishing trip divided by the number of hours spent fishing (i.e., the number of fish caught per hour per angler). The estimated catch rates are averages across all anglers in a given year over the five-year period.

The catch rate variables include total catch, including fish caught and kept and fish released. Some studies use the catch-and-keep measure as the relevant catch rate. Although a greater error may be associated with measured number of fish not kept, the total catch measure is most appropriate because a large number of anglers catch and release fish. For anglers who don't target any species, EPA used the "general" catch rate to characterize fishing quality.

Table G4-3 summarizes average catch rates by species for all sites with data in the study area. Anglers who target bass or perch catch the most fish per hour, followed by anglers who target walleye or pike, and anglers who target salmon or trout.

Table G4-3: Average Catch Rates (1997-2001) for MI Great Lakes Sites with Measured Catch Rates (N=105) (number of fish per hour)

Species	Mean Value	Std Dev	Minimum	Maximum
Bass-Perch	0.8166	1.35	0	7.95
Walleye-Pike	0.2157	0.36	0	2.15
Salmon-Trout	0.126	0.11	0	0.67
General	0.2861	0.28	0	1.54

Source: MDNR, 2002.

In addition to catch rates, anglers may view boat launching facilities and fish stocking at a site as important factors that may affect their site choice. EPA therefore included dummy variables in the model to indicate whether a site had boat launch facilities, and whether stocking occurs at each site. The boat launch dummy was not statistically significant, so only the stocking dummy was including in the final model. Each stocking site was linked to the closest survey site within 1 kilometer. Of the 105 sites with measured catch rates, 56 (53.3 percent) had stocking sites within 1 kilometer.

G4-1.4 Travel Cost

EPA used ArcView 3.2a software to estimate distances from each angler's zip code to each fishing site. The Agency obtained fishing site locations from a database supplied by the MDNR. The distance estimation program measured the distance in miles for the shortest route, using state and U.S. highways, from the household zip code to each fishing site, then added the distances from the zip code location to the closest highway and from the site location to the closest highway. The average one way distance to the visited site for all modes is 30.6 miles.

EPA estimated trip "price" as the sum of travel costs plus the opportunity cost of time following the procedure described in Haab et al. (2000). Based on Parsons and Kealy (1992), this study assumed that time spent "on-site" is constant across sites and can be ignored in the price calculation. To estimate anglers' travel costs, EPA multiplied round trip distance by average motor vehicle cost per mile ($0.345, 2001 dollars).[10] To estimate the opportunity cost of travel time, EPA first divided round trip distance by 40 miles per hour to estimate trip time, and next used one third of the household's wage to yield the opportunity cost of time. EPA estimated household wage by dividing household income by 2,080 (i.e., the number of full time hours potentially worked).

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[10] EPA used the 2001 government rate ($0.345) for travel reimbursement to estimate travel costs per mile traveled. This estimate includes vehicle operating cost only.

EPA calculated visit price as:

$$Visit\ Price = (Round\ Trip\ Distance \times \$.345) + \left[\frac{Round\ Trip\ Distance}{40\ mph} \times (Wage) \times 0.33 \right] \qquad (G4\text{-}1)$$

G4-2 SITE CHOICE MODELS

EPA used a RUM model, as described in Chapter A11 of this report, to estimate anglers' site choices. The model assumes that the individual angler makes a choice among mutually exclusive site alternatives based on the attributes of those alternatives. EPA identified each angler's choice set based on a travel distance constraint. All fishing sites within a 120 mile distance from the angler's hometown are eligible for inclusion in the angler's choice set. To prevent the model from becoming overly complex, EPA estimated the site choice model using the site actually visited and up to 22 randomly drawn sites from the choice set for each angler.

An angler's choice of sites relies on utility maximization. An angler will choose site *j* if the utility (u_j) from visiting site *j* is greater than that from vising other sites (*h*), such that:

$$u_j > u_h \qquad for\ h = 1, \ldots J\ and\ h \neq j \qquad (G4\text{-}2)$$

Recreational fishing models generally assume that anglers first choose a fishing mode (i.e., boat or shore) and species (e.g., warm water or cold water), and then a site. Instead of incorporating the angler's decision regarding the mode of fishing and target species in the model, the Agency assumed that the mode/species choice is exogenous to the model and the angler simply chooses the site. EPA used the following general model to specify the deterministic part of the utility function:

$$v_j = f\,(TC_j\ STOCK_j,\ TARGET_s * \sqrt{CATCH_{sj}}) \qquad (G4\text{-}3)$$

where:

v_j = the expected utility for site *j* (*j*=1,...105);
TC_j = travel cost to site *j*;
$STOCK_j$ = fish stocking at site *j*;
$TARGET_s$ = dummy variable indicating whether species *s* is targeted or not; and
$CATCH_{sj}$ = catch rate for species s at site *j*.

Table G4-4 gives the parameter estimates for this model.

Table G4-4: Estimated Coefficients for the Conditional Site Choice Model

Variable	Estimated Coefficient	t-statistic
TRAVEL COST	-0.0501	-84.24
SQRT(BASS-PERCH)	1.4185	33.23
SQRT(WALLEYE-PIKE)	3.0271	23.70
SQRT(SALMON-TROUT)	3.1975	25.46
SQRT(GENERAL)	0.9351	5.59
STOCK	0.5121	19.28

Source: U.S. EPA analysis for this report.

Table G4-4 shows that all coefficients have the expected signs and are statistically significant at the 99th percentile. Travel cost has a negative effect on the probability of selecting a site, indicating that anglers prefer to visit sites closer to their homes (other things being equal). A positive sign on the stock variable indicates that anglers are more likely to choose sites where fish are stocked.

EPA estimated a number of model specifications, including models that allowed values to vary by fishing mode, and a nested model that distinguished between cold- and warm-water species. The Agency found the model presented here provided the best fit for the data.

G4-3 WELFARE ESTIMATES

This section presents estimates of welfare losses to recreational anglers from fish mortality due to I&E, and potential welfare gains from improvements in fishing opportunities due to reduced fish mortality stemming from the final section 316(b) rule.

G4-3.1 Estimating Changes in the Quality of Fishing Sites

To estimate changes in the quality of fishing sites under different policy scenarios, EPA used estimates of recreational losses from I&E, combined with recreational fishery landings data by state. I&E affects recreational species in two ways: by directly killing recreational species, and by killing forage species, thus indirectly affecting recreational species through the food chain. The indirect effects on recreational species were calculated in two steps. First, EPA estimated the total number of fish lost due to forage fish losses. Second, EPA allocated this total number of fish among recreational species according to each species' percent of total recreational landings.

EPA obtained recreational landings data from each state in the Great Lakes region: New York, Pennsylvania, Ohio, Michigan, Illinois, Indiana, Wisconsin, and Minnesota. Some states reported both the number of fish harvested and the total number of fish caught, which includes fish caught and released. EPA used the total number of fish caught to measure total landings. For states that only reported fish harvested, EPA adjusted harvest figures upward, using adjustment factors based on the average proportion of catch to harvest in Indiana, Pennsylvania, and Michigan, the three states that reported both values. The adjustment factors ranged from 1.09 for walleye to 9.28 for bass.

The Agency estimated changes in the quality of recreational fishing sites under different policy scenarios in terms of the percentage change in the historic catch rate. The Agency assumed that catch rates will change uniformly across all fishing sites in the region where each species is found.[11,12] For each species included in the model, EPA used five-year recreational landings data (1997-2001) to calculate average landings per year. EPA then divided losses to the recreational fishery from I&E by the total recreational landings for the region to calculate the percent change in historic catch rate from eliminating I&E completely. Table G4-5 presents results of this analysis. Table G4-6 presents estimated improvements in catch rates, over baseline losses, for the preferred technology option at each facility. The preferred technology is estimated to reduce impingement by 51.5 percent, and entrainment by 40.1 percent.

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[11] This assumption may not hold across lakes, as some lakes (e.g., Lakes Michigan and Erie) have more facilities, and therefore are likely to have greater benefits from reduced I&E. However, data were not sufficient to estimate welfare changes by lake.

[12] Fish lost to I&E are most often very small fish, which are too small to catch. Because of the migratory nature of most affected species, by the time these fish have grown to catchable size, they may have traveled some distance from the facility where I&E occurs. Without collecting extensive data on migratory patterns of all affected fish, it is not possible to evaluate whether catch rates will change uniformly or in some other pattern. Thus, EPA assumed that catch rates will change uniformly across each lake.

Table G4-5: Estimated Changes in Catch Rates from Eliminating all I&E of Affected Species in the Great Lakes Region

Species	Total Recreational Losses from I&E (number of fish)	Total Recreational Landings (fish per year)	Percent Increase in Recreational Catch from Elimination of I&E
Bass-Perch	1,466,453	13,856,741	10.58%
Walleye-Pike	94,289	1,693,872	5.57%
Salmon-Trout	120,661	1,905,185	6.33%
No Target/General[a]	3,061,981	28,885,829	6.61%

[a] Total landings for the no target/general category include all fish reported in catch or harvest data by each state. Total recreational losses for this category are the sum of losses over all species.

Sources: MDNR, 2002; U.S. EPA analysis for this report.

Table G4-6: Estimated Changes in Catch Rates from Reducing I&E of Affected Species in the Great Lakes Region under the Preferred Technology Option

Species	Total Recreational Losses from I&E (number of fish)	Total Recreational Landings (fish per year)[a]	Percent Increase in Recreational Catch from Reduction of I&E
Bass-Perch	692,338	13,856,741	5.0%
Walleye-Pike	46,874	1,693,872	2.77%
Salmon-Trout	60,360	1,905,185	3.22%
No Target/General[a]	1,484,324	28,885,829	3.20%

[a] Total landings for the no target/general category include all fish reported in catch or harvest data by each state. Total recreational losses for this category are the sum of losses over all species.

Sources: MDNR, 2002; U.S. EPA analysis for this report.

G4-3.2 Estimating Losses from I&E in the Great Lakes

The recreational behavior model described in the preceding sections provides a means for estimating the economic effects of recreational fishery losses from I&E in the Great Lakes region. First, EPA estimated welfare gain to recreational anglers from eliminating fishery losses due to I&E. This estimate represents economic damages to recreational anglers from I&E of recreational fish species in the Great Lakes region under the baseline scenario. EPA then estimated benefits to recreational anglers from implementing the preferred CWIS technologies.

EPA estimated anglers' willingness-to-pay (WTP) for improvements in the quality of recreational fishing by first calculating an average per-day welfare gain based on the expected changes in catch rates from eliminating I&E. Table G4-7 presents the compensating variation per trip (averaged over all anglers in the sample) associated with reduced fish mortality from eliminating I&E for each fish species group of concern, and the per-trip welfare gain attributable to reduced I&E resulting from the preferred technology option.[13] Table G4-7 also shows the per-trip welfare gain for a one fish increase in catch rates.

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[13] A compensating variation equates the expected value of realized utility under the baseline and post-compliance conditions. For more detail, see Chapter A11 of this report.

Table G4-7: Per-Trip Welfare Gain from Eliminating I&E and I&E Reductions with the Preferred Technology in the Great Lakes Region

Targeted Species Group	Per-Trip Welfare Gain (2002$)		WTP for an Additional Fish per Trip (2002$)
	Eliminating I&E	Reduced I&E with Preferred Technology	
Bass-Perch	$2.37	$1.13	$3.11
Walleye-Pike	$1.18	$0.59	$11.55
Salmon-Trout	$0.81	$0.42	$15.11
General - No Target	$0.33	$0.16	$3.60

Source: U.S. EPA analysis for this report.

Table G4-7 shows that anglers targeting bass or perch have the largest per-trip gain ($2.37) from eliminating I&E; followed by anglers targeting walleye or pike ($1.18), anglers targeting salmon or trout ($0.81), and no-target anglers ($0.33). Table G4-7 also reports the WTP for a one-unit increase in historic catch rate by species. For anglers who target a particular species, salmon and trout are the most highly valued fish, followed by walleye and pike, and bass and perch. The values for a one fish increase in catch are consistent with values estimated in other studies (Whitehead and Aiken, 2000; Lupi and Hoehn, 1997).

EPA calculated the total economic value of eliminating I&E in the Great Lakes region by multiplying the estimated per-trip welfare gain by the total number of fishing days in the region. The Great Lakes data did not indicate whether a trip was a single- or multiple-day trip. EPA assumes that by limiting travel distance in selecting angler's choice sets, the Agency has eliminated most multiple-day trips from the data. Therefore, EPA assumes that per-trip values as estimated in the model are equivalent to per-day values.

EPA obtained data on the total number of fishing days from the U.S. Fish and Wildlife Services' (FWS) annual survey of fishing, hunting, and wildlife-related recreation (U.S. Fish and Wildlife Service, 2001). This total number of fishing days includes both single- and multiple-day trips. Table G4-8 presents the number of fishing days by species. The number of days presented for each species in the table were adjusted downward from the FWS totals to avoid double counting of days per species.[14]

Table G4-8: Recreational Fishing Participation in 2001, by Species, for the Great Lakes Region

Species	Total Number of Fishing Days per Year
Bass-Perch	8,038,933
Walleye-Pike	4,295,665
Salmon-Trout	8,467,817
No Target	1,237,618
All Other Species	1,097,967

Source: U.S. Fish and Wildlife Service, 2001.

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[14] Some anglers surveyed by FWS reported targeting more than one species. Therefore, EPA adjusted the total number of days per species to add up to the total number of reported fishing days for all species. EPA multiplied the total reported days for each species by that species' portion of total days for all species.

The Agency assumed that the welfare gain per day of fishing is independent of the number of days fished per trip and therefore equivalent for both single- and multiple-day trips.[15] Each day of a multiple-day trip is valued the same as a single-day trip. In the Great Lakes region, anglers who target salmon or trout fish the most days, followed by anglers who target bass or perch, anglers who target walleye or pike, anglers targeting any species (i.e., no-target anglers), and anglers who target all other species. When estimating total welfare, EPA used the no-target per-day welfare estimates to estimate welfare changes for anglers who target all other species.[16]

The estimated number of trips represents the baseline level of participation. Anglers may take more fishing trips as recreational fishing circumstances change. However, EPA was unable to estimate a trip participation model for the Great Lakes, because the required data were not available. Therefore, the welfare estimates presented here do not account for likely increases in the number of trips due to elimination of I&E, and thus understate total welfare effects.

Tables G4-9 and G4-10 provide total annual welfare estimates for two policy scenarios. These values were discounted, to reflect the fact that fish must grow to a certain size before they will be caught by recreational anglers. EPA calculated discount factors separately for I&E of each species. To estimate discounted total benefits, EPA calculated weighted averages of these discount factors for each species group, and applied them to estimated WTP values. Discount factors were calculated for both a 3 percent discount rate and a 7 percent discount rate. For the preferred technology option, an additional discount factor was applied to account for the 1-year lag between the date when installation costs are incurred and the installation of the required cooling water technology is completed.

Table G4-9 presents annual losses to recreational anglers from baseline I&E effects in the Great Lakes region. Total recreational losses (2002$) to Great Lakes anglers, before discounting, from I&E of bass, perch, walleye, pike, and other species are $31.7 million per year. Total discounted baseline losses are $29.4 million, discounted using a 3 percent discount rate; and $26.7 million, discounted using a 7 percent discount rate.

Table G4-10 presents the annual welfare gain to recreational anglers resulting from installation of the preferred CWIS technology at Great Lakes facilities. Total undiscounted gain to recreational anglers is $15.5 million under the preferred technology option. Total discounted gain is $13.9 million, discounted using a 3 percent discount rate; and $12.2 million, discounted using a 7 percent discount rate.

Table G4-9: Total Estimated Annual Baseline Losses from I&E for Great Lakes Anglers (2002$)

Species	Total Losses Before Discounting	Total Losses with 3% Discounting	Total Losses with 7% Discounting
Bass-Perch	$19,053,075	$17,597,267	$15,937,097
Walleye-Pike	$5,064,160	$4,639,135	$4,167,403
Salmon-Trout	$6,887,722	$6,456,509	$5,973,391
No Target (Anything)	$406,310	$374,458	$338,613
Other Targets	$360,463	$331,084	$298,419
Total Recreational Use Losses	$31,771,730	$29,398,453	$26,714,923

Source: U.S. EPA analysis for this report.

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[15] See section G4-4.2 for limitations and uncertainties associated with ths assumption.

[16] Other species that are affected by I&E include crappie, sunfish, catfish, whitefish, rainbow smelt, and bluegill.

Table G4-10: Total Estimated Annual Welfare Gain to Great Lakes Anglers Under the Preferred Technology Option (2002$)

Species	Total Before Discounting	Total with 3% Discounting	Total with 7% Discounting
Bass-Perch	$9,083,190	$8,151,197	$7,114,519
Walleye-Pike	$2,530,147	$2,251,517	$1,948,356
Salmon-Trout	$3,525,999	$3,209,732	$2,859,389
No Target (Anything)	$198,390	$177,587	$154,691
Other Targets	$176,004	$156,970	$136,231
Total Recreational Use Losses	$15,513,730	$13,947,003	$12,213,186

Source: U.S. EPA analysis for this report.

G4-4 LIMITATIONS AND UNCERTAINTIES

G4-4.1 Considering Only Recreational Values

This study understates the total benefits of improvements in fishing site quality because estimates are limited to recreation benefits. Many other forms of benefits, such as habitat values for a variety of species (in addition to recreational fish), non-use values, etc., are also likely to be important.

G4-4.2 Modeling

a. Multiple-day trips

The Michigan survey data did not distinguish between single-day and multiple-day trips. EPA deleted all trips with one way travel distance greater than 120 miles, assuming that most of these trips would be multiple-day trips. It is possible that anglers who take multiple-day trips have different values for fishing site quality than anglers who take single-day trips. EPA estimated total welfare using data provided by the FWS on total number of fishing days in the Great Lakes, including both single-day and multiple-day trips. It is not clear how these issues will affect total welfare.

b. Substitute sites

Due to data and software limitations, inland sites (i.e., fishing sites not located on the Great Lakes or their tributaries) were not included in the RUM model. Thus, the model did not include the full range of substitute sites for each angler. However, it is likely that other inland sites do not provide close substitutes to Great Lakes fishing sites. In addition, the RUM model included a large number of sites for each angler.

G4-4.3 Data

a. Estimates of total recreational landings

EPA did not have total catch (i.e., catch and release plus catch and keep) data for all Great Lakes states. Five of the eight Great Lakes states only provided data on harvest (i.e., catch and keep). Therefore, EPA adjusted harvest estimates to total catch estimates based on the percent difference between harvest and catch and release for the three states that reported both. For yellow perch, walleye, and salmon-trout, the adjustment factors were similar across the three states for which data were available. For bass, the adjustment factor ranged from 2.6 to 15.8, with an average of 9.3. Therefore, it is likely that the bass adjustment factor differs across the other five states. It is not possible to determine whether, on average, these variations would result in higher or lower estimated changes in catch rates.

b. Survey sampling effects

Recreational demand studies frequently face observations that do not fit general recreation patterns, such as observations of avid participants. These observations tend to be overly influential even when the reports are correct (Thomson, 1991).

G4-4.4 Assumption of Uniform Change in Catch Rates Across All Lakes

Each of the Great Lakes has a different number of power plants, and therefore will have different levels of losses caused by I&E. For this study, EPA averaged I&E losses over all lakes, and assumed that catch rates would change uniformly across lakes with elimination or reduction of I&E. While this is not a completely realistic assumption, the data were not sufficient to estimate separate welfare changes for each lake. Therefore, the total welfare could be either overstated or understated.

G4-4.5 Extrapolation of Michigan Values to Other Great Lakes States

EPA estimated recreational fishing values for the Great Lakes using data for the state of Michigan only. The benefit estimates from Michigan were applied to all other states in the Great Lakes region. This may result in either overstatement or understatement of total benefits for the Great Lakes, depending on how recreational fishing values vary across states. Recreational fishing values depend on availability of substitute sites and presence and abundance of recreational species, among other things.

Chapter G5: Non-Use Benefits

INTRODUCTION

CHAPTER CONTENTS

Aquatic species without any direct uses account for the majority of losses due to impingement and entrainment (I&E) at cooling water intake structures (CWIS). However, EPA's analysis of direct use benefits includes values only for organisms with direct uses, which comprise a very small percentage of total losses (approximately two percent). Because the other 98 percent of losses, consisting of organisms without direct uses, are not without value, the potential exists for significant non-use values that have not been addressed under EPA's estimation of use benefits. For this reason it is important to consider non-use benefits to the human population, produced by the increased numbers of organisms without direct use values, under the final section 316(b) rule.

One way to consider the impact of the section 316(b) rule is to estimate the non-use value of baseline I&E losses and I&E reductions due to the final rule for each case study region using the non-use meta-analysis results. The non-use meta-analysis is presented in detail in Chapter A12, Non-Use Meta-Analysis Methodology, which includes discussions of the literature review process, the estimated regression models and results, and the general methodology used to estimate household and aggregate non-use benefits based on regression results. Total regional non-use benefits can be estimated using the following three steps:

1. Estimate annual changes in non-use value of the affected fishery resources per household due to the baseline impingement and entrainment (I&E) losses and the post-compliance reduction in impingement and entrainment;

2. Estimate the population of households in the Great Lakes region holding non-use value for the affected resources; and

3. Estimate the total non-use value to the affected Great Lakes populations for completely eliminating baseline I&E losses, and for reducing I&E losses from the baseline to post-compliance levels.

EPA explored this approach for the Great Lakes region. However, EPA did not include the results of this approach in the benefit analysis because of limitations and uncertainties associated with estimation of non-use benefits on a regional scale. For further discussion of the limitations and uncertainties of this method, refer to Chapter A12.

G5-1 QUALITATIVE ASSESSMENT OF ECOLOGICAL BENEFITS FOR THE GREAT LAKES REGION

Changes in CWIS design or operations resulting from the section 316(b) regulations for existing facilities are expected to reduce I&E losses of fish, shellfish, and other aquatic organisms and, as a result, are expected to increase the numbers of individuals present, increase local and regional fishery populations, and ultimately contribute to the enhanced environmental functioning of affected waterbodies (rivers, lakes, estuaries, and oceans) and associated ecosystems. The economic welfare of human populations is expected to increase as a consequence of the improvements in fisheries and associated aquatic ecosystem functioning.

The aquatic resources affected by cooling water intake structures provide a wide range of services. Ecosystem services are the physical, chemical, and biological functions performed by natural resources and the human benefits derived from those functions, including both ecological and human use services (Daily, 1997; Daily et al., 1997). Scientific and public interest in protecting ecosystem services is increasing with the recognition that these services are vulnerable to a wide range of human activities and are difficult, if not impossible, to replace with human technologies (Meffe, 1992).

In addition to their importance in providing food and other goods of direct use to humans, the organisms lost to I&E are critical to the continued functioning of the ecosystems of which they are a part. Fish are essential for energy transfer in aquatic food webs, regulation of food web structure, nutrient cycling, maintenance of sediment processes, redistribution of bottom substrates, the regulation of carbon fluxes from water to the atmosphere, and the maintenance of aquatic biodiversity (Peterson and Lubchenco, 1997; Postel and Carpenter, 1997; Holmund and Hammer, 1999; Wilson and Carpenter, 1999). Examples of ecological and public services disrupted by I&E include:

- decreased numbers of ecological keystone, rare, or sensitive species;
- decreased numbers of popular species that are not fished, perhaps because the fishery is closed;
- decreased numbers of special status (e.g., threatened or endangered) species;
- increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E;
- disruption of ecological niches and ecological strategies used by aquatic species;
- disruption of organic carbon and nutrient transfer through the food web;
- disruption of energy transfer through the food web;
- decreased local biodiversity;
- disruption of predator-prey relationships;
- disruption of age class structures of species;
- disruption of natural succession processes;
- disruption of public uses other than fishing, such as diving, boating, and nature viewing; and
- disruption of public satisfaction with a healthy ecosystem.

Many of these services can only be maintained by the continued presence of all life stages of fish and other aquatic species in their natural habitats.

The traditional approach of EPA and other natural resource agencies to quantifying the environmental benefits of proposed regulations has focused on active use values, particularly direct use values such as recreational or commercial fishing. Nonconsumptive uses (such as the importance of fish for aquatic food webs), and passive use or non-use values (including the value of protecting a resource for its own sake), are seldom considered because they are difficult to monetize with available economic methods. However, even though economists debate methods for indirect and non-use valuation, there is general agreement that these values exist and can be important. The potential magnitude of non-use values remains an empirical matter. EPA believes that non-use values are applicable for the section 316(b)-related I&E and that these values are likely to be appreciable for the Great Lakes region.

Chapter G6: Habitat Based Analysis

CHAPTER CONTENTS

INTRODUCTION

Aquatic species without primary or direct uses account for the majority of losses at cooling water intake structures (CWIS). These species are not, however, without value to society. It is important to consider the non-use benefits to the human population produced by the increased number of these fish under the final section 316(b) rulemaking.

One way to put impingement and entrainment (I&E) losses into perspective is to value the habitat necessary to replace the lost organisms. The value of fish habitat can then provide an indirect basis for valuing the fish that are supported by the habitat.

EPA explored this approach for the Great Lakes region. However, EPA did not include the results of this approach in the benefit analysis because of certain limitations and uncertainties regarding the application of this methodology to the national level. These limitations and uncertainties are discussed in Chapter A15. Thus, this chapter outlines the approach explored by EPA, but does not present benefit estimates.

The approach discussed here uses values that survey respondents indicated for preservation/restoration of wetlands to evaluate losses of fishery resources in the Great Lakes region. This analysis is not intended to value directly benefits provided by the lost fish and shellfish, but to provide another perspective on the I&E losses by looking at values of habitat necessary to replace them. The method first estimates the quantity of wetland habitat required to replace fish and shellfish lost to I&E, and then assesses respondents' values for these habitats. These data are then combined to yield an estimate of household values for improvements in fish and shellfish habitat, which provides an indirect estimate of the benefits of reducing or eliminating I&E.

This benefit transfer approach involves three general steps, described in detail in Chapter A15:

1. Estimate the amount of restored wetlands needed to produce organisms at a level necessary to offset I&E losses for the subset of species for which potential production information is available.
2. Develop willingness-to-pay (WTP) values for fish production services of wetlands ecosystems.
3. Estimate the total value of baseline I&E losses by multiplying the WTP values for fish and shellfish services of restored wetlands by the number of acres needed to offset I&E losses.
4. Estimate the total benefits of the final section 316(b) rule, in terms of the value of decreased I&E losses, by multiplying the WTP values for fish and shellfish services of restored habitat by the number of acres of each habitat type needed to offset decreased I&E losses.

The rest of this chapter outlines EPA's exploratory application of this method to the Great Lakes region.

G6-1 DATA SUMMARY

EPA used available fish sampling data for Great Lakes wetland habitat (Brazner, 1997; personal communication, J. Brazner, U.S. EPA, 2001) to determine the number of acres required to offset I&E losses. To estimate public WTP, EPA used information from two studies of public values for wetlands: a study of the Maumee River Basin, located in the northwestern corner of Ohio near Lake Erie (de Zoysia, 1995); and a stated preference study from Narragansett Bay, Rhode Island (Johnston et al., 2002). These studies are described in detail in Chapter A15.

EPA based the benefit transfer of total value for fish habitat provided by wetlands on the Maumee River Basin study. Conducted in 1994, the study describes wetlands as providing a number of functions, including waterfowl and other bird habitat, fish nursery habitat, endangered species habitat, and water purification services. Thus, EPA assigned only part of the estimated WTP for wetlands restoration to fish habitat services, based on results from the Johnston et al. (2002) study.

G6-2 BENEFIT TRANSFER FOR THE GREAT LAKES REGION

G6-2.1 Estimating the Amount of Wetlands Needed to Offset Losses for Specific Species

The first step in the analysis involves calculating the estimated area of wetland habitat needed to offset I&E losses for the subset of species for which this habitat is limiting and for which production information is available. Details of this analysis are presented in Appendix G2. Based on a commonly used restoration scaling rule, the estimates of the acres of wetlands restoration needed to offset losses of these I&E species is based on the acreage needed for the species requiring the maximum quantity of habitat.

For any given species, the number of acres of restored habitat needed to offset I&E losses is determined by dividing the species average annual age one equivalent I&E loss by its estimated abundance per acre in that habitat.

G6-2.2 Estimating the Proportion of Wetland Value Attributable to Fish Habitat

Because fresh water wetlands provide a number of services such as bird habitat, water purification, and fish nursery habitat, EPA attempted to separate values for fish habitat from values for other wetland services. Given survey data available from the Maumee River Basin study, however, there is no direct means to estimate the proportion of total wetland value associated with fish habitat services alone. EPA therefore used the stated preference study from Narragansett Bay, Rhode Island, to adjust wetland values to reflect fish habitat services (Johnston et al., 2002). As discussed in Chapter A15, section A15-2.4, EPA used the results of the study to estimate the proportion of total WP value for wetlands that can be attributed to fish production services. Based on the Agency’s calculations, 25.64 percent of total wetland restoration value is attributable to gains in fish habitat services, given representative, mean values for other wetland services.

Despite the fact that the Maumee River Basin study evaluated the importance of fresh water wetlands, and the Narragansett Bay study was conducted for coastal wetlands, EPA believes that the Narragansett Bay study is still applicable, for three main reasons:

1. According to the Maumee River Basin study survey, the services provided by fresh water wetlands include waterfowl and other bird habitat, fish nursery habitat, other endangered species habitat, and water purification services. The services listed in Johnston et al. (2002) for coastal wetlands include bird habitat services, fish habitat services, shellfish habitat services, and mosquito control. Because of the similarities between these services, EPA believes that the proportion from the Johnston et al. (2002) study that was calculated for use with the Peconic Estuary study can be applied to the results from the Maumee River Basin study.

2. This result is similar to the result from a study of fresh water wetlands by Schultze et al. (1995), which estimated that between 32.98 percent and 33.44 percent of WTP for resource cleanup in the Clark Fork River Basin was associated with “aquatic resources and riparian habitat.”

3. Based on the results of EPA's analysis, the proportions of total value attributable to the four dominant wetland services in Narragansett Bay (bird habitat services, fish habitat services, shellfish habitat services, and mosquito control) are very similar. Each service provides roughly 25 percent of the total marginal utility associated with the combination of habitat improvements and mosquito control. This correspondence suggests that restoration providing similar scale improvements for each of these services should produce a roughly equivalent increment to utility. For wetlands that do not provide substantial access provisions (e.g., boardwalks) and that are of moderate or small size, it would be highly improbable for the proportion of value associated with fish habitat to fall significantly below the 25.64 percent approximation estimated here.

G6-2.3 Values per Acre of Wetlands for the Maumee River Basin

EPA first multiplied the value per household by the 25.64 percent, the proportion of wetlands value attributed to fish habitat, to get the value per acre per household for fish habitat services of wetlands. This value is $.0064 per acre per household. The Agency then multiplied this value per acre by the total number of households in the Maumee River Basin study area (235,721), yielding the value per acre of wetlands for the population surrounding the Maumee River Basin. The Maumee study defined the affected population as the total number of households in the 15 counties located in the Maumee River Basin. For this region, the total annual value per acre for fish habitat services of wetlands is $1,507.12. Table G6-1 shows these values.

Table G6-1: Estimated WP Values for Fish Habitat Services Provided by Wetlands from the Maumee River Basin Study (2002$)

	$/HH/Acre/Year[a]	Total WP/Acre/Year[b]
Total Value	$0.0064	$1,507.12

[a] Values shown are WP per household per *additional* (i.e, marginal) acre per year.

[b] Total WP per acre is calculated as household WP per acre times 235,721 total households in the study area.

G6-2.4 Applicability of Study Area to Policy Area

The values from the Maumee River Basin study were not adjusted to reflect the socioeconomic and demographic characteristics of the Great Lakes region. This creates uncertainty in the analysis. However, a comparison of selected demographic characteristics of residents of the Maumee River area to residents in the area around one facility — the JR Whiting facility — shows that their residents have similar levels of education and income. Respondents to the Maumee River Basin survey had a similar level of household income, and slightly more years of education. EPA believes that adjustment for socioeconomic differences is not necessary, given the minor differences in education and income between the two areas. Table G6-2 presents median household income and highest level of educational attainment for respondents to the Maumee River Basin survey, for residents of the Maumee River Basin study area, for residents in counties abutting Lake Erie, and for residents in abutting counties or within 32.4 miles of JR. Whiting.

Table G6-2: Comparison of the Income and Educational Attainment of the Maumee River Basin Study Area and the JR. Whiting Case Study Area

Population	Median Household Income (2002$)[a]	Percent of Residents, 25 Years of Age or Older, by Highest Level of Educational Attainment			
		Some or No High School	High School	Some College	College
Respondents to the Maumee River Basin survey	$46,922	14%	55%		31%
Residents in 13 counties in Maumee River Basin study area	$44,077	16%	39%	20%	25%
Residents in counties abutting Lake Erie near JR. Whiting	$46,880	17%	34%	23%	27%
Residents in abutting counties plus residents within 32.4 miles of JR. Whiting	$46,615	20%	31%	23%	27%

[a] For respondents to the Maumee River Basin survey, this table presents mean household income instead of median household income.

Sources: U.S. Census Bureau, 2000; de Zoysia, 1995.

G6-2.5 Determining the Affected Population

Evaluating the total value per acre of wetlands for the coastal population of the Lake Erie area requires a definition of the geographical extent of the affected population. The Maumee River Basin study defined the affected population as the total number of households in counties within the Maumee River Basin. Similarly, as described in Chapter A15, EPA defined the affected population for the Great Lakes region as households residing in the counties that:

1. Abut the affected water bodies; and
2. Are located within 10 miles of the facility.

These households are likely to value gains of fish in the affected water body, due to their close proximity to the affected resource.

As discussed further in Chapter A15, households in counties that do not directly abut the affected water bodies will also likely value the water body's resources.

G6-2.6 Habitat Values per Acre for the Affected Population

The total value per acre for the affected population is calculated by multiplying the value per acre per household by the total number of affected households.

G6-2.7 Estimating the Value of Habitat Needed to Offset I&E Losses for the Region

Due to limitations and uncertainties that make this valuation approach difficult to implement on a regional scale, EPA does not present aggregate values for I&E losses. These values would be calculated by multiplying the total number of acres of each habitat required to offset losses by the value per acre for the affected population.

G6-3 LIMITATIONS AND UNCERTAINTY

A number of issues are common to all benefit transfers. Benefit transfer involves adapting research conducted for another purpose in the available literature to address the policy questions at hand. Because benefits analysis of environmental regulations rarely affords enough time to develop original stated preference surveys that are specific to the policy effects, benefit transfer is often the only option to inform a policy decision. Specific issues associated with this approach are discussed in Chapter A15.

Appendix G1: Life History Parameter Values Used to Evaluate I&E in the Great Lakes Region

The tables in this appendix summarize the life history parameter values used by EPA to calculate age 1 equivalents, fishery yield, and production foregone from I&E data for the Great Lakes region.

Table G1-1: Alewife Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lb)
Eggs	11.5	0	0	0.00000128
Larvae	5.50	0	0	0.00000141
Juvenile	6.21	0	0	0.00478
Age 1+	0.500	0	0	0.0160
Age 2+	0.500	0	0	0.0505
Age 3+	0.500	0	0	0.0764
Age 4+	0.500	0	0	0.0941
Age 5+	0.500	0	0	0.108
Age 6+	0.500	0	0	0.130
Age 7+	0.500	0	0	0.149

Sources: Froese and Pauly, 2003; NMFS, 2003a; PG&E National Energy Group, 2001; and Spigarelli et al., 1981.

Table G1-2: Bass Species (Micropterus sp.) Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000731
Larvae	2.70	0	0	0.0000198
Juvenile	0.446	0	0	0.0169
Age 1+	0.860	0	0	0.202
Age 2+	1.17	0.32	0.50	0.518
Age 3+	0.755	0.21	1.0	0.733
Age 4+	1.05	0.29	1.0	1.04
Age 5+	0.867	0.24	1.0	1.44
Age 6+	0.867	0.24	1.0	2.24
Age 7+	0.867	0.24	1.0	2.56
Age 8+	0.867	0.24	1.0	2.92
Age 9+	0.867	0.24	1.0	3.30

[a] Includes largemouth bass, smallmouth bass, and other sunfish not identified to species level.

Sources: Bartell and Campbell, 2000; Carlander, 1977; Froese and Pauly, 2001; NMFS, 2003a; Scott and Crossman, 1973; and Wang, 1986.

Table G1-3: Black Bullhead Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.0000312
Larvae	4.61	0	0	0.000186
Juvenile	1.39	0	0	0.00132
Age 1+	0.446	0	0	0.0362
Age 2+	0.223	0.22	0.50	0.0797
Age 3+	0.223	0.22	1.0	0.137
Age 4+	0.223	0.22	1.0	0.233
Age 5+	0.223	0.22	1.0	0.402
Age 6+	0.223	0.22	1.0	0.679
Age 7+	0.223	0.22	1.0	0.753
Age 8+	0.223	0.22	1.0	0.815
Age 9+	0.223	0.22	1.0	0.823

Sources: Carlander, 1969; Froese and Pauly, 2001; Geo-Marine Inc., 1978; NMFS, 2003a; and Scott and Crossman, 1973.

Table G1-4: Black Crappie Life History Parameter

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.80	0	0	0.000000929
Larvae	0.498	0	0	0.00000857
Juvenile	2.93	0	0	0.0120
Age 1+	0.292	0	0	0.128
Age 2+	0.292	0.29	0.50	0.193
Age 3+	0.292	0.29	1.0	0.427
Age 4+	0.292	0.29	1.0	0.651
Age 5+	0.292	0.29	1.0	0.888
Age 6+	0.292	0.29	1.0	0.925
Age 7+	0.292	0.29	1.0	0.972
Age 8+	0.292	0.29	1.0	1.08
Age 9+	0.292	0.29	1.0	1.26

Sources: Bartell and Campbell, 2000; Carlander, 1977; Froese and Pauly, 2001; NMFS, 2003a; and Wang, 1986.

Table G1-5: Bluegill Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.73	0	0	0.00000130
Larvae	0.576	0	0	0.00000156
Juvenile	4.62	0	0	0.00795
Age 1+	0.390	0	0	0.00992
Age 2+	0.151	0	0	0.0320
Age 3+	0.735	0.74	0.50	0.0594
Age 4+	0.735	0.74	1.0	0.104
Age 5+	0.735	0.74	1.0	0.189
Age 6+	0.735	0.74	1.0	0.193
Age 7+	0.735	0.74	1.0	0.209
Age 8+	0.735	0.74	1.0	0.352
Age 9+	0.735	0.74	1.0	0.393

Sources: Bartell and Campbell, 2000; Carlander, 1977; Froese and Pauly, 2001; NMFS, 2003a; and Wang, 1986.

Table G1-6: Brown Bullhead Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000115
Larvae	4.61	0	0	0.0000192
Juvenile	1.39	0	0	0.00246
Age 1+	0.446	0	0	0.0898
Age 2+	0.223	0.22	0.50	0.172
Age 3+	0.223	0.22	1.0	0.278
Age 4+	0.223	0.22	1.0	0.330
Age 5+	0.223	0.22	1.0	0.570
Age 6+	0.223	0.22	1.0	0.582

Sources: Carlander, 1969; Froese and Pauly, 2001; Geo-Marine Inc., 1978; and NMFS, 2003a.

Table G1-7: Bullhead Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.0000312
Larvae	4.61	0	0	0.000186
Juvenile	1.39	0	0	0.00132
Age 1+	0.446	0	0	0.0362
Age 2+	0.223	0.22	0.50	0.0797
Age 3+	0.223	0.22	1.0	0.137
Age 4+	0.223	0.22	1.0	0.233
Age 5+	0.223	0.22	1.0	0.402
Age 6+	0.223	0.22	1.0	0.679
Age 7+	0.223	0.22	1.0	0.753
Age 8+	0.223	0.22	1.0	0.815
Age 9+	0.223	0.22	1.0	0.823

[a] Includes black bullhead, stonecat, tadpole madtom, yellow bullhead, and other bullheads not identified to species level.

Sources: Carlander, 1969; Froese and Pauly, 2001; Geo-Marine Inc., 1978; NMFS, 2003a; and Scott and Crossman, 1973.

Table G1-8: Burbot Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000154
Larvae	7.13	0	0	0.00000160
Juvenile	0.916	0	0	0.0154
Age 1+	0.562	0	0	0.129
Age 2+	0.562	0	0	0.513
Age 3+	0.562	0	0	0.842
Age 4+	0.562	0	0	1.23
Age 5+	0.562	0	0	1.99
Age 6+	0.562	0	0	2.68
Age 7+	0.562	0	0	2.97
Age 8+	0.562	0	0	3.35
Age 9+	0.562	0	0	3.57
Age 10+	0.562	0	0	4.09

Sources: NMFS, 2003a; Schram et al., 1998; Scott and Crossman, 1998; and Snyder, 1998.

Table G1-9: Carp Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000673
Larvae	4.61	0	0	0.0000118
Juvenile	1.39	0	0	0.0225
Age 1+	0.130	0	0	0.790
Age 2+	0.130	0	0	1.21
Age 3+	0.130	0	0	1.81
Age 4+	0.130	0	0	5.13
Age 5+	0.130	0	0	5.52
Age 6+	0.130	0	0	5.82
Age 7+	0.130	0	0	6.76
Age 8+	0.130	0	0	8.17
Age 9+	0.130	0	0	8.55
Age 10+	0.130	0	0	8.94
Age 11+	0.130	0	0	9.76
Age 12+	0.130	0	0	10.2
Age 13+	0.130	0	0	10.6
Age 14+	0.130	0	0	11.1
Age 15+	0.130	0	0	11.5
Age 16+	0.130	0	0	12.0
Age 17+	0.130	0	0	12.5

[a] Includes bowfin, carp, goldfish, and other similar carps not identified to species level.

Sources: Carlander, 1969; Froese and Pauly, 2001; Geo-Marine Inc., 1978; NMFS, 2003a; and Wang, 1986.

Table G1-10: Carp/Minnow Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000115
Larvae	2.06	0	0	0.000375
Juvenile	2.06	0	0	0.00208
Age 1+	1.00	0	0	0.00585
Age 2+	1.00	0	0	0.0121
Age 3+	1.00	0	0	0.0171

[a] Includes bluntnose minnow, fathead minnow, hornyhead chub, lake chub, longnose dace, and other similar minnows not identified to species level.

Sources: Carlander, 1969; Froese and Pauly, 2001; NMFS, 2003a; and Ohio Department of Natural Resources Division of Wildlife, 2003.

Table G1-11: Crappie Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.80	0	0	0.000000929
Larvae	0.498	0	0	0.00000857
Juvenile	2.93	0	0	0.0120
Age 1+	0.292	0	0	0.128
Age 2+	0.292	0.29	0.50	0.193
Age 3+	0.292	0.29	1.0	0.427
Age 4+	0.292	0.29	1.0	0.651
Age 5+	0.292	0.29	1.0	0.888
Age 6+	0.292	0.29	1.0	0.925
Age 7+	0.292	0.29	1.0	0.972
Age 8+	0.292	0.29	1.0	1.08
Age 9+	0.292	0.29	1.0	1.26

[a] Includes white crappie and other crappies not identified to the species level.

Sources: Bartell and Campbell, 2000; Carlander, 1977; Froese and Pauly, 2001; NMFS, 2003a; and Wang, 1986.

Table G1-12: Freshwater Catfish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.0000539
Larvae	4.61	0	0	0.0000563
Juvenile	1.39	0	0	0.0204
Age 1+	0.410	0.41	0.50	0.104
Age 2+	0.410	0.41	1.0	0.330
Age 3+	0.410	0.41	1.0	0.728
Age 4+	0.410	0.41	1.0	1.15
Age 5+	0.410	0.41	1.0	1.92
Age 6+	0.410	0.41	1.0	2.41
Age 7+	0.410	0.41	1.0	3.45
Age 8+	0.410	0.41	1.0	4.01
Age 9+	0.410	0.41	1.0	5.06
Age 10+	0.410	0.41	1.0	8.08
Age 11+	0.410	0.41	1.0	8.39
Age 12+	0.410	0.41	1.0	8.53

[a] Includes channel catfish and flathead catfish.

Sources: Carlander, 1969; Froese and Pauly, 2001; Geo-Marine Inc., 1978; Miller, 1966; NMFS, 2003a; Salia et al., 1997; and Wang, 1986.

Table G1-13: Freshwater Drum Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.27	0	0	0.00000115
Larvae	6.13	0	0	0.00000295
Juvenile	2.30	0	0	0.0166
Age 1+	0.310	0	0	0.0500
Age 2+	0.155	0.16	0.50	0.206
Age 3+	0.155	0.16	1.0	0.438
Age 4+	0.155	0.16	1.0	0.638
Age 5+	0.155	0.16	1.0	0.794
Age 6+	0.155	0.16	1.0	0.950
Age 7+	0.155	0.16	1.0	1.09
Age 8+	0.155	0.16	1.0	1.26
Age 9+	0.155	0.16	1.0	1.44
Age 10+	0.155	0.16	1.0	1.60
Age 11+	0.155	0.16	1.0	1.78
Age 12+	0.155	0.16	1.0	2.00

Sources: Bartell and Campbell, 2000; Froese and Pauly, 2001; NMFS, 2003a; Scott and Crossman, 1973; and Virginia Tech, 1998.

Table G1-14: Gizzard Shad Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.000000487
Larvae	6.33	0	0	0.00000663
Juvenile	0.511	0	0	0.0107
Age 1+	1.45	0	0	0.141
Age 2+	1.27	0	0	0.477
Age 3+	0.966	0	0	0.640
Age 4+	0.873	0	0	0.885
Age 5+	0.303	0	0	1.17
Age 6+	0.303	0	0	1.54

[a] Includes gizzard shad and other shad not identified to species level.

Sources: Froese and Pauly, 2003; NMFS, 2003a; and Wapora, 1979.

Table G1-15: Logperch Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000260
Larvae	1.90	0	0	0.000512
Juvenile	1.90	0	0	0.00434
Age 1+	0.700	0	0	0.0132
Age 2+	0.700	0	0	0.0251
Age 3+	0.700	0	0	0.0377

Sources: Carlander, 1997; Froese and Pauly, 2001; and NMFS, 2003a.

Table G1-16: Pike Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.08	0	0	0.0000189
Larvae	5.49	0	0	0.0133
Juvenile	5.49	0	0	0.0451
Age 1+	0.150	0	0	0.365
Age 2+	0.150	0	0	1.10
Age 3+	0.150	0	0	1.53
Age 4+	0.150	0	0	2.72
Age 5+	0.150	0	0	6.19
Age 6+	0.150	0	0	7.02
Age 7+	0.150	0	0	8.92
Age 8+	0.150	0	0	12.3
Age 9+	0.150	0	0	13.9
Age 10+	0.075	0.08	0.50	16.6
Age 11+	0.075	0.08	1.0	19.0
Age 12+	0.075	0.08	1.0	24.2
Age 13+	0.075	0.08	1.0	25.3
Age 14+	0.075	0.08	1.0	30.0
Age 15+	0.075	0.08	1.0	32.4
Age 16+	0.075	0.08	1.0	34.3
Age 17+	0.075	0.08	1.0	45.6
Age 18+	0.075	0.08	1.0	45.8
Age 19+	0.075	0.08	1.0	47.7
Age 20+	0.075	0.08	1.0	48.8
Age 21+	0.075	0.08	1.0	48.9
Age 22+	0.075	0.08	1.0	49.0
Age 23+	0.075	0.08	1.0	49.1
Age 24+	0.075	0.08	1.0	49.2
Age 25+	0.075	0.08	1.0	49.3
Age 26+	0.075	0.08	1.0	49.4
Age 27+	0.075	0.08	1.0	49.4

[a] Includes grass pickerel, muskellunge, and northern pike.

Sources: Carlander, 1969; Froese and Pauly, 2001; NMFS, 2003a; and Pennsylvania, 1999.

Table G1-17: Rainbow Smelt Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	11.5	0	0	0.000000990
Larvae	5.50	0	0	0.00110
Juvenile	0.916	0	0	0.00395
Age 1+	0.400	0	0	0.0182
Age 2+	0.400	0.03	0.50	0.0460
Age 3+	0.400	0.03	1.0	0.0850
Age 4+	0.400	0.03	1.0	0.131
Age 5+	0.400	0.03	1.0	0.180
Age 6+	0.400	0.03	1.0	0.228

Sources: Froese and Pauly, 2003; NMFS, 2003a; PG&E National Energy Group, 2001; and Spigarelli et al., 1981.

Table G1-18: Redhorse Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000115
Larvae	2.30	0	0	0.00000370
Juvenile	2.99	0	0	0.0267
Age 1+	0.548	0	0	0.0521
Age 2+	0.548	0	0	0.180
Age 3+	0.548	0	0	0.493
Age 4+	0.548	0	0	0.653
Age 5+	0.548	0	0	0.916
Age 6+	0.548	0	0	2.78
Age 7+	0.548	0	0	3.07

[a] Includes golden redhorse, shorthead redhorse, and silver redhorse.

Sources: Bartell and Campbell, 2000; Carlander, 1969; Froese and Pauly, 2001, 2003; and NMFS, 2003a.

Table G1-19: Salmonids Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lb)
Eggs	1.90	0	0	0.0000240
Larvae	8.20	0	0	0.000171
Juvenile	0.250	0	0	0.0117
Age 1+	0.250	1.0	0.50	0.705
Age 2+	0.250	1.0	1.0	1.27
Age 3+	0.250	1.0	1.0	2.32
Age 4+	0.250	1.0	1.0	2.85
Age 5+	0.250	1.0	1.0	3.52
Age 6+	0.250	1.0	1.0	4.09
Age 7+	0.250	1.0	1.0	4.76
Age 8+	0.250	1.0	1.0	5.70
Age 9+	0.250	1.0	1.0	5.73
Age 10+	0.250	1.0	1.0	5.85
Age 11+	0.250	1.0	1.0	6.10
Age 12+	0.250	1.0	1.0	6.83
Age 13+	0.250	1.0	1.0	7.11
Age 14+	0.250	1.0	1.0	7.29
Age 15+	0.250	1.0	1.0	7.32
Age 16+	0.250	1.0	1.0	8.66

[a] Includes bloater, brown trout, chinook salmon, coho salmon, lake herring, lake trout, lake whitefish, rainbow trout, round whitefish, and other salmonids not identified to species level.

Sources: Fish, 1932; Froese and Pauly, 2001; NMFS, 2003a; Scott and Crossman, 1998; and Schorfhaar and Schneeberger, 1997.

Table G1-20: Shiner Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000473
Larvae	4.61	0	0	0.000285
Juvenile	0.777	0	0	0.00209
Age 1+	0.371	0	0	0.00387
Age 2+	4.61	0	0	0.00683
Age 3+	4.61	0	0	0.0143

[a] Includes common shiner, emerald shiner, golden shiner, spotfin shiner, spottail shiner and other shiners not identified to species level.

Sources: Froese and Pauly, 2003; Fuchs, 1967; NMFS, 2003a; Trautman, 1981; and Wapora, 1979.

Table G1-21: Spotted Sucker Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.79	0	0	0.00000115
Larvae	2.81	0	0	0.00000198
Juvenile	3.00	0	0	0.0213
Age 1+	0.548	0	0	0.0863
Age 2+	0.548	0	0	0.690
Age 3+	0.548	0	0	1.24
Age 4+	0.548	0	0	1.70
Age 5+	0.548	0	0	1.92
Age 6+	0.548	0	0	1.99

Sources: Bartell and Campbell, 2000; Carlander, 1969; Froese and Pauly, 2001, 2003; and NMFS, 2003a.

Table G1-22: Sucker Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.05	0	0	0.0000312
Larvae	2.56	0	0	0.0000343
Juvenile	2.30	0	0	0.000239
Age 1+	0.274	0	0	0.0594
Age 2+	0.274	0	0	0.310
Age 3+	0.274	0	0	0.377
Age 4+	0.274	0	0	0.735
Age 5+	0.274	0	0	0.981
Age 6+	0.274	0	0	1.10

[a] Includes carpsucker buffalo, lake chubsucker, longnose sucker, northern hog sucker, quillback, white sucker, and other suckers not identified to species.

Sources: Bartell and Campbell, 2000; Carlander, 1969; Froese and Pauly, 2003; and NMFS, 2003a.

Table G1-23: Sunfish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.71	0	0	0.00000115
Larvae	0.687	0	0	0.00000123
Juvenile	0.687	0	0	0.000878
Age 1+	1.61	0	0	0.00666
Age 2+	1.61	0	0	0.0271
Age 3+	1.50	1.5	0.50	0.0593
Age 4+	1.50	1.5	1.0	0.0754
Age 5+	1.50	1.5	1.0	0.142
Age 6+	1.50	1.5	1.0	0.180
Age 7+	1.50	1.5	1.0	0.214
Age 8+	1.50	1.5	1.0	0.232

[a] Includes green sunfish, orange-spotted sunfish, pumpkinseed, rock bass, warmouth, and other sunfish not identified to species.

Sources: Carlander, 1977; Froese and Pauly, 2001; NMFS, 2003a; PSE&G, 1999; and Wang, 1986.

Table G1-24: Walleye Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.05	0	0	0.00000619
Larvae	3.55	0	0	0.0000768
Juvenile	1.93	0	0	0.0300
Age 1+	0.431	0	0	0.328
Age 2+	0.161	0.27	0.50	0.907
Age 3+	0.161	0.27	1.0	1.77
Age 4+	0.161	0.27	1.0	2.35
Age 5+	0.161	0.27	1.0	3.37
Age 6+	0.161	0.27	1.0	3.97
Age 7+	0.161	0.27	1.0	4.66
Age 8+	0.161	0.27	1.0	5.58
Age 9+	0.161	0.27	1.0	5.75

Sources: Bartell and Campbell, 2000; Carlander, 1997; Froese and Pauly, 2001, 2003; NMFS, 2003a; and Thomas and Haas, 2000.

Table G1-25: White Bass Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.000000396
Larvae	4.61	0	0	0.00000174
Juvenile	1.39	0	0	0.174
Age 1+	0.420	0	0	0.467
Age 2+	0.420	0.70	0.50	0.644
Age 3+	0.420	0.70	1.0	1.02
Age 4+	0.420	0.70	1.0	1.16
Age 5+	0.420	0.70	1.0	1.26
Age 6+	0.420	0.70	1.0	1.66
Age 7+	0.420	0.70	1.0	1.68

Sources: Carlander, 1997; Froese and Pauly, 2001; Geo-Marine Inc., 1978; McDermot and Rose, 2000; NMFS, 2003a; Van Oosten, 1942; and Virginia Tech, 1998.

Table G1-26: White Perch Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.75	0	0	0.000000330
Larvae	5.37	0	0	0.00000271
Juvenile	1.71	0	0	0.00259
Age 1+	0.693	0	0	0.0198
Age 2+	0.693	0	0	0.0567
Age 3+	0.693	0	0	0.103
Age 4+	0.689	0	0	0.150
Age 5+	1.58	0	0	0.214
Age 6+	1.54	0	0	0.265
Age 7+	1.48	0	0	0.356
Age 8+	1.46	0	0	0.387
Age 9+	1.46	0	0	0.516
Age 10+	1.46	0	0	0.619

Sources: Horseman and Shirey, 1974; NMFS, 2003a; and PSE&G, 1999.

Table G1-27: Yellow Perch Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.75	0	0	0.000000655
Larvae	3.56	0	0	0.000000728
Juvenile	2.53	0	0	0.0232
Age 1+	0.361	0	0	0.0245
Age 2+	0.249	0	0	0.0435
Age 3+	0.844	0.36	0.50	0.0987
Age 4+	0.844	0.36	1.0	0.132
Age 5+	0.844	0.36	1.0	0.166
Age 6+	0.844	0.36	1.0	0.214

Sources: NMFS, 2003a; PSE&G, 1999; Thomas and Haas, 2000; and Wapora, 1979.

Table G1-28: Other Recreational Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.50	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] Includes deepwater sculpin, mottled sculpin, slimy sculpin, and other sculpins not identified to species.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; NMFS, 2003a; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table G1-29: Other Forage Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000186
Larvae	7.70	0	0	0.00000158
Juvenile	1.29	0	0	0.000481
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] Includes central mudminnow, chestnut lamprey, johnny darter, lake sturgeon, longnose gar, ninespine stickleback, pirate perch, sea lamprey, silver lamprey, and other forage fish not identified to species.

Sources: Derickson and Price, 1973; and PSE&G, 1999.

Appendix G2:
Scaling Habitat Restoration

INTRODUCTION

APPENDIX CONTENTS

This appendix presents the data and methods used to develop estimates of fish production in wetland habitats for wetland-dependent species lost to impingement and entrainment (I&E) in the Great Lakes region and estimates of the scale of wetland restoration required to offset I&E losses at the J.R. Whiting facility. EPA relied on quantitative information on fish species abundances in Green Bay to estimate the expected increase in fish production in Great Lakes wetlands as a result of restoration (Brazner, 1997). Use of abundance as a proxy for production was necessary because of a lack of quantitative information on fish productivity in wetlands in this region. EPA's analysis assumes that, when restored wetland acres have reached their full potential, they will produce additional age-1 fish in the same mix of species and at the quantities observed in undisturbed habitats.

G2-1 CALCULATING AGE 1 FISH ABUNDANCE IN GREAT LAKES WETLANDS TO ESTIMATE INCREASED PRODUCTION FROM RESTORATION

After examining the data from the Brazner (1997) study and discussing them with the author, a match was found between I&E species and species captured at the southern sites in the Brazner (1997) study. Table G2-1 presents information on the species caught by Brazner (1997) that were paired with species lost to I&E at the J.R. Whiting facility.[1]

EPA developed wetland abundance estimates for each species using aggregate sampling results from 5 sampling efforts by Brazner for each of four lower Green Bay sites (J. Brazner, U.S. EPA, Duluth Lab, personal communication, 2001). In the first step of this process, capture data for the four lower Green Bay locations were averaged. Second, to convert the sampling data to an estimate of fish abundance per acre of wetland habitat, EPA assumed that each sampling event of 100 m of linear coastal wetland frontage corresponded to an average of 100 m of perpendicular width of connected coastal wetlands (i.e., each sampling event included fish from an assumed 100 m x 100 m area of wetlands) based on discussions with Brazner about the likely perpendicular width of the sampled wetlands (J. Brazner, U.S. EPA, personal communication, 2001). Third, based on discussions with Brazner, the capture data were increased by a factor of 100 (1/0.01), to account for sampling efficiency reflecting the assumption that only 1 percent of the fish present were actually captured in the sampling event. Finally, the capture data were divided by 5 to reflect an average abundance per sampling effort and scaled to account for the difference in the presumed area effectively sampled (10,000 m^2) and the size of an acre (4,047 m^2).

Brazner (1997) reported capturing young-of-year fish (younger than age 1), age-1 fish, and adult fish (older than age 1) in Green Bay wetlands. For simplicity, EPA assumed that all captured fish were age 1, eliminating the need to apply an adjustment to express all ages of sampled fish as age 1 equivalents. Because Brazner (1997) reports a high percentage of young-of-year fish captured in the sites he sampled, this assumption most likely results in a slight overestimation of age-1 equivalent fish abundances.

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[1] The species listed in Table G2-1 represent only a fraction of the species caught in the southern locations in the Brazner study).

Table G2-1: I&E Species and Losses at J.R. Whiting and Corresponding Species from the Brazner (1997) Study

Species with I&E Losses at J.R. Whiting	Average Annual Age 1 Equivalent I&E at J.R. Whiting	Corresponding Species Caught in Sampling of Green Bay Coastal Wetlands (Brazner, 1997)
Alewife	3	Alewife
Bluntnose minnow	2,762	Bluntnose minnow
Bullhead spp.	161	Sum of values for black, brown, and yellow bullheads
Carp	48,717	Carp
Channel catfish	1,833	Channel catfish
Crappie	5,533	Black crappie
Emerald shiner	2,593,094	Emerald shiner
Freshwater drum	19,950	Freshwater drum
Gizzard shad	6,450,915	Gizzard shad
Logperch	8,147	Logperch
Other Forage Species	36,348	Not considered
Rainbow smelt	865	Rainbow smelt
Shiner spp.	542,890	Sum of values for spottail, spotfin, common, and golden shiners
Sucker spp.	3,903	White sucker
Sunfish	355,396	Green sunfish
Walleye	268	Walleye
White bass	43,278	White bass
White perch	1,725	White perch
Yellow perch	21,558	Yellow perch
Total	10,137,346	

Table G2-2 provides a summary of the capture data by species for the 5 sampling trips conducted in each of the lower Green Bay wetlands (J. Brazner, U.S. EPA, Duluth Lab, personal communication, 2001), along with the adjusted estimates of abundance per wetland acre after accounting for the number of sampling trips, sampling efficiency, and the size of the effective wetland area being sampled.

Table G2-2: Green Bay Wetland Capture Data and Estimates of Age-1 Equivalent Abundance per Acre of Wetland Habitat

Species	Assumed Number of Age-1 Equivalent Fish Captured in Sampling of Lower Green Bay Wetlands[a]				Estimated Age-1 Equivalent Abundance per Acre of Wetland Habitat
	Long Tail Point Wetland	Little Tail Point Wetland	Atkinson Marsh	Sensiba Wildlife Refuge	
Yellow perch	3,525	942	333	1,108	11,955
Gizzard shad	384	264	160	137	1,912
Spottail, spotfin, common, and golden shiners (for I&E shiner spp.)	1,089	468	275	545	4,810
Bluntnose minnow	285	116	15	259	1,366
Alewife	265	142	92	124	1,261
Emerald shiner	113	31	251	224	1,253
White bass	52	226	106	9	795
White sucker (for I&E sucker spp.)	14	10	1	103	259
Carp	19	10	3	1	67
Green sunfish (for I&E sunfish)	3	5	22	2	65
Freshwater drum	4	4	7	1	32
Black, brown, and yellow bullheads (for I&E bullhead spp.)	9	4	0	2	30
White perch	0	0	0	7	14
Black crappie (for I&E crappie spp.)	1	2	1	1	10
Channel catfish	0	0	3	0	6
Logperch	0	0	0	1	2
Rainbow smelt	0	1	0	0	2
Walleye	1	0	0	0	2
Other forage	Not addressed with available capture data				

[a] Number captured cumulatively in 5 sampling efforts conducted along 100 meters linear coastal wetland frontage.

G2-2 SCALE THE HABITAT RESTORATION ALTERNATIVES TO OFFSET I&E LOSSES

To estimate the required scale of wetland restoration to offset the I&E loss of each wetland-dependent species at the J.R. Whiting facility, EPA divided the I&E loss estimates in Table G2-1 by the per-acre abundance estimates for each species in Table G2-2. Results are provided in Table G2-3.

Typically, the estimate for the species requiring the maximum amount of restoration is used to scale the amount of restoration needed to offset losses of all species. However, for the J.R. Whiting scaling, EPA used the estimate for the third highest species, gizzard shad, because gizzard shad account for most of the total loss.

Table G2-3: I&E Losses at J.R. Whiting and the Corresponding Species whose Capture Data from Green Bay Wetland Sampling Was Used by EPA to Estimate Wetland Abundance

Species with I&E Loss Estimates at J.R. Whiting	Estimate of Average Annual Age-1 Equivalent I&E at J.R. Whiting	Estimated Age-1 Equivalent Abundance per Acre of Wetland Habitat (rounded for presentation to nearest whole number of fish)	Required Acres of Wetland Restoration to Offset I&E at J.R. Whiting (rounded to nearest acre)
Other forage species	36,348	Abundance not estimated	n/a
Sunfish	355,396	65	5,489
Logperch	8,147	2	4,026
Gizzard shad	6,450,915	1,912	3,374
Emerald shiner	2,593,094	1,253	2,070
Carp	48,717	67	730
Freshwater drum	19,950	32	616
Crappie	5,533	10	547
Rainbow smelt	865	2	427
Channel catfish	1,833	6	302
Walleye	268	2	132
White perch	1,725	14	122
Shiner spp.	542,890	4,810	113
White bass	43,278	795	54
Sucker spp.	3,903	259	15
Bullhead spp.	161	30	5
Bluntnose minnow	2,762	1,366	2
Yellow perch	21,558	11,955	2
Alewife	3	1,261	0
Acres of wetland required to offset I&E losses for species with abundance estimates (based on gizzard shad)		3,374	

Part H

The Inland Region

Chapter H1: Background

CHAPTER CONTENTS

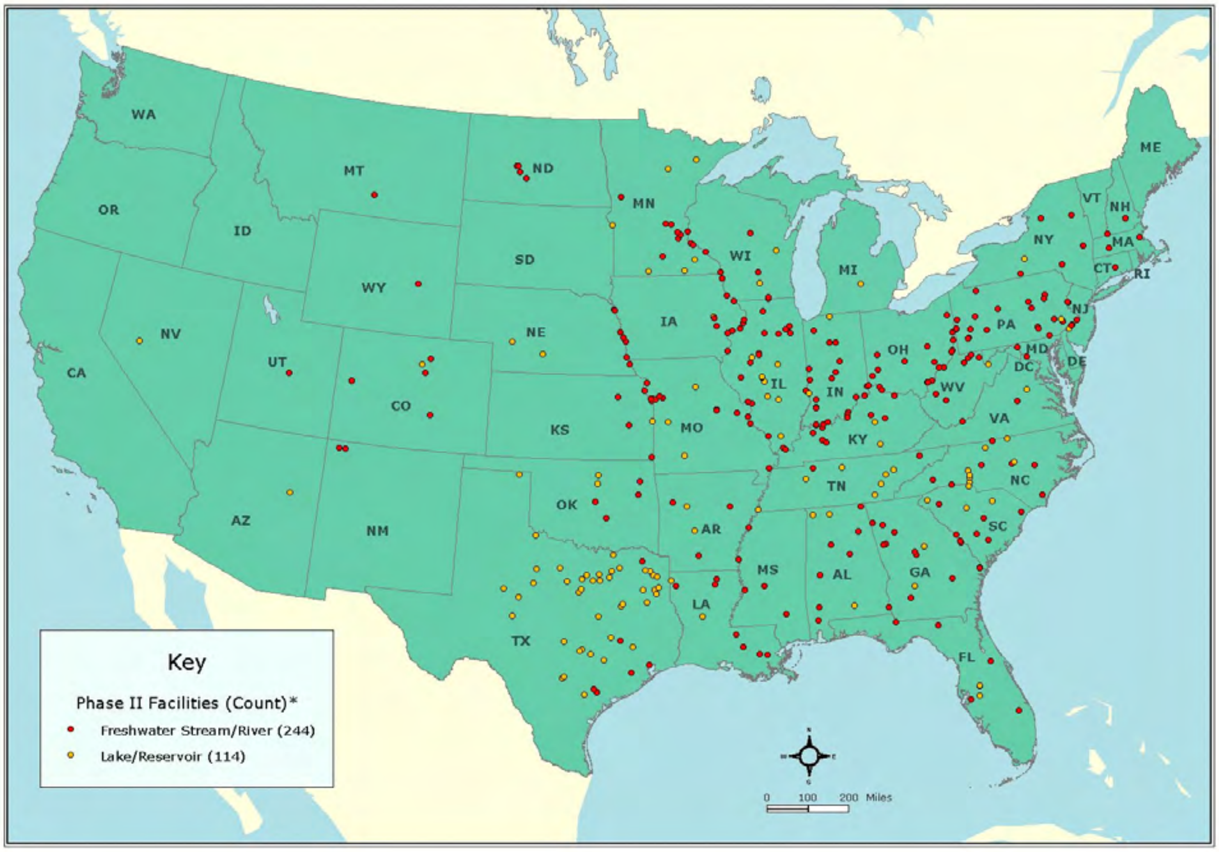
INTRODUCTION

This chapter presents an overview of the Phase II facilities in the Inland study region and summarizes their key operating, economic, technical, and compliance characteristics. For further discussion of operating and economic characteristics of Phase II facilities, refer to Chapter A3 of the *Economic and Benefits Analysis for the Final Section 316(b) Phase II Existing Facilities Rule*; for further discussion of the technical and compliance characteristics of Phase II facilities, refer to the *Technical Development Document for the Final Section 316(b) Phase II Existing Facilities Rule* (U.S. EPA, 2004a,b).

H1-1 OVERVIEW

The Inland Study includes 358 facilities that are in scope for the final Phase II regulation. Two-hundred and forty-four of the 358 facilities withdraw cooling water from an freshwater stream or river while 114 withdraw water from a lake or reservoir. Figure H1-1 presents a map of the 358 in-scope Phase II facilities located in the Inland study region.

Figure H1-1: In-Scope Phase II Facilities in the Inland Study[a]



[a] The Inland Study includes one facility in Alaska.

Source: U.S. EPA analysis for this report.

H1-2 OPERATING AND ECONOMIC CHARACTERISTICS

Most of the 358 Inland Study facilities (234) are coal steam facilities; 81 are oil/gas facilities; 34 are nuclear facilities; and nine are combined-cycle facilities. In 2001, these 358 facilities accounted for 320 gigawatts of generating capacity, 1,604,000 gigawatt hours of generation, and $63.2 billion in revenues.

The operating and economic characteristics of the Inland Study facilities are summarized in Table H1-1. Section H1-4 provides further information on each facility [including facility state, North American Electric Reliability Council (NERC) region, plant type, capacity, 2001 generation, and whether impingement and entrainment estimates were developed for the facility].

Waterbody Type	Number of Facilities by Plant Type[a]					Total Capacity (MW)[b]	Total Generation (MWh)[b]	Electric Revenue (millions)
	Coal Steam	Combined Cycle	Nuclear	Oil/Gas Steam	Total			
Freshwater Stream / River								
AK	1	-	-	-	1	28	194,288	$6
AL	7	-	1	-	8	11,825	64,190,937	$2,057
AR	-	-	-	4	4	1,238	1,051,249	$63
CO	1	1	-	2	4	928	4,388,422	$153
CT	-	-	-	1	1	825	1,569,547	$63
FL	1	1	-	3	5	6,315	24,045,701	$995
GA	10	-	2	1	13	18,238	100,051,997	$4,082
IA	12	-	-	-	12	4,272	23,511,689	$560
IL	11	-	5	1	17	21,618	118,833,806	$3,038
IN	17	-	-	-	17	14,759	76,372,350	$2,291
KS	5	-	1	-	6	4,335	27,622,485	$872
KY	12	-	-	-	12	11,056	57,694,077	$1,838
LA	1	-	1	7	9	10,474	35,034,518	$1,955
MA	1	-	-	1	2	243	1,242,703	$41
MD	2	-	-	-	2	1,040	3,403,597	$253
MN	4	-	2	3	9	3,615	20,230,460	$322
MO	11	-	1	-	12	10,851	57,626,594	$1,752
MS	-	-	-	4	4	2,526	7,145,965	$358
MT	1	-	-	-	1	163	1,029,287	$45
NC	7	-	-	-	7	4,394	14,568,148	$665
ND	4	-	-	-	4	1,695	10,960,362	$316
NE	2	-	2	-	4	2,634	16,642,632	$417
NH	1	-	-	-	1	496	2,934,532	$128
NJ	-	1	-	-	1	745	610,527	$26
NM	1	1	-	-	2	2,320	15,268,344	$722
NY	2	1	-	2	5	1,053	2,073,423	$86
OH	17	-	-	-	17	20,173	105,492,132	$3,455
OK	2	-	-	2	4	5,476	21,010,609	$680
PA	15	-	4	4	23	21,161	105,844,277	$6,336
SC	7	-	-	-	7	2,744	12,372,518	$455
TN	2	-	-	-	2	3,400	23,127,870	$1,076
TX	2	-	-	4	6	7,394	26,591,650	$1,210
UT	-	-	-	-	-	-	-	$0
VA	2	-	-	-	2	592	2,744,946	$114
VT	-	-	1	-	1	563	4,171,120	$119
WI	7	-	-	1	8	3,045	16,639,604	$527
WV	10	-	-	-	10	9,280	48,580,305	$1,589
WY	1	-	-	-	1	817	5,633,726	$256

Table H1-1: Operating and Economic Characteristics of Phase II Facilities

Waterbody Type	Number of Facilities by Plant Type[a]					Total Capacity (MW)[b]	Total Generation (MWh)[b]	Electric Revenue (millions)
	Coal Steam	Combined Cycle	Nuclear	Oil/Gas Steam	Total			
Subtotal	*179*	*5*	*20*	*40*	*244*	*212,327*	*1,060,506,397*	*$38,923*
Lake / Reservoir								
AL	1	1	1	-	3	5,467	25,182,468	$1,161
AR	1	-	1	1	3	3,155	19,933,553	$705
AZ	1	-	-	-	1	1,105	7,151,659	$326
CO	1	-	-	-	1	211	1,479,194	$62
FL	1	2	-	-	3	1,613	5,592,919	$269
GA	1	-	-	1	2	1,764	7,868,990	$328
IA	1	-	-	-	1	85	169,060	$6
IL	7	-	1	-	8	5,725	25,677,911	$701
IN	2	-	-	-	2	1,103	6,716,108	$230
KS	1	-	-	-	1	1,578	7,598,121	$173
KY	2	-	-	-	2	2,049	6,053,233	$167
LA	1	-	-	1	2	1,282	4,087,861	$197
MI	1	-	-	-	1	375	1,547,747	$43
MN	4	-	-	2	6	1,594	8,796,532	$285
MO	3	-	-	-	3	2,150	13,011,259	$360
NC	5	-	2	-	7	11,878	73,296,119	$3,583
NE	1	-	-	1	2	1,471	9,449,338	$264
NV	-	-	-	1	1	210	1,328,149	$73
NY	1	-	-	-	1	306	2,221,901	$63
OK	1	-	-	1	2	1,161	7,307,304	$228
PA	-	-	1	1	2	3,845	22,407,400	$1,565
SC	-	-	4	-	4	7,022	50,787,029	$2,383
SD	1	-	-	-	1	457	3,462,038	$104
TN	5	-	2	-	7	12,801	64,002,660	$2,860
TX	9	1	1	32	43	34,287	137,555,681	$6,551
UT	1	-	-	-	1	1,472	8,300,173	$407
VA	-	-	1	-	1	1,960	13,099,598	$700
WI	2	-	-	-	2	210	452,911	$11
WV	1	-	-	-	1	1,681	8,930,790	$519
Subtotal	*55*	*4*	*14*	*41*	*114*	*108,017*	*543,467,706*	*$24,326*
TOTAL	**234**	**9**	**34**	**81**	**358**	**320,334**	**1,603,974,103**	**$63,250**

[a] Based on largest steam-electric capacity at facilities.
[b] MW is an abbreviation for megawatt; MWh is an abbreviation for megawatt hour.

Sources: Plant type (IPM Analysis, U.S. EPA, 2002; Form EIA-860, U.S. DOE, 2001a); capacity (Form EIA-860, U.S. DOE, 2001a); generation (Form EIA-906, U.S. DOE, 2001c); revenue (Form EIA-861, U.S. DOE, 2001b; Form EIA-906, U.S. DOE, 2001c).

H1-3 TECHNICAL AND COMPLIANCE CHARACTERISTICS

The 358 Inland Study facilities have a combined design intake flow of 209,950 million gallons per day (MGD). Two-hundred and forty-six of the facilities employ a once-through cooling system in the baseline; 68 facilities employ a recirculating cooling system; 37 facilities currently employ a combination cooling system; and 7 facilities employ other types of cooling systems. The 358 facilities incur a combined pre-tax compliance cost of $170 million. Table H1-2 summarizes the flow, compliance responses, and compliance costs for these 358 facilities.

Table H1-2: Technical and Compliance Characteristics of Phase II Facilities

	Cooling Water System (CWS) Type[a]				
	Once-Through	**Recirculating**	**Combination**	**Other**	**All**
Design Flow (MGD)	**150,713**	**35,046**	**21,626**	**2,566**	**209,950**
Number of Facilities by Compliance Response					
Fish H&R	70	-	7	2	79
Fine Mesh Traveling Screens w/Fish H&R	24	-	4	3	31
New Larger Intake Structure with Fine Mesh and Fish H&R	7	-	-	-	7
Passive Fine Mesh Screens	36	-	6	-	42
Fish Barrier Net/Gunderboom	27	-	3	-	30
Relocate Intake to Submerged Offshore with Passive Screen	6	-	2	1	9
Velocity Cap	5	-	-	-	5
Double-Entry, Single-Exit with Fine Mesh and Fish H&R	4	-	2	-	6
Multiple	7	-	1	-	8
None	60	68	12	1	141
Total	246	68	37	7	358
Compliance Cost (2002$; millions)	**$139.1**	**$5.4**	**$22.3**	**$3.4**	**$170.1**

[a] Combination and "other" CWSs are costed as if they were once-through CWSs.

Source: U.S. EPA analysis for this report.

H1-4 PHASE II FACILITIES IN THE INLAND REGIONAL STUDY

Table H1-3 presents economic and operating characteristics of the Inland Study facilities.

Table H1-3: Phase II Facilities in the Inland Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
Freshwater Stream / River							
6288	Healy	AK	ASCC	Coal Steam	28	194,288	N
3	Barry	AL	SERC	Coal Steam	2,665	15,798,765	N
7	Gadsden	AL	SERC	Coal Steam	138	479,276	N
8	Gorgas	AL	SERC	Coal Steam	1,417	7,245,827	N
10	Greene County	AL	SERC	Coal Steam	1,288	4,105,758	N
26	E C Gaston	AL	SERC	Coal Steam	2,034	12,528,720	N
50	Widows Creek	AL	SERC	Coal Steam	1,969	8,398,426	N
56	Charles R Lowman	AL	SERC	Coal Steam	538	3,473,849	N
6001	Joseph M Farley	AL	SERC	Nuclear	1,776	12,160,316	N
173	Robert E Ritchie	AR	SERC	O/G Steam	923	134,262	N
201	Fitzhugh	AR	SPP	O/G Steam	59	69,069	N
202	Bailey	AR	SPP	O/G Steam	120	531,910	N
203	McClellan	AR	SPP	O/G Steam	136	316,008	N
460	Pueblo	CO	WSCC	O/G Steam	25	67,763	N
468	Cameo	CO	WSCC	Coal Steam	66	552,874	N
478	Zuni	CO	WSCC	O/G Steam	101	71,953	N
6112	Fort St Vrain	CO	WSCC	Combined Cycle	736	3,695,832	N
562	Middletown	CT	NPCC	O/G Steam	825	1,569,547	N
620	Sanford	FL	FRCC	O/G Steam	1,028	3,084,728	N
638	Suwannee River	FL	FRCC	O/G Steam	331	499,240	N
642	Scholz	FL	FRCC	Coal Steam	98	250,396	N
6042	Manatee	FL	FRCC	O/G Steam	1,727	6,436,819	N
6043	Martin	FL	FRCC	Combined Cycle	3,132	13,774,518	N
649	Vogtle	GA	SERC	Nuclear	2,320	19,601,061	N
699	Arkwright	GA	SERC	Coal Steam	214	214,138	N
700	Atkinson	GA	SERC	O/G Steam	282	(1,453)	N
703	Bowen	GA	SERC	Coal Steam	3,540	19,977,350	N
708	Hammond	GA	SERC	Coal Steam	953	4,178,505	N
710	Jack McDonough	GA	SERC	Coal Steam	682	2,997,675	N
727	Mitchell	GA	SERC	Coal Steam	344	487,361	N
728	Yates	GA	SERC	Coal Steam	1,487	5,738,019	N

Table H1-3: Phase II Facilities in the Inland Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
733	Kraft	GA	SERC	Coal Steam	356	1,263,575	N
6051	Edwin I Hatch	GA	SERC	Nuclear	1,722	14,080,708	N
6052	Wansley	GA	SERC	Coal Steam	1,957	11,360,588	N
6124	McIntosh	GA	SERC	Coal Steam	818	1,030,791	N
6257	Scherer	GA	SERC	Coal Steam	3,564	19,123,679	N
1046	Dubuque	IA	MAPP	Coal Steam	85	344,061	N
1047	Lansing	IA	MAPP	Coal Steam	341	1,336,958	N
1048	M L Kapp	IA	MAPP	Coal Steam	237	1,120,959	N
1073	Prairie Creek	IA	MAPP	Coal Steam	245	992,590	N
1081	Riverside	IA	MAPP	Coal Steam	141	516,676	N
1082	Council Bluffs	IA	MAPP	Coal Steam	856	5,910,861	N
1091	Neal North	IA	MAPP	Coal Steam	1,046	6,037,783	N
1104	Burlington	IA	MAPP	Coal Steam	302	1,107,161	N
1167	Muscatine Plant #1	IA	MAPP	Coal Steam	294	1,328,758	N
1218	Fair Station	IA	MAPP	Coal Steam	63	337,977	N
7343	Neal South	IA	MAPP	Coal Steam	640	4,388,441	N
54775	University of Iowa Main Power Plant	IA	MAIN	Coal Steam	23	89,464	N
384	Joliet 29	IL	MAIN	Coal Steam	1,320	4,999,560	N
856	E D Edwards	IL	MAIN	Coal Steam	780	3,801,058	N
862	Grand Tower	IL	MAIN	Coal Steam	447	397,059	N
863	Hutsonville	IL	MAIN	Coal Steam	153	559,753	N
864	Meredosia	IL	MAIN	Coal Steam	564	1,150,125	N
869	Dresden	IL	MAIN	Nuclear	1,740	11,954,052	N
874	Joliet 9	IL	MAIN	Coal Steam	508	1,195,223	N
879	Powerton	IL	MAIN	Coal Steam	1,786	7,961,158	N
880	Quad Cities	IL	MAIN	Nuclear	1,656	12,497,792	N
887	Joppa Steam	IL	MAIN	Coal Steam	1,100	8,154,550	N
891	Havana	IL	MAIN	Coal Steam	718	1,698,526	N
892	Hennepin	IL	MAIN	Coal Steam	306	1,734,044	N
898	Wood River	IL	MAIN	Coal Steam	650	2,491,380	N
6022	Braidwood	IL	MAIN	Nuclear	2,450	20,241,464	N
6023	Byron	IL	MAIN	Nuclear	2,450	19,443,098	N
6025	Collins	IL	MAIN	O/G Steam	2,650	1,970,582	N
6026	LaSalle	IL	MAIN	Nuclear	2,340	18,584,382	N
983	Clifty Creek	IN	ECAR	Coal Steam	1,303	8,025,400	Y
988	Tanners Creek	IN	ECAR	Coal Steam	1,100	5,118,265	Y
990	Elmer W Stout	IN	ECAR	Coal Steam	1,000	3,970,009	N

Table H1-3: Phase II Facilities in the Inland Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
991	H T Pritchard	IN	ECAR	Coal Steam	396	1,356,810	N
994	Petersburg	IN	ECAR	Coal Steam	1,881	11,421,002	N
1001	Cayuga	IN	ECAR	Coal Steam	1,193	6,584,218	N
1004	Edwardsport	IN	ECAR	Coal Steam	144	460,733	N
1007	Noblesville	IN	ECAR	Coal Steam	100	283,763	N
1008	R Gallagher	IN	ECAR	Coal Steam	600	2,970,182	N
1010	Wabash River	IN	ECAR	Coal Steam	1,173	4,478,954	N
1012	F B Culley	IN	ECAR	Coal Steam	415	2,454,827	N
1032	Logansport	IN	ECAR	Coal Steam	61	176,173	N
1037	Peru	IN	ECAR	Coal Steam	35	12,589	N
1043	Frank E Ratts	IN	ECAR	Coal Steam	233	1,696,146	N
6085	R M Schahfer	IN	ECAR	Coal Steam	2,201	8,922,013	N
6166	Rockport	IN	ECAR	Coal Steam	2,600	17,570,417	N
6705	Warrick	IN	ECAR	Coal Steam	323	870,849	N
210	Wolf Creek	KS	SPP	Nuclear	1,236	10,346,651	N
1239	Riverton	KS	SPP	Coal Steam	133	493,104	N
1294	Kaw	KS	SPP	Coal Steam	161	23,768	N
1295	Quindaro	KS	SPP	Coal Steam	385	827,995	N
6064	Nearman Creek	KS	SPP	Coal Steam	261	1,599,155	N
6068	Jeffrey EC	KS	SPP	Coal Steam	2,160	14,331,812	N
1356	Ghent	KY	ECAR	Coal Steam	2,226	12,654,217	N
1357	Green River	KY	ECAR	Coal Steam	264	954,123	N
1361	Tyrone	KY	ECAR	Coal Steam	137	267,097	N
1363	Cane Run	KY	ECAR	Coal Steam	661	3,301,952	N
1364	Mill Creek	KY	ECAR	Coal Steam	1,717	8,882,437	N
1374	Elmer Smith	KY	ECAR	Coal Steam	445	2,756,272	N
1378	Paradise	KY	SERC	Coal Steam	2,558	14,430,648	N
1379	Shawnee	KY	SERC	Coal Steam	1,750	8,455,618	N
1381	K C Coleman	KY	ECAR	Coal Steam	521	3,041,994	N
1382	HMP&L Station 2	KY	ECAR	Coal Steam	405	1,423,424	N
1383	R A Reid	KY	ECAR	Coal Steam	195	345,386	N
1385	Dale	KY	ECAR	Coal Steam	176	1,180,909	N
1394	Willow Glen	LA	SERC	O/G Steam	2,178	3,917,915	N
1402	Little Gypsy	LA	SERC	O/G Steam	1,251	2,968,709	N
1403	Ninemile Point	LA	SERC	O/G Steam	2,142	4,383,337	N
1404	Sterlington	LA	SERC	O/G Steam	648	1,141,083	N
1416	Arsenal Hill	LA	SPP	O/G Steam	125	137,581	N

Table H1-3: Phase II Facilities in the Inland Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
1448	Monroe	LA	SERC	O/G Steam	138	39,685	N
4270	Waterford 3	LA	SERC	Nuclear	1,200	9,535,930	N
6055	Big Cajun 2	LA	SERC	Coal Steam	1,903	11,026,893	N
8056	Waterford 1 & 2	LA	SERC	O/G Steam	891	1,883,385	N
1595	Kendall Square	MA	NPCC	O/G Steam	107	144,971	N
1606	Mount Tom	MA	NPCC	Coal Steam	136	1,097,732	N
1570	R P Smith	MD	ECAR	Coal Steam	110	529,748	N
1572	Dickerson	MD	MAAC	Coal Steam	930	2,873,849	Y
1904	Black Dog	MN	MAPP	Coal Steam	512	1,051,380	N
1912	High Bridge	MN	MAPP	Coal Steam	277	1,413,134	N
1915	King	MN	MAPP	Coal Steam	598	3,227,806	N
1922	Monticello	MN	MAPP	Nuclear	600	3,876,322	N
1925	Prairie Island	MN	MAPP	Nuclear	1,137	7,912,705	N
1926	Red Wing	MN	MAPP	O/G Steam	23	112,231	N
1927	Riverside	MN	MAPP	Coal Steam	404	2,356,239	N
1934	Wilmarth	MN	MAPP	O/G Steam	25	120,916	N
2039	Elk River	MN	MAPP	O/G Steam	39	159,727	N
2079	Hawthorn	MO	SPP	Coal Steam	1,071	2,513,097	N
2094	Sibley	MO	SPP	Coal Steam	524	2,897,223	N
2098	Lake Road	MO	MAPP	Coal Steam	273	603,435	N
2103	Labadie	MO	MAIN	Coal Steam	2,389	15,800,442	N
2104	Meramec	MO	MAIN	Coal Steam	985	3,560,293	N
2107	Sioux	MO	MAIN	Coal Steam	1,099	5,645,812	N
2167	New Madrid	MO	SERC	Coal Steam	1,200	7,154,141	N
2169	Chamois	MO	MAIN	Coal Steam	59	35,425	N
2171	Missouri City	MO	SPP	Coal Steam	46	63,718	N
6065	Iatan	MO	SPP	Coal Steam	726	4,396,469	N
6153	Callaway	MO	MAIN	Nuclear	1,236	8,384,240	N
6155	Rush Island	MO	MAIN	Coal Steam	1,242	6,572,299	N
2046	Eaton	MS	SERC	O/G Steam	68	4,172	N
2050	Baxter Wilson	MS	SERC	O/G Steam	1,328	4,287,962	N
2053	Rex Brown	MS	SERC	O/G Steam	349	473,389	N
8054	Gerald Andrus	MS	SERC	O/G Steam	781	2,380,442	N
2187	Corette	MT	WSCC	Coal Steam	163	1,029,287	N
2706	Asheville	NC	SERC	Coal Steam	1,049	2,562,213	N
2708	Cape Fear	NC	SERC	Coal Steam	431	1,654,667	N
2709	Lee	NC	SERC	Coal Steam	508	1,860,938	N

Table H1-3: Phase II Facilities in the Inland Study							
EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
2713	L V Sutton	NC	SERC	Coal Steam	763	2,500,852	N
2720	Buck	NC	SERC	Coal Steam	474	1,522,193	N
2721	Cliffside	NC	SERC	Coal Steam	781	3,729,416	N
2723	Dan River	NC	SERC	Coal Steam	388	737,869	N
2790	Heskett	ND	MAPP	Coal Steam	115	584,212	N
2817	Leland Olds	ND	MAPP	Coal Steam	656	4,378,283	N
2823	Milton R Young	ND	MAPP	Coal Steam	734	4,637,171	N
2824	Stanton	ND	MAPP	Coal Steam	190	1,360,696	N
2289	Fort Calhoun	NE	MAPP	Nuclear	502	3,519,572	N
2291	North Omaha	NE	MAPP	Coal Steam	645	3,233,261	N
6096	Nebraska City	NE	MAPP	Coal Steam	652	4,683,258	N
8036	Cooper	NE	MAPP	Nuclear	836	5,206,541	N
2364	Merrimack	NH	NPCC	Coal Steam	496	2,934,532	N
2399	Burlington	NJ	MAAC	Combined Cycle	745	610,527	N
2442	Four Corners	NM	WSCC	Coal Steam	2,270	15,061,359	N
2465	Animas	NM	WSCC	Combined Cycle	50	206,985	N
2493	East River	NY	NPCC	O/G Steam	356	732,011	N
2526	Goudey	NY	NPCC	Coal Steam	119	872,056	N
2529	Hickling	NY	NPCC	Coal Steam	70	0	N
2539	Albany	NY	NPCC	O/G Steam	400	340,356	Y
10617	CH Resources Inc Beaver Falls	NY	NPCC	Combined Cycle	108	129,000	N
2828	Cardinal	OH	ECAR	Coal Steam	1,880	9,708,439	Y
2830	Walter C Beckjord	OH	ECAR	Coal Steam	1,433	6,029,354	Y
2832	Miami Fort	OH	ECAR	Coal Steam	1,444	6,799,924	Y
2840	Conesville	OH	ECAR	Coal Steam	2,175	8,693,451	N
2843	Picway	OH	ECAR	Coal Steam	106	341,544	N
2848	O H Hutchings	OH	ECAR	Coal Steam	447	848,564	N
2850	J M Stuart	OH	ECAR	Coal Steam	2,452	13,703,893	N
2861	Niles	OH	ECAR	Coal Steam	285	1,296,019	N
2864	R E Burger	OH	ECAR	Coal Steam	423	1,826,754	N
2866	W H Sammis	OH	ECAR	Coal Steam	2,468	12,866,668	Y
2872	Muskingum River	OH	ECAR	Coal Steam	1,529	7,793,071	N
2876	Kyger Creek	OH	ECAR	Coal Steam	1,086	7,409,696	Y
2917	Hamilton	OH	ECAR	Coal Steam	138	301,965	N
2937	Piqua	OH	ECAR	Coal Steam	81	1,194	N
6019	W H Zimmer	OH	ECAR	Coal Steam	1,426	9,632,328	N
7286	Richard Gorsuch	OH	ECAR	Coal Steam	200	1,295,182	N

Table H1-3: Phase II Facilities in the Inland Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
8102	Gen J M Gavin	OH	ECAR	Coal Steam	2,600	16,944,086	N
165	GRDA	OK	SPP	Coal Steam	1,010	6,517,676	N
2951	Horseshoe Lake	OK	SPP	O/G Steam	853	1,072,349	N
2952	Muskogee	OK	SPP	Coal Steam	1,889	9,639,171	N
2956	Seminole	OK	SPP	O/G Steam	1,724	3,781,413	N
3098	Elrama	PA	ECAR	Coal Steam	510	2,390,034	N
3113	Portland	PA	MAAC	Coal Steam	621	1,201,263	N
3115	Titus	PA	MAAC	Coal Steam	261	828,684	N
3130	Seward	PA	MAAC	Coal Steam	218	922,411	N
3131	Shawville	PA	MAAC	Coal Steam	632	2,934,127	N
3132	Warren	PA	MAAC	Coal Steam	137	142,761	N
3138	New Castle	PA	ECAR	Coal Steam	431	1,824,502	N
3140	Brunner Island	PA	MAAC	Coal Steam	1,567	6,412,187	N
3148	Martins Creek	PA	MAAC	O/G Steam	2,113	2,960,586	N
3149	Montour	PA	MAAC	Coal Steam	1,642	9,381,471	N
3152	Sunbury	PA	MAAC	Coal Steam	492	1,934,539	N
3159	Cromby	PA	MAAC	O/G Steam	420	1,143,140	N
3160	Delaware	PA	MAAC	O/G Steam	392	95,361	N
3166	Peach Bottom	PA	MAAC	Nuclear	2,304	17,048,886	N
3169	Schuylkill	PA	MAAC	O/G Steam	233	36,918	N
3176	Hunlock Power Sta	PA	MAAC	Coal Steam	94	170,089	N
3178	Armstrong	PA	ECAR	Coal Steam	319	1,906,213	N
3181	Mitchell	PA	ECAR	Coal Steam	449	1,591,948	N
6040	Beaver Valley	PA	ECAR	Nuclear	1,847	13,179,236	N
6094	Bruce Mansfield	PA	ECAR	Coal Steam	2,741	13,884,249	N
6103	Susquehanna	PA	MAAC	Nuclear	2,336	16,866,720	N
8011	Three Mile Island	PA	MAAC	Nuclear	837	5,416,763	N
8226	Cheswick	PA	ECAR	Coal Steam	565	3,572,189	N
3264	W S Lee	SC	SERC	Coal Steam	460	1,074,238	N
3280	Canadys Steam	SC	SERC	Coal Steam	490	2,283,447	N
3295	Urquhart	SC	SERC	Coal Steam	372	1,242,199	N
3297	Wateree	SC	SERC	Coal Steam	772	4,213,629	N
3317	Dolphus M Grainger	SC	SERC	Coal Steam	163	915,146	N
7210	Cope	SC	SERC	Coal Steam	417	2,502,965	N
7652	USDOE SRS (D-Area)	SC	SERC	Coal Steam	70	140,894	N
3399	Cumberland	TN	SERC	Coal Steam	2,600	17,978,931	N
3405	John Sevier	TN	SERC	Coal Steam	800	5,148,939	N

Table H1-3: Phase II Facilities in the Inland Study							
EIA Code	**Plant Name**	**Plant State**	**NERC Region**	**Steam Plant Type**	**2001 Capacity (MW)**	**2001 Net Generation (MWh)**	**I&E Data?**
3443	Victoria	TX	ERCOT	O/G Steam	516	819,513	N
3460	Cedar Bayou	TX	ERCOT	O/G Steam	2,295	5,306,310	N
3470	W A Parish	TX	ERCOT	Coal Steam	3,969	17,078,016	N
3503	River Crest	TX	ERCOT	O/G Steam	113	8,358	N
3631	Sam Rayburn	TX	ERCOT	O/G Steam	48	27,353	N
6136	Gibbons Creek	TX	ERCOT	Coal Steam	454	3,352,100	N
3776	Glen Lyn	VA	ECAR	Coal Steam	338	1,458,170	N
3796	Bremo Bluff	VA	SERC	Coal Steam	254	1,286,776	N
3751	Vermont Yankee	VT	NPCC	Nuclear	563	4,171,120	N
4048	Blackhawk	WI	MAIN	O/G Steam	50	13,821	N
4054	Nelson Dewey	WI	MAIN	Coal Steam	200	1,072,048	N
4057	Rock River	WI	MAIN	Coal Steam	294	171,566	N
4078	Weston	WI	MAIN	Coal Steam	565	3,169,258	N
4140	Alma	WI	MAPP	Coal Steam	181	592,357	N
4143	Genoa	WI	MAPP	Coal Steam	346	1,997,218	N
4271	John P Madgett	WI	MAPP	Coal Steam	387	2,310,619	N
8023	Columbia	WI	MAIN	Coal Steam	1,023	7,312,717	N
3935	John E Amos	WV	ECAR	Coal Steam	2,933	13,003,896	N
3936	Kanawha River	WV	ECAR	Coal Steam	439	2,574,883	N
3938	Phil Sporn	WV	ECAR	Coal Steam	1,106	5,482,588	Y
3942	Albright	WV	ECAR	Coal Steam	278	1,363,785	N
3944	Harrison	WV	ECAR	Coal Steam	2,052	12,681,820	N
3945	Rivesville	WV	ECAR	Coal Steam	110	444,510	N
3946	Willow Island	WV	ECAR	Coal Steam	213	1,126,533	N
3947	Kammer	WV	ECAR	Coal Steam	713	3,799,801	Y
6004	Pleasants	WV	ECAR	Coal Steam	1,368	7,795,978	N
10743	Morgantown Energy Facility	WV	ECAR	Coal Steam	69	306,511	N
4158	Dave Johnston	WY	WSCC	Coal Steam	817	5,633,726	N
Lake / Reservoir							
46	Browns Ferry	AL	SERC	Nuclear	3,494	18,196,747	N
47	Colbert	AL	SERC	Coal Steam	1,826	6,690,214	N
533	McWilliams	AL	SERC	Combined Cycle	147	295,507	N
170	Lake Catherine	AR	SERC	O/G Steam	752	1,454,399	N
6138	Flint Creek	AR	SPP	Coal Steam	558	3,698,365	N
8055	Arkansas Nuclear One	AR	SERC	Nuclear	1,845	14,780,789	N
113	Cholla	AZ	WSCC	Coal Steam	1,105	7,151,659	N
477	Valmont	CO	WSCC	Coal Steam	211	1,479,194	N

Table H1-3: Phase II Facilities in the Inland Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
675	Larsen Memorial	FL	FRCC	Combined Cycle	218	440,657	N
676	C D McIntosh Jr	FL	FRCC	Coal Steam	874	3,449,742	N
7242	Polk	FL	FRCC	Combined Cycle	521	1,702,520	N
709	Harllee Branch	GA	SERC	Coal Steam	1,746	7,867,069	N
753	Plant Crisp	GA	SERC	O/G Steam	18	1,921	N
1058	Sixth Street	IA	MAPP	Coal Steam	85	169,060	N
204	Clinton	IL	MAIN	Nuclear	990	7,878,964	N
861	Coffeen	IL	MAIN	Coal Steam	1,005	3,659,838	N
876	Kincaid	IL	MAIN	Coal Steam	1,319	2,394,722	N
963	Dallman	IL	MAIN	Coal Steam	388	1,868,481	N
964	Lakeside	IL	MAIN	Coal Steam	75	255,168	N
976	Marion	IL	MAIN	Coal Steam	272	1,364,295	N
6016	Duck Creek	IL	MAIN	Coal Steam	441	2,159,389	N
6017	Newton	IL	MAIN	Coal Steam	1,235	6,097,054	N
6213	Merom	IN	ECAR	Coal Steam	1,080	6,716,108	N
50366	University of Notre Dame Power Plant	IN	ECAR	Coal Steam	23	0	N
1241	Lacygne	KS	SPP	Coal Steam	1,578	7,598,121	N
1355	E W Brown	KY	ECAR	Coal Steam	1,728	3,915,986	N
1384	Cooper	KY	ECAR	Coal Steam	321	2,137,247	N
1417	Lieberman	LA	SPP	O/G Steam	278	280,382	N
6190	Rodemacher	LA	SPP	Coal Steam	1,004	3,807,479	N
1831	Eckert Station	MI	ECAR	Coal Steam	375	1,547,747	N
1888	Fox Lake	MN	MAPP	O/G Steam	134	75,853	N
1891	Syl Laskin	MN	MAPP	Coal Steam	116	659,429	N
1893	Clay Boswell	MN	MAPP	Coal Steam	1,073	6,947,707	N
1943	Hoot Lake	MN	MAPP	Coal Steam	138	824,445	N
1960	Austin DT	MN	MAPP	O/G Steam	34	3,474	N
2008	Silver Lake	MN	MAPP	Coal Steam	99	285,624	N
2080	Montrose	MO	SPP	Coal Steam	564	2,749,293	N
2161	James River Power St	MO	SPP	Coal Steam	451	1,593,458	N
2168	Thomas Hill	MO	SERC	Coal Steam	1,135	8,668,508	N
2712	Roxboro	NC	SERC	Coal Steam	2,575	14,636,011	N
2718	G G Allen	NC	SERC	Coal Steam	1,155	5,426,420	N
2727	Marshall	NC	SERC	Coal Steam	1,996	13,061,663	N
2732	Riverbend	NC	SERC	Coal Steam	601	2,111,347	N
6015	Harris	NC	SERC	Nuclear	951	5,368,496	N
6038	McGuire	NC	SERC	Nuclear	2,441	18,562,982	N

Table H1-3: Phase II Facilities in the Inland Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
8042	Belews Creek	NC	SERC	Coal Steam	2,160	14,129,200	N
2226	Canaday	NE	MAPP	O/G Steam	109	112,156	N
6077	Gentleman	NE	MAPP	Coal Steam	1,363	9,337,182	N
2330	Fort Churchill	NV	WSCC	O/G Steam	210	1,328,149	N
2535	Milliken	NY	NPCC	Coal Steam	306	2,221,901	N
3000	Boomer Lake Station	OK	SPP	O/G Steam	23	1,310	N
6095	Sooner	OK	SPP	Coal Steam	1,138	7,305,994	N
3161	Eddystone	PA	MAAC	O/G Steam	1,569	3,916,008	N
6105	Limerick	PA	MAAC	Nuclear	2,276	18,491,392	N
3251	H B Robinson	SC	SERC	Nuclear	992	6,432,070	N
3265	Oconee	SC	SERC	Nuclear	2,666	19,040,496	N
6036	Catawba	SC	SERC	Nuclear	2,410	18,551,115	N
6127	Summer	SC	SERC	Nuclear	954	6,763,348	N
6098	Big Stone	SD	MAPP	Coal Steam	457	3,462,038	N
3393	Allen	TN	SERC	Coal Steam	1,611	4,712,127	N
3396	Bull Run	TN	SERC	Coal Steam	950	6,715,632	N
3403	Gallatin	TN	SERC	Coal Steam	1,918	7,198,942	N
3406	Johnsonville	TN	SERC	Coal Steam	2,911	7,704,576	N
3407	Kingston	TN	SERC	Coal Steam	1,700	9,094,952	N
6152	Sequoyah	TN	SERC	Nuclear	2,441	18,949,856	N
7722	Watts Bar Nuclear	TN	SERC	Nuclear	1,270	9,626,575	N
3452	Lake Hubbard	TX	ERCOT	O/G Steam	928	2,047,729	N
3453	Mountain Creek	TX	ERCOT	O/G Steam	958	1,680,430	N
3454	North Lake	TX	ERCOT	O/G Steam	709	1,409,304	N
3457	Lewis Creek	TX	SERC	O/G Steam	543	2,525,762	N
3476	Knox Lee	TX	SPP	O/G Steam	501	1,021,105	N
3477	Lone Star	TX	SPP	O/G Steam	40	15,073	N
3478	Wilkes	TX	SPP	O/G Steam	882	2,012,978	N
3489	Eagle Mountain	TX	ERCOT	O/G Steam	706	589,943	N
3490	Graham	TX	ERCOT	O/G Steam	635	1,307,984	N
3491	Handley	TX	ERCOT	O/G Steam	1,433	1,945,836	N
3492	Morgan Creek	TX	ERCOT	O/G Steam	1,364	2,457,028	N
3497	Big Brown	TX	ERCOT	Coal Steam	1,187	7,272,835	N
3502	Lake Creek	TX	ERCOT	O/G Steam	322	537,413	N
3504	Stryker Creek	TX	ERCOT	O/G Steam	713	1,729,686	N
3506	Tradinghouse	TX	ERCOT	O/G Steam	1,380	5,089,680	N
3507	Trinidad	TX	ERCOT	O/G Steam	243	415,958	N

Table H1-3: Phase II Facilities in the Inland Study

EIA Code	Plant Name	Plant State	NERC Region	Steam Plant Type	2001 Capacity (MW)	2001 Net Generation (MWh)	I&E Data?
3508	Valley	TX	ERCOT	O/G Steam	1,175	2,362,792	N
3521	Lake Pauline	TX	ERCOT	O/G Steam	40	7,468	N
3523	Oak Creek	TX	ERCOT	O/G Steam	75	346,654	N
3524	Paint Creek	TX	ERCOT	O/G Steam	242	348,762	N
3527	San Angelo	TX	ERCOT	Combined Cycle	126	660,569	N
3548	Decker Creek	TX	ERCOT	O/G Steam	932	1,944,510	N
3549	Holly Street	TX	ERCOT	O/G Steam	558	777,190	N
3576	Ray Olinger	TX	ERCOT	O/G Steam	428	863,316	N
3601	Sim Gideon	TX	ERCOT	O/G Steam	639	1,475,704	N
3611	O W Sommers	TX	ERCOT	O/G Steam	892	1,206,473	N
3612	V H Braunig	TX	ERCOT	O/G Steam	894	972,703	N
3627	North Texas	TX	ERCOT	O/G Steam	71	3,959	N
3628	R W Miller	TX	ERCOT	O/G Steam	604	1,242,148	N
4195	Powerlane Plant	TX	ERCOT	O/G Steam	85	0	N
4937	Thomas C Ferguson	TX	ERCOT	O/G Steam	446	929,060	N
4938	Fort Phantom	TX	ERCOT	O/G Steam	363	1,482,191	N
6139	Welsh	TX	SPP	Coal Steam	1,674	10,852,977	N
6145	Comanche Peak	TX	ERCOT	Nuclear	2,430	18,322,265	N
6146	Martin Lake	TX	ERCOT	Coal Steam	2,380	15,224,026	N
6147	Monticello	TX	ERCOT	Coal Steam	1,980	12,880,627	N
6178	Coleto Creek	TX	ERCOT	Coal Steam	600	4,380,429	N
6179	Fayette Power Prj	TX	ERCOT	Coal Steam	1,690	11,675,030	N
6181	J T Deely	TX	ERCOT	Coal Steam	892	5,764,924	N
6243	Dansby	TX	ERCOT	O/G Steam	105	180,191	N
7097	J K Spruce	TX	ERCOT	Coal Steam	546	4,470,735	N
7902	Pirkey	TX	SPP	Coal Steam	721	3,681,203	N
8063	DeCordova	TX	ERCOT	O/G Steam	1,157	3,441,031	N
6165	Hunter	UT	WSCC	Coal Steam	1,472	8,300,173	N
6168	North Anna	VA	SERC	Nuclear	1,960	13,099,598	N
3992	Blount Street	WI	MAIN	Coal Steam	188	443,626	N
4127	Menasha	WI	MAIN	Coal Steam	22	9,285	N
3954	Mt Storm	WV	ECAR	Coal Steam	1,681	8,930,790	N

Source: U.S. EPA analysis for this report.

Chapter H2: Evaluation of Impingement and Entrainment in the Inland Region

H2-1 I&E SPECIES AND SPECIES GROUPS EVALUATED

Table H2-1 provides a list of species and associated species groups that were evaluated in EPA's analysis of impingement and entrainment (I&E) in the Inland region.

CHAPTER CONTENTS

Table H2-1: Species Groups Evaluated by EPA

Species Group	Species	Recreational	Commercial	Forage
Alewife	Alewife			X
American shad	American shad	X		
Bigmouth buffalo	Bigmouth buffalo	X		
	Smallmouth buffalo	X		
Black bullhead	Black bullhead	X		
Black crappie	Black crappie	X		
Blueback herring	Alosa herring			X
	Blueback herring			X
Bluegill	Bluegill	X		
Bluntnose minnow	Bluntnose minnow			X
	Central stoneroller			X
	Chub			X
	Creek chub			X
	Fathead minnow			X
	Silver chub			X
	Silverjaw minnow			X
	Stoneroller			X
Brown bullhead	Brown bullhead	X		
	Stonecat	X		
	Yellow bullhead	X		

Table H2-1: Species Groups Evaluated by EPA

Species Group	Species	Recreational	Commercial	Forage
Carp	Common carp			X
	Goldfish			X
Channel catfish	Blue catfish	X		
	Channel catfish	X		
	Flathead catfish	X		
	White catfish	X		
Crappie	White crappie	X		
Darter species	Etheostoma darter	X		
	Fantail darter	X		
	River darter	X		
	Tessellated darter	X		
Emerald shiner	Bigeye shiner			X
	Common shiner			X
	Emerald shiner			X
	Golden shiner			X
	Mimic shiner			X
	River shiner			X
	Rosyface shiner			X
	Sand shiner			X
	Spotfin shiner			X
	Spottail shiner			X
Freshwater drum	Freshwater drum	X		
Gizzard shad	Gizzard shad			X
	Threadfin shad			X
Golden redhorse	Golden redhorse	X		
	Redhorse	X		
	River redhorse	X		
	Shorthead redhorse	X		
	Silver redhorse	X		
Logperch	Logperch	X		
Muskellunge	Grass pickerel	X		
	Muskellunge	X		
	Northern pike	X		
Other (forage)	American eel			X
	Chestnut lamprey			X
	Goldeye			X
	Longnose gar			X
	Mooneye			X
	Silver lamprey			X

Table H2-1: Species Groups Evaluated by EPA

Species Group	Species	Recreational	Commercial	Forage
Other (recreational)	Banded sculpin			X
	Coho salmon	X		
	Rainbow trout	X		
	Troutperch	X		
Paddlefish	Paddlefish	X		
Rainbow smelt	Rainbow smelt	X		
River carpsucker	River carpsucker	X		
Sauger	Sauger	X		
Skipjack herring	Skipjack herring			X
Smallmouth bass Spotted sucker	Largemouth bass	X		
	Red bass	X		
	Smallmouth bass	X		
	Spotted bass	X		
	Spotted sucker	X		
Striped bass	Striped bass	X		
Striped killifish	Eastern banded killifish	X		
Sucker species	Carpiodes sucker	X		
	Carpsucker buffalo	X		
	Catostomidae sucker	X		
	Highfin carpsucker	X		
	Northern hog sucker	X		
	Quillback	X		
	White sucker	X		
Sunfish	Centrarchidae sunfish	X		
	Green sunfish	X		
	Hybrid sunfish	X		
	Lepomis sunfish	X		
	Longear sunfish	X		
	Pumpkinseed	X		
	Redear sunfish	X		
	Rock bass	X		
	Warmouth	X		
Walleye	Walleye	X		
White bass	White bass	X		
White perch	White perch	X		
Yellow perch	Yellow perch	X		

Life histories of the species with the highest losses are summarized in the following section. The life history data used in EPA's analysis and associated data sources are provided in Appendix H1 of this report.

H2-2 LIFE HISTORIES OF PRIMARY SPECIES IMPINGED AND ENTRAINED IN THE INLAND REGION

The life history characteristics of the primary species impinged and entrained at Ohio River CWIS are summarized in the following sections. The species described are those with the highest I&E rates at the facilities examined.

Emerald shiner (*Notropis atherinoides*)

Emerald shiner is a member of the family Cyprinidae. It is found in large open lakes and rivers from Canada south throughout the Mississippi Valley to the Gulf Coast in Alabama (Scott and Crossman, 1973). Emerald shiner prefer clear waters in the mid- to upper sections of the water column, and are most often found in deep, slow moving rivers (Trautman, 1981). Because of its small size, emerald shiner is an important forage fish for many species.

Spawning occurs from July to August in Lake Erie (Scott and Crossman, 1973). Females lay anywhere from 870 to 8,700 eggs (Campbell and MacCrimmon, 1970), which hatch within approximately 24 hours (Scott and Crossman, 1973). Young-of-year remain in large schools in inshore waters until the fall, when they move into deeper waters to overwinter (Scott and Crossman, 1973). Young-of-year average 5.1 to 7.6 cm (2 to 3 in) in length (Scott and Crossman, 1973).

Emerald shiner move in schools and prefer clear waters over sand or gravel (Froese and Pauly, 2000). They surface at dusk to feed on microcrustaceans, midge larvae, zooplankton, and algae (Campbell and MacCrimmon, 1970). During the day, they descend to deeper waters.

Emerald shiner are sexually mature by age 2, though some larger individuals may mature at age 1 (Campbell and MacCrimmon, 1970). Most do not live beyond 3 years of age (Fuchs, 1967). Adults typically range in size from 6.4 to 8.4 cm (2.5 to 3.3 in) (Trautman, 1981). Populations may fluctuate dramatically from year to year (Trautman, 1981).

EMERALD SHINER
(*Notropis atherinoides*)

Family: Cyprinidae.

Common names: Emerald shiner.

Similar species: Silver shiner, rosyface shiner.[a]

Geographic range: From Canada south throughout the Mississippi valley to the gulf coast in Alabama.[b,c]

Habitat: Large open lakes and rivers.[b]

Lifespan: Emerald shiner live to 3 years of age.[a,d]

Fecundity: Mature by age 2, although some may mature at age 1. Females can lay approximately 870 to 8,700 eggs.[c]

Food Sources: Microcrustaceans, midge larvae, zooplankton, algae.[d]

Prey for: Gulls, terns, mergansers, cormorants, smallmouth bass, yellow perch, and others.[d]

Life Stage Information

Eggs: demersal
- Eggs hatch in less than 24 hours.[d]

Larvae: pelagic
- Individuals from different year classes can have varying body proportions and fin length, as can individuals from different localities.[a]

Adults
- Typically range in size from 6.4 to 8.4 cm (2.5 to 3.3 in).[a]

[a] Trautman, 1981.
[b] Froese and Pauly, 2000.
[c] Campbell and MacCrimmon, 1970.
[d] Scott and Crossman, 1973.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

Freshwater drum (*Aplodinotus grunniens*)

Freshwater drum is a member of the drum family, Sciaenidae. Possibly exhibiting the greatest latitudinal range of any North American freshwater species, its distribution ranges north from Manitoba, Canada, south to Guatemala, and throughout the Mississippi River drainage basin (Scott and Crossman, 1973). Freshwater drum is not a favored food item of either humans or other fish (Edsall, 1967; Trautman, 1981; Bur, 1982).

Based on studies in Lake Erie, the spawning season peaks in July (Daiber, 1953), although spent females have been found as late as September (Scott and Crossman, 1973). Females in Lake Erie produce from 43,000 to 508,000 eggs (Daiber, 1953). The eggs are buoyant, floating at the surface of the water (Daiber, 1953; Scott and Crossman, 1973). This unique quality may be one explanation for the freshwater drum's exceptional distribution (Scott and Crossman, 1973). Yolk-sac larvae are buoyant as well, floating inverted at the surface of the water with the posterior end of the yolk sac and tail touching the surface (Swedberg and Walburg, 1970).

Larvae develop rapidly over the course of their first year. Maturity appears to be reached earlier among freshwater drum females from the Mississippi River than females from Lake Erie. Daiber (1953) found Lake Erie females begin maturing at age 5, and 46 percent reach maturity by age 6. Lake Erie males begin maturing at age 4, and by age 5, 79 percent had reached maturity.

Freshwater drum in western Lake Erie were found to live an average of 4 years, although the oldest male was 8 years of age, and the oldest female was 14 years (Edsall, 1967). Adults tend to be between 30 to 76 cm (12 to 30 in) long. The largest reported freshwater drum from the Ohio River was between 88.9 and 99.1 cm (35 and 39 in) long (Trautman, 1981).

FRESHWATER DRUM
(*Aplodinotus grunniens*)

Family: Sciaenidae.

Common names: Freshwater drum, white perch, sheepshead.[a]

Similar species: White bass, carpsuckers.[a]

Geographic range: From Manitoba, Canada, south to Guatemala. They can be found throughout the Mississippi River drainage basin.

Habitat: Bottoms of medium to large sized rivers and lakes.[b]

Lifespan: The average freshwater drum lives 4 years, although individuals up to 14 years have been reported.[c]

Fecundity: Females in Lake Erie produced from 43,000 to 508,000 eggs.[e]

Food Sources:
Juveniles: Cladocerans (plankton), copepods, dipterans.[d]
Adults: Dipterans, cladocerans,[4] darters, emerald shiner.[e]

Prey for:
- Very few species.

Life Stage Information

Eggs: *Pelagic*
- The buoyant eggs float at the surface of the water, possibly accounting for the species' high distribution.[e]

Larvae:
- Prolarvae float inverted at the surface of the water with the posterior end of the yolk sac and their tail touching the surface.[f]

Adults:
- The species owes its name to the audible "drumming" sound that it is often heard emitting during summer months.[e]
- Tend to be between 30 to 76 cm (12 to 30 in) long.[a]

[a] Trautman, 1981.
[b] Froese and Pauly, 2001.
[c] Edsall, 1967.
[d] Bur, 1982.
[e] Scott and Crossman, 1973.
[f] Swedberg and Walburg, 1970.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

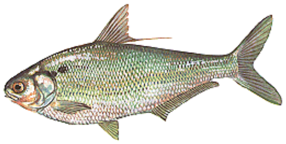
Gizzard shad (*Dorosoma cepedianum*)

Gizzard shad is a member of the family Clupeidae. Its distribution is widespread throughout the eastern United States and into southern Canada, with occurrences from the St. Lawrence River south to eastern Mexico (Miller, 1960; Scott and Crossman, 1973). Gizzard shad are found in a range of salinities from freshwater inland rivers to brackish estuaries and marine waters along the Atlantic Coast of the United States (Miller, 1960; Carlander, 1969). Gizzard shad often occur in schools (Miller, 1960). Young-of-year are considered an important forage fish (Miller, 1960), though their rapid growth rate limits the duration of their susceptibility to many predators (Bodola, 1966). Gizzard shad occur in all of the impoundment pools of the Ohio River and account for nearly half of the fish sampled in Ohio River surveys (Hunter Environmental Services Inc., 1989).

Spawning occurs from late winter or early spring to late summer, depending on temperature. Spawning has been observed in early June to July in Lake Erie (Bodola, 1966), and in May elsewhere in Ohio (Miller, 1960). The spawning period generally lasts two weeks (Miller, 1960). Males and females release sperm and eggs while swimming in schools near the surface of the water. Eggs sink slowly toward the bottom or drift with the current, and adhere to any surface they encounter (Miller, 1960). Females produce an average of 378,990 eggs annually (Bodola, 1960), which average 0.75 mm (0.03 in) in diameter (Wallus et al., 1990).

Hatching time may be anywhere from 36 hours to one week, depending on temperature (Bodola, 1966). Young shad may remain in upstream natal waters if conditions permit (Miller, 1960). By age 2 all gizzard shad are sexually mature, though some may mature as early as age 1 (Bodola, 1966). Unlike many other fish, fecundity in gizzard shad declines with age (Electric Power Research Institute, 1987).

Gizzard shad generally live up to 5 to 7 years, but individuals up to 10 years have been reported in southern locations (Miller, 1960; Scott and Crossman, 1973). Mass mortalities due to extreme temperature changes have been documented in several locations during winter months (Williamson and Nelson, 1985).



GIZZARD SHAD
(*Dorosoma cepedianum*)

Family: Clupeidae (herrings).

Common names: Gizzard shad.

Similar species: Threadfin shad.[a]

Geographic range: Eastern North America from the St. Lawrence River to Mexico.[b,c]

Habitat: Inhabits inland lakes, ponds, rivers, and reservoirs to brackish estuaries and ocean waters.[b,c]

Lifespan: Gizzard shad generally live 5 to 7 years, but have been reported at ages of up to 10 years.[b]

Fecundity: Maturity is reached at ages 2 to 3, females may produce between 59,480 and 378,990 eggs.[b]

Food Sources: Larvae consume protozoans, zooplankton, and small crustaceans.[c] Adults are mainly herbivorous, feeding on plants, phytoplankton, and algae. They are one of the few species able to feed solely on plant material.[b]

Prey for: Walleye, white bass, largemouth bass, crappie; among others (immature shad only).[b]

Life Stage Information

Eggs: *Demersal*
- During spawning, eggs are released near the surface and sink toward the bottom, adhering to any surface they touch.

Larvae: *Pelagic*
- Larvae serve as forage to many species.
- After hatching, larvae travel in schools for the first few months.

Adults
- May grow as large as 52.1 cm (20.5 in).[a]
- May be considered a nuisance species because of sporadic mass winter die-offs.[c]

[a] Trautman, 1981.
[b] Miller, 1960.
[c] Scott and Crossman, 1973.
Fish graphic from Iowa Department of Natural Resources, 2001.

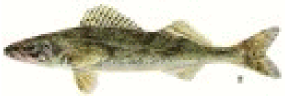
Sauger (*Stizostedion canadense*)

Sauger is a member of the perch family, Percidae. Its distribution extends from the St. Lawrence River system south to northern Louisiana and throughout the Mississippi drainage. Sauger is primarily limited to freshwater systems and only occasionally found in brackish water (Scott and Crossman, 1973; Carlander, 1997). It is a close relative of the walleye, and the two species were once thought to be a single species, with the darker colored sauger mistaken for the male of the species (Trautman, 1981). Once plentiful in western Lake Erie, sauger have declined over the last 100 years. Commercial fishing of sauger in Lake Erie was banned in 1968. While abundance in the Ohio River was never as high as in Lake Erie, it has remained more stable over the years (Trautman, 1981).

Spawning in early April has been documented in Tennessee and in Lake Erie (Carlander, 1997). Males arrive at the spawning grounds before the females. Estimates of female fecundity range from 9,000 to 96,000 eggs per female (Scott and Crossman, 1973). Sauger are able to hybridize with walleye, producing what are locally known as “saugeyes” (Carlander, 1997).

Females broadcast their sticky eggs, which harden and become semibuoyant and nonadhesive. Eggs are 1.44 to 1.86 mm (0.06 to 0.07 in) in diameter. Hatching takes place anywhere from 25 to 29 days at temperatures of 4.4 to 12.8 ˚C (40 to 55 ˚F (Scott and Crossman, 1973). Yolk-sac larvae are 4.5 to 6.2 mm (0.18 to 0.24 in) long after hatching (Scott and Crossman, 1973), and in Ohio, young-of-year are 7.6 to 15.2 cm (2.6 to 6.0 in) by October (Trautman, 1981).

Male sauger typically mature at age 2, and females have been documented to mature anywhere from age 2 to 8 (Scott and Crossman, 1973; Carlander, 1997). In the Ohio River region, sauger generally do not live more than 8 years (Carlander, 1997). Adult male sauger in the Ohio River usually obtain average lengths of 23 cm (9 in), and females obtain lengths of 25.4 to 40.6 cm (10 to 16 in) (Trautman, 1981). The Ohio State record for sauger is 62.2 cm (24.5 in) (Ohio Department of Natural Resources, 2001).



SAUGER
(*Stizostedion canadense*)

Family: Percidae (perches)

Common names: Sauger, Jack salmon.[a]

Similar species: Walleye, blue pike.[b]

Geographic range: St. Lawrence River system south to northern Louisiana throughout the Mississippi drainage.[c]

Habitat: Inhabits sand and gravel runs, and sandy or muddy pools of rivers. Occasionally found in lakes and impoundments.[d]

Lifespan: Up to 8 years in the Ohio River region.[e]

Fecundity: Females produce anywhere from 9,000 to 96,000 eggs.[c]

Food Source: Juveniles feed on cladocerans, chironomids, fish fry.[e] Adults are sight predators, feeding mainly on gizzard shad and emerald shiner; other prey include freshwater drum, channel catfish, mimic shiner.[f]

Prey for: Other sauger, northern pike, walleye, and yellow perch.[c]

Life Stage Information

Eggs: *Demersal*
- Eggs sink to the bottom after hardening, falling between rocks and gravel.[c]
- Eggs may take 25 to 29 days to hatch.

Larvae: *Pelagic*
- Yolk-sac larvae are 4.5 to 6.2 mm (0.18 to 0.24 in) long after hatching.[c]

Adults
- Can hybridize with walleye (hybrids are known as saugeyes).[e]
- Males in the Ohio River average 23 cm (9 in), females are 25.4 to 40.6 cm (10 to 16 in).[b]

[a] Ohio Department of Natural Resources, 2001.
[b] Trautman, 1981.
[c] Scott and Crossman, 1973.
[d] Froese and Pauly, 2001.
[e] Carlander, 1997.
[f] Wahl, D.H. and L.A. Nielsen, 1985.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

White bass (*Morone chrysops*)

White bass is a member of the temperate bass family, Percichthyidae. It ranges from the St. Lawrence River south through the Mississippi valley to the Gulf of Mexico, though the species is most abundant in the Lake Erie drainage (Van Oosten, 1942). Although white bass is native to the Ohio River, populations were introduced to several of the river's impoundments following dam construction (Trautman, 1981).

Spawning take place in May in Lake Erie and may extend into June, depending on temperatures. Spawning bouts can last from 5 to 10 days (Scott and Crossman, 1973). Adults typically spawn near the surface, and eggs are fertilized as they sink toward the bottom. Fecundity increases directly with size in females. The average female lays approximately 565,000 eggs. Eggs hatch within 46 hours at a water temperature of 15.6 °C (60 °F) (Scott and Crossman, 1973).

Larvae grow rapidly, and young white bass reach lengths of 13 to 16 cm (5.1 to 6.3 in) by the fall (Scott and Crossman, 1973). They feed on microscopic crustaceans, insect larvae, and small fish. As adults, the diet switches to fish. Yellow perch are an especially important prey species for white bass (Scott and Crossman, 1973).

Most white bass mature at age 3 (Van Oosten, 1942). Upon reaching sexual maturation, adults tend to form unisexual schools, traveling up to 11.1 km (6.9 mi) a day. Adults tend to occupy the upper portion of the water column, maintaining depths of 6 m or less (Scott and Crossman, 1973). On average, adults are between 25.4 to 35.6 cm (10 to 14 in) long (Ohio Department of Natural Resources, 2001). White bass rarely live beyond 7 years (Scott and Crossman, 1973).

WHITE BASS
(*Morone chrysops*)

Family: Percichthyidae.

Common names: White bass, silver bass.

Similar species: White perch, striped bass.[a]

Geographic range: St. Lawrence River south through the Mississippi valley to the Gulf of Mexico, highly abundant in the Lake Erie drainage.[b]

Habitat: Occurs in lakes, ponds, and rivers.[c]

Lifespan: White bass may live up to 7 years.[d]

Fecundity: The average female lays approximately 565,000 eggs.[b]

Food Source: Juveniles consume microscopic crustaceans, insect larvae, and small fish.[b] Adults have been found to consume yellow perch, bluegill, white crappie,[b] and carp.[b,d]

Prey for: Other white bass.[a]

Life Stage Information

Eggs: *Demersal*
- Eggs are approximately 0.8 mm (0.03 in) in diameter.[b]

Larvae: *Pelagic*
- White bass experience their maximum growth in their first year.[b]

***Adults*:**
- Travel in schools, traveling up to 11.1 km (6.9 mi) a day.[b]
- Most mature at age 3.[e]
- Adults prefer clear waters with firm bottoms.[a]

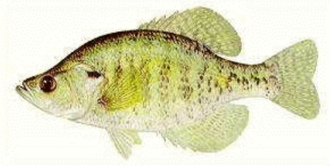
[a] Trautman, 1981.
[b] Scott and Crossman, 1973.
[c] Froese and Pauly, 2000.
[d] Carlander, 1997.
[e] Van Oosten, 1942.
Fish graphic courtesy of New York Sportfishing and Aquatic Resources Educational Program, 2001.

White crappie (*Pomoxis annularis*)

White crappie is a member of the Centrachidae family and is found in the central United States from the Great Lakes to the Gulf of Mexico (Scott and Crossman, 1973). It occurs in freshwater pools, creeks, small to large rivers, and lakes and ponds over sand and mud bottoms. It is found most often in moderately turbid waters (Froese and Pauly, 2000). White crappie tend to school near submerged trees, brush, aquatic vegetation, and boulders (Edwards et al., 1982). Young white crappie feed primarily on zooplankton, and adults feed primarily on small fish, especially gizzard shad (Scott and Crossman, 1973).

White crappie reach sexual maturity between 2 and 3 years (Wang, 1986). Spawning begins in the spring when water temperatures are between 16 and 20 ˚C (60 and 68 ˚F). Males construct nests by fanning out a depression on the bottom near brush, rocks, and vegetation in water that is usually less than 1.5 m (4.9 ft) deep (Wang, 1986; Ohio Department of Natural Resources, 2001). Nests have been observed at average depths of 10 to 420 cm (0.3 to 13.8 ft) (Edwards et al., 1982). Females lay 5,000 to 30,000 eggs per season, but release only a few eggs at a time and often mate with multiple males (Scott and Crossman, 1973; Ohio Department of Natural Resources, 2001). Males guard their nests until the larvae can swim freely into adjacent plant beds (Wang, 1986).

Crappie are very popular for sport fishing (Hansen 1951; Dames and Moore, 1977). Because white crappie are such a prolific species, they often become overcrowded. This can lead to depletion of their food supply and result in slower growth rates and smaller sizes (Carlander, 1969; Steiner, 2000).



WHITE CRAPPIE
(*Pomoxis annularis*)

Family: Centrarchidae (sunfishes).[a]

Common names: White crappie, papermouth, specks.[b]

Similar species: Black crappie, rockbass.[c]

Geographic range: Central United States, including the Mississippi and Great Lakes basins to the Gulf Coast.[c,d]

Habitat: Prefers pools, backwaters of creek, rivers, lakes, and ponds over sand and mud bottoms. Often found in turbid water, and near aquatic vegetation.[a]

Lifespan: The highest reported age is 10 years.[a]

Fecundity: Mature at 2-3 years.[d] Females produce between 5,000 and 30,000 eggs.[b]

Food Sources: Larvae feed on algae, insects, and microcrustaceans; young feed primarily on zooplankton; and adults eat several different types of fish, including gizzard shad, perch, and small crappie.[f]

Prey for: Northern pike, muskellunge.[a]

Life Stage Information

Eggs: *Demersal*
- Laid in nests and guarded by the male. Females often mate with several males in a single spawning season.[d,e]

Larvae:
- 1.22-1.98 mm (0.05 to 0.08 in) at hatching.[d]
- Remain in nest until they can swim freely.[d]

Adults: *Demersal*
- Average length: 15.4 to 30.5 cm (6-12 in).[b]
- Noted as an abundant species in the Ohio River in studies done in 1957-1959 and 1976-1978.[c]

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[a] Froese and Pauly, 2000.
[b] Ohio Department of Natural Resources, 2001.
[c] Trautman, 1981.
[d] Wang, 1986.
[e] Dames and Moore, 1977.
[f] Carlander, 1969.
Fish graphic from North Dakota Game and Fish Department, 1986.

White sucker (*Catostomus commersoni*)

The white sucker is a member of the Catostomidae family, and is found throughout most of Canada, and south to North Carolina and New Mexico in the United States (Froese and Pauly, 2000). It inhabits small and large streams, ponds, lakes, and reservoirs.

Male white suckers reach sexual maturity between ages 2 and 6, and females mature 1 to 2 years later (Twomey et al., 1984). White suckers typically run upstream in the spring to spawn. They spawn over shallow gravel substrate, usually in riffles or swift water, but they have been observed spawning in lakes (Carlander, 1969). Females may scatter 20,000 to 50,000 eggs with several males (Steiner, 2000). The eggs may drift downstream before sticking to the gravel (Steiner, 2000). After hatching, larvae remain in the safety of the gravel for up to 2 weeks before moving on.

Adults primarily inhabit pools and areas of slow to moderate velocity, but are tolerant of a wide range of conditions. White suckers move toward shore at dawn and dusk to feed. They are omnivorous bottom feeders, feeding on plants, zooplankton, insects, mollusks, and crustaceans (Steiner, 2000).

Since 1925, this species has been one of the six most abundant fishes in collections across Ohio (Trautman, 1981). It is a popular catch among anglers, and is especially easy to catch during spawning runs (Ohio Department of Natural Resources, 2001).

WHITE SUCKER
(*Catostomus commersoni*)

Family: Catostomidae (suckers).

Common names: White sucker, common sucker, mullet.[a]

Similar species: Longnose sucker.[b]

Geographic range: Most of Canada, and south through North Carolina to New Mexico in the United States.[a]

Habitat: Small and large streams, ponds, lakes, and reservoirs. Adults primarily inhabit pools and areas of slow to moderate velocity, but are tolerant of a wide range of conditions. Prefer swift water and gravel bottoms for spawning.[c,d]

Lifespan: The average lifespan is 5-7 years.

Fecundity: Males mature between 2 and 6 years, females 1 to 2 years later.[d] Females produce 20,000 to 50,000 eggs.[f]

Food Sources: Fry feed on plankton and small invertebrates; bottom feeding commences upon reaching a length of 1.6 to 1.8 cm (0.6 to 0.7 in).[a] Adults are omnivorous, feeding on plants, zooplankton, insects, mollusks, and crustaceans.[f]

Prey for: Birds, fishes, lamprey, and mammals.[a]

Life Stage Information

Eggs:
- Eggs are released over shallow gravel substrate.[d]

Larvae:
- Approximately 8 mm (0.3 in) upon hatching.[e]
- Remain in gravel substrate for up to 2 weeks.[f]

Adults: *Demersal*
- Maximum size is approximately 64 cm (25 in).[a]
- One of the six most abundant fishes in collections in Ohio since 1925.[b]

[a] Froese and Pauly, 2000.
[b] Trautman, 1981.
[c] Ohio Department of Natural Resources, 2001.
[d] Twomey et al., 1984.
[e] Stewart, 1926.
[f] Steiner, 2000.
Fish graphic from North Dakota Game and Fish Department, 1986.

H2-3 I&E DATA EVALUATED

Table H2-2 lists Inland facilities in scope of the Phase II rule and the facility I&E data evaluated by EPA to estimate current I&E rates for the region.

Table H2-2: Inland Facilities In Scope of the Section 316(b) Phase II Rule and Facility I&E Data Evaluated

In Scope Facilities	I&E Data?	Years of Data
AES Somerset (NY)	No - extrapolated	
Ashtabula (OH)	No - extrapolated	
Avon Lake (OH)	No - extrapolated	
B C Cobb (MI)	No - extrapolated	
Bailly (IN)	No - extrapolated	
Bay Front (WI)	No - extrapolated	
Bay Shore (OH)	No - extrapolated	
Belle River (MI)	No - extrapolated	
C R Huntley (NY)	No - extrapolated	
Conners Creek (MI)	No - extrapolated	
Crawford (IL)	No - extrapolated	
Dan E Karn (MI)	No - extrapolated	
Davis-Besse (OH)	No - extrapolated	
Dean H Mitchell (IN)	No - extrapolated	
Donald C Cook Nuclear (MI)	Yes	1975-1982
Dunkirk (NY)	No - extrapolated	
Eastlake (OH)	No - extrapolated	
Edgewater (OH)	No - extrapolated	
Edgewater (WI)	No - extrapolated	
Fermi Nuclear (MI)	No - extrapolated	
Fisk (IL)	No - extrapolated	
Ginna (NY)	No - extrapolated	
Harbor Beach (MI)	No - extrapolated	
J B Sims (MI)	No - extrapolated	
J C Weadock (MI)	No - extrapolated	
J H Campbell (MI)	No - extrapolated	
J R Whiting (MI)	Yes	1978-1983, 1987, 1991
James A Fitzpatrick (NY)	No - extrapolated	
James De Young (MI)	No - extrapolated	
Kewaunee Nuclear (WI)	No - extrapolated	
Lake Shore (OH)	No - extrapolated	
M L Hibbard (MN)	No - extrapolated	
Manitowoc (WI)	No - extrapolated	
Marysville (MI)	No - extrapolated	
Michigan City (IN)	No - extrapolated	

Table H2-2: Inland Facilities In Scope of the Section 316(b) Phase II Rule and Facility I&E Data Evaluated

In Scope Facilities	I&E Data?	Years of Data
Midland Cogeneration Venture (MI)	No - extrapolated	
Mistersky (MI)	No - extrapolated	
Monroe (MI)	Yes	1974, 1975, 1982, 1985
Nine Mile Point Nuclear (NY)	No - extrapolated	
Oswego (NY)	No - extrapolated	
Palisades Nuclear (MI)	No - extrapolated	
Perry Nuclear (OH)	No - extrapolated	
Point Beach Nuclear (WI)	No - extrapolated	
Port Washington (WI)	No - extrapolated	
Presque Isle (MI)	No - extrapolated	
Pulliam (WI)	No - extrapolated	
River Rouge (MI)	No - extrapolated	
Rochester 7 (NY)	No - extrapolated	
Shiras (MI)	No - extrapolated	
South Oak Creek (WI)	No - extrapolated	
St Clair (MI)	No - extrapolated	
Trenton Channel (MI)	No - extrapolated	
Valley (WI)	No - extrapolated	
Waukegan (IL)	No - extrapolated	
Will County (IL)	No - extrapolated	
Wyandotte (MI)	No - extrapolated	

H2-4 EPA'S ESTIMATE OF CURRENT I&E IN THE INLAND REGION EXPRESSED AS AGE 1 EQUIVALENTS, FOREGONE YIELD, AND PRODUCTION FOREGONE

Table H2-3 provides EPA's estimate of the annual age 1 equivalents, foregone fishery yield, and production foregone resulting from the impingement of aquatic species at facilities located in the Inland region. Table H2-4 displays this information for entrainment.

Table H2-3: Current Annual Impingement in the Inland Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species Group	Age 1 Equivalents (#s)	Yield (lbs)	Production Foregone
American shad	96,989	23,736	51,667
Alewife	513,592	0	8,073
Bass (Micropterus sp.)	64,569	2,611	5,426
Black crappie	10,921	1,821	457
Blueback herring	3,415,663	0	156,342
Bluegill	25,045	484	298
Bullheads	19,322	1,503	704

Table H2-3: Current Annual Impingement in the Inland Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species Group	Age 1 Equivalents (#s)	Yield (lbs)	Production Foregone
Carp minnow	141,981	0	36,676
Crappie	86,981	14,501	3,637
Darters	461	0	0
Freshwater catfish	797,219	165,061	70,836
Freshwater drum	1,094,178	260,737	104,058
Gizzard shad	58,399,773	0	2,111,658
Logperch	3,641	0	15
Other (forage)	62,803,622	0	6,778
Other (recreational)	3,741	727	480
Paddlefish	14,721	77,235	37,399
Pikes	50	190	29
Rainbow smelt	49	0	1
Redhorse	7,128	0	383
River carpsucker	7,192	0	747
Sauger	164,452	43,452	58,600
Shiners	51,283,780	0	85,826
Skipjack herring	103,190	0	18,483
Spotted sucker	577	0	142
Striped bass	293,950	407,991	82,512
Striped killifish	2,223	0	14
Suckers	54,729	0	9,641
Sunfish	1,527,419	1,102	2,578
Walleye	1,616	1,414	476
White bass	556,594	169,643	52,090
White perch	1,240,736	546	15,517
Yellow perch	9,467	126	103

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Table H2-4: Current Annual Entrainment in the Inland Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species Group	Age 1 Equivalents (#s)	Yield (lbs)	Production Foregone
Bass (Micropterus sp.)	2,519,031	101,867	439,407
Blueback herring	20,498	0	23,455
Bluegill	1,687	33	88
Bullheads	57,419	4,473	10,475
Carp minnow	89,771,852	0	22,697,892
Crappie	1,009,726	168,335	693,908

Table H2-4: Current Annual Entrainment in the Inland Region Expressed as Age 1 Equivalents, Foregone Fishery Yield, and Production Foregone

Species Group	Age 1 Equivalents (#s)	Yield (lbs)	Production Foregone
Darters	2,976,999	0	30,060
Freshwater catfish	595,138	123,221	173,303
Freshwater drum	423,876	101,008	270,007
Gizzard shad	3,959,229	0	737,286
Logperch	55,167	0	4,577
Other (forage)	6,318,596	0	65,193
Paddlefish	12,637	66,302	54,539
Redhorse	21,815	0	38,873
Sauger	3,454,069	912,651	5,112,177
Shiners	8,095,946	0	313,151
Skipjack herring	7,578	0	19,417
Suckers	54,117,525	0	87,608,444
Sunfish	12,309,725	8,884	135,994
Walleye	33,729	29,527	84,589
White bass	247,685	75,491	426,277
Yellow perch	248,681	3,313	143,785

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H2-5 ASSUMPTIONS USED IN CALCULATING RECREATIONAL AND COMMERCIAL LOSSES

Unlike the other regions, all losses in the Inland region are assumed to be to recreational fisheries. Therefore, it was not necessary to partition losses between commercial and recreational fisheries. It was also not necessary to collect data on commercial value per pound for the Inland region.

Age-1 equivalent fish that are spared from I&E are not necessarily old enough or large enough to be attractive to anglers. It may take one or more years for these fish to reach a harvestable age. For this reason, EPA discounts recreational benefits so that the cost and benefits estimates will be comparable. Table H2-5 presents the multiplicative discounting factors used in discounting benefits assuming a 3 percent real discount rate and a 7 percent real discount rate. For details on how these factors are developed, see Chapter A14.

Table H2-5: Factors Applied to Recreational Benefits to Implement Discounting in the Inland Region

Species Group	Discount Factors for Entrainment		Discount Factors for Impingement	
	3% Discount Rate	7% Discount Rate	3% Discount Rate	7% Discount Rate
American shad	na	na	0.897	0.780
Bass (Micropterus sp.)	0.926	0.839	0.953	0.897
Bluegill	0.899	0.783	0.925	0.838
Bullheads	0.904	0.795	0.925	0.839
Crappie	0.901	0.789	0.928	0.845
Freshwater catfish	0.938	0.866	0.966	0.926
Freshwater drum	0.871	0.734	0.897	0.785
Other (recreational)	na	na	0.950	0.889
Paddlefish	0.897	0.782	0.924	0.837
Pikes	na	na	0.696	0.439
Rainbow smelt	na	na	0.931	0.851
Sauger	0.905	0.799	0.932	0.855
Striped bass	na	na	0.879	0.749
Sunfish	0.908	0.803	0.936	0.859
Walleye	0.890	0.770	0.917	0.823
White bass	0.919	0.826	0.947	0.883
White perch	na	na	0.904	0.796
Yellow perch	0.899	0.783	0.925	0.838
Other (forage)	0.919	0.829	0.919	0.829

Chapter H3: Commercial Fishing Valuation

There is not a significant level of commercial fishing in the interior U.S. Therefore, EPA has assumed that all I&E losses in this region affect recreational fisheries only. As a result baseline commercial fishing losses and benefits for the Inland region are assumed to be $0.

Chapter H4: Recreational Benefits Analysis

INTRODUCTION

This case study uses a benefit transfer approach to estimate the effects of improved recreational fishing opportunities due to reduced impingement and entrainment (I&E) in the Inland region. The Inland region includes all facilities that withdraw water from freshwater lakes, rivers, and reservoirs that are not included in the Great Lakes region.

CHAPTER CONTENTS

Cooling Water Intake Structures (CWIS) withdrawing water from lakes, rivers, and reservoirs impinge and entrain many species sought by recreational anglers, including panfish, perch, walleye/pike, bass, and anadromous gamefish.[1] In addition, these facilities impinge and entrain forage species, resulting in indirect losses of recreational species that feed on those forage species. Inland CWIS are located in nearly every state, although most are found in the northeastern and south-central U.S. This case study uses estimates of the marginal value per fish from a number of studies conducted in the contiguous U.S. to estimate recreational fishing values for the Inland region.

The following sections discuss the sources of data and methodologies used in the analysis, and present the welfare analysis.

H4-1 DATA SUMMARY

Many published studies value fishing trips and increases in catch rates on fishing trips. Primary studies have shown that anglers value fishing trips and that catch rates are one of the most important attributes contributing to the quality of their trips. For this analysis, EPA conducted a search of the academic literature to identify studies that estimated the marginal value of catching one additional fish. Studies were judged relevant if they valued at least one species affected by I&E, and if they were conducted in the contiguous U.S.[2] Based on these criteria, EPA identified 10 relevant studies.

Most of these studies provided direct estimates of the value of one additional fish, but a few reported values in other metrics, such as willingness-to-pay (WTP) for a doubling of catch rates. Based on information contained in the studies on catch rates and angling trips per season, EPA was able to convert these values for increases in catch rates into values per additional fish. Table H4-1 presents summary information about each of the 10 studies, including the species valued in the study, the WTP per additional fish reported in the study, the study methodology, and the study location.

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[1] The specific species included in each of these groups are shown in Table H4-2.

[2] Benefit transfer analysis is ideally done with studies conducted in similar geographic locations to the location being valued. Because the Inland region includes sites from all over the U.S., estimates from any study that took place in the continental U.S. were included in this analysis.

Table H4-1: Studies with Estimates of the Marginal Value of Freshwater Fish Species

Study Reference	Species Valued	WTP per Additional Fish Caught (2002$)	Study Type	Location of Study
Hicks, R., S. Steinback, A. Gautam, and E. Thunberg. (1999). Volume II: The Economic Value of New England and Mid-Atlantic Sportfishing in 1994. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. NOAA Technical Memorandum NMFS-F/SPO-38.	Small game fish (including striped bass)	$3.27 - $3.65	Travel cost (RUM)	DE
McConnell, K.E. and I.E. Strand. (1994). The Economic Value of Mid and South Atlantic Sportfishing. University of Maryland, Report to the USEPA and NOAA.	Small game fish (includes striped bass)	$9.60 - $16.14	Travel cost (RUM)	DE
Milliman, S.R., B.L. Johnson, R.C. Bishop, and K.J. Boyle. (1992). The Bioeconomics of Resource Rehabilitation: A Commercial-Sport Analysis for a Great Lakes Fishery. Land Economics. 68(2):191-210.	Perch	$0.33	Contingent valuation	WI
Norton, V., T. Smith, and I.E. Strand. (1983). Stripers, The Economic Value of the Atlantic Coast Commercial and Recreational Striped Bass Fisheries. Maryland Sea Grant Publication No. 12.	Striped bass	$16.25	n/a	Mid-Atlantic coast
Pendleton, L.H. and R. Mendelsohn. (1998). Estimating the Economic Impact of Climate Change on the Freshwater Sports fisheries of the Northeastern U.S. Land Economics. 74(4):483-96.	Panfish (warm- and cold-water species)[a]	$4.06 - $4.60	Travel cost (hedonic; RUM)	ME, NH, VT, NY (excluding NYC)
U.S. EPA (2003). Watershed Case Studies Analysis for the Final Section 316(b) Phase Two Existing Facilities Rule. Part D: The Mid-Atlantic Region, and Part G: The Great Lakes.	Striped bass	$18.95	Travel cost (RUM)	DE, NJ
	Walleye and pike	$11.55	travel cost (RUM)	Great Lakes region
U.S. Fish and Wildlife Service. (1998). 1996 Net Economic Values for Bass, Trout and Walleye Fishing, Deer, Elk and Moose Hunting, and Wildlife Watching: Addendum to the 1996 National Survey of Fishing, Hunting and Wildlife-Associated Recreation. Report 96-2.	Smallmouth and largemouth bass	$4.13	Contingent valuation	Northern region (includes DE, IA, IL, KS, KY, MD, MA, MO, NE, RI, VA, WV)
U.S. Fish and Wildlife Service and Stratus Consulting. (1999). Recreational Fishing Damages from Fish Consumption Advisories in the Waters of Green Bay. Prepared by Stratus Consulting Inc., Boulder, CO, for the U.S. Fish and Wildlife Service, U.S. Department of Justice, and U.S. Department of Interior. November 1.	Smallmouth bass	$1.82	Contingent valuation (choice analysis)	WI, MI
	Yellow perch	$0.43		
	Walleye	$1.52		
Vaughan, W.J. and C.S. Russell. (1982). Valuing a Fishing Day: An Application of a Systematic Varying Parameter Model. Land Economics. 58:45-63.	Catfish	$0.77	Travel cost	U.S.
Whitehead, J.C. and R. Aiken. (2000). An Analysis of Trends in Net Economic Values for Bass Fishing from the National Survey of Fishing, Hunting, and Wildlife-associated Recreation East Carolina University, Department of Economics. April.	Bass	$4.50 - $10.16	Contingent valuation	U.S.

[a] Two values for panfish from this study are not reported here because they are negative.

Source: U.S. EPA analysis for this report.

H4-2 BENEFIT TRANSFER METHODOLOGY

Because estimates of WTP per additional fish were not available for every species affected by I&E, EPA assigned species affected by I&E into five categories: panfish, perch, walleye/pike, bass, and anadromous gamefish. Species that were not biologically associated with one of these groupings were classified based on their recreational angling characteristics. For example, the rainbow smelt, although not typically considered to be a panfish, was assigned to that category because of its small size (Wisconsin Sea Grant, 2003). The last column of Table H4-2 lists the species affected by I&E and the category to which they were assigned.

Based on information from the studies listed in Table H4-1, EPA calculated mean WTP per additional fish for each of the five species categories. EPA calculated the means by weighting different estimates taken from the same study so that every study had an equal overall weight, regardless of the number of estimates it presented. Table H4-2 presents summary statistics on value per additional fish, and the number of studies and number of observations used to calculate the values for each species group.

Table H4-2: Value per Additional Fish Caught (2002$)

Species Group	Mean	Median	Minimum	Maximum	# of Studies	# of Observations	I&E Species Included in Category
Panfish	$2.55	$4.06	$0.77	$4.60	2	3	black bullhead, brown bullhead, black crappie, bluegill, channel catfish, crappie, freshwater drum, paddlefish, rainbow smelt, sunfish, other miscellaneous recreational species
Perch	$0.38	$0.38	$0.33	$0.43	2	2	yellow perch, white perch
Walleye/pike	$6.54	$6.54	$1.52	$11.55	2	2	muskellunge, sauger, walleye
Bass	$4.18	$5.81	$1.82	$10.16	2	8	smallmouth bass, white bass
Anadromous gamefish	$11.95	$15.19	$3.27	$16.25	4	7	striped bass, American shad

Source: U.S. EPA analysis for this report.

In addition to calculating per-fish values for these species groupings, EPA estimated value per additional fish for recreational fish losses caused indirectly by losses of forage species due to I&E. The species of these fish are unknown, but EPA assumed that these fish have an average value per additional fish that is equal to the average value per additional fish of the panfish, perch, walleye/pike, and bass groups ($3.41 per fish).

To calculate welfare estimates, EPA multiplied the estimates of value per additional fish shown in Table H4-2 by the number of fish in each species group lost to I&E. These values were discounted at 3 percent and 7 percent over species-specific time periods, to reflect the fact that fish must grow to a certain size before they will be caught by recreational anglers. The recreational benefits under the final section 316(b) rule were further discounted to account for a 1-year lag between the date when installation costs are incurred and the installation of the required cooling water technology.

H4-3 WELFARE ESTIMATES

Tables H4-3 and H4-4 provide annual welfare estimates for two policy scenarios at Inland facilities: completely eliminating I&E (the baseline scenario), and implementation of the final section 316(b) rule. As shown in Table H4-3, total baseline recreational angling losses for the Inland region are estimated to be 3.2 million fish, with a total undiscounted value of $11.6 million. Discounted at 3 percent, the total value is $10.6 million, and at 7 percent, $9.5 million. The largest portion of biological and monetary baseline losses are from indirect losses of predatory fish due to I&E of forage species, equivalent to 1.3 million age-one equivalent fish with an undiscounted value of $4.4 million. Losses of species classified as panfish are also large, equivalent to 1.1 million age-one equivalent fish with an undiscounted value of $2.7 million. Although the number of fish from the walleye/pike and bass groups is relatively small, the larger per fish value for these species results in monetized baseline losses from these groups of $2.3 million and $1.6 million, respectively. Biological and monetary losses of perch and anadromous gamefish are relatively small.

Table H4-3: Baseline Losses for the Inland Region, by Species

Species	Recreational Value per Fish	Number of Fish Lost to I&E	Value of Loss		
			0% Discount Rate	3% Discount Rate	7% Discount Rate
Panfish (total)	**$2.55**	**1,072,917**	**$2,734,357**	**$2,491,154**	**$2,219,857**
bullhead	$2.55	15,212	$38,769	$35,300	$31,344
black crappie	$2.55	2,763	$7,042	$6,533	$5,947
bluegill	$2.55	5,057	$12,889	$11,906	$10,758
crappie	$2.55	277,464	$707,125	$638,445	$561,250
freshwater catfish	$2.55	232,854	$593,435	$566,251	$534,255
freshwater drum	$2.55	372,335	$948,907	$844,205	$731,296
other recreational species	$2.55	1,113	$2,836	$2,693	$2,522
paddlefish	$2.55	5,211	$13,280	$12,102	$10,780
rainbow smelt	$2.55	1	$3	$3	$3
sunfish	$2.55	160,905	$410,071	$373,716	$331,704
Perch (total)	**$0.38**	**29,681**	**$11,213**	**$10,090**	**$8,815**
white perch	$0.38	2,350	$888	$803	$707
yellow perch	$0.38	27,330	$10,325	$9,287	$8,108
Walleye/Pike (total)	**$6.54**	**353,852**	**$2,312,966**	**$2,094,599**	**$1,851,925**
pikes	$6.54	6	$40	$28	$18
sauger	$6.54	343,995	$2,248,535	$2,037,152	$1,802,192
walleye	$6.54	9,851	$64,391	$57,419	$49,715
Bass (total)	**$4.18**	**389,261**	**$1,628,233**	**$1,521,516**	**$1,396,014**
bass (Micropterus sp.)	$4.18	125,128	$523,394	$484,806	$439,699
white bass	$4.18	264,133	$1,104,839	$1,036,710	$956,315
Anadromous Gamefish (total)	**$11.95**	**42,284**	**$505,123**	**$445,399**	**$380,476**
American shad	$11.95	5,714	$68,263	$61,219	$53,240
striped bass	$11.95	36,569	$436,861	$384,180	$327,236
Other (total)[a]	**$3.41**	**1,300,103**	**$4,435,212**	**$4,075,847**	**$3,678,100**
other unidentified fish (from forage losses)	$3.41	1,300,103	$4,435,212	$4,075,847	$3,678,100
Total	**n/a**	**3,188,097**	**$11,627,105**	**$10,638,606**	**$9,535,187**

[a] The “other” category includes indirect losses of fish that result from losses of forage fish due to I&E. The species of these fish is not known, so they are assumed to have a per fish value equal to the average value of perch, panfish, bass, and walleye/pike.

Source: U.S. EPA analysis for this report.

Table H4-4 presents the recreational fish losses prevented by the final section 316(b) rule in the Inland region, and the value of those prevented losses at a 0 percent, 3 percent, and 7 percent discount rate. Total prevented losses are 931,000 fish, or approximately one-third of total baseline losses. The undiscounted benefit to recreational anglers of this increase in fish catch is $3.3 million, and the discounted benefits are $3.0 million and $2.6 million at 3 percent and 7 percent, respectively. The largest portion of the benefits are attributable to reductions in losses of predatory species due to I&E losses of forage species. Prevented losses of this category of fish are 404,000 fish with a value of $1.4 million. The remaining benefits are due to reductions of I&E of panfish (317,000 fish with a value of $807,000), bass (121,000 fish with a value of $507,000), walleye/pike (63,000 fish with a value of $412,000), and anadromous gamefish (20,000 fish with a value of $239,000). Reduction of I&E for perch are insignificant.

Table H4-4: Recreational Benefits of the Final Section 316(b) Rule for the Inland Region, by Species

Species	Recreational Value per Fish	Prevented Losses of Fish to I&E	Value of Loss		
			0% Discount Rate	3% Discount Rate	7% Discount Rate
Panfish (total)	**$2.55**	**316,625**	**$806,927**	**$717,283**	**$619,665**
bullhead	$2.55	3,631	$9,254	$8,239	$7,107
black crappie	$2.55	1,305	$3,325	$2,995	$2,625
bluegill	$2.55	2,290	$5,835	$5,239	$4,564
crappie	$2.55	52,268	$133,207	$117,184	$99,633
freshwater catfish	$2.55	79,270	$202,022	$188,376	$172,512
freshwater drum	$2.55	143,764	$366,387	$317,959	$266,717
other recreational species	$2.55	525	$1,339	$1,235	$1,113
paddlefish	$2.55	1,719	$4,380	$3,901	$3,375
rainbow smelt	$2.55	1	$1	$1	$1
sunfish	$2.55	31,852	$81,177	$72,154	$62,019
Perch (total)	**$0.38**	**5,899**	**$2,229**	**$1,951**	**$1,646**
white perch	$0.38	1,110	$419	$368	$312
yellow perch	$0.38	4,789	$1,809	$1,583	$1,334
Walleye/Pike (total)	**$6.54**	**62,967**	**$411,587**	**$362,685**	**$309,598**
pikes	$6.54	3	$19	$13	$8
sauger	$6.54	61,210	$400,105	$352,726	$301,275
walleye	$6.54	1,754	$11,463	$9,947	$8,315
Bass (total)	**$4.18**	**121,122**	**$506,640**	**$462,549**	**$411,840**
bass (Micropterus sp.)	$4.18	21,476	$89,833	$80,892	$70,746
white bass	$4.18	99,646	$416,807	$381,657	$341,094
Anadromous Gamefish (total)	**$11.95**	**19,966**	**$238,512**	**$204,186**	**$167,902**
American shad	$11.95	2,698	$32,233	$28,065	$23,495
striped bass	$11.95	17,268	$206,280	$176,121	$144,408
Other (total) [a]	**$3.41**	**404,031**	**$1,378,324**	**$1,229,752**	**$1,068,259**
other unidentified fish (from forage losses)	$3.41	404,031	$1,378,324	$1,229,752	$1,068,259
Total	**n/a**	**930,610**	**$3,344,219**	**$2,978,407**	**$2,578,910**

[a] The "other" category includes indirect losses of fish that result from losses of forage fish due to I&E. The species of these fish is not known, so they are assumed to have a per fish value equal to the average value of perch, panfish, bass, and walleye/pike.

Source: U.S. EPA analysis for this report.

H4-4 LIMITATIONS AND UNCERTAINTIES

A number of issues are common to all benefit transfers. Benefit transfer involves adapting research conducted for another purpose in the available literature to address the policy questions at hand. EPA has identified a number of limitations and uncertainties in the use of benefit transfer to value recreational losses for the Inland region.

H4-4.1 Considering Only Recreational Values

This study understates the total benefits of improvements in fishing site quality because estimates are limited to recreational use benefits. Many other forms of benefits, such as habitat values for a variety of species (in addition to recreational fish), non-use values, etc., are also likely to be important.

H4-4.2 Applicability of Valuation Studies to Inland Region

This study classifies all inland sites that are not in the Great Lakes region as part of the Inland region. All I&E losses from the Inland region are aggregated in this analysis for the purpose of valuation. However, the studies used to provide values per fish are based on samples of recreational anglers from specific geographic regions. This may result in an unknown degree of error in the analysis. However, most plants with CWIS are located in the eastern region of the country, and since the majority of the studies included in this analysis are also from that region of the country, this may reduce uncertainty associated with the analysis.

H4-4.3 Uncertainty in the Valuation Studies

There is considerable variation in estimates of per fish value provided by different studies and even within estimates taken from the same study. This variation can be attributed to a number of factors, including differences in geographic, economic, and social characteristics of the survey respondents; differences in study methods and analytical techniques; and potential biases and errors within the studies. By using an average of the values taken from several studies, EPA has attempted to minimize the uncertainty arising from these differences.

H4-4.4 Values for Individual Species

Values were not available for every species affected by I&E. Therefore, EPA combined species into groups, based on biological and recreational angling characteristics of each species. To the extent that the average value for each category does not exactly match the value per fish for each species in that category, the benefit estimates may be overstated or understated.

H4-4.5 Values for Predatory Species Affected by I&E of Forage Species

EPA used the average per fish value of species in the perch, panfish, bass, and walleye/pike groups as an approximation of the average per fish value of predatory species affected by I&E losses of forage species. Because the Agency was not able to determine how many fish of each predatory species were affected by losses of forage species, this estimated average per fish value may not accurately reflect the actual average value of fish in this category.

Chapter H5: Non-Use Benefits

INTRODUCTION

CHAPTER CONTENTS

Aquatic species without any direct uses account for the majority of losses due to impingement and entrainment (I&E) at cooling water intake structures (CWIS). However, EPA's analysis of direct use benefits includes values only for organisms with direct uses, which comprise a very small percentage of total losses (approximately two percent). Because the other 98 percent of losses, consisting of organisms without direct uses, are not without value, the potential exists for significant non-use values that have not been addressed under EPA's estimation of use benefits. For this reason it is important to consider non-use benefits to the human population, produced by the increased numbers of organisms without direct use values, under the final section 316(b) rule.

One way to consider the impact of the section 316(b) rule is to estimate the non-use value of baseline I&E losses and I&E reductions due to the final rule for each case study region using the non-use meta-analysis results. The non-use meta-analysis is presented in detail in Chapter A12, Non-Use Meta-Analysis Methodology, which includes discussions of the literature review process, the estimated regression models and results, and the general methodology used to estimate household and aggregate non-use benefits based on regression results. Total regional non-use benefits can be estimated using the following three steps:

1. Estimate annual changes in non-use value of the affected fishery resources per household due to the baseline impingement and entrainment (I&E) losses and the post-compliance reduction in impingement and entrainment;

2. Estimate the population of households in the Inland region holding non-use value for the affected resources; and

3. Estimate the total non-use value to the affected Inland populations for completely eliminating baseline I&E losses, and for reducing I&E losses from the baseline to post-compliance levels.

EPA explored this approach for the Inland region. However, EPA did not include the results of this approach in the benefit analysis because of limitations and uncertainties associated with estimation of non-use benefits on a regional scale. For further discussion of the limitations and uncertainties of this method, refer to Chapter A12.

H5-1 QUALITATIVE ASSESSMENT OF ECOLOGICAL BENEFITS FOR THE INLAND REGION

Changes in CWIS design or operations resulting from the section 316(b) regulations for existing facilities are expected to reduce I&E losses of fish, shellfish, and other aquatic organisms and, as a result, are expected to increase the numbers of individuals present, increase local and regional fishery populations, and ultimately contribute to the enhanced environmental functioning of affected waterbodies (rivers, lakes, estuaries, and oceans) and associated ecosystems. The economic welfare of human populations is expected to increase as a consequence of the improvements in fisheries and associated aquatic ecosystem functioning.

The aquatic resources affected by cooling water intake structures provide a wide range of services. Ecosystem services are the physical, chemical, and biological functions performed by natural resources and the human benefits derived from those functions, including both ecological and human use services (Daily, 1997; Daily et al., 1997). Scientific and public interest in protecting ecosystem services is increasing with the recognition that these services are vulnerable to a wide range of human activities and are difficult, if not impossible, to replace with human technologies (Meffe, 1992).

In addition to their importance in providing food and other goods of direct use to humans, the organisms lost to I&E are critical to the continued functioning of the ecosystems of which they are a part. Fish are essential for energy transfer in aquatic food webs, regulation of food web structure, nutrient cycling, maintenance of sediment processes, redistribution of bottom substrates, the regulation of carbon fluxes from water to the atmosphere, and the maintenance of aquatic biodiversity

(Peterson and Lubchenco, 1997; Postel and Carpenter, 1997; Holmund and Hammer, 1999; Wilson and Carpenter, 1999). Examples of ecological and public services disrupted by I&E include:

- decreased numbers of ecological keystone, rare, or sensitive species;
- decreased numbers of popular species that are not fished, perhaps because the fishery is closed;
- decreased numbers of special status (e.g., threatened or endangered) species;
- increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E;
- disruption of ecological niches and ecological strategies used by aquatic species;
- disruption of organic carbon and nutrient transfer through the food web;
- disruption of energy transfer through the food web;
- decreased local biodiversity;
- disruption of predator-prey relationships;
- disruption of age class structures of species;
- disruption of natural succession processes;
- disruption of public uses other than fishing, such as diving, boating, and nature viewing; and
- disruption of public satisfaction with a healthy ecosystem.

Many of these services can only be maintained by the continued presence of all life stages of fish and other aquatic species in their natural habitats.

The traditional approach of EPA and other natural resource agencies to quantifying the environmental benefits of proposed regulations has focused on active use values, particularly direct use values such as recreational or commercial fishing. Nonconsumptive uses (such as the importance of fish for aquatic food webs), and passive use or non-use values (including the value of protecting a resource for its own sake), are seldom considered because they are difficult to monetize with available economic methods. However, even though economists debate methods for indirect and non-use valuation, there is general agreement that these values exist and can be important. The potential magnitude of non-use values remains an empirical matter. EPA believes that non-use values are applicable for the section 316(b)-related I&E and that these values are likely to be appreciable for the Inland region.

Appendix H1: Life History Parameter Values Used to Evaluate I&E in the Inland Region

The tables in this appendix summarize the life history parameter values used by EPA to calculate age 1 equivalents, fishery yield, and production foregone from I&E data for the Inland region.

Table H1-1: Alewife Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lb)
Eggs	11.5	0	0	0.00000128
Larvae	5.50	0	0	0.00000141
Juvenile	6.21	0	0	0.00478
Age 1+	0.500	0	0	0.0160
Age 2+	0.500	0	0	0.0505
Age 3+	0.500	0	0	0.0764
Age 4+	0.500	0	0	0.0941
Age 5+	0.500	0	0	0.108
Age 6+	0.500	0	0	0.130
Age 7+	0.500	0	0	0.149

Sources: Froese and Pauly, 2003; NMFS, 2003a; PG&E National Energy Group, 2001; and Spigarelli et al., 1981.

Table H1-2: American Shad Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	0.496	0	0	0.000000716
Yolksac larvae	0.496	0	0	0.000000728
Post-yolksac larvae	2.52	0	0	0.00000335
Juvenile	7.40	0	0	0.000746
Age 1+	0.300	0	0	0.309
Age 2+	0.300	0	0	1.17
Age 3+	0.300	0	0	2.32
Age 4+	0.540	0.21	0.45	3.51
Age 5+	1.02	0.21	0.9	4.56
Age 6+	1.50	0.21	1.0	5.47
Age 7+	1.50	0.21	1.0	6.20
Age 8+	1.50	0.21	1.0	6.77

Sources: Able and Fahay, 1998; Froese and Pauly, 2001; NMFS, 2003a; PSE&G, 1999; and U.S. Fish and Wildlife Service, 1978.

Table H1-3: Bass Species (Micropterus sp.) Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000731
Larvae	2.70	0	0	0.0000198
Juvenile	0.446	0	0	0.0169
Age 1+	0.860	0	0	0.202
Age 2+	1.17	0.32	0.5	0.518
Age 3+	0.755	0.21	1.0	0.733
Age 4+	1.05	0.29	1.0	1.04
Age 5+	0.867	0.24	1.0	1.44
Age 6+	0.867	0.24	1.0	2.24
Age 7+	0.867	0.24	1.0	2.56
Age 8+	0.867	0.24	1.0	2.92
Age 9+	0.867	0.24	1.0	3.30

[a] Includes largemouth bass, red bass, smallmouth bass, spotted bass, and other sunfish not identified to species.

Sources: Bartell and Campbell, 2000; Carlander, 1977; Froese and Pauly, 2001; NMFS, 2003a; Scott and Crossman, 1973; and Wang, 1986.

Table H1-4: Black Bullhead Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.0000312
Larvae	4.61	0	0	0.000186
Juvenile+	1.39	0	0	0.00132
Age 1+	0.446	0	0	0.0362
Age 2+	0.223	0.22	0.50	0.0797
Age 3+	0.223	0.22	1.0	0.137
Age 4+	0.223	0.22	1.0	0.233
Age 5+	0.223	0.22	1.0	0.402
Age 6+	0.223	0.22	1.0	0.679
Age 7+	0.223	0.22	1.0	0.753
Age 8+	0.223	0.22	1.0	0.815
Age 9+	0.223	0.22	1.0	0.823

Sources: Carlander, 1969; Froese and Pauly, 2001; Geo-Marine Inc., 1978; NMFS, 2003a; and Scott and Crossman, 1973.

Table H1-5: Black Crappie Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.80	0	0	0.000000929
Larvae	0.498	0	0	0.00000857
Juvenile	2.93	0	0	0.0120
Age 1+	0.292	0	0	0.128
Age 2+	0.292	0.29	0.50	0.193
Age 3+	0.292	0.29	1.0	0.427
Age 4+	0.292	0.29	1.0	0.651
Age 5+	0.292	0.29	1.0	0.888
Age 6+	0.292	0.29	1.0	0.925
Age 7+	0.292	0.29	1.0	0.972
Age 8+	0.292	0.29	1.0	1.08
Age 9+	0.292	0.29	1.0	1.26

Sources: Bartell and Campbell, 2000; Carlander, 1977; Froese and Pauly, 2001; NMFS, 2003a; and Wang, 1986.

Table H1-6: Blueback herring Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lb)
Eggs	0.558	0	0	0.000000716
Larvae	3.18	0	0	0.00000204
Juvenile	6.26	0	0	0.000746
Age 1+	0.300	0	0	0.0160
Age 2+	0.300	0	0	0.0905
Age 3+	0.300	0	0	0.204
Age 4+	0.900	0	0	0.318
Age 5+	1.50	0	0	0.414
Age 6+	1.50	0	0	0.488
Age 7+	1.50	0	0	0.540
Age 8+	1.50	0	0	0.576

[a] Includes blueback herring and other herrings not identified to the species.

Sources: Able and Fahay, 1998; Froese and Pauly, 2001; NMFS, 2003a; PSE&G, 1999; and U.S. Fish and Wildlife Service, 1978.

Table H1-7: Bluegill Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.73	0	0	0.00000130
Larvae	0.576	0	0	0.00000156
Juvenile	4.62	0	0	0.00795
Age 1+	0.390	0	0	0.00992
Age 2+	0.151	0	0	0.0320
Age 3+	0.735	0.74	0.50	0.0594
Age 4+	0.735	0.74	1.0	0.104
Age 5+	0.735	0.74	1.0	0.189
Age 6+	0.735	0.74	1.0	0.193
Age 7+	0.735	0.74	1.0	0.209
Age 8+	0.735	0.74	1.0	0.352
Age 9+	0.735	0.74	1.0	0.393

Sources: Bartell and Campbell, 2000; Carlander, 1977; Froese and Pauly, 2001; NMFS, 2003a; and Wang, 1986.

Table H1-8: Brown Bullhead Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000115
Larvae	4.61	0	0	0.0000192
Juvenile	1.39	0	0	0.00246
Age 1+	0.446	0	0	0.0898
Age 2+	0.223	0.22	0.50	0.172
Age 3+	0.223	0.22	1.0	0.278
Age 4+	0.223	0.22	1.0	0.330
Age 5+	0.223	0.22	1.0	0.570
Age 6+	0.223	0.22	1.0	0.582

[a] Includes brown bullhead, stonecat, yellow bullhead, and other bullheads not identified to the species.

Sources: Carlander, 1969; Froese and Pauly, 2001; Geo-Marine Inc., 1978; and NMFS, 2003a.

Table H1-9: Carp Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000673
Larvae	4.61	0	0	0.0000118
Juvenile	1.39	0	0	0.0225
Age 1+	0.130	0	0	0.790
Age 2+	0.130	0	0	1.21
Age 3+	0.130	0	0	1.81
Age 4+	0.130	0	0	5.13
Age 5+	0.130	0	0	5.52
Age 6+	0.130	0	0	5.82
Age 7+	0.130	0	0	6.76
Age 8+	0.130	0	0	8.17
Age 9+	0.130	0	0	8.55
Age 10+	0.130	0	0	8.94
Age 11+	0.130	0	0	9.76
Age 12+	0.130	0	0	10.2
Age 13+	0.130	0	0	10.6
Age 14+	0.130	0	0	11.1
Age 15+	0.130	0	0	11.5
Age 16+	0.130	0	0	12.0
Age 17+	0.130	0	0	12.5

[a] Includes carp, goldfish, and other minnows not identified to species.

Sources: Carlander, 1969; Froese and Pauly, 2001; Geo-Marine Inc., 1978; NMFS, 2003a; and Wang, 1986.

Table H1-10: Carp/Minnow Life History Parameters[a]				
Stage Name	**Natural Mortality (per stage)**	**Fishing Mortality (per stage)**	**Fraction Vulnerable to Fishery**	**Weight (lbs)**
Eggs	1.90	0	0	0.00000115
Larvae	2.06	0	0	0.000375
Juvenile	2.06	0	0	0.00208
Age 1+	1.00	0	0	0.00585
Age 2+	1.00	0	0	0.0121
Age 3+	1.00	0	0	0.0171

[a] Includes bluntnose minnow, central stoneroller, creek chub, fathead minnow, silver chub, silverjaw minnow, and other minnows not identified to species.

Sources: Carlander, 1969; Froese and Pauly, 2001; NMFS, 2003a; and Ohio Department of Natural Resources Division of Wildlife, 2003.

Table H1-11: Crappie Species Life History Parameters[a]				
Stage Name	**Natural Mortality (per stage)**	**Fishing Mortality (per stage)**	**Fraction Vulnerable to Fishery**	**Weight (lbs)**
Eggs	1.80	0	0	0.000000929
Larvae	0.498	0	0	0.00000857
Juvenile	2.93	0	0	0.0120
Age 1+	0.292	0	0	0.128
Age 2+	0.292	0.29	0.50	0.193
Age 3+	0.292	0.29	1.0	0.427
Age 4+	0.292	0.29	1.0	0.651
Age 5+	0.292	0.29	1.0	0.888
Age 6+	0.292	0.29	1.0	0.925
Age 7+	0.292	0.29	1.0	0.972
Age 8+	0.292	0.29	1.0	1.08
Age 9+	0.292	0.29	1.0	1.26

[a] Includes white crappie and other crappies not identified to the species.

Sources: Bartell and Campbell, 2000; Carlander, 1977; Froese and Pauly, 2001; NMFS, 2003a; and Wang, 1986.

Table H1-12: Darter Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000619
Larvae	1.95	0	0	0.0000497
Juvenile	1.95	0	0	0.000490
Age 1+	0.700	0	0	0.00161
Age 2+	0.700	0	0	0.00321
Age 3+	0.700	0	0	0.00496

[a] Includes fantail darter, river darter, tessallated darter, and other darters not identified to species.

Sources: Carlander, 1997; Froese and Pauly, 2001, 2003; and NMFS, 2003a.

Table H1-13: Freshwater Catfish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.0000539
Larvae	4.61	0	0	0.0000563
Juvenile	1.39	0	0	0.0204
Age 1+	0.410	0.41	0.50	0.104
Age 2+	0.410	0.41	1.0	0.330
Age 3+	0.410	0.41	1.0	0.728
Age 4+	0.410	0.41	1.0	1.15
Age 5+	0.410	0.41	1.0	1.92
Age 6+	0.410	0.41	1.0	2.41
Age 7+	0.410	0.41	1.0	3.45
Age 8+	0.410	0.41	1.0	4.01
Age 9+	0.410	0.41	1.0	5.06
Age 10+	0.410	0.41	1.0	8.08
Age 11+	0.410	0.41	1.0	8.39
Age 12+	0.410	0.41	1.0	8.53

[a] Includes blue catfish, channel catfish, flathead catfish, white catfish, and other catfish not identified to the species.

Sources: Carlander, 1969; Froese and Pauly, 2001; Geo-Marine Inc., 1978; Miller, 1966; NMFS, 2003a; Salia et al., 1997; and Wang, 1986.

Table H1-14: Freshwater Drum Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.27	0	0	0.00000115
Larvae	6.13	0	0	0.00000295
Juvenile	2.30	0	0	0.0166
Age 1+	0.310	0	0	0.0500
Age 2+	0.155	0.16	0.50	0.206
Age 3+	0.155	0.16	1.0	0.438
Age 4+	0.155	0.16	1.0	0.638
Age 5+	0.155	0.16	1.0	0.794
Age 6+	0.155	0.16	1.0	0.950
Age 7+	0.155	0.16	1.0	1.09
Age 8+	0.155	0.16	1.0	1.26
Age 9+	0.155	0.16	1.0	1.44
Age 10+	0.155	0.16	1.0	1.60
Age 11+	0.155	0.16	1.0	1.78
Age 12+	0.155	0.16	1.0	2.00

[a] Includes freshwater drum and other drum not identified in species.

Sources: Bartell and Campbell, 2000; Froese and Pauly, 2001; NMFS, 2003a; Scott and Crossman, 1973; and Virginia Tech, 1998.

Table H1-15: Gizzard Shad Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.000000487
Larvae	6.33	0	0	0.00000663
Juvenile	0.511	0	0	0.0107
Age 1+	1.45	0	0	0.141
Age 2+	1.27	0	0	0.477
Age 3+	0.966	0	0	0.640
Age 4+	0.873	0	0	0.885
Age 5+	0.303	0	0	1.17
Age 6+	0.303	0	0	1.54

[a] Includes gizzard shad, threadfin shad, and other shad not identified to species.

Sources: Froese and Pauly, 2003; NMFS, 2003a; and Wapora, 1979.

Table H1-16: Killifish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lb)
Eggs	2.30	0	0	0.0000180
Larvae	3.00	0	0	0.0000182
Juvenile	0.916	0	0	0.000157
Age 1+	0.777	0	0	0.0121
Age 2+	0.777	0	0	0.0327
Age 3+	0.777	0	0	0.0551
Age 4+	0.777	0	0	0.0778
Age 5+	0.777	0	0	0.0967
Age 6+	0.777	0	0	0.113
Age 7+	0.777	0	0	0.158

[a] Includes eastern banded killifish.

Sources: Able and Fahay, 1998; Carlander, 1969; Meredith and Lortich, 1979; NMFS, 2003a; and Stone & Webster Engineering Corporation, 1977.

Table H1-17: Logperch Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000260
Larvae	1.90	0	0	0.000512
Juvenile	1.90	0	0	0.00434
Age 1+	0.700	0	0	0.0132
Age 2+	0.700	0	0	0.0251
Age 3+	0.700	0	0	0.0377

Sources: Carlander, 1997; Froese and Pauly, 2001; and NMFS, 2003a.

Table H1-18: Paddlefish Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.0000434
Larvae	3.23	0	0	0.0000816
Juvenile	3.23	0	0	0.0578
Age 1+	0.570	0	0	0.453
Age 2+	0.285	0.29	0.50	7.10
Age 3+	0.285	0.29	1.0	16.3
Age 4+	0.285	0.29	1.0	27.4
Age 5+	0.285	0.29	1.0	31.6
Age 6+	0.285	0.29	1.0	37.3
Age 7+	0.285	0.29	1.0	41.6
Age 8+	0.285	0.29	1.0	43.7
Age 9+	0.285	0.29	1.0	49.2
Age 10+	0.285	0.29	1.0	51.9
Age 11+	0.285	0.29	1.0	54.6
Age 12+	0.285	0.29	1.0	60.6
Age 13+	0.285	0.29	1.0	63.5
Age 14+	0.285	0.29	1.0	68.1
Age 15+	0.285	0.29	1.0	72.7
Age 16+	0.285	0.29	1.0	75.5
Age 17+	0.285	0.29	1.0	80.8
Age 18+	0.285	0.29	1.0	82.6
Age 19+	0.285	0.29	1.0	85.4
Age 20+	0.285	0.29	1.0	87.9
Age 21+	0.285	0.29	1.0	96.2
Age 22+	0.285	0.29	1.0	102

Sources: Carlander, 1969; Froese and Pauly, 2001, and NMFS, 2003a.

Table H1-19: Pike Life History Parameters[a]				
Stage Name	**Natural Mortality (per stage)**	**Fishing Mortality (per stage)**	**Fraction Vulnerable to Fishery**	**Weight (lbs)**
Eggs	1.08	0	0	0.0000189
Larvae	5.49	0	0	0.0133
Juvenile	5.49	0	0	0.0451
Age 1+	0.150	0	0	0.365
Age 2+	0.150	0	0	1.10
Age 3+	0.150	0	0	1.53
Age 4+	0.150	0	0	2.72
Age 5+	0.150	0	0	6.19
Age 6+	0.150	0	0	7.02
Age 7+	0.150	0	0	8.92
Age 8+	0.150	0	0	12.3
Age 9+	0.150	0	0	13.9
Age 10+	0.075	0.08	0.50	16.6
Age 11+	0.075	0.08	1.0	19.0
Age 12+	0.075	0.08	1.0	24.2
Age 13+	0.075	0.08	1.0	25.3
Age 14+	0.075	0.08	1.0	30.0
Age 15+	0.075	0.08	1.0	32.4
Age 16+	0.075	0.08	1.0	34.3
Age 17+	0.075	0.08	1.0	45.6
Age 18+	0.075	0.08	1.0	45.8
Age 19+	0.075	0.08	1.0	47.7
Age 20+	0.075	0.08	1.0	48.8
Age 21+	0.075	0.08	1.0	48.9
Age 22+	0.075	0.08	1.0	49.0
Age 23+	0.075	0.08	1.0	49.1
Age 24+	0.075	0.08	1.0	49.2
Age 25+	0.075	0.08	1.0	49.3
Age 26+	0.075	0.08	1.0	49.4
Age 27+	0.075	0.08	1.0	49.4

[a] Includes grass pickerel, muskellunge, and northern pike.

Sources: Carlander, 1969; Froese and Pauly, 2001; NMFS, 2003a; and Pennsylvania, 1999.

Table H1-20: Rainbow Smelt Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	11.5	0	0	0.000000990
Larvae	5.50	0	0	0.00110
Juvenile	0.916	0	0	0.00395
Age 1+	0.400	0	0	0.0182
Age 2+	0.400	0.03	0.50	0.0460
Age 3+	0.400	0.03	1.0	0.0850
Age 4+	0.400	0.03	1.0	0.131
Age 5+	0.400	0.03	1.0	0.180
Age 6+	0.400	0.03	1.0	0.228

Sources: Froese and Pauly, 2003; NMFS, 2003a; PG&E National Energy Group, 2001; and Spigarelli et al., 1981.

Table H1-21: Redhorse Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.00000115
Larvae	2.30	0	0	0.00000370
Juvenile	2.99	0	0	0.0267
Age 1+	0.548	0	0	0.0521
Age 2+	0.548	0	0	0.180
Age 3+	0.548	0	0	0.493
Age 4+	0.548	0	0	0.653
Age 5+	0.548	0	0	0.916
Age 6+	0.548	0	0	2.78
Age 7+	0.548	0	0	3.07

[a] Includes golden redhorse, river redhorse, shorthead redhorse, silver redhorse, and other redhorses not identified to species.

Sources: Bartell and Campbell, 2000; Carlander, 1969; Froese and Pauly, 2001, 2003; and NMFS, 2003a.

Table H1-22: River Carpsucker Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.05	0	0	0.0000312
Larvae	2.56	0	0	0.0000343
Juvenile	2.30	0	0	0.000239
Age 1+	0.548	0	0	0.0594
Age 2+	0.548	0	0	0.310
Age 3+	0.548	0	0	0.377
Age 4+	0.548	0	0	0.735
Age 5+	0.548	0	0	0.981
Age 6+	0.548	0	0	1.10

Sources: Bartell and Campbell, 2000; Carlander, 1969; Froese and Pauly, 2001, 2003; and NMFS, 2003a.

Table H1-23: Sauger Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.05	0	0	0.00000619
Larvae	3.55	0	0	0.00000681
Juvenile	1.62	0	0	0.0341
Age 1+	0.230	0.05	0.50	0.505
Age 2+	0.230	0.05	1.0	1.03
Age 3+	0.230	0.05	1.0	1.53
Age 4+	0.230	0.05	1.0	2.19
Age 5+	0.230	0.05	1.0	2.27
Age 6+	0.230	0.05	1.0	3.82
Age 7+	0.230	0.05	1.0	4.65
Age 8+	0.230	0.05	1.0	4.80

[a] Includes sauger and walleye.

Sources: Bartell and Campbell, 2000; Carlander, 1997; Froese and Pauly, 2001; and NMFS, 2003a.

Table H1-24: Shiner Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.00000473
Larvae	4.61	0	0	0.000285
Juvenile	0.777	0	0	0.00209
Age 1+	0.371	0	0	0.00387
Age 2+	4.61	0	0	0.00683
Age 3+	4.61	0	0	0.0143

[a] Includes bigeye shiner, common shiner, emerald shiner, golden shiner, mimic shiner, river shiner, rosyface shiner, sand shiner, spotfin shiner, spottail shiner, and other shiners not identified to species.

Sources: Froese and Pauly, 2003; Fuchs, 1967; NMFS, 2003a; Trautman, 1981; and Wapora, 1979.

Table H1-25: Skipjack Herring Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.30	0	0	0.0000227
Larvae	4.25	0	0	0.000381
Juvenile	4.25	0	0	0.0572
Age 1+	0.700	0	0	0.301
Age 2+	0.700	0	0	0.833
Age 3+	0.700	0	0	1.74

Sources: Froese and Pauly, 2001; NMFS, 2003a; Trautman, 1981; and Wallus et al., 1990.

Table H1-26: Spotted Sucker Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.79	0	0	0.00000115
Larvae	2.81	0	0	0.00000198
Juvenile	3.00	0	0	0.0213
Age 1+	0.548	0	0	0.0863
Age 2+	0.548	0	0	0.690
Age 3+	0.548	0	0	1.24
Age 4+	0.548	0	0	1.70
Age 5+	0.548	0	0	1.92
Age 6+	0.548	0	0	1.99

Sources: Bartell and Campbell, 2000; Carlander, 1969; Froese and Pauly, 2001, 2003; and NMFS, 2003a.

Table H1-27: Striped Bass Life History Parameters				
Stage Name	**Natural Mortality (per stage)**	**Fishing Mortality (per stage)**	**Fraction Vulnerable to Fishery**	**Weight (lbs)**
Eggs	1.39	0	0	0.000000224
Larvae	7.32	0	0	0.00000606
Juvenile	3.29	0	0	0.0109
Age 1+	1.10	0	0	0.485
Age 2+	0.150	0.31	0.06	2.06
Age 3+	0.150	0.31	0.20	3.31
Age 4+	0.150	0.31	0.63	4.93
Age 5+	0.150	0.31	0.94	6.50
Age 6+	0.150	0.31	1.0	8.58
Age 7+	0.150	0.31	0.90	12.3
Age 8+	0.150	0.31	0.90	14.3
Age 9+	0.150	0.31	0.90	16.1
Age 10+	0.150	0.31	0.90	18.8
Age 11+	0.150	0.31	0.90	19.6
Age 12+	0.150	0.31	0.90	22.4
Age 13+	0.150	0.31	0.90	27.0
Age 14+	0.150	0.31	0.90	34.6
Age 15+	0.150	0.31	0.90	41.5

Sources: Bason, 1971; NMFS, 2003a; and PSE&G, 1999.

Table H1-28: Sucker (*Ictiobus* sp.) Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.87	0	0	0.00000390
Larvae	1.73	0	0	0.00214
Juvenile	2.98	0	0	0.00851
Age 1+	0.548	0	0	1.14
Age 2+	0.548	0	0	1.82
Age 3+	0.548	0	0	2.63
Age 4+	0.548	0	0	3.48
Age 5+	0.548	0	0	4.64
Age 6+	0.548	0	0	5.04
Age 7+	0.548	0	0	11.1
Age 8+	0.548	0	0	12.7
Age 9+	0.548	0	0	16.8
Age 10+	0.548	0	0	27.8
Age 11+	0.548	0	0	28.0
Age 12+	0.548	0	0	36.1
Age 13+	0.548	0	0	36.2
Age 14+	0.548	0	0	36.3
Age 15+	0.548	0	0	36.5

[a] Includes bigmouth buffalo and smallmouth buffalo.

Sources: Bartell and Campbell, 2000; Carlander, 1969; Kleinholtz, 2000; and NMFS, 2003a.

Table H1-29: Sucker Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.05	0	0	0.0000312
Larvae	2.56	0	0	0.0000343
Juvenile	2.30	0	0	0.000239
Age 1+	0.274	0	0	0.0594
Age 2+	0.274	0	0	0.310
Age 3+	0.274	0	0	0.377
Age 4+	0.274	0	0	0.735
Age 5+	0.274	0	0	0.981
Age 6+	0.274	0	0	1.10

[a] Includes carpsuckers, highfin carpsucker, northern hog sucker, quillback , white sucker, and other suckers not identified to species.

Sources: Bartell and Campbell, 2000; Carlander, 1969; Froese and Pauly, 2003; and NMFS, 2003a.

Table H1-30: Sunfish Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.71	0	0	0.00000115
Larvae	0.687	0	0	0.00000123
Juvenile	0.687	0	0	0.000878
Age 1+	1.61	0	0	0.00666
Age 2+	1.61	0	0	0.0271
Age 3+	1.50	1.5	0.50	0.0593
Age 4+	1.50	1.5	1.0	0.0754
Age 5+	1.50	1.5	1.0	0.142
Age 6+	1.50	1.5	1.0	0.180
Age 7+	1.50	1.5	1.0	0.214
Age 8+	1.50	1.5	1.0	0.232

[a] Includes green sunfish, longear sunfish, pumpkinseed, redear sunfish, rock bass, warmouth, and other sunfish not identified to species.

Sources: Carlander, 1977; Froese and Pauly, 2001; PSE&G, 1999; NMFS, 2003a; and Wang, 1986.

Table H1-31: Walleye Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.05	0	0	0.00000619
Larvae	3.55	0	0	0.0000768
Juvenile	1.93	0	0	0.0300
Age 1+	0.431	0	0	0.328
Age 2+	0.161	0.27	0.50	0.907
Age 3+	0.161	0.27	1.0	1.77
Age 4+	0.161	0.27	1.0	2.35
Age 5+	0.161	0.27	1.0	3.37
Age 6+	0.161	0.27	1.0	3.97
Age 7+	0.161	0.27	1.0	4.66
Age 8+	0.161	0.27	1.0	5.58
Age 9+	0.161	0.27	1.0	5.75

Sources: Bartell and Campbell, 2000; Carlander, 1997; Froese and Pauly, 2001, 2003; NMFS, 2003a; and Thomas and Haas, 2000.

Table H1-32: White Bass Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.90	0	0	0.000000396
Larvae	4.61	0	0	0.00000174
Juvenile	1.39	0	0	0.174
Age 1+	0.420	0	0	0.467
Age 2+	0.420	0.70	0.50	0.644
Age 3+	0.420	0.70	1.0	1.02
Age 4+	0.420	0.70	1.0	1.16
Age 5+	0.420	0.70	1.0	1.26
Age 6+	0.420	0.70	1.0	1.66
Age 7+	0.420	0.70	1.0	1.68

[a] Includes white bass and temperate bass not identified to species.

Sources: Carlander, 1997; Froese and Pauly, 2001; Geo-Marine Inc., 1978; McDermot and Rose, 2000; NMFS, 2003a; Van Oosten, 1942; and Virginia Tech, 1998.

Table H1-33: White Perch Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lb)
Eggs	2.75	0	0	0.000000330
Larvae	5.37	0	0	0.00000271
Juvenile	1.71	0	0	0.00259
Age 1+	0.693	0	0	0.0198
Age 2+	0.693	0	0	0.0567
Age 3+	0.693	0.15	0.0008	0.103
Age 4+	0.689	0.15	0.027	0.150
Age 5+	1.58	0.15	0.21	0.214
Age 6+	1.54	0.15	0.48	0.265
Age 7+	1.48	0.15	0.84	0.356
Age 8+	1.46	0.15	1.0	0.387
Age 9+	1.46	0.15	1.0	0.516
Age 10+	1.46	0.15	1.0	0.619

Sources: Horseman and Shirey, 1974; NMFS, 2003a; and PSE&G, 1999.

Table H1-34: Yellow Perch Life History Parameters

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.75	0	0	0.000000655
Larvae	3.56	0	0	0.000000728
Juvenile	2.53	0	0	0.0232
Age 1+	0.361	0	0	0.0245
Age 2+	0.249	0	0	0.0435
Age 3+	0.844	0.36	0.50	0.0987
Age 4+	0.844	0.36	1.0	0.132
Age 5+	0.844	0.36	1.0	0.166
Age 6+	0.844	0.36	1.0	0.214

Sources: NMFS, 2003a; PSE&G, 1999; Thomas and Haas, 2000; and Wapora, 1979.

Table H1-35: Other Recreational Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	2.08	0	0	0.000000716
Larvae	5.71	0	0	0.00000204
Juvenile	2.85	0	0	0.000746
Age 1+	0.450	0	0	0.0937
Age 2+	0.450	0.80	0.50	0.356
Age 3+	0.450	0.80	1.0	0.679
Age 4+	0.450	0.80	1.0	0.974
Age 5+	0.450	0.80	1.0	1.21
Age 6+	0.450	0.80	1.0	1.38

[a] Includes banded sculpin, coho salmon, rainbow trout, and trout-perch.

Sources: Able and Fahay, 1998; ASMFC, 2001b; Durbin et al., 1983; Entergy Nuclear Generation Company, 2000; NMFS, 2003a; PSE&G, 1999; Ruppert et al., 1985; and U.S. Fish and Wildlife Service, 1978.

Table H1-36: Other Forage Species Life History Parameters[a]

Stage Name	Natural Mortality (per stage)	Fishing Mortality (per stage)	Fraction Vulnerable to Fishery	Weight (lbs)
Eggs	1.04	0	0	0.0000000186
Larvae	7.70	0	0	0.00000158
Juvenile	1.29	0	0	0.000481
Age 1+	1.62	0	0	0.00381
Age 2+	1.62	0	0	0.00496
Age 3+	1.62	0	0	0.00505

[a] Includes American eel, chestnut lamprey, goldeye, longnose gar, madtoms, mooneye, silver lamprey, and other forage fish not identified to species.

Sources: Derickson and Price, 1973; and PSE&G, 1999.

Part I

National Benefits

Chapter I1: National Benefits

INTRODUCTION

This chapter summarizes the results of the seven regional analyses and presents total monetary values of national baseline losses and final rule benefits for all 554 facilities subject to the final rule.

CHAPTER CONTENTS

Greater detail on the methods and data used in the regional analyses is provided in the previous chapters of this Regional Study Document. See Chapter A5 for a discussion of the methods used to estimate I&E, and Chapters A9 through A15 for discussion of the methods used to estimate the value of I&E losses and the benefits of the rule. The results of the regional analyses are presented in Parts B through H.

I1-1 CALCULATING NATIONAL LOSSES AND BENEFITS

In total, EPA found 554 facilities to be in scope of the section 316(b) Phase II final rule. However, the regional estimates of baseline losses and final rule benefits reflect only the 541 in-scope facilities that completed section 316(b) questionnaires (excluding three facilities in Hawaii). In order to calculate national losses and benefits for all 554 facilities, EPA estimated values for the three facilities located in Hawaii and the 11 other facilities that did not complete the questionnaire. To calculate losses and benefits for the three Hawaii facilities, EPA extrapolated losses and benefits from four coastal regions (the North Atlantic, Mid-Atlantic, Gulf of Mexico, and California regions), based on total intake flows in those regions and in Hawaii. To estimate commercial and recreational losses and benefits for the 11 facilities that did not complete the section 316(b) questionnaire, EPA developed and applied a set of statistical sample weights to the commercial and recreational losses and benefits of all facilities that did answer the questionnaire. Finally, to calculate national losses and benefits for all 554 in-scope facilities, EPA summed losses and benefits from all of the regional analyses, from the three Hawaii facilities, and from the 11 facilities that did not return the section 316(b) questionnaire.

EPA notes that quantifying and monetizing reductions in impingement and entrainment (I&E) due to the final section 316(b) rule is extremely challenging, and the preceding sections of this Regional Study Document discuss specific limitations and uncertainties associated with estimation of commercial, recreational, and non-use benefits. National benefit estimates, which are based on the regional estimates, are subject to the same uncertainties inherent in the valuation approaches used for assessing the three benefits categories. The combined effect of these uncertainties is of unknown magnitude and direction (i.e., the estimates may over- or understate the anticipated national-level benefits); however, EPA has no data to indicate that the results for the commercial and recreational benefit categories are atypical or unreasonable. As mentioned in Chapter A12, EPA has estimated non-use values only qualitatively.

I1-2 SUMMARY OF BASELINE LOSSES AND EXPECTED REDUCTIONS IN I&E

Based on the results of the regional analyses, EPA calculated total I&E losses at the current baseline and under the final rule. In Table I1-1, the baseline results are presented for three measures of I&E:

1. Age 1 equivalent losses (the number of individual fish of different ages impinged and entrained by facility intakes, expressed as age 1 equivalents);
2. Foregone fishery yield (pounds of commercial harvest and numbers of recreational fish and shellfish that are not harvested due to I&E, including indirect losses of harvested species due to losses of forage species); and
3. Foregone biomass production (the expected total amount of future growth, expressed as pounds, of individuals that were impinged or entrained, had they not been impinged or entrained).

Table I1-1: Total Current Annual I&E, By Region

Region[a]	Age 1 Equivalents (millions)	Foregone Fishery Yield (million lbs)	Foregone Biomass Production (million lbs)
California	312.9	28.9	43.6
North Atlantic	65.7	1.3	289.1
Mid-Atlantic	1,733.1	67.2	110.9
South Atlantic[b]	342.5	18.3	28.3
Gulf of Mexico	191.2	35.8	48.1
Great Lakes	319.1	3.6	19.3
Inland	369.0	3.5	122.0
Total (weighted)	**3,449.4**	**165.0**	**717.1**

[a] Regional estimates are unweighted. National totals are sample-weighted and include Hawaii.
[b] EPA estimated I&E losses in the South Atlantic by extrapolating results from the Mid-Atlantic and Gulf of Mexico regions.

Source: U.S. EPA analysis for this report.

Table I1-1 shows that total national losses of age 1 equivalents for all 554 facilities equals 3.4 billion fish. Nationwide, EPA estimates that 165.0 million pounds of fishery yield is foregone under current rates of I&E, and 717.1 million pounds of future biomass production is lost. The table shows about half of all age 1 equivalent losses, or 1.7 billion fish, occur in the Mid-Atlantic region. The Mid-Atlantic region also has the highest foregone fishery yield, followed by the Gulf of Mexico region and the California region. The largest amount of foregone future biomass production, 289.1 million pounds, is attributable to I&E in the North Atlantic region. More detailed discussions of the losses in each region are provided in Sections B through H of this Regional Study Document.

EPA also calculated the total national I&E losses prevented by the final rule. These prevented losses were based on the expected reductions in I&E at each facility due to technology required by the final rule. Table I1-2 presents average regional expected reductions in I&E. The table also presents estimates of regional and national prevented I&E losses, expressed as age 1 equivalents lost, foregone fishery yield, and foregone biomass production. The table shows that, at the 554 national in-scope facilities, the final rule reduces age 1 equivalent losses by 1.4 billion fish, prevents 64.9 million pounds of fishery yield from being lost, and prevents 217.1 million pounds of future biomass production from being lost.

Table I1-2 also shows that the expected reductions vary across the regions. Facilities in the Gulf of Mexico are expected to make the largest average percentage reductions in impingement (59.0 percent), and facilities in the Mid-Atlantic are expected to make the largest average percentage reductions in entrainment (47.9 percent). More than half of age 1 equivalent losses that are prevented by the final rule, 846.4 million fish, are attributable to facilities in the Mid-Atlantic region. Judged by prevention of fishery losses, the final rule generates the largest benefits in the Mid-Atlantic region; judged by prevention of foregone biomass production, the final rule generates the largest benefits in the North Atlantic region. More detailed discussions of regional benefits are provided in Sections B through H of this Regional Study Document.

Table I1-2: Expected Reduction in I&E Under Final Rule, by Region

Region[a]	Expected Reductions in I&E Under Final Rule				
	Impingement	Entrainment	Age 1 Equivalents (millions)	Foregone Fishery Yield (million lbs)	Foregone Biomass Production (million lbs)
California	30.9%	21.0%	66.39	6.10	9.19
North Atlantic	43.8%	29.1%	19.34	0.37	84.28
Mid-Atlantic	53.5%	47.9%	846.37	34.28	54.66
South Atlantic	43.7%	17.1%	76.67	5.31	6.31
Gulf of Mexico	59.0%	31.9%	89.55	13.84	16.50
Great Lakes	51.5%	40.1%	159.52	1.73	8.51
Inland	47.2%	16.4%	116.83	1.06	20.90
Total (weighted)	**n/a**	**n/a**	**1,420.20**	**64.92**	**217.09**

[a] National totals are sample-weighted and include Hawaii. Hawaii benefits are calculated based on average loss per MGD in North Atlantic, Mid-Atlantic, Gulf of Mexico, California, and the total intake flow in Hawaii.

Source: U.S. EPA analysis for this report.

I1-3 VALUE OF NATIONAL LOSSES AND BENEFITS

Based on the monetized regional values of baseline losses and the final rule benefits presented in Sections B through H of this document, EPA calculated estimates of the total national monetized losses and benefits for all 554 facilities subject to the final rule. Table I1-3 and Table I1-4 present these results, for each region and for the nation as a whole.[1] Because EPA did not estimate non-use benefits quantitatively, the monetary values of national losses and benefits presented in these tables reflect use values only. As mentioned in Chapter A12, the Agency was not able monetize benefits for 98.2 percent of the age-one equivalent losses of all commercial, recreational, and forage species for the section 316(b) Phase II regulation. This means that the estimates of losses and benefits presented in this section represent the losses and benefits associated with less than two percent of the total age-one equivalents lost due to I&E by cooling water intake structures, and should be interpreted with caution. See Chapter A9 of the Regional Case Study document for a detailed description of the ecological benefits from reduced I&E.

Table I1-3 shows that the total national value of fishery resources lost to I&E includes $23.2 million in commercial fishing benefits, $189.4 million in recreational fishing benefits, and an unknown amount in non-use benefits (2002$, discounted at three percent). The total use value of fishery resources lost is approximately $212.5 million per year. Total commercial and recreational losses are greatest in the Mid-Atlantic region, at $8.4 million and $89.6 million, respectively, for a total use value of $97.9 million in the Mid-Atlantic region. More detailed discussions of the value of the losses in each region are provided in Sections B through H of this document. Additionally, as a sensitivity analysis, the appendix to this chapter presents the value of baseline losses evaluated at a seven percent discount rate.

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[1] All benefits in this chapter are calculated using a three percent social discount rate. For comparison, Chapter D1 of the EBA presents total national and regional social benefits using a seven percent discount rate.

Table I1-3: Summary of Monetary Values of Current I&E Losses (millions; 2002$; 3% discount rate)

Region[a]	Use Value of I&E Losses			Non-Use Value of I&E Losses[b]	Total Value of I&E Losses
	Commercial Fishing	Recreational Fishing	Total Use Value		
California	$6.1	$7.5	$13.6	n/a	n/a
North Atlantic	$0.5	$4.9	$5.4	n/a	n/a
Mid-Atlantic	$8.4	$89.6	$97.9	n/a	n/a
South Atlantic	$1.9	$30.0	$32.0	n/a	n/a
Gulf of Mexico	$4.1	$12.4	$16.5	n/a	n/a
Great Lakes	$1.0	$29.4	$30.4	n/a	n/a
Inland	n/a	$10.6	$10.6	n/a	n/a
Total (weighted)	**$23.2**	**$189.4**	**$212.5**	**n/a**	**n/a**

[a] Regional numbers are unweighted. National totals are sample-weighted and include Hawaii.
[b] EPA estimated non-use values only qualitatively.

Source: U.S. EPA analysis for this report.

Table I1-4 presents EPA's estimates of the national and regional values of reductions in I&E under the final rule. The table shows that the final rule results in national monetized use benefits of $82.9 million per year (2002$, discounted at three percent) and an unknown amount of non-use benefits. Recreational fishing benefits, which are $79.3 million, make up the majority of total national monetized use benefits. National commercial benefits are relatively small, at $3.5 million. The final rule is expected to generate the largest commercial and recreational benefits in the Mid-Atlantic region ($1.7 million and $43.4 million, respectively), resulting in total use benefits in the Mid-Atlantic region of $45.0 million. More detailed discussions of regional benefits are provided in Sections B through H of this Regional Study Document. Additionally, as a sensitivity analysis, the appendix to this chapter presents the value of the monetized benefits of the final rule evaluated at a seven percent discount rate.

Table I1-4: Summary of Social Benefits (millions; 2002$; 3% discount rate)[a]

Region[b]	Use Benefits of I&E Reductions			Non-Use Benefits of I&E Reductions[c]	Total Benefits of I&E Reductions
	Commercial Fishing	Recreational Fishing	Total Use Benefits		
California	$0.5	$2.5	$3.0	n/a	n/a
North Atlantic	$0.1	$1.4	$1.4	n/a	n/a
Mid-Atlantic	$1.7	$43.4	$45.0	n/a	n/a
South Atlantic	$0.2	$6.9	$7.1	n/a	n/a
Gulf of Mexico	$0.7	$6.2	$6.9	n/a	n/a
Great Lakes	$0.2	$14.0	$14.1	n/a	n/a
Inland	n/a	$3.0	$3.0	n/a	n/a
Total (weighted)	**$3.5**	**$79.3**	**$82.9**	**n/a**	**n/a**

[a] Discounted to account for lag in implementation and lag in time required for fish lost to I&E to reach a harvestable age.
[b] Regional numbers are unweighted. National totals are sample-weighted and include Hawaii.
[c] EPA estimated non-use values only qualitatively.

Source: U.S. EPA analysis for this report.

Appendix to Chapter I1

This appendix summarizes the monetary values of current I&E losses and the monetary benefits of the final rule using a 7 percent social discount rate instead of a 3 percent rate. The results of this sensitivity analysis are presented in the following tables.

Table I1-A-1: Summary of Monetary Values of Current I&E Losses (millions; 2002$; 7% discount rate)

Region[a]	Use Value of I&E Losses			Non-Use Value of I&E Losses[b]	Total Value of I&E Losses
	Commercial Fishing	Recreational Fishing	Total Use Value		
California	$4.4	$6.1	$10.5	n/a	n/a
North Atlantic	$0.4	$4.3	$4.7	n/a	n/a
Mid-Atlantic	$7.3	$82.5	$89.9	n/a	n/a
South Atlantic	$1.7	$28.1	$29.8	n/a	n/a
Gulf of Mexico	$3.4	$11.2	$14.6	n/a	n/a
Great Lakes	$0.9	$26.7	$27.6	n/a	n/a
Inland	n/a	$9.5	$9.5	n/a	n/a
Total (weighted)	**$18.9**	**$172.9**	**$191.8**	**n/a**	**n/a**

[a] Regional numbers are unweighted. National totals are sample-weighted and include Hawaii.
[b] EPA estimated non-use values only qualitatively.

Source: U.S. EPA analysis for this report.

Table I1-A-2: Summary of Social Benefits (millions; 2002$; 7% discount rate)[a]

Region[b]	Use Benefits of I&E Reductions			Non-Use Benefits of I&E Reductions[c]	Total Benefits of I&E Reductions
	Commercial Fishing	Recreational Fishing	Total Use Benefits		
California	$0.4	$1.9	$2.3	n/a	n/a
North Atlantic	$0.1	$1.2	$1.2	n/a	n/a
Mid-Atlantic	$1.5	$38.5	$39.9	n/a	n/a
South Atlantic	$0.2	$6.2	$6.4	n/a	n/a
Gulf of Mexico	$0.6	$5.5	$6.2	n/a	n/a
Great Lakes	$0.2	$12.2	$12.4	n/a	n/a
Inland	n/a	$2.6	$2.6	n/a	n/a
Total (weighted)	**$3.0**	**$70.0**	**$72.9**	**n/a**	**n/a**

[a] Discounted to account for lag in implementation and lag in time required for fish lost to I&E to reach a harvestable age.
[b] Regional numbers are unweighted. National totals are sample-weighted and include Hawaii.
[c] EPA estimated non-use values only qualitatively.

Source: U.S. EPA analysis for this report.

Glossary

7Q10: The lowest average seven-consecutive-day low flow with an average recurrence frequency of once in 10 years determined hydrologically.

Adipose fin: A small, fleshy fin behind the main dorsal fin in bony fish; most common in trout and salmon.

Adverse environmental impact (AEI): Within the context of this case study and the section 316(b) regulation, adverse environmental impacts are said to occur whenever there is entrainment or impingement of aquatic organisms due to the operation of a specific cooling water intake structure.

Aerobic: Requiring the presence of free oxygen to support life.

Agnathan: Any member of the vertebrate class Agnatha, the jawless fishes.

Air/swim bladder: A large, thin-walled sac in many fish species that may function in several ways, e.g., as a buoyant float, a sound producer and receptor, and a breathing organ.

Alevin(s): A young fish; especially a newly hatched salmon when still attached to the yolk sac; In North America alevins are sometimes called ‘sac-fry.’

Algal blooms: The exponential growth of algal populations in response to excessive nutrient input. Algal blooms can adversely affect water quality.

Amphipods: A group of mostly small (5 to 20 mm), predominantly marine crustacean species characterized by a laterally-compressed, many-segmented body; most live on or in bottom substrates.

Anadromous: Pertaining to fish that spend a part of their life cycle in the sea and return to freshwater streams to spawn, for example, salmon, steelhead, and shad. Contrast with catadromous.

Anal fin: The median, unpaired fin on the ventral margin between the anus and the caudal fin in fishes.

Anoxic: Absence of oxygen. Usually used in reference to an aquatic habitat.

Anthropogenic: Coming from or associated with human activities.

Anus: The opening at the lower end of the alimentary canal, through which the solid refuse of digestion is excreted to the outside.

Aortic arch: One member of a series of paired, curved blood vessels that arise from the ventral aorta, pass through the gills, and join with the dorsal aorta.

Arteries: Blood vessels that carry blood away from the heart to all parts of the body.

Arterioles: The smallest branches of an artery, which eventually merge with capillaries.

Arthropods: An extremely large group of related terrestrial and aquatic invertebrate species; well-known aquatic representatives, all of them crustaceans, include shrimps, copepods, crabs, mysids, and amphipods.

Atrium: A muscular heart chamber that receives blood from the veins and in turn pumps it into the ventricle.

Axial musculature: The large muscle mass that runs from head to tail on both sides of the body in fish. It is the power plant responsible for swimming, and typically represents up to half the mass of a fish.

Bayou: A sluggish marshy inlet or outlet associated with a lake, river, or other surface waterbody.

Benefits transfer: An approach to valuing an environmental improvement in which the results of existing research on the benefits of an environmental improvement are applied to estimate the benefits in a different, but similar, situation.

Benthic: Adjective that refers to something of or pertaining to benthos. See also: Benthos.

Benthic invertebrates: Those animals without backbones (e.g., insects, crayfish, etc.) that live on or in the sediments of an aquatic habitat.

Benthic zone: The lowermost region of a freshwater or marine profile in which the benthos resides. In bodies of deep water where little light penetrates to the bottom the zone is referred to as the benthic abyssal region and productivity is relatively low. In shallower (i.e., coastal) regions where the benthic zone is well lit, the zone is referred to as the benthic littoral region and it supports some of the world's most productive ecosystems.

Benthos: Plants or animals that live in or on the bottom of an aquatic environment such as an estuary.

Bequest (value): The value that people place on conserving a natural resource for use by future generations.

Best technology available (BTA): The best technology treatment techniques for field application, taking cost into consideration.

Bile: A bitter, alkaline, yellow or greenish liquid secreted by the liver, that aids in absorption and digestion, especially of fats.

Biocide: A chemical which can kill or inhibit the growth of living organisms such as bacteria, fungi, molds, and slimes.

Biological surplus: In fisheries, the annual excess of organisms that can be harvested without reducing future productivity.

Biological oxygen demand (BOD): The amount of dissolved oxygen consumed by microorganisms as they decompose organic material in polluted water.

Biomass: (1) the amount of living matter in an area, including plants, large animals and insects; (2) plant materials and animal waste used as fuel.

Blood: The fluid pumped throughout the body by the heart; it consists of plasma in which red blood cells, white blood cells, thrombocytes, and other specialized cell types are suspended.

Blood plasma: The plasma or liquid portion of blood.

Brackish: Having a salinity between that of fresh and sea water.

Branchial cavity: The area in the mouth containing the gills in fish.

Buccal cavity: The inner cavity associated with the mouth.

Buoyancy: The ability to float or rise in a fluid.

Buoyant: Having buoyancy; capable of floating.

Cannibalism: Animals eating other members of their own species.

Capillaries: Tiny blood vessels, usually < 1mm long, with a diameter no wider than a single red blood cell; they form dense networks that connect arterioles and venules, and are the site for physiological exchange with individual cells.

Carapace: Shell, as in a turtle shell or crab shell.

Cartilage: A firm, elastic, flexible type of connective tissue of a translucent whitish or yellowish color.

Cartilaginous: Pertaining to cartilage.

Cartilaginous ray: A supporting rod in fish fins made from cartilage.

Catadromous: Descriptive of fish species which mature in freshwater environments but migrate to the ocean to spawn.

Caudal fin: The tail of a fish, used mainly to generate forward propulsion.

Caudal peduncle: A narrow, stalk-like structure connecting the tail to the posterior end of the fish's body.

Central nervous system (CNS): The part of the nervous system comprising the brain and spinal cord.

Chloride cell: A specialized cell located in the gills and used by both salt- and freshwater fish to regulate internal salt balances.

Chondrichthyes: The class of vertebrates composed of cartilaginous fish species, including sharks, rays, skates and chimaeras.

Chromatophores: A group of specialized pigment cells located in the dermis, partially responsible for coloration in fish.

Circulatory vessels: A tube of the circulatory system, such as an artery or vein, which contains or conveys blood.

Closed-cycle (cooling system): A cooling water system in which heat is transferred by recirculating water contained within the system.

Cohort: A group of individuals having a statistical factor (as age or class membership) in common in a demographic study.

Colonial: Term describing the habit by certain bird species to nest in large groups called colonies.

Combined sewer overflow (CSO): Discharge of a mixture of storm water and domestic waste when the flow capacity of a combined sewer system is exceeded during rainstorms.

Cone: One of two types of light-sensitive cells located in the retina of the eye; sensitive to color and light intensity.

Confluence: The area where two or more streams or rivers join together.

Conjoint analysis: A method for using surveys to determine the values that people place on a good by asking them to choose between several combinations of environmental quality and the cost of providing that level of quality**.**

Consumer surplus: The extra value that consumer would be willing to pay for a good beyond the good's actual sale price.

Consumptive use: The loss of water through various processes, including:

Consumptive use (of water): Refers to water use practices whereby water is not returned to its source due to loss from evaporation, evapotranspiration, or incorporation in a manufacturing process.

Continental shelf: Part of the continental margin. The ocean floor from the coastal shore of continents to the continental slope, usually to a depth of about 200 meters. The continental shelf usually has a very slight slope, roughly 0.1 degrees.

Contingent valuation method (CVM): A stated preference method for using surveys to ask people what they would be willing pay for a non-market good (especially an environmental good) contingent on a specific hypothetical scenario and description of the good.

Conus arteriosus: Muscular heart chamber responsible for passing blood from the ventricle into the ventral aorta, toward the gills.

Cooling water intake structures (CWISs): The total physical structure and any associated constructed waterways used to withdraw water from waters of the U.S. The cooling water intake structure extends from the point at which water is withdrawn from the surface water source to the first intake pump or series of pumps.

Copepods: A large group of planktonic or benthic crustacean species; one defining characteristic of this group are the single or double egg sacs carried posteriorly by the females.

Cornea: The transparent, exterior part of the eye located in front of the pupil.

Countercurrent exchange: The transfer of heat or gases between currents of blood passing by one another in capillary beds; the beds run parallel to each other but in opposite directions.

Cranium: The part of the skull that encloses the brain.

Critical habitat: Term used in the Federal Endangered Species Act to denote the whole or any part or parts of an area or areas of land comprising the habitat of an endangered species, an endangered population or an endangered ecological community that is essential for the survival of the species, population or ecological community.

DDT: Dichlorodiphenyltrichloroethane is a chlorinated pesticide which is banned in the U.S.

Dermal denticles: Small, toothlike scales covering the skin of most sharks, skates, and rays, giving their skin the feel of sandpaper.

Demersal: (1) Dwelling at or near the bottom of a body of water, such as demersal fish. (2) Sinking to or deposited near the bottom of a body of water, such as demersal fish eggs.

Demersal egg: A fish or aquatic invertebrate egg that sinks to the bottom.

Dermis: The dense inner layer of skin underneath the epidermis.

Dermo: A disease caused by a single-cell organism (protozoan) that infects oysters. (http://www.bayjournal.com/95-04/oyster1.htm)

Desiccation: The loss of water from pore spaces of sediments through compaction or through evaporation caused by exposure to air.

Diatoms: Any of the microscopic unicellular or colonial algae constituting the class Bacillarieae. They have a silicified cell wall, which persists as a silica skeleton after death and forms kieselguhr (loose or porous diatomite). Diatoms occur abundantly in fresh and salt waters, in soil, and as fossils. They form a large part of plankton.

Dinoflagellates: Any of numerous, chiefly marine, plankton of the phylum Pyrrophyta (or, in some classification schemes, the order Dinoflagellata), usually having flagella, one in a groove around the body and the other extending from its center.

Direct use benefits: The benefits that people derive from the use (or consumption) of a good.

Dissolved oxygen (DO): Oxygen gas which is dissolved in the water column and available for breathing by aquatic organisms; DO levels vary by temperature, salinity, turbulence, photosynthetic activity and internal oxygen demand.

Diurnal: Pertaining to fish and other species that are active during the day (opposed to nocturnal).

Dorsal aorta: A major blood vessel in fish, which carries oxygenated blood from the gills to the rest of the body.

Dorsal fin: The fin(s) present on the back of most fish.

Dorsal musculature: That part of the axial musculature located above the horizontal septum.

Ecological niche: The portion of the environment which a species occupies. A niche is defined in terms of the conditions under which an organism can survive, and may be affected by the presence of other competing organisms.

Ecosystem: All the organisms in a particular region and the environment in which they live. The elements of an ecosystem interact with each other in some way, and so depend on each other either directly or indirectly.

Effector cell: A cell that carries out a response to a nerve impulse.

Effluent: Wastewater — treated or untreated — that flows out of a treatment plant, sewer, or industrial outfall. Generally refers to wastes discharged into surface waters.

Endemism: Native to a particular area or region.

Endocrine system: An integrated group of glands that releases hormones into the blood stream.

Endolymph: The fluid contained within the canals and sacs of the inner ear.

Entrainment: The incorporation of fish, eggs, larvae, and other plankton with intake water flow entering and passing through a cooling water intake structure and into a cooling water system.

Environmental stressor: A physical or chemical disturbance that changes the quality of terrestrial or aquatic habitats

Epidermis: The outer layer of the skin.

Epipelagic (zone): The uppermost, normally photic layer of the ocean between the ocean surface and the thermocline, usually between depths of 0-200 m; living or feeding on surface waters or at midwater to depths of 200 m.

Epithelium: Any animal tissue that covers a surface or lines a cavity, and which performs various secretory, transporting, or regulatory functions.

Equilibrium population: Population in a state of balance.

Esophagus: A muscular tube connecting the mouth to the stomach.

Estuarine: Living mainly in the lower part of a river or estuary; coastlines where marine and freshwaters meet and mix; waters often brackish (i.e., mixohaline, with salt content 0.5-30%).

Euryhaline: Descriptive term for an organisms that can tolerate wide ranges in salt concentrations.

Eutrophication: The uncontrolled growth of aquatic plants in response to excessive nutrient inputs to surface waters; the process of enrichment of water bodies by nutrients.

Evapotranspiration: The loss of water from the soil both by evaporation and by transpiration from the plants growing in the soil.

Existence value: The value that people derive from knowledge that a good exists, even if they do not use it and have no plans to use it.

Exotic species: Species that evolve in one region of the world but are intentionally or accidentally introduced in another, where they lack natural enemies and can take over local ecosystems.

Extinction: The death of an entire species.

Fecundity: Number of eggs an animal produces during each reproductive cycle; the potential reproductive capacity of an organism or population.

Filter feeding: A food gathering strategy which consists of passing water over gill structures to strain out food particles.

Fish consumption advisories: Limitations imposed by regulatory agencies on the number of fish or shellfish meals that can be consumed by particular segments of the general population, due to the presence of chemical residues in the target organisms.

Fledging: Period in a bird's life from hatching to first flight.

Fledgling: Young bird in the fledging stage.

Food web: All the interactions of predator and prey, included along with the exchange of nutrients into and out of the soil. These interactions connect the various members of an ecosystem, and describe how energy passes from one organism to another.

Forage: Prey or food species of an animal.

Fry: Newly hatched young fish.

Gall bladder: A small sac, located in the liver, that stores and concentrates bile.

Gill bar: One of a series of bony or cartilaginous arches on each side of the pharynx that support the gills; also referred to as "branchial arches."

Gill filament: One of a series of structures that project out of a gill bar and support numerous gill lamellae.

Gill lamellae: Tiny, parallel, thin-walled and leaf-like projections which cover the gill filaments; these are the actual locations within the gill where gases are exchanged between water and blood.

Gill netting: A passive fish capturing device which uses vertical walls of netting set out in a straight line; capture is based on the fortuitous encounter of aquatic organisms with the net.

Gill raker: Stiff projections along the inner margins of the branchial arches; some fish species use these structures to strain incoming food particles.

Gill septum: Flap-like gill cover in cartilaginous fish, which prevents oxygen-poor water from being drawn back into the branchial cavity during breathing**.**

Glycogen: The principal carbohydrate storage material in animals.

Gonads: Generic name for sex organs (ovaries and testes).

Growth rate: Rate of change over time the body mass or body length of a species.

Habitat-based replacement costs (HRC): Method which determines the cost of offsetting ecological losses by increasing production of those resources through restoration of natural habitats.

Habitat equivalency analysis (HEA): A service-to service approach for restoration scaling that quantifies changes in the flow of services from natural resources while accounting for the magnitude, timing, and duration of those service flow changes over time.

Haemal spines: The ventral spine in the caudal vertebra.

Heart: A hollow, multi-chambered, muscular organ used for pumping blood throughout the circulatory system.

Hemoglobin: Iron-rich protein packed in red blood cells; responsible for carrying oxygen to the tissues and removing carbon dioxide.

Heteroskedasticity: A condition in regression analysis in which the size of the error term is correlated with one or more explanatory variables, potentially creating biased regression estimates.

Horizontal septum: A tough membrane dividing the axial musculature into dorsal and ventral halves.

Hybridize: To crossbreed between two different species.

Hydrodynamics: The study of fluid motion and fluid-boundary interaction.

Ichthyoplankton: Earliest life stages (chiefly eggs and larvae) of certain fish species which remain suspended in the water column as plankton for up to several weeks.

Imbricate scale: A type of scale in fish, which overlaps like tiles on a roof.

Impingement: The entrapment of aquatic organisms on the outer part of an intake structure or against a screening device during periods of intake water withdrawal.

Impingement and Entrainment (I&E): impingement is the entrapment of aquatic organisms on the outer part of an intake structure or against a screening device during periods of intake water withdrawal; entrainment is the incorporation of fish, eggs, larvae, and other plankton with intake water flow entering and passing through a cooling water intake structure and into a cooling water system.

Inelastic: Not elastic; slow to react or respond to changing conditions.

Inner ear: Equilibrium organ located in the skull.

Integument: Covering or skin.

Intertidal: The area along the coastline exposed to the air and submerged by the sea during each tidal cycle.

Intestine: The lower part of the alimentary canal, extending from the pyloric caeca to the anus.

Invertebrate: Animals that lack a spinal column or backbone, including mollusks (e.g., clams and oysters), crustaceans (e.g., crabs and shrimp), insects, starfish, jellyfish, sponges, and many types of worms.

Invertebrate drift: Invertebrates that float with the current.

Kidneys: In fish, a pair of elongated organs that run along the dorsal part of the abdominal cavity; they form and excrete urine, regulate fluid and electrolyte balance, and act as endocrine glands.

Lacustrine: Related to open freshwater bodies such as lakes, reservoirs, and impounded rivers.

Lateral line: The line, or system of lines, of sensory organs located along the head and sides by which fish detect water current and pressure changes and vibrations.

Lens: A transparent spherical object in the eye, situated behind the iris, which focuses incoming light on the retina.

Leptocephali: A colorless, transparent, flattened larva, esp. of certain eels and ocean fishes.

Leptoid scale: A type of scale found mostly in higher bony fish.

Limnetic (zone): Surface layer where most photosynthesis takes place.

Littoral (zone): Shallow nearshore region defined by the band from 0 depth to the outer edge of rooted plants.

Liver: A large, reddish-brown, glandular organ with multiple functions, including: bile secretion, fat and carbohydrate storage, yolk manufacture, blood detoxification, blood cell production, and other metabolic processes.

Lymph: A clear, yellowish fluid formed from liquid constituents of blood that have leaked out of capillaries and into the surrounding tissues.

Lymphatics: A network of vessels for returning lymph back to the circulatory system.

Macula: A sensory tissue found in inner ear sacs and canals.

Mangrove: One of several different species of semi-aquatic trees growing along marine and estuarine shorelines in tropical and subtropical regions of the world; also refers to the habitat created by these trees.

Marine: Refers to the ocean.

Marine Recreational Fishery Statistics Survey (MRFSS): a long-term monitoring program that provides estimates of effort, participation, and finfish catch by recreational anglers. The MRFSS survey consists of two independent, but complementary, surveys: a random digit-dial telephone survey of households and an intercept survey of anglers at fishing access sites. Sampling is stratified by state, fishing mode (shore, private/rental boat, party/charter boat), and wave, and allocated according to fishing pressure. Fishing sites are randomly selected from an updated list of access sites.

Mean: Arithmetic average computed by dividing the sum of a set of terms by the number of terms.

Mean annual flow: The average of daily flows over a calendar year.

Median: A value in an ordered set of values below and above which there is an equal number of values or which is the arithmetic mean of the two middle values if there is no one middle number.

Median fin: See vertical fin.

Mesohaline: Water with a salt content ranging between 5 and 18 parts per thousand (ppt).

Metric: A standard of measurement.

Migration: The movement of animals in response to seasonal changes or changes in the food supply.

Mollusks*:* A large group of invertebrate species; major subgroups in freshwater habitats are represented by gastropods (i.e., snails) and bivalves (i.e., clams and mussels).

Monetization: In the context of this rulemaking, the process of placing a monetary value on a physical environmental change**.**

Monte Carlo: A stochastic modeling technique that involves the random selection of sets of input data for use in repetitive model runs. Probability distributions are generated as the output of a Monte Carlo simulation.

Mortality rate: Death rate. Includes **Natural mortality rate** and **Fishing mortality rate**.

Mosaic scale: *An arrangement whereby scales do not overlap but instead abut each other like pieces in a mosaic.*

Mouth: The opening through which food and water passes into the buccal cavity of fish.

MSX: A disease caused by a protozoan that infects oysters.

Mud flats: An intertidal area characterized by soft, muddy substrate; typically found along tidal creeks or in quiet backwaters.

Muscle segment: a.k.a. myomeres; a block of muscles, the contraction of which produces movement in the body.

Myomeres: Individual W-shaped muscle blocks that are a part of the axial musculature.

Mysids: Small (<3 cm), shrimp-like crustaceans of the order Mysidacea that go by the common name of opossum shrimp; they are morphologically similar to crayfish but have greatly elongated and modified appendages for use in active swimming.

Nasal pit: One or two small depressions in the head region of fish, which contain the olfactory epithelium.

National Marine Fisheries Service (NMFS): a division of the National Oceanic and Atmospheric Administration (NOAA), NMFS is the primary fisheries service in the U.S., responsible for fisheries management and marine ecosystem health.

Navigation pool: A long stretch of river maintained at a minimum depth by a dam, and accessible via one or more gated locks.

Nearctic: Designates a biogeographic subregion which includes the arctic and temperate parts of North America and Greenland.

Nematodes: Unsegmented round worms, some of which are parasitic.

Neritic Province: Area over the continental shelf.

Neural circuitry: The intricate and interconnected web of nerves that make up the nervous system.

Neural spine: A thin, upward-facing bony outgrowth of the vertebrae in most fish species.

Neuromast: A group of sensory cells that together make up the lateral line.

Non-consumptive use (of water): Refers to water use practices whereby water is returned to its source after it has been used.

Non-native species: a.k.a. exotic or invasive species; these terms refer species which evolve in one region of the world but are intentionally or accidentally introduced in another where they lack natural enemies and can take over local ecosystems.

Non-response bias: Potential bias in survey results that occurs when people who choose not to respond to a survey would have answered in ways that significantly differ from those who did respond.

Non-use benefits: The value that people derive from a good that they do not use (types of non-use benefits include bequest value, existence value, and option value).

Notochord: A stiff, rod-like structure that provides the major axial support in the body of adult lower chordates, including cyclostomes.

Nursery habitat: Any one of a number of aquatic habitats used by the early life stages of many fish and invertebrate species to complete their development or find food and shelter.

Oceanic Province: A pelagic division of the ocean, located beyond the continental shelf.

Ocular fluid: The transparent liquid that fills the inside of the eye.

Olfaction: The sense used to perceive and distinguish odors.

Olfactory bulbs: That part of the brain involved with the sense of smell.

Olfactory cell: A specialized cell used to detect the presence of odor molecules.

Olfactory epithelium: The collection of olfactory cells, supporting cells, mucus glands, and nerve endings located inside the nasal pit.

Oligohaline: Water with salinity ranging between 0.5 to 5 parts per thousand (ppt).

Omnivorous: Feeding on both animals and plants.

Open-cycle (cooling system): A cooling water system in which heat is transferred using water (fresh or saline) that is withdrawn from a river, stream or other waterbody (man-made or natural), or a well, that is passed through a steam condenser one time, and then returned to the stream or waterbody some distance from the intake. Typically, such waters are required to be cooled in cooling ponds before returning to a stream or other body of water. Also referred to as once-through cooling.

Operculum: The bony gill cover of fishes which prevents oxygen-poor water from being drawn back into the branchial cavity during breathing.

Optic nerve: A bundle of sensory tissue that conducts electrical impulses from the retina to the brain.

Ornithological: Of, or relating to birds.

Osmoregulation: The process by which organisms maintain a proper internal fluid and salt balance.

Osmoregulatory adjustment: An change in the internal fluid and salt balance of fish in response to fluctuations in external salt concentrations.

Ossified: Hardened like or into bone.

Osteichthyes: The class of lower vertebrates comprising the bony fishes.

Otolith: A small mass of calcified material deposited on top of the macula within the inner ear.

Ova: Plural of ovum; egg or female gamete.

Paired fins: Pectoral fins, placed just behind the gills, and the pelvic fins, variable in position and sometimes lacking entirely.

Pancreas: A gland, situated near the stomach, that secretes digestive juices into the intestine through one or more ducts.

Parr: Life stage of fish between the fry and smolt stages where ovoid parr markings are well developed along the side of the fish; a young salmon or trout living and feeding in freshwater, before the migration to a sea.

Pathogen: An organism (usually microbial) capable of inducing disease in humans or wildlife receptors.

Pectoral fin: Either of a pair of fins usually situated behind the head, one on each side of the fish.

Pelagic: Referring to the open sea at all depths (pelagic animals live in the open sea and are not limited to the ocean bottom).

Pelagic egg: A fish or aquatic invertebrate egg that stays suspended in the water column for part or whole of its development.

Pelvic fin: Either of a pair of fins on the lower surface of the body located behind the pectoral fins.

Pelvic girdle: A bony or cartilaginous arch supporting the pelvic fins.

Percentile: A value on a scale of one hundred that indicates the percent of a distribution that is equal to or below it.

Peripheral nervous system: The portion of the nervous system lying outside the brain and spinal cord.

Pharyngeal region: The area of the mouth located near the pharynx.

Pharynx: The part of the throat into which the gill slits open.

Photic (zone): Zone where light is sufficient for photosynthesis; in oceanic waters above approximately 200 m in depth.

Photosynthesis: The process in green plants and certain other organisms by which carbohydrates are synthesized from carbon dioxide and water using light as an energy source. Most forms of photosynthesis release oxygen as a byproduct. Chlorophyll typically acts as the catalyst in this process.

Phytoplankton: Small, often single-celled plants that live suspended in bodies of water (e.g., estuaries).

Piscivorous: Feeding on fish.

Placoid scale: Another name for dermal denticle.

Planktivorous: Feeding on plankton.

Planktonic: Free-floating. Plankton are tiny free-floating organisms.

Pneumatic duct: The duct connecting the air bladder to the gut in the adults of certain fish species.

Polychaetes: Scientific name for marine worms.

Polychlorinated biphenyls (PCBs): A large group of related chemicals with oil-like properties which were widely used in the past in electrical transformers.

Polycyclic aromatic hydrocarbons (PAHs): A large group of related chemicals characterized by multiple ring structures; derived mainly from crude oil or from combustion processes.

Potamodramous: Fish that migrate from lakes up rivers or streams, like salmon, walleye, and white bass.

Predator: Organism which hunts and eats other organisms. This includes both carnivores, which eat animals, and herbivores, which eat plants.

Prey: Organism hunted and eaten by a predator.

Primary consumer: An organism that feeds mostly on plant material; all herbivores are primary consumers.

Primary productivity: Transformation of chemical or solar energy to biomass. Most primary production occurs through photosynthesis, whereby green plants convert solar energy, carbon dioxide, and water to glucose and eventually to plant tissue.

Producer surplus: The extra value that producers receive for a good beyond the price they would be willing to sell the good for.

Profundal (zone): Deep-water zone in lakes or oceans that is not penetrated by sunlight.

Propagule: A floating structure used for reproduction in sea grasses and other aquatic plant species; the propagule is transported by currents and takes root when reaching a favorable habitat.

Protrusible mouth: A mouth that projects forward as a tube when opened.

Purse seine: A large seine, for use generally by two boats, that is drawn around a school of fish and then closed at the bottom by means of a line passing through rings attached along the lower edge of the net.

Pyloric caeca: A number of finger-like extensions located at the end of the stomach in bony fish species, which probably help in food digestion and absorption.

Random Utility Model (RUM): a model of consumer behavior. The model contains observable determinants of consumer behavior and a random element.

Recall bias: Potential bias in a survey results that occurs when participants provide false information because they cannot (or incorrectly) remember their actions in the past.

Receptor cells: A class of cells of the nervous system that specialize in detecting external stimuli.

Recruitment: Usually refers to the addition of new individuals to the fished component of stock. It may also refer to new additions to sub-components, e.g., ‘recruitment to the fishery’ refers to fish entering the actual fishery, and this is determined by the size and age at which they are first caught.

Rectum: The comparatively straight, terminal section of the intestine, ending in the anus.

Red blood cells: One of several types of cells that make up blood; they are packed with hemoglobin and carry oxygen to the cells and tissues and carbon dioxide back to the respiratory organs.

Red body: The blood-rich organ that secretes gases into the swim bladder.

Red tide: The explosive growth of toxic unicellular algae which can cause the affected surface waters to turn reddish.

Replacement cost: The cost of replacing the services provided by an environmental good that has been damaged or destroyed.

Restoration: The return of an ecosystem or habitat to its original community structure, natural complement of species, and natural functions.

Rete mirabile: A dense bundle of countercurrent capillaries located in the red body; it extracts gases from the incoming blood for secretion into the swim bladder.

Retina: The light-sensitive tissue at the back of the eye that receives the image produced by the lens; contains the rods and cones.

Revealed preference: Refers to a class of valuation methods that analyze consumer purchases of a good (especially housing) to determine the values they place on the characteristics of the good.

Riparian: Having to do with the edges of streams or rivers.

River debit: The volume of water which flows downstream during a certain period of time.

Riverine: Living in a river; living in flowing water.

Rod: One of two types of light-sensitive cells located in the retina; provides vision in dim light or semidarkness.

Rotifer: Any microscopic animal of the phylum (or class) Rotifera, found in fresh and salt waters, having one or more rings of cilia on the anterior end.

Salinity: A measure of the salt concentration of water. Higher salinity means more dissolved salts.

Salt barrens: A type of habitat created when low lying land along a coastline is flooded by spring tides; the area develops into a hyper saline habitat that supports salt resistant terrestrial plants after the sea water recedes or evaporates.

Salt marsh: A tidally-influenced semi-aquatic habitat which supports salt tolerant plant species.

Secchi disk: A 20 cm-wide black and white round plastic disk which is lowered into the water to measure the transparency of the water column.

Sedge: Any rushlike or grasslike plant of the genus Carex, growing in wet places.

Sedimentation: (1) Strictly, the act or process of depositing sediment from suspension in water. Broadly, all the processes whereby particles of rock material are accumulated to form sedimentary deposits. Sedimentation, as commonly used, involves not only aqueous but also glacial, aeolian, and organic agents. (2) (Water Quality) Letting solids settle out of wastewater by gravity during treatment.

Sinus venosus: The heart region that collects incoming oxygen-poor blood and passes it on to the atrium.

Skull: The bony framework or skeleton of the head, enclosing the brain and supporting the face.

Smolt: The post-parr form in which the young of sea-going fish (especially trout and salmon) migrate from freshwater to the sea.

Spartina: A genus of salt-tolerant grasses found in coastal regions.

Spawning/spawn: Release or deposition of spermatozoa or ova, of which some will fertilize or be fertilized to produce offspring; fish reproduction process characterized by females and males depositing eggs and sperm into the water simultaneously or in succession so as to fertilize the eggs.

Speciation: Formation of new species, through reproductive isolation?

Species diversity: Number, evenness, and composition of species in an ecosystem; the total range of biological attributes of all species present in an ecosystem.

Species evenness: The distribution of individual organisms among the species present in a sample or area; evenness is low when most individuals belong to a few species, as is often the case in disturbed or contaminated environments. Evenness increases when the organisms belong to many different species, as is the case in more pristine environments.

Species richness: The number of species present in a sample.

Sphincter: A circular band of voluntary or involuntary muscle that encircles an orifice of the body or one of its hollow organs.

Spinal cord: The thick bundle of nerve tissue that comes from the brain and extends through the spinal column.

Spine: The spinal or vertebral column; also referred to as the backbone.

Spiral valve: A structure located in the intestine of all Chondrichthyes and some primitive bony fish species, which controls the flow of digested food and enhances the absorption of food molecules.

Spleen: A highly vascular, glandular, ductless organ that serves as a blood reservoir; it also forms mature lymphocytes and removes old red blood cells from the circulatory system.

Squalene: Oil found in the liver of many shark species, which creates buoyancy.

Staging area: Places where birds temporarily stay, feed, and rest during their annual migrations.

Stated preference: Refers to a class of valuation methods that use surveys to elicit the value that people place on non-market good.

Static: Not changing.

Stochastic: Random.

Stock: Group of individuals of a species which can be regarded as an entity for management or assessment purposes; a separate breeding population of a species; term used to identify a management unit of fishery species.

Stomach: A sac-like enlargement of the alimentary canal, forming an organ for storing, diluting, and digesting food.

Stratified random sample: A sample in which the survey population is separated into several groups (or strata) and then subjects are randomly selected from each group.

Striated muscle: The skeletal portion of the muscle tissue; striated muscle forms the bulk of the body’s muscle tissue and gives the body its general shape.

Subsistence (fishing or angling): Fishing primarily to supply food (as opposed to fishing for recreation).

Substrate: “Supporting surface” on which an organism grows. The substrate may simply provide structural support, or may provide water and nutrients. A substrate may be inorganic, such as rock or soil, or it may be organic, such as wood.

Subtidal: The area of the ocean or estuary starting at the low tide line and extending outwards; the subtidal zone remains submerged, even during low tide.

Suspended solids: Minute particles (e.g., clay flecks or unicellular algae) present in the water column, which are small enough to resist rapid settling.

Swale: A low place in a tract of land, usually moister and often having ranker vegetation than the adjacent higher land.

Sympatric: Occurring in the same area; capable of occupying the same geographic ranges without loss of identity by interbreeding.

Tailwater: The turbulent river water immediately adjacent to or just downstream of a lock and dam (L&D) structure; it includes areas around the lock flushing valves and the dams themselves.

Tapetum: A highly-reflective membrane located in the back of the retina, which enhances night vision.

Taste bud: One of numerous small, flask-shaped bodies, chiefly in the epithelium of the tongue, which are responsible for detecting taste molecules.

Taste pore: The opening of the taste bud to the outside world.

Taxa: Plural of taxon; a taxon is a group of organisms comprising one of the categories in taxonomnic classification (i.e., phylum, class, order, family, genus, or species). The term is used when organisms cannot be identified at the species level. Such organisms include larval or juvenile life stages that do not yet have their adult forms; they can be designated with certainty only at a higher taxonomic level.

Teleost: A subgroup of the bony fish; includes most species of aquarium, sport, and food fish.

Temperate: Moderate climate with long, warm summers and short, cold winters.

Terminal mouth: A mouth located in the front of a fish (as opposed to a sub-terminal mouth, located underneath the head).

Threatened and endangered (species) (T&E): Animals, birds, fish, plants, or other living organisms recognized as threatened with extinction by anthropogenic (man-caused) or other natural changes in the environment. Used interchangeably in this document with “special status species.”

Thrombocytes: One of the three principal types of blood cells found in blood plasma; they help initiate the clotting process.

Tidal range: The difference in height between the average low tide and high tide line.

Trophic cascade: An impact that trickles down through the food web with repercussions for the larger ecosystem; top-down effect of predators on the biomass of organisms at lower trophic levels.

Trophic level: A feeding level in an ecological community; plant eaters are at a lower trophic level than meat eaters.

Trophic transfer efficiency: Proportion of production of prey that is converted to production of consumers at the next trophic level.

Tropical: Climate characterized by high temperature, humidity and rainfall, found in a belt on both sides of the equator.

Turbidity: Suspended particles in a water sample causing light to scatter or absorb; high turbidity may be harmful to aquatic life because it can decrease light penetration and inhibits photosynthesis in the water column.

Urea: A toxic compound occurring in urine as a product of protein metabolism.

Variance: The square of the standard deviation. A measure of the dispersion of data or how much values in a sample differ from the sample average.

Vegetative growth: An asexual reproductive strategy used by sea grasses and other plants; it consists of sending out one or more shoots that grow into new plants in the immediate vicinity of its “parent.”

Vein: One of the system of branching vessels conveying blood from various parts of the body back to the heart.

Ventral aorta: The artery that carries blood from the heart to the aortic arches (Kimmel et al., 1995).

Ventral fin: Either of a pair of fins on the lower surface of the body in fish; variable in position and sometimes lacking entirely.

Ventral musculature: Part of the axial musculature that is located below the horizontal septum.

Ventricle: A muscular heart chamber that receives blood from the atrium and pumps it into the conus arteriosus

Venule: A small vein.

Vertebrae: The bones or segments composing the backbone.

Vertebrate: Any species having vertebrae; having a backbone or spinal column; examples include fish, amphibians, reptiles, birds, and mammals.

Vertical fins: Fins situated along the centerline of the body; include dorsal, anal, and caudal fins.

Visceral nervous system: An additional component of the nervous system that serves the gut, circulatory system, glands, and other internal organs.

Visual pigments: Light-sensitive molecules found in rods and cones within the retina.

Watershed: Drainage area of a stream, river, or lake leading to a single outlet for its runoff; synonymous with catchment.

Water withdrawal: The removal of water from the ground or diversion from a surface water source for use by agriculture, municipalities, or industries.

Weberian ossicles: A chain of bony processes of the anterior vertebrae that connect the swim bladder to the head region in certain fish species.

Welfare gain: In the context of this rulemaking, the benefit to society from an environmental improvement.

White blood cells: One of the three principal types of blood cells found in blood plasma; they fight bacterial infections and other diseases.

Willingness-to-pay: The value that people will pay to obtain a good (usually associated with the results of a stated preference study).

Zooplankton: A generic term referring to the small life stages (i.e., eggs, larvae, juveniles, and adults) of many fish and invertebrate species.

(Sources: Cole, 1983; Goldman and Horne, 1983; Nicholson, 1994; Maryland Department of Natural Resources, 1995; Madigan et al., 1997; San Diego Natural History Museum, 1998; Shaw, 1998; U.S. EPA, 1998c; Water Quality Association, 1999; Children's Mercy Hospital, 2000; Washington Tourist.com, 2000; Froese and Pauly, 2001; Lackey, 2001; Madzura, 2001; Mouratov, 2001; University of Wisconsin Sea Grant Institute, 2001b; Badman's Tropical Fish, 2002; Chapin, 2002; Chudler, 2002; Eckhardt, 2002; Ehlinger, 2002; Encyclopedia Britannica Online, 2002; European Environment Agency, 2002; Fish Endocrinology Research Group, 2002; Greenhalgh, 2002; King and Mazzotta, 2002; Lexico LLC, 2002; Lycos, Inc., 2002; Merriam-Webster Online, 2002; Nature Conservation Council of NSW, 2002; NRDC, 2002; UCMP, 2002; U.S. EPA, 2002e)

References

Able, K.W. and M.P. Fahay. 1998. The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight. Rutgers University Press, New Brunswick, NJ.

Adamowicz, W., P. Boxall, M. Williams, and J. Louviere. 1998. Stated preference approaches for measuring passive use values: Choice experiments and contingent valuation. *American Journal of Agricultural Economics* 80(1):64-75.

Addelman, S. 1962a. Orthogonal main-effect plan for asymmetrical factorial experiments. *Technometrics* 4(1)(February):21-46.

Addelman, S. 1962b. Symmetrical and asymmetrical fractional factorial plans. *Technometrics* 4(1)(February):47-57.

Aiken, R.A. 1985. Public Benefits of Environmental Protection in Colorado. Masters thesis, Colorado State University, Fort Collins.

Akçakaya, H.R. and L.R. Ginzburg. 1991. Ecological risk analysis for single and multiple populations. In *Species Conservation: A Population-Biological Approach*, A. Seitz and V. Loeschcke (eds.). Birkhaeuser Verlag, Basel, Switzerland, pp. 73-87.

Alaska Department of Fish and Game. 1999. White-winged Scoters! What are they? Alaska Department of Fish and Game. http://www.state.ak.us/adfg/wildlife/duck/scoter/wwscoter.htm. Accessed 4/1/02.

Allan, J.D. 1995. *Stream Ecology, Structure and Function of Running Waters*. Chapman & Hall, New York.

Allen, D.M., J.H. Hudson, and T.J. Costello. 1980. Postlarval shrimp (*Penaeus*) in the Florida Keys: Species, size, and seasonal abundance. *Bulletin of Marine Science* 30(1):21-33.

Allen, M.A. and T.J. Hassler. 1986. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest) — Chinook Salmon. U.S. Fish and Wildlife Service Biological Report 82(11.49). U.S. Army Corps of Engineers TR EL-82-4. http://www.nwrc.gov/publications/specintro.htm. Accessed 7/03.

Anderson, G.D. and S.F. Edwards. 1986. Protecting Rhode Island's coastal salt ponds: An economic assessment of downzoning. *Coastal Zone Management Journal* 14(½):67-91.

Anderson, L.G. 1980. Necessary components of economic surplus in fisheries economics. *Canadian Journal of Fisheries and Aquatic Sciences* 37:858-870.

Arrow, K., R. Solow, P. Portney, E. Leamer, R. Radner, and H. Schuman. 1993. Report of the NOAA panel on contingent valuation. *Federal Register* 58(10):4602-4614.

Atlantic States Marine Fisheries Commission (ASMFC). 2000a. Interstate Fisheries Management Program: Atlantic Croaker. http://www.asmfc.org/Programs/Fish%20Mgnt/croaker1.html. Accessed 7/12/00.

Atlantic States Marine Fisheries Commission (ASMFC). 2000b. Interstate Fisheries Management Program: Shad and River Herring. http://www.asmfc.org/Programs/Fish%20Mgnt/SHAD6.html. Accessed 7/13/00.

Atlantic States Marine Fisheries Commission (ASMFC). 2000c. Interstate Fisheries Management Program: Spot. http://www.asmfc.org/Programs/Fish%20Mgnt/SPOT1.html. Accessed 7/13/00.

Atlantic States Marine Fisheries Commission (ASMFC). 2000d. Interstate Fisheries Management Program: Striped Bass. http://www.asmfc.org/Programs/Fish%20Mgnt/STRBASS6.html. Accessed 7/13/00.

Atlantic States Marine Fisheries Commission (ASMFC). 2000e. Interstate Fisheries Management Program: Tautog. http://www.asmfc.org/Programs/Fish%20Mgnt/TAUTOG1.html. Accessed 11/27/00.

Atlantic States Marine Fisheries Commission (ASMFC). 2000f. Interstate Fisheries Management Program: Weakfish. http://www.asmfc.org/Programs/Fish%20Mgnt/WEAKFISH1.html. Accessed 7/13/00.

Atlantic States Marine Fisheries Commission (ASMFC). 2000g. Review of the Fishery Management Plan for Striped Bass. http://www.asmfc.org/Programs/Fish%20Mgnt/2000%20FMP%20Reviews/StrBassFMPRev2000_FMP.html. Accessed 7/12/00.

Atlantic States Marine Fisheries Commission (ASMFC). 2000h. Review of the ASMFC Fishery Management Plan for Tautog (*Tautoga onitis*). http://www.asmfc.org/Programs/Fish%20Mgnt/FMP%20Reviews/2000%20Tautog%20Reviews.htm. Accessed 11/00.

Atlantic States Marine Fisheries Commission (ASMFC). 2001a. Interstate Fisheries Management Program: Atlantic Herring. http://www.asmfc.org/Programs/Fish%20Mgnt/AHERRING1.html. Accessed 2/12/01.

Atlantic States Marine Fisheries Commission (ASMFC). 2001b. Review of the Fishery Management Plan for Atlantic Menhaden. http://www.asmfc.org/Programs/Fish%20Mgnt/2000%20FMP%20Reviews/menhaden2000_FMP.HTM. Accessed 3/19/01.

Ault, J.S., G.A. Diaz, S.G. Smith, J. Luo, and J.E. Serafy. 1999. An efficient sampling survey design to estimate pink shrimp population abundance in Biscayne Bay, Florida. *North American Journal of Fisheries Management* 19:696-712.

Auster, P.J. 1989. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North and Mid-Atlantic) Tautog and Cunner. U.S. Fish and Wildlife Service Biological Report 82. U.S. Army Corps of Engineers TR EL-82-4.

Azevedo, C., J.A. Herriges, and C.L. Kling. 2001. Valuing Preservation and Improvements of Water Quality in Clear Lake. Staff Report 01-SR 94. Iowa State University, Center for Agricultural and Rural Development, Ames.

Badman's Tropical Fish. 2002. Glossary of Terms. http://badmanstropicalfish.com/glossary.html. Accessed 3/29/02.

Bailey, R.M. and G.E. Smith. 1981. Origin and geography of the fish fauna of the Laurentian Great Lakes. *Canadian Journal of Fisheries and Aquatic Science* 38:1539-1561.

Baird, P.H. 1990. Influence of abiotic factors and prey distribution on diet and reproductive success of three seabird species in Alaska. *Ornis Scand*. 21:224-235.

Barrett, R.T. and Y.V. Krasnov. 1996. Recent responses to changes in stocks of prey species by seabirds breeding in the southern Barents Sea. *J. Mar. Sci*. 53:713-722.

Bartell, S.M. and K.R. Campbell. 2000. Ecological Risk Assessment of the Effects of the Incremental Increase of Commercial Navigation Traffic (25, 50, 75, and 100 Percent Increase of 1992 Baseline Traffic) on Fish. ENV Report 16. Prepared for U.S. Army Engineer District, Rock Island. July. http://www.mvr.usace.army.mil/pdw/nav_study/env_reports/ENVRPT16.htm. Accessed 2000.

Bason, W.H. 1971. Ecology and early life history of striped bass, *Morone saxatilis*, in the Delaware Estuary. *Ichthyol. Assoc. Bulletin* 4:112. Ichthyological Associates, Middletown, DE.

Bateman, I.J. and A.P. Jones. 2003. Contrasting conventional with multi-level modeling approaches to meta-analysis: Expectation consistency in U.K. woodland recreation values. *Land Economics* 79(2):235-258.

BEA. 1998. Bureau of Economic Analysis National Accounts Data: Gross Product by Industry. http://www.bea.doc.gov/bea/dn2/gpoc.htm.

Beardsley, Jr., G.L. 1970. Distribution of migrating juvenile pink shrimp, *Penaeus duorarum duorarum* Burkenroad, in Burronwood Canal, Everglades National Park, Florida. *Transactions of the American Fisheries Society* 99(2):401-408.

Beauchamp, D.A., M.F. Shepard, and G.B. Pauley. 1983. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest): Chinook Salmon. U.S. Fish and Wildlife Service FWS/OBS-82/11.6. U.S. Army Corps of Engineers TR EL-82-4.

Beck, A.D. and the Committee on Entrainment. 1978. Cumulative effects: A field assessment. In *Power Plant Entrainment: A Biological Assessment*, J.R. Schubel and B.C. Marcy, Jr. (eds.). Academic Press, New York, pp. 189-210.

Beck, S. 1995. White perch. In *Living Resources of the Delaware Estuary*, L.E. Dove and R.M. Nyman (eds.), pp. 235-243.

Becker, P.H., T. Troschje, A. Behnke, and M. Wagener. 1997. Starvation of common tern *Sterna hirundo* fledglings during heat waves. *J. Fur Ornithologie* 138:171-182.

Beintema, A.J. 1997. European black terns (*Chlidonias niger*) in trouble: Examples of dietary problems. *Colon. Waterbirds* 20:558-565.

Ben-Akiva, M. and S.R. Lerman. 1985. *Discrete Choice Analysis: Theory and Applications to Travel Demand*. MIT Press, Cambridge, MA.

Bergstrom, J.C. and P. De Civita. 1999. Status of benefits transfer in the United States and Canada: A review. *Canadian Journal of Agricultural Economics* 47(1):79-87.

Berman, M., S. Haley, and H. Kim. 1997. Estimating net benefits of reallocation: Discrete choice models of sport and commercial fishing. *Marine Resource Economics* 12:307-327.

Berrens, R.P., P. Ganderston, and C.L. Silva. 1996. Valuing the protection of minimum instream flows in New Mexico. *Journal of Agricultural and Resource Economics* 21(2):294-309.

Bert, T.M., R.E. Warner, and L.D. Kessler. 1978. The Biology and Florida Fishery of the Stone Crab, *Menippe mercenaria* (Say), with Emphasis on Southwest Florida. Technical Paper No. 9. State University System of Florida Sea College Program, Gainesville. October.

Bielsa, L.M., W.H. Murdich, and R.F. Labisky. 1983. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Florida) — Pink Shrimp. U.S. Fish and Wildlife Service FWS/OBS-82/11.17. U.S. Army Corps of Engineers TR EL-82-4. http://www.nwrc.usgs.gov/wdb/pub/0098.pdf.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wildlife Service Fisheries Bulletin, Volume 53. http://www.gma.org/fogm/. Accessed 8/03.

Bishop, R.C. and M.T. Holt. 2003. Estimating Post-Harvest Benefits from Increases in Commercial Fish Catches with Implications for Remediation of Impingement and Entrainment Losses at Power Plants. Staff Paper No. 458. University of Wisconsin-Madison, Department of Agricultural and Applied Economics, Madison.

Bockstael, N.E., W.M. Hanemann, and C.L. Kling. 1987. Estimating the value of water quality improvements in a recreational demand framework. *Water Resources Research* 23(5):951-960.

Bockstael, N.E., K.E. McConnell, and I.E. Strand. 1989. Measuring the benefits of improvements in water quality: The Chesapeake Bay. *Marine Resource Economics* 6:1-18.

Bockstael, N.E., K.E. McConnell, and I.E. Strand. 1991. Recreation. In *Measuring the Demand for Environmental Quality*, J.B. Braden and C.D. Kolstad (eds.). Elsevier Science Publishers, New York.

Bodola, A. 1966. Life history of the gizzard shad, *Dorosoma cepedianum* (Le Sueur), in western Lake Erie. *Fishery Bulletin* 65(2):391-425.

Bolz, G.R., J.P. Monaghan, Jr., K.L. Lang, R.W. Gregory, and J.M. Burnett. 2000. Proceedings of the Summer Flounder Aging Workshop, 1-2 February 1999. Woods Hole, MA. http://www.nefsc.noaa.gov/nefsc/publications/tm/tm156/tm156toc.htm. Accessed 12/02.

Boreman, J. 1977. Impacts of Power Plant Intake Velocities on Fish. FWS/OBS-76/20.1. U.S. Department of the Interior, Fish and Wildlife Service, Biological Services Program.

Boreman, J. 2000. Surplus production, compensation, and impact assessments of power plants. *Environmental Science & Policy* 3:S445-S449.

Boreman, J. and C.P. Goodyear. 1981. Biases in the estimation of entrainment mortality. In *Fifth National Workshop on Entrainment and Impingement: Issues Associated with Impact Assessment*, L.D. Jensen (ed.). Ecological Analysts Inc., Sparks, MD, pp. 79-89.

Bowker, J.M. and J.R. Stoll. 1988. Use of dichotomous choice nonmarket methods to value the whooping crane resource. *American Journal of Agricultural Economics* 70(May):372-381.

Boyd, J., D. King, and L.A. Wainger. 2001. Compensation for lost ecosystem services: The need for benefit-based transfer ratios and restoration criteria. *Stanford Environmental Law Journal* 20(2):393-412.

Boydstun, L.B., R.J. Hallock, and T.J. Mills. 1992. Anadromous fishes: Salmon. In *California's Living Marine Resources and their Utilization*, W.S. Leet, C.M. Dewees, and C.W. Haugen (eds.). California Sea Grant Extension Publication UCSGEP-92-12. California Sea Grant Extension Program, University of California, Davis, pp. 60-65.

Boyle, K.J. and J.C. Bergstrom. 1992. Benefit transfer studies: Myths, pragmatism, and idealism. *Water Resources Research* 28(3):657-664.

Boyle, K.J. and R.C. Bishop. 1987. Valuing wildlife in benefit-cost analyses: A case study involving endangered species. *Water Resources Research* 23:943-950.

Brazner, J.C. 1997. Regional, habitat, and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. *Journal of Great Lakes Research* 23(1):36-51.

Brown Jr., G.M. and H.O. Pollakowski. 1976. Economic valuation of shoreline. *Review of Economics and Statistics* 59:272-278.

Brown, R. and W. Kimmerer. 2002. Delta Smelt and CALFED's Environmental Water Account: A Summary of the 2002 Delta Smelt Workshop. http://calwater.ca.gov/Programs/Science/adobe_pdf/2002_Delta_Smelt_Workshop_Summary.pdf. Accessed 10/02.

Brown, T.C. 1993. Measuring Non-Use Value: A Comparison of Recent Contingent Valuation Studies. W-133 Sixth Interim Report. University of Georgia, Department of Agriculture and Applied Economics, Athens.

Buckley, J. 1989a. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic). Rainbow Smelt. U.S. Fish and Wildlife Service Biological Report 82(11.106). U.S. Army Corps of Engineers TR EL-82-4.

Buckley, J. 1989b. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic). Winter Flounder. U.S. Fish and Wildlife Service Biological Report 82(11.87). U.S. Army Corps of Engineers TR EL-82-4.

Buckley, L.J. 1982. Effects of temperature on growth and biochemical composition of larval winter flounder *Pseudopleuronectes americanus*. *Marine Ecology Progress Series* 8:181-186.

Bur, M.T. 1982. Food of freshwater drum in western Lake Erie. *Journal of Great Lakes Research* 8(4):672-675.

Burgman, M.A., S. Ferson, and H.R. Akçakaya. 1993. *Risk Assessment in Conservation Biology*. Chapman & Hall, London, UK.

Cailliet, G.M. 2000. Biological Characteristics of Nearshore Fishes of California. A Review of Existing Knowledge and Proposed Additional Studies for the Pacific Ocean Interjurisdictional Fisheries Management Plan Coordination and

Development Project. Submitted to Mr. Al Didier. Pacific States Marine Fisheries Commission. August 31. http://www.dfg.ca.gov/mrd/lifehistories/index.html. Accessed 11/02.

CALFED. 2000. Ecosystem Restoration Program Plan. Volume I — Ecological Attributes of the San Francisco Bay-Delta Watershed. http://calfed.water.ca.gov/environmental_docs/july2000_eis.html. Accessed 7/03.

CALFED. 2001a. California Bay-Delta Public Advisory Committee Charter. http://calfed.ca.gov/BDPAC/US_Dept_of_Interior_Charter.pdf. Accessed 11/27/02.

CALFED. 2001b. Ecosystem Subcommittee Members. http://calfed.ca.gov/BDPAC/Subcommittees/EcosystemSubcommitteeMembers.shtml. Accessed 11/29/02.

CALFED. 2001c. News Release 10/22/01. New Citizens Group to Advise State and Federal Agencies on the Bay-Delta Program. http://calfed.ca.gov/Newsroom/NewsReleases_2001/Newsrelease_10-22-01.shtml. Accessed 11/29/02.

CALFED. 2001d. Public Advisory Committee Committee Members. http://calfed.ca.gov/BDPAC/BDPAC_Members.shtml. Accessed 11/27/02.

CALFED. 2003. Ecosystem Restoration. http://calwater.ca.gov/Programs/EcosystemRestoration/Ecosystem.shtml. Accessed 6/23/03.

California Department of Fish and Game. 2000a. How Old Are the Fish I'm Catching? California Department of Fish and Game. http://www.dfg.ca.gov/mrd/howold.pdf. Accessed 8/03.

California Department of Fish and Game. 2000b. Striped Bass Information Page. Age Your Fish. http://www.delta.dfg.ca.gov/stripedbass/age_your_fish.asp. Accessed 6/03.

California Department of Fish and Game. 2002a. Marine Sportfish Identification Pictures. http://www.dfg.ca.gov/mrd/msfindx1.html. Accessed 1/21/02.

California Department of Fish and Game. 2002b. Wildlife Gallery-Anadromous Species Resources. http://www.delta.dfg.ca.gov/gallery/anad.html. Accessed 1/21/02.

California Department of Fish and Game. 2003. Summary of 2003 California Ocean Salmon Seasons. http://www.dfg.ca.gov/mrd/oceansalmon.html. Accessed 1/03.

California Department of Water Resources (CDWR). 1994. Effects of the Central Valley Project and State Water Project on Delta Smelt and Sacramento Splittail. Biological Assessment prepared for the U.S. Fish and Wildlife Service, Ecological Services, Sacramento Field Office by California Department of Water Resources and U.S. Bureau of Reclamation, Mid Pacific Region, August.

California Department of Water Resources and U.S. Bureau of Reclamation. 1994. Biological Assessment: Effects of the Central Valley Project and State Water Project on Delta Smelt and Sacramento Splittail. Prepared for the U.S. Fish and Wildlife Service, Sacramento, CA. August.

Cameron, T.A. 1988. A new paradigm for valuing non-market goods using referendum data: Maximum likelihood estimation by censored logistic regression. *Journal of Environmental Economics and Management* 15(3):355-379.

Cameron, T.A. and D.D. Huppert. 1989. OLS versus ML estimation of non-market resource values with payment card interval data. *Journal of Environmental Economics and Management* 17:230-246.

Campbell, J.S. and H.R. MacCrimmon. 1970. Biology of the emerald shiner, *Notropis atherinoides* Rafinesque in Lake Simcoe, Canada. *Journal of Fish Biology* 2:259-273.

Carlander, K.D. 1969. Handbook of Freshwater Fishery Biology: Life History Data on Freshwater Fishes of the United States and Canada, Exclusive of the Perciformes. Iowa State University Press, Ames.

Carlander, K.D. 1977. Handbook of Freshwater Fishery Biology, Volume 3: Life History Data on Ichthyopercid and Percid Fishes of the United States and Canada. Iowa State University Press, Ames.

Carlander, K.D. 1997. Handbook of Freshwater Fishery Biology: Life History Data on Icthyopercid and Percid Fishes of the United States and Canada. Volume Three. Iowa State University Press, Ames.

Carroll, J.C. 1982. Seasonal abundance, size composition, and growth of rock crab, *Cancer antennarius* Stimpson, off central California. *Journal of Crustacean Biology* 2(4):549-561.

Carson, R.T. and R.C. Mitchell. 1993. The value of clean water: The public's willingness to pay for boatable, fishable, and swimmable quality water. *Water Resources Research* 29(7):2445-2454.

Carson, R.T., N.E. Flores, and R.C. Mitchell. 1999. The theory and measurement of passive use value. In *Valuing Environmental Preferences: Theory and Practice of the Contingent Valuation Method in the US, EU, and Developing Countries*, I.J. Bateman and K.G. Willis (eds). Oxford University Press, New York.

Carson, R.T., T. Groves, and M.J. Machina. 2000. Incentive and Informational Properties of Preference Questions. Draft Paper. University of California, La Jolla.

Carson, R.T., N.E. Flores, K.M. Martin, and J.L. Wright. 1996. Contingent valuation and revealed preference methodologies: Comparing the estimates for quasi-public goods. *Land Economics* 72(1):80-99.

Carson, R.T., W.M. Hanemann, R.J. Kopp, J.A. Krosnick, R.C. Mitchell, S. Presser, P.A. Ruud, and V.K. Smith. 1994. Prospective Interim Lost Use Value due to DDT and PCB Contamination in the Southern California Bight. Volume 2. Prepared for the National Oceanic and Atmospheric Administration by Natural Resources Damage Assessment Inc., La Jolla, CA.

Carter, S.R. 1978. Macroinvertebrate Entrainment Study at Fort Calhoun Station. Fourth National Workshop on Entrainment and Impingement. EA Communications, Melville, NY.

Castro, L.R. and R.K. Cowen. 1991. Environmental factors affecting the early life history of bay anchovy *Anchoa mitchilli* in Great South Bay, New York. *Marine Ecology Progress Series* 76:235-247.

CCI Environmental Services. 1996. Zooplankton Entrainment Survival Study, Anclote Power Plant, Pasco County, Florida. Prepared for Florida Power Corporation by CCI Environmental Services, Inc., Palmetto, FL.

Chang, S., P.L. Berrien, D.L. Johnson, and W.W. Morse. 1999. Essential Fish Habitat Source Document: Windowpane, *Scophthalmus aquosus*, Life History and Habitat Characteristics. NOAA Technical Memorandum NMFS-NE-137. September. http://www.nefsc.nmfs.gov/nefsc/publications/.

Chao, L.N. and J.A. Musick. 1977. Life history, feeding habits, and functional morphology of juvenile *sciaenid* fishes in the York River estuary. *Virginia Fish. Bull*. 75(4):657-702.

Chapin III, F.S. 2002. Textbook: Principles of Ecosystem Ecology (Draft): Glossary. http://www.faculty.uaf.edu/fffsc/Ecotext.html. Accessed 4/1/02.

Chesapeake Bay Program. 2003. Blue Crab Photo. http://www.chesapeakebay.net/images/cover_graphics/graphic3_large.jpg. Accessed 10/6/03.

Children's Mercy Hospital. 2000. Strata: What is a Stratified Random Sample and Why Would I Want to Use One? http://www.cmh.edu/stats/ask/strata.htm. Accessed 4/2/02.

Chittenden, Jr., M.E. 1971. Status of the striped bass, *Morone saxatilis*, in the Delaware River. *Chesapeake Sci.* 12:131-136.

Chudler, E.H. 2002. Adventures in Neuroanatomy: Divisions of the Nervous System. http://faculty.washington.edu/chudler/nsdivide.html. Accessed 4/1/02.

Clayton, G., C. Cole, S. Murawski, and J. Parrish. 1978. Common Marine Fishes of Coastal Massachusetts. Contribution No. 54 of the Massachusetts Cooperative Fishery Research Unit. University of Massachusetts, Amherst.

Cleland, C.C. and R.C. Bishop. 1984. An Assessment of the Economic Conditions of the Bay Mills Indian Community, Sault Saint Marie Tribe of Chippewa Indians, and Grand Traverse Band of Ottawa and Chippewa Indians, and a Cost-Return Analysis of Treaty Commercial Fishermen — 1981.

Clonts, H.A. and J.W. Malone. 1990. Preservation attitudes and consumer surplus in free flowing rivers. In *Social Science and Natural Resource Recreation Management*, J. Vining (ed.). Westview Press, Boulder, CO, pp. 301-317.

Cohen, M.A. 1986. The costs and benefits of oil spill prevention and enforcement. *Journal of Environmental Economics and Management* 13:167-188.

Colarusso, P. 2000. Winter Flounder Life History Information. Draft. From Phil Colarusso, EPA Region 1. Brayton Point TAC Meeting, 11/17/00.

Cole, G.A. 1983. *Textbook of Limnology*. Third Edition. Waveland Press, Prospect Heights, IL.

Collins, M.R. 1985. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Florida): Striped Mullet. U.S. Fish and Wildlife Service Biological Report 82(11.34). U.S. Army Corps of Engineers TR EL-82-4. http://www.nwrc.gov/publications/specindex.htm. Accessed 7/03.

Costello, T.J. and D.M. Allen. 1966. Migrations and geographic distribution of pink shrimp, *Penaeus duorarum*, of the Tortugas and Sanibel grounds, Florida. *Fishery Bulletin* 65(2):449-459.

Costello, T.J. and D.M. Allen. 1970. Synopsis of biological data on the pink shrimp. In *Proceedings of the World Scientific Conference on the Biology and Culture of Shrimps and Prawns*. Volume IV: Species Synopses, Mexico City, June 12-21, 1967. *FAO Fisheries Report* 57(4):1499-1537.

Coutant, C.A. and M.S. Bevelhimer. 2001. Comments on Lawler, Matusky & Skelly Engineers, LLP. 1999 Draft Brayton Point Power Plant Entrainment Survival Study 1997-1998. Report for US Gen New England, Inc., Pearl River, NY. Oak Ridge National Laboratory, Oak Ridge, TN. February 12.

Cowan, J.H., Jr. and R.S. Birdsong. 1995. Seasonal occurrence of larval and juvenile fishes in a Virginia Atlantic coast estuary with emphasis on drums (Family Sciaenidae). *Estuaries* 8(1):48-59.

Crawford, R.J. and B.M. Dyer. 1995. Responses by four seabird species to a fluctuating availability of Cape Anchovy Engraulis Capensis off South Africa. *Ibis* 137:329-339.

Croke, K., R.G. Fabian, and G. Brenniman. 1986-1978. Estimating the value of improved water quality in an urban river system. *Journal of Environmental Systems* 16(1):13-24.

Cronin, F.J. 1982. Valuing nonmarket goods through contingent markets. PNL-4255. Pacific Northwest Laboratory, Richland, WA.

Crutchfield, J.A., S. Langdon, O.A. Mathisen, and P.H. Poe. 1982. The Biological, Economic, and Social Values of a Sockeye Salmon Stream in Bristol Bay, Alaska: A Case Study of Tazimina River. Circular No. 82-2. Fisheries Research Institute, College of Fisheries, University of Washington, Seattle. October.

Cummings, R., P. Ganderton, and T. McGuckin. 1994. Substitution effects in CVM values. *Am. J. Agric. Economics* 76:205-214.

Cummings, W.C. 1961. Maturation and spawning of the pink shrimp, *Penaeus duorarum* Burkenroad. *Transactions of the American Fisheries Society* 90:462-468.

Daiber, F.C. 1953. Notes on the spawning population of the freshwater drum (*Aplodinotus grunniens* Rafinesque) in western Lake Erie. *American Midland Naturalist* 50(1):159-171.

Daily, G.C. (ed.). 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington, DC.

Daily, G.C., S. Alexander, P.R. Ehrlich, L. Goulder, J. Lubchenco, P.A. Matson, H.A. Mooney, S. Postel, S.H. Schneider, D. Tilman, and G.M. Woodwell. 1997. Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems. Ecological Society of America, Washington, DC.

Dalhuisen, J.M., R.J.G.M. Florax, H.L.F. de Groot, and P. Nijkamp. 2003. Price and income elasticities of residential water demand: A meta analysis. *Land Economics* 79(2):292-308.

Damage Assessment and Restoration Program (DARP). 1997. Natural Resource Damage Assessment Guidance Document: Scaling Compensatory Restoration Actions (Oil Pollution Act of 1990). National Oceanic and Atmospheric Administration. http://www.darp.noaa.gov/pdf/scaling.pdf.

Dames & Moore. 1977. 316(b) Demonstration for the Cayuga and Wabash River Generating Stations. Prepared for Public Service Indiana. August 30.

Daniels, R.A. and P.B. Moyle. 1983. Life history of splittail (Cyprinidae: *Pogonichthys macrolepidotus*) in the Sacramento-San Joaquin Estuary. *Fishery Bulletin* 81(3):647-654.

Davis, G., M.D. Nichols, and T.M. Hannigan. 1999. Management of the California State Water Project. Department of Natural Resources. Bulletin 231-98. November.

Day Jr., J.W., C.A.S. Hall, W.M. Hall, and A. Yáñez-Arancibia. 1989. Zooplankton, the drifting consumers. In *Estuarine Ecology*. John Wiley & Sons, New York, pp. 311-337.

Delaware Department of Natural Resources and Environmental Control (DDNREC). 2000. Striped Bass Spawning Stock Assessment. Project: F-47-R-9 Anadromous Species Investigations. Delaware Department of Natural Resources and Environmental Control, Dover.

Deree, H.L. 1999. Age and growth, dietary habits, and parasitism of the fourbeard rockling, *Enchelyopus cimbrius*, from the Gulf of Maine. *Fishery Bulletin* 97(1):39-52. http://fishbull.noaa.gov/04dereef.pdf. Accessed 1/03.

Derickson, W.K. and K.S. Price. 1973. The fishes of the shore zone of Rehoboth and Indian River Bays, Delaware. *Trans. Amer. Fish. Soc.* 102(3):552-562.

Desfosse, J., H. Austin, L. Daniel, W. Laney, and H. Speir. 1999. 1999 Review of the Fishery Management Plan for Atlantic Croaker (*Micropogonias undulatus*). http://www.asmfc.org/Programs/Fish%20Mgnt/croaker98_FMP.HTM.

Desvousges, W.H., F.R. Johnson, and H.S. Banzhaf. 1998. *Environmental Policy Analysis with Limited Information: Principles and Applications of the Transfer Method*. Edward Elgar Publishers, Northampton, MA.

Desvousges, W.H., M.C. Naughton, and G.R. Parsons. 1992. Benefit transfer: Conceptual problems in estimating water quality benefits using existing studies. *Water Resources Research* 28(3):675-683.

Desvousges, W.H., V.K. Smith, and M.P. McGivney. 1983. A Comparison of Alternative Approaches for Estimating Recreation and Related Benefits of Water Quality Improvements. U.S. Environmental Protection Agency, Economic Analysis Division, Washington, DC.

de Sylva, D.P., F. Kalber, Jr., and C.N. Shuster, Jr. 1962. Fishes and ecological conditions in the shore zone of the Delaware Estuary, with notes on other species collected in deeper water. *Marine Lab Information Series Publication No. 5*. University of Delaware Marine Lab, Lewes.

De Zoysa, A.D.N. 1995. A Benefit Evaluation of Programs to Enhance Groundwater Quality, Surface Water Quality and Wetland Habitat in Northwest Ohio. Dissertation, Ohio State University, Columbus.

Dietrich, C.S. 1979. Fecundity of the Atlantic menhaden, *Brevoortia tyrannus*. *Fishery Bulletin* 77(1):308-311.

Dionne, M., F.T. Short, and D.M. Burdick. 1999. Fish utilization of restored, created, and reference salt-marsh habitat in the Gulf of Maine. In *Fish Habitat: Essential Fish Habitat and Rehabilitation*. American Fisheries Society, Bethesda, MD, pp. 384-404.

Dixon, D.A. 1999. Catalog of Assessment Methods for Evaluating the Effects of Power Plant Operations on Aquatic Communities. Final Report. Report number TR-112013. Electric Power Research Institute, Palo Alto, CA.

Dorsey, S.E., E.D. Houde, and J.C. Gamble. 1996. Cohort abundances and daily variability in mortality of eggs and yolk-sac larvae of bay anchovy, *Anchoa mitchilli*, in Chesapeake Bay. *U.S. Fish. Bull*. 94:257-267.

Drudi, D. 1998. Fishing for a living is dangerous work. *Compensation and Working Conditions* Summer:3-7.

Dryfoos, R.L. 1965. The Life History and Ecology of the Longfin Smelt in Washington. University of Washington, PhD Zoology. University Microfilms Inc., Ann Arbor, MI.

Duffield, J. and D. Patterson. 1992. Field Testing Existence Values: Comparison of Hypothetical and Cash Transaction Values. Benefits and Costs in Natural Resource Planning, 5th Report. W-133 Western Regional Research Publication. B. Rettig, Compiler, Department of Agricultural and Resource Economics, Oregon State University, Corvallis.

Durbin, A.G., E.G. Durbin, T.J. Smayda, and P.G. Verity. 1983. Age, size, growth, and chemical composition of Atlantic menhaden, *Brevoortia tyrannus*, from Narragansett Bay, Rhode Island. *Fishery Bulletin* 81(1):133-141.

EA Engineering, Science, and Technology. 1986. Entrainment and Impingement Studies at Oyster Creek Nuclear Generating Station 1984-1985. Prepared for GPU Nuclear Corporation by EA Engineering, Science, and Technology, Hunt Valley, MD. July.

EA Engineering, Science, and Technology. 1989. Indian Point Generating Station 1988 Entrainment Survival Study. Final. Prepared for Consolidated Edison Company of New York Inc. and New York Power Authority by EA Engineering, Science, and Technology, Hunt Valley, MD. August.

EA Engineering, Science, and Technology. 2000. Review of Entrainment Survival Studies: 1970-2000. Prepared for Electric Power Research Institute, Inc. by EA Engineering, Science, and Technology, Hunt Valley, MD.

EA Science and Technology. 1986. Indian Point Generating Station Entrainment Survival Study. 1985 Annual Report. Prepared under contract with Consolidated Edison Company of New York Inc. and New York Power Authority by EA Engineering, Science, and Technology, Hunt Valley, MD.

EA Science and Technology. 1990. Results of Entrainment and Impingement Studies Conducted at the Braidwood Nuclear Station and the Adjacent Kankakee River. Prepared for Commonwealth Edison Company by EA Engineering, Science, and Technology, Hunt Valley, MD.

Eckhardt, G.A. 2002. The Edwards Aquifer Homepage: Glossary of Water Resource Terms. http://www.edwardsaquifer.net/glossary.html. Accessed 3/29/02.

Ecological Analysts Inc. 1976a. Bowline Point Generating Station Entrainment Survival and Abundance Studies, Volume I, 1975 Annual Interpretive Report. Prepared for Orange and Rockland Utilities, Inc.

Ecological Analysts Inc. 1976b. Danskammer Point Generating Station Impingement and Entrainment Survival Studies, 1975 Annual Report. Prepared for Central Hudson Gas & Electric Corporation.

Ecological Analysts Inc. 1976c. Roseton Generating Station Impingement and Entrainment Survival Studies, 1975 Annual Report. Prepared for Central Hudson Gas & Electric Corporation.

Ecological Analysts Inc. 1977. Bowline Point Generating Station Entrainment and Impingement Studies, 1976 Annual Report. Prepared for Orange and Rockland Utilities, Inc.

Ecological Analysts Inc. 1978a. Bowline Point Generating Station Entrainment Survival Studies, 1977 Annual Interpretive Report. Prepared for Orange and Rockland Utilities, Inc.

Ecological Analysts Inc. 1978b. Impact of the Cooling Water Intake at the Indian River Power Plant: A 316(b) Evaluation. Prepared for Delmarva Power & Light Co. May.

Ecological Analysts Inc. 1978c. Indian Point Generating Station Entrainment Survival and Related Studies, 1977 Annual Report. Prepared for Consolidated Edison Company of New York, Inc.

Ecological Analysts Inc. 1978d. Port Jefferson Generating Station Entrainment Survival Study. Prepared for Long Island Lighting Company. December.

Ecological Analysts Inc. 1978e. Roseton Generating Station Entrainment Survival Studies, 1976 Annual Report. Prepared for Central Hudson Gas & Electric Corporation.

Ecological Analysts Inc. 1978f. Roseton Generating Station Entrainment Survival Studies, 1977 Annual Report. Prepared for Central Hudson Gas & Electric Corporation.

Ecological Analysts Inc. 1979a. An Assessment of the Potential for Ichthyoplankton Entrainment Survival at the Muskingum River Plant. Prepared for American Electric Power Service Corp.

Ecological Analysts Inc. 1979b. Bowline Point Generating Station Entrainment Abundance and Survival Studies, 1978 Annual Report. Prepared for Orange and Rockland Utilities, Inc.

Ecological Analysts Inc. 1979c. Indian Point Generating Station Entrainment Survival and Related Studies, 1978 Annual Report. Prepared for Consolidated Edison Company of New York, Inc.

Ecological Analysts Inc. 1980a. Entrainment Survival Studies at the Cayuga Generating Plant. Prepared for Public Service of Indiana. March.

Ecological Analysts Inc. 1980b. Potrero Power Plant Cooling Water Intake Structures 316(b) Demonstration. Prepared for Pacific Gas and Electric Company. January.

Ecological Analysts Inc. 1980c. Roseton Generating Station Entrainment Survival Studies, 1978 Annual Report. Prepared for Central Hudson Gas and Electric Corporation.

Ecological Analysts Inc. 1981a. Bowline Point Generating Station Entrainment Abundance and Survival Studies, 1979 Annual Report with Overview of 1975-1979 Studies. Prepared for Orange and Rockland Utilities, Inc.

Ecological Analysts Inc. 1981b. Contra Costa Power Plant Cooling Water Intake Structures 316b Demonstration. Prepared for PG&E.

Ecological Analysts Inc. 1981c. Entrainment Survival Studies. Prepared for Empire State Electric Energy Research Corporation.

Ecological Analysts Inc. 1981d. Indian Point Generating Station Entrainment Survival and Related Studies 1979 Annual Report. Prepared for Consolidated Edison Company of New York and Power Authority of the State of New York. April.

Ecological Analysts, Inc. 1981e. Pittsburg Power Plant Cooling Water Intake Structures 316b Demonstration. Prepared for PG&E.

Ecological Analysts Inc. 1982a. Hunters Point Power Plant Cooling Water Intake Structures 316(b) Demonstration. Prepared for Pacific Gas and Electric Company. March.

Ecological Analysts Inc. 1982b. Indian Point Generating Station Entrainment Survival and Related Studies 1980 Annual Report. Prepared for Consolidated Edison Company of New York and Power Authority of the State of New York. January.

Ecological Analysts Inc. 1983. Roseton Generating Station Entrainment Survival Studies, 1980 Annual Report. Prepared for Central Hudson Gas and Electric Corporation.

Edsall, T.A. 1967. Biology of the freshwater drum in western Lake Erie. *Ohio Journal of Science* 67(6):321-340.

Edwards, E.A., D.A. Krieger, G. Gebhart, and O.E. Maughan. 1982. Habitat Suitability Index Models: White Crappie. FWS/OBS-82/10.7 U.S. DOI Fish and Wildlife Service.

Ehlinger, T. 2002. General Glossary Homepage. http://www.uwm.edu/People/ehlinger/glossary.htm. Accessed 3/29/02.

Ehrhardt, N.M., D.J. Die, and V.R. Restrepo. 1990. Abundance and impact of fishing on a stone crab (*Menippe mercenaria*) population in Everglades National Park, Florida. *Bull. Mar. Sci*. 46(2):311-323.

Electric Power Research Institute. 1987. Gizzard shad. In *Compensatory Mechanisms in Fish Populations: Literature Reviews Volume 2: Compensation in Fish Populations Subject to Catastrophic Impact*. EPRI EA-5200, Project 1633-6. Prepared for Electric Power Research Institute, Palo Alto, CA, by University of Rhode Island, Narragansett, pp. 3-18-3-27.

Emmett, R.L., S.L. Stone, S.A. Hinton, and M.E. Monaco. 1991. Distribution and Abundance of Fishes and Invertebrates in West Coast Estuaries, Volume II: Species Life History Summaries. ELMR (Estuarine Living Marine Resources) Report No. 8. NOAA/NOS Strategic Environmental Assessments Division, Rockville, MD.

Encyclopedia Britannica Online. 2002. Encyclopedia Britannica Online. http://www.eb.com/. Accessed 4/1/02.

ENSR and Marine Research Inc. 2000. Study of Winter Flounder Transport in Coastal Cape Cod Bay and Entrainment at Pilgrim Nuclear Power Station. Prepared for Entergy Nuclear Generation Company.

Entergy Nuclear Generation Company. 2000. Marine Ecology Studies Related to Operation of Pilgrim Station. Semi-Annual Report Number 55, January 1999-December 1999.

Environment Canada. 2001. Double-Crested Cormorant. Environment Canada. http://www.qc.ec.gc.ca/faune/oiseaux_de_mer/html/double-crested_cormorant.html. Accessed 4/1/02.

Epifanio, C.E. 1995. Atlantic blue crab. In *Living Resources of the Delaware Estuary*, L.E. Dove and R.M. Nyman (eds.). pp. 43-49.

European Environment Agency. 2002. EUNIS Habitat Classification. February. http://mrw.wallonie.be/dgrne/sibw/EUNIS/home.html. Accessed 3/29/02.

Farber, S. 1987. The value of coastal wetlands for protection of property against hurricane wind damage. *Journal of Environmental Economics and Management* 14:143-151.

Fay, C.W., R.J. Neves, and G.B. Pardue. 1983a. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic): Alewife/Blueback Herring. U.S. Fish and Wildlife Service FWS/OBS-82/11.9. U.S. Army Corps of Engineers TR EL-82-4.

Fay, C.W., R.J. Neves, and G.B. Pardue. 1983b. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic) Atlantic Silverside. U.S. Fish and Wildlife Service FWS/OBS-82/11.10. U.S. Army Corps of Engineers TR EL-82-4.

Fay, C.W., R.J. Neves, and G.B. Pardue. 1983c. Species Profiles: Life Histories and Environmental Requirements of Coastal

Fishes and Invertebrates I. (Mid-Atlantic). Striped Bass. U.S. Fish and Wildlife Service FWS/OBS-82/11.8. U.S. Army Corps of Engineers TR EL-82-4.

Feather, P., D. Hellerstein, and L. Hansen. 1999. Economic Valuation of Environmental Benefits and the Targeting of Conservation Programs: The Case of the CRP. U.S. Department of Agriculture. Agricultural Economic Report Number 778.

Feather, P.M., D. Hellerstein, and T. Thomaso. 1995. A discrete-count model of recreational demand. *Journal of Environmental Economics and Management* 29:214-227.

Federal Register. 1999. Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for Sacramento Splittail. U.S. Department of the Interior, Fish and Wildlife Service. Final Rule 64(25):5963-5981.

Feinerman, E. and K. Knapp. 1983. Benefits from groundwater management: Magnitude, sensitivity, and distribution. *American Journal of Agricultural Economics* 65(4):703-710.

Fell, P.E., R.S. Warren, and W.A. Niering. 2000. Restoration of salt and brackish tidelands in southern New England. In *Concepts and Controversies in Tidal Marsh Ecology*, M.P. Weinstein and D.A. Kreeger (eds.). Kluwer Academic Publishers, Boston, MA, pp. 845-858.

Finkel, A.M. 1990. Confronting Uncertainty in Risk Management. Center for Risk Management, Resources for the Future, Washington, DC.

Fischman, R.L. 2001. The EPA's NEPA duties and ecosystem services. *Stanford Environmental Law Journal* 20(2):497-536.

Fish, M.P. 1932. Contributions to the early life histories of sixty-two species of fishes from Lake Erie, and its tributary waters. *Bulletin of the Bureau of Fisheries* 47:293-398.

Fish Endocrinology Research Group. 2002. Endocrine Control of Teleost Osmoregulation. University of St. Andrews. http://www.st-and.ac.uk/~seeb/ferg/teleost.htm. Accessed 4/1/02.

Fisher, A. and R. Raucher. 1984. Intrinsic benefits of improved water quality: Conceptual and empirical perspectives. *Advances in Applied Micro-Economics* 3:37-66.

Florida Fish and Wildlife Conservation Commission. 2001. Fishing Lines Fish Identification Section. http://marinefisheries.org/fishinglines/fish_id2.pdf. Accessed 12/12/01.

Fonseca, M.S. 1992. Restoring seagrass systems in the United States. In *Restoring the Nation's Marine Environment*, G.W. Thayer (ed.). Maryland Sea Grant College, College Park, pp. 79-109.

Freeman III, A.M. 1993. Non-use values in natural resource damage assessment. In *Valuing Natural Assets*, R.J. Kopp and V. Kerry Smith (eds). Resources for the Future, Washington, DC.

Freeman III, A.M. 2003. The Measurement of Environmental and Resource Values: Theory and Methods. Resources for the Future, Washington, DC.

Froese, R. and C. Binohlan. 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. Fishbase. http://filaman.uni-kiel.de/Download/index.htm. Accessed 12/17/02.

Froese, R. and D. Pauly (eds). 2000. FishBase 2000. International Center for Living Aquatic Resources Management, Los Baños, Laguna, Phillippines.

Froese, R. and D. Pauly (eds.). 2001. FishBase. http://www.fishbase.org. Accessed 10/01.

Froese, R. and D. Pauly (eds.). 2002. FishBase. http://www.fishbase.org, Accessed 11/02.

Froese, R. and D. Pauly (eds.). 2003. FishBase. http://www.fishbase.org. Accessed 1/03.

Fuchs, E.H. 1967. Life history of the emerald shiner, *Notropis atherinoides*, in Lewis and Clark Lake, South Dakota. *Transactions of the American Fisheries Society* 96:247-256.

Galbraith, H., I.C.T. Nisbet, J.J. Hatch, and T.H. Kunz. 1999. Age-related changes in efficiency among breeding common terns *Sterna hirundo*: Measurement of energy expenditure using doubly-labeled water. *J. Avian Biol.* 30:85-96.

Garwood, G.P. 1968. Notes on the life histories of the silversides, *Menidia beryllina* (Cope) and Membras martinica (*Valenciennes*) in Mississippi Sound and adjacent water. *Proceedings of the Southeastern Association of Game and Fish Commissioners* 21:314-323.

Geo-Marine Inc. 1978. 316(b) Demonstration for the W.H. Sammis Generating Station. Prepared for Ohio Edison Company. Plano, TX. September 8.

Gilbert, D.J. 1988. Use of a simple age-structured bioeconomic model to estimate optimal long-run surpluses. *Marine Resource Economics* 5:23-42.

Ginzburg, L.R., L.B. Slobodkin, K. Johnson, and A.G. Bindman. 1982. Quasi-extinction probabilities as a measure of impact on population growth. *Risk Analysis* 2:171-181.

Glass, G.V. 1976. Primary, secondary, and meta-analysis of research. *Educational Researcher* 5(10):3-8.

Goldman, C.R. and A.R. Horne. 1983. *Limnology*. McGraw-Hill, New York.

Goldstein, H. 1995. *Multilevel Statistical Models*. 2nd ed. Edward Arnold, London, UK.

Goodyear, C.P. 1977. Mathematical Methods to Evaluate Entrainment of Aquatic Organisms by Power Plants. Report No. FWS/OBS-76/20.3. U.S. Fish and Wildlife Service, National Power Plant Team, Ann Arbor, MI.

Goodyear, C.P. 1978. Entrainment Impact Estimates Using the Equivalent Adult Approach. FWS/OBS - 78/65. U.S. Department of the Interior, Fish & Wildlife Service, Washington, DC. July.

Government of Canada. 2001. The Fisheries Then and Now: Prince Edward Island. http://collections.ic.gc.ca/peifisheries/species. Accessed 12/12/01.

Great Lakes Fishery Commission. 2003. Great Lakes Fishery Commission. Protecting Our Fishery. http://www.glfc.org/pubs/fact_10.pdf.. Accessed 2/03.

Greene, W.H. 1995. Limdep Version 7 User's Manual. Econometric Software, Inc., Plainville, NY.

Greenhalgh, M. 2002. The Wild Trout: Glossary. http://www.wild-trout.co.uk/glossary.htm. Accessed 3/29/02.

Griffiths, C. undated. The Use of Benefit-Cost Analysis in Environmental Policy Making. Working Paper. National Center for Environmental Economics, U.S. Environmental Protection Agency, Washington, DC.

Grigalunas, T.A., J.J. Opaluch, D. French, and M. Reed. 1988. Measuring damages to marine natural resources from pollution incidents under CERCLA: Applications of an integrated ocean systems/economic model. *Marine Resources Economics* 5:1-21.

Grimes, B.H., M.T. Huish, J.H. Kerby, and D. Moran. 1989. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic) Summer and Winter Flounder. U.S. Fish and Wildlife Service Biological Report 82(11.112). U.S. Army Corps of Engineers TR EL-82-4.

Haab, T.C., J. Whitehead, and T. McConnell. 2000. The Economic Value of Marine Recreational Fishing in the Southeast United States: 1997 Southeast Economic Data Analysis. Final Report. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. July.

Hadderingh, R.H. 1978. Mortality of young fish in the cooling water system of Bergum power station. *Proceedings International Association of Theoretical and Applied Limnology* 20:347-352.

Hafner, H., P.J. Dugan, M. Kersten, O. Pinneau, and J.P. Wallace. 1993. Flock feeding and food intake in little egrets *Egretta garzetta* and their effects on food provisioning and reproductive success. *Ibis* 135:25-32.

Hagen, D., J. Vincent, and P. Welle. 1992. Benefits of preserving old growth forests and the spotted owl. *Contemporary Policy Issues* 10:13-25.

Hales, L.S. and M.J. Van Den Avyle. 1989. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Atlantic) — Spot. U.S. Fish and Wildlife Service Biological Report 82(11.91). U.S. Army Corps of Engineers TR EL-82-4.

Hall, W.R. 1995. Atlantic menhaden. In *Living Resources of the Delaware Estuary*, L.E. Dove and R.M. Nyman (eds.). The Delaware Estuary Program, Wilmington, pp. 219-225.

Hanemann, M., J. Loomis, and B. Kanninen. 1991. Statistical efficiency of double-bounded dichotomous choice contingent valuation. *American Journal of Agricultural Economics* 73(4):1255-1263.

Hanemann, W.M. 1984. Welfare evaluations in contingent valuation experiments with discrete responses. *American Journal of Agricultural Economics* 66(3):332-341.

Hansen, D.F. 1951. Biology of the white crappie in Illinois. *Illinois Natural History Survey Bulletin* 25(4):211-265.

Harpman, D.A., M.P. Welsh, and R.C. Bishop. 1993. Nonuse economic value: Emerging policy analysis tool. *Rivers* 4(4):280-291.

Harrison, P. 1983. *Seabirds — An Identification Guide*. Houghton Mifflin, Boston.

Hartman, K.J. 1993. Striped Bass, Bluefish, and Weakfish in the Chesapeake Bay: Energetics, Trophic Linkages, and Bioenergenics Model Applications. PhD Dissertation, University of Maryland, College Park.

Hausman, J.A., G.K. Leonard, and D. McFadden. 1995. A utility-consistent, combined discrete choice and count model: Assessing recreational use losses due to natural resource damage. *Journal of Public Economics* 56:1-30.

Hayes, K.M., T.J. Tyrell, and G. Anderson. 1992. Estimating the benefits of water quality improvements in the upper Narragansett Bay. *Marine Resource Economics* 7:75-85.

Hazleton Environmental Science Corporation. 1978. The Survival of Entrained Icthyoplankton at Quad-Cities Station 1978. Prepared for Commonwealth Edison Company, Chicago, IL.

Heal, G., G.C. Daily, P.R. Ehrlich, J. Salzman, C. Boggs, J. Hellmann, J. Hughes, C. Kremen, and T. Ricketts. 2001. Protecting natural capital through ecosystem service districts. *Stanford Environmental Law Journal* 20(2):333-364.

Heck, K.L., K.W. Able, M.P. Fahay, and C.T. Roman. 1989. Fishes and decapod crustaceans of Cape Cod eelgrass meadows: Species composition, seasonal abundance patterns and comparison with unvegetated substrates. *Estuaries* 12(2):59-65.

Helfman, G.S., B.B. Collette, and D.E. Facey. 1997. *The Diversity of Fishes*. Blackwell Science, Malden, MA.

Hendrickson, L. 2000. Windowpane Flounder. NOAA. http://www.nefsc.nmfs.gov/sos/spsyn/fldrs/window. Accessed 2/1/02.

Herbold, B. and P.B. Moyle. 1989. The Ecology of the Sacramento-San Joaquin Delta: A Community Profile. U.S. Fish and Wildlife Service Biological Report No 85(7.22).

Herman, J.S., D.C. Culver, and J. Salzman. 2001. Groundwater ecosystems and the service of water. *Stanford Environmental Law Journal* 20(2):479-496.

Herriges, J.A. and J.F. Shogren. 1996. Starting point bias in dichotomous choice valuation with follow-up questioning. *Journal of Environmental Economics and Management* 30(1):112-131.

Hicks, R., S. Steinback, A. Gautam, and E. Thunberg. 1999. Volume II: The Economic Value of New England and Mid-Atlantic Sportfishing in 1994. NOAA Technical Memorandum NMFS-F/SPO-38. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Hilborn, R. 1987. Living with uncertainty in resource management. *North American Journal of Fisheries Management* 7:1-5.

Hilborn, R. and C.J. Walters. 1992. *Quantitative Fisheries Stock Assessment, Choice, Dynamics and Uncertainty*. Chapman and Hall, London and New York.

Hildebrand, S.F. 1922. Notes on habits and development of eggs and larvae of the silversides *Menidia menidia* and *Menidia beryllina*. *Fishery Bulletin* 38:113-120.

Hildebrand, S.F. and W.C. Schroeder. 1928. Fishes of Chesapeake Bay. *Bull. U.S. Bur. Fisheries* 43 (Part 1):1-388.

Hill, J., J.W. Evans, and M.J. Van Den Avyle. 1989. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Atlantic) Striped Bass. U.S. Fish and Wildlife Service Biological Report 82(11.118). U.S. Army Corps of Engineers TR EL-82-4.

Holmlund, C.M. and M. Hammer. 1999. Ecosystem services generated by fish populations. *Ecological Economics* 29:253-268.

Holt, M.T. and R.C. Bishop. 2002. A semiflexible normalized quadratic inverse demand system: An application to the price formation of fish. *Empirical Economics* 27(1):23-48.

Horseman, L.O. and C.A. Shirey. 1974. Age, growth, and distribution of white perch in the Chesapeake and Delaware Canal. In: Anonymous. Ecological Studies in the Vicinity of the Proposed Summit Power Station, January through December 1973. Vol. I, Part B.

Horst, T.J. 1975a. The assessment of impact due to entrainment of ichthyoplankton. In *Fisheries and Energy Production*, S.B. Saila (ed.). D.C. Heath, Lexington, MA, pp. 107-118.

Houde, E.D., W.J. Richards, and V.P. Saksena. 1974. Description of eggs and larvae of scaled sardine, *Harengula jaguana*. *Fishery Bulletin* 72(4):1106-1122.

Howe, A. and P. Coates. 1975. Winter flounder movements, growth, and mortality off Massachusetts. *Transactions of the American Fisheries Society* 104:13-29.

Howell, P., A. Howe, M. Gibson, and S. Ayvanzian. 1992. Fishery Management Plan for Inshore Stocks of Winter Flounder (*Pleuronectes americanus*). Fishery Management Report 21 of the Atlantic States Marine Fisheries Commission, Washington, DC.

Huang, J-C., T.C. Haab, and J.C. Whitehead. 1997. Willingness to pay for quality improvements: Should revealed and stated preference data be combined? *Journal of Environmental Economics and Management* 34(3):240-255.

Hughes, J.E., L.A. Deegan, J.C. Wyda, and A. Wright. 2000. An Index of Biotic Integrity Based on Fish Community Structure Applied to Rhode Island and Connecticut Estuaries. The Ecosystems Center, Marine Biological Laboratory, Woods Hole, MA.

Hunter Environmental Services Inc. 1989. Ohio River Ecological Research Program Final Report. 1988.

Huppert, D.D. and D. Squires. 1987. Potential economic benefits and optimum fleet size in the Pacific Coast trawl fleet. *Marine Resource Economics* 3(4):297-318.

Hynes, H.B.N. 1970. *The Ecology of Running Water*. University of Toronto Press, Toronto, Ontario.

Iowa Department of Natural Resources. 2001. Fishes of Iowa. http://www.state.ia.us/dnr/organiza/fwb/fish/iafish/iafish.htm. Accessed 11/5/01.

Isaacson, P.A. 1964. Length-weight relationship of the white croaker. *Transactions of the American Fisheries Society* 93:302-303.

Jackson, H.W. and R.E. Tiller. 1952. Preliminary observations on spawning potential in the striped bass, *Roccus saxatilis* (Walbaum). *Md. Dep. Res. Educ*. 93(15 pp.).

Jinks, S.M., G.J. Lauer, and M.E. Loftus. 1981. Advances in techniques for assessment of ichthyoplankton entrainment survival. In *Fifth National Workshop on Entrainment and Impingement: Issues Associated with Impact Assessment,* L.D. Jensen (ed.). Ecological Analysts Inc., Sparks, MD, pp. 91-110.

Johnson, D.R. and W. Seaman. 1986. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Florida): Spotted Seatrout. U.S. Fish and Wildlife Service Biological Report 82(11.43). U.S. Army Corps of Engineers TR EL-82-4. http://www.nwrc.gov/wdb/pub/0139.pdf.

Johnston, R.J., S.K Swallow, and T.F. Weaver. 1999. Estimating willingness-to-pay and resource trade-offs with different payment mechanisms: An evaluation of a funding guarantee for watershed management. *Journal of Environmental Economics and Management* 38(1):97-120.

Johnston, R.J., G. Magnusson, M. Mazzotta, and J.J. Opaluch. 2002. Combining economic and ecological indicators to prioritize salt marsh restoration actions. *American Journal of Agricultural Economics* 84(5):1362-1370.

Johnston, R.J., J.J. Opaluch, T.A. Grigalunas, and M.J. Mazzotta. 2001a. Estimating amenity benefits of coastal farmland. *Growth and Change* 32:305-325.

Johnston, R.J., T.F. Weaver, L.A. Smith, and S.K. Swallow. 1995. Contingent valuation focus groups: Insights from ethnographic interview techniques. *Agricultural and Resource Economics Review* 24(1):56-69.

Johnston, R.J., T.A. Grigalunas, J.J. Opaluch, J. Diamantides, and M. Mazzotta. 2001b. Valuing estuarine resource services using economic and ecological models: The Peconic estuary system study. *Coastal Management* 30(1):47-65.

Jones, P.W., F.D. Martin, and J.D. Hardy, Jr. 1978. Development of Fishes of the Mid-Atlantic Bight: An Atlas of Egg, Larval, and Juvenile Stages. Vol. I. *Acipenseridae* through *Ictaluridae*. Chesapeake Biological Laboratory, Center for Environmental and Estuarine Studies, University of Maryland. Prepared for U.S. Fish and Wildlife Services. U.S. Government Printing Office, Washington, DC.

Jordan, F., S. Coyne, and J.C. Trexler. 1997. Sampling fishes in vegetated habitats: Effects of habitat structure on sampling characteristics of the 1-m2 throw trap. *Transactions of the American Fisheries Society* 126:1012-1020.

Joseph, E.B. 1972. Status of *Sciaenid* stocks of the middle Atlantic Coast. *Chesapeake Sci.* 13(2):87-100.

Jude, D.J., F.J. Tesar, S.F. Deboe, and T.J. Miller. 1987b. Diet and selection of major prey species by Lake Michigan salmonines, 1973-1982. *Transactions of the American Fisheries Society* 116(5):677-691.

Jury, S.H., J.D. Field, S.L. Stone, D.M. Nelson, and M.E. Monaco. 1994. Distribution and Abundance of Fishes and Invertebrates in North Atlantic Estuaries. ELMR Rep. No. 13. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD.

Kaiser, S.C. and M.J. Neuman. 1995. Flounder. In *Living Resources of the Delaware Estuary*, L.E. Dove and R.M. Nyman (eds.). The Delaware Estuary Program, Wilmington.

Kaoru, Y. 1993. Differentiating use and nonuse values for coastal pond water quality improvements. *Environmental and Resource Economics* 3:487-494.

Karpoff, J.M. 1985. Non-pecuniary benefits in commercial fishing: Empirical findings from the Alaska salmon fisheries. *Economic Inquiry* 23:159-174.

Kaufman, K. 1996. *Lives of North American Birds*. Houghton Mifflin, Boston.

Kelly, J.F. and B. Van Horne. 1997. Effects of food supplementation on the timing of nest initiation in belted kingfishers. *Ecology* 78:2504-2511.

Kelso, J.R.M. and G.S. Milburn. 1979. Entrainment and impingement of fish by power plants in the Great Lakes which use the once-through cooling process. *Journal of Great Lakes Research* 5:182-194.

Kennish, M.J. 2000. Case study 4: San Francisco estuary project. Chapter 5 in *Estuary Restoration and Maintenance: The National Estuary Program*, M.J. Kennish (ed.). CRC Press LLC, Boca Raton, FL, pp. 255-336.

Kennish, M.J. 2002. Coastal salt marsh systems in the U.S.: A review of anthropogenic impacts. *Journal of Coastal Research* 17(3):731-748.

King, D.M. and V.G. Flagg. 1984. The Economic Structure of California's Commercial Fisheries 1982. Working Paper No. P-T -32. California Sea Grant College Program, La Jolla.

King, D.M. and M. Mazzotta. 2002. Ecosystem Valuation. Methods, Section 6: Contingent Valuation Method. http://www.cbl.umces.edu/~dkingweb/contingent_valuation.htm. Accessed 4/2/02.

Kleinholz, C.W. 2000. Species Profile: Bigmouth Buffalo. SRAC Publication No. 723. Southern Regional Aquaculture Center, Stoneville, MS. June.

Kling, C.L. and J.A. Herriges. 1995. An empirical investigation of the consistency of nested logit models with utility maximization. *American Journal of Agricultural Economics* 77(November):875-884.

Kocik, J. 2000. River Herring. Status of Fisheries Resources off Northeastern United States website. http://www.wh.whoi.edu/sos/spsyn/af/herring/. Accessed 3/26/01.

Kotchen, M.J. and S.D. Reiling. 2000. Environmental attitudes, motivations, and contingent valuation of nonuse values: A case study involving endangered species. *Ecological Economics* 32:93-107.

Krinsky, I. and A.L. Robb. 1986. Approximating the statistical properties of elasticities. *Review of Economics and Statistics* 68(4):715-719.

Kucas, S.T. and T.J. Hassler. 1986. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest) — California Halibut. U.S. Fish and Wildlife Service Mol. Report 82t11.44. U.S. Army Corps of Engineers TR EL-82-4.

Lackey, R.T. 2001. Fisheries: History, Science, and Management. National Health and Environmental Effects Research Laboratory. November. http://www.epa.gov/wed/pages/staff/lackey/pubs/history.htm. Accessed 4/1/02.

Lane, J.A., C.B. Portt, and C.K. Minns. 1996a. Adult habitat characteristics of Great Lakes fishes. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* No. 2358.

Lane, J.A., C.B. Portt, and C.K. Minns. 1996b. Nursery habitat characteristics of Great Lakes fishes. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* No. 2338.

Lant, C.L. and R.S. Roberts. 1990. Greenbelts in the cornbelt: Riparian wetlands, intrinsic values, and market failure. *Environment and Planning* 22:1375-1388.

Larkin, S.L., C.M. Adams, and D.J. Lee. 2000. Reported trip costs, gross revenues, and net returns for U.S. Atlantic pelagic longline vessels. *Marine Fisheries Review* 62(2):49-60.

Lassuy, D.R. 1983. Species Profiles: Life Histories and Environmental Requirements (Gulf of Mexico) - Spotted Seatrout. U.S. Fish and Wildlife Service FWS/OBS-82/11.4. U.S. Army Corps of Engineers TR EL-82-4.

Lassuy, D.R. 1989. Species Profile: Life History and Environmental Requirements of Coastal Fishes: Pacific Herring. U.S. Fish and Wildlife Service Biological Report 82(11.126). U.S. Army Corps of Engineers TR EL-82-4. http://www.nwrc.usgs.gov/wdb/pub/0151.pdf. Accessed 7/3/01.

Lauer, G.J., W.T. Waller, D.W. Bath, W. Meeks, D. Heffner, T. Ginn, L. Zubarik, P. Bibko, and P.C. Storm. 1974. Entrainment studies on Hudson River organisms. In *Proceedings of the Second Workshop on Entrainment and Intake screening*. Report. 15. EPRI, Palo Alto, CA, pp. 37-82.

Lawler Matusky & Skelly Engineers. 1985. 2.0 entrainment survival studies. In *Quad Cities Aquatic Program 1984 Annual Report*. Prepared for Commonwealth Edison, Chicago, IL, by Lawler Matusky & Skelly Engineers, Pearl River, NY.

Lawler Matusky & Skelly Engineers. 1999. Brayton Point Power Station Entrainment Survival Study, 1997-1998. Draft. Prepared for USGen New England, Inc., Brayton Point Station, Somerset, MA, by Lawler Matusky & Skelly Engineers, Pearl River, NY.

Layton, D. and G. Brown. 1998. Heterogenous Preferences Regarding Global Climate Change. Presented at NOAA Applications of Stated Preference Methods to Resource Compensation Workshop, Washington, DC.

Leak, J.C. and E.D. Houde. 1987. Cohort growth and survival of bay anchovy, *Anchoa mitchilli*, larvae in Biscayne Bay, Florida. *Marine Ecology Progress Series* 37:109-122.

Leard, R., R. Matheson, K. Meador, W. Keithly, C. Luquet, M. Van Hoose, C. Dyer, S. Gordon, J. Robertson., D. Horn, and R. Scheffler. 1993. The black drum fishery of the Gulf of Mexico, United States: A regional management plan. Gulf States Marine Fisheries Commission Report Number 28, Ocean Springs, MS.

Leet, W.S., C.M. Dewees, R. Klingbeil, and E.J. Larson (eds). 2001. California's Living Marine Resources: A Status Report. California Department of Fish and Game. December. http://www.dfg.ca.gov/mrd/status/.

Lexico LLC. 2002. Dictionary.com. Lexico Publishing Group, LLC. http://www.dictionary.com/. Accessed 4/2/02.

Light, P.R. and K.W. Able. 2003. Juvenile Atlantic menhaden (*Brevoortia tyrannus*) in Delaware Bay, USA are the result of local and long-distance recruitment. *Estuarine, Coastal and Shelf Science* 57:1007-1014.

Lindberg, W.J. and M.J. Marshall. 1984. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Florida) — Stone Crab. U.S. Fish and Wildlife Service FWS/OBS-82/11.21. U.S. Army Corps of Engineers TR EL-82-4.

Lockwood, R.N., D.M. Benjamin, and J.R. Bence. 1999. Estimating Angling Effort and Catch from Michigan Roving and Access Site Angler Survey Data. Research Report. State of Michigan, Department of Natural Resources, Fisheries Division, Ann Arbor. January 31.

Loesch, J.G. and W.A. Lund, Jr. 1977. A contribution to the life history of the blueback herring, *Alosa aestivalis*. *Trans. Am. Fish. Soc.* 106:583-589.

Loomis, J. and E. Ekstrand. 1997. Economic benefits of critical habitat for the Mexican spotted owl: A scope test using a multiple bounded contingent valuation survey. *Journal of Agricultural and Resource Economics* 22(2):356-366.

Loomis, J.B. 1996. How large is the extent of the market for public goods: Evidence from a nation wide contingent valuation survey. *Applied Economics* 28(7):779-782.

Loomis, J.B. and D.M. Larson. 1994. Total economic values of increasing gray whale populations: Results from a contingent valuation survey of visitors and households. *Marine Resource Economics* 9:275-286.

Loomis, J.B. and D.S. White. 1996. Economic benefits of rare and endangered species: Summary and meta-analysis. *Ecological Economics* 18:197-206.

Loomis, J., P. Kent, E.M. Strange, K. Fausch, and A. Covich. 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. *Ecological Economics* 33:103-117.

Ludwigs, J.D. 1998. Kleptoparasitism in common terns *Sterna hirundo* as an indicator of food shortage. *Vogelwelt* 119:193-203.

Lupi, F. and J.P. Hoehn. 1997. Recreational Fishing Use-Values for Michigan's Great Lake Trout and Salmon Fisheries. Michigan State University, Department of Agricultural Economics, East Lansing.

Lupi, F. and J.P. Hoehn. 1998. The effect of trip lengths on travel cost parameters in recreation demand. In Western Regional Research Publication: W-133, Benefits and Costs of Resource Policies Affecting Public and Private Land. Eleventh Interim Report, June 1998. Michigan State University, East Lansing.

Lycos, Inc. 2002. Infoplease.com. http://infoplease.lycos.com/. Accessed 4/1/02.

Lyke, A.J. 1993. Discrete Choice Models to Value Changes in Environmental Quality: A Great Lakes Case Study. Dissertation submitted to the Graduate School of the University of Wisconsin, Madison.

Maddala, G.S. 1983. *Limited-Dependent and Qualitative Variables in Econometrics*. Cambridge University Press, Cambridge, UK.

Madigan, M.T., J.M. Martinko, and J. Parker. 1997. *Brock Biology of Microorganisms*. Prentice Hall, Upper Saddle River, NJ.

Madzura, T. 2001. Glossary of Water-Related Terms. University of Missouri Outreach and Extension. http://outreach.missouri.edu/mowin/Resources/glossary/glossary.html. Accessed 3/29/02.

Magat, W.A., J. Huber, K.W. Viscusi, and J. Bell. 2000. An iterative choice approach to valuing clean lakes, rivers, and streams. *Journal of Risk and Uncertainty* 21(1):7-43.

Mansueti, R.J. and E.H. Hollis. 1963. Striped Bass in Maryland Tidewater. Educ. Ser. 61. University of Maryland Natural Resources Institute, College Park.

Marcy, B.C., Jr. 1971. Survival of young fish in the discharge canal of a nuclear power plant. *Journal Fisheries Research Board of Canada* 28:1057-1060.

Marcy, B.C., Jr. 1973. Vulnerability and survival of young Connecticut River fish entrained at a nuclear power plant. *Journal Fisheries Research Board of Canada* 30:1195-1203.

Marcy, B.C., Jr. 1975. Entrainment of organisms at power plants, with emphasis on fishes – an overview. In *Fisheries and Energy Production*, S.B. Sailia (ed.). D.C. Heath and Company, Lexington, MA, pp. 89-106.

Marcy, B.C., A.D. Beck, and R.E. Ulanowicz. 1978. Effects and impacts of physical stress on entrained organisms. In *Power Plant Entrainment: A Biological Assessment*. Academic Press, New York, pp. 136-188.

Martosubroto, P. 1974. Fecundity of pink shrimp, *Penaeus duorarum* Burkenroad. *Bulletin of Marine Science* 24(3):606-627.

Maryland Department of Natural Resources. 1995. About oyster diseases. *Bay Journal* 5(2):April. http://www.bayjournal.com/95-04/oyster1.htm. Accessed 4/1/02.

Masnik, M.T. and J.H. Wilson. 1980. Assessment of the Impacts of the Salem and Hope Creek Stations on Shortnose Sturgeon, *Acipenser brevirostrum LeSueur*. Prepared by the U.S. Nuclear Regulatory Commission, Washington, DC. April.

Mason, D. 2002. Natural Recruitment of Salmonids in the Muskegon River, Michigan. NOAA Great Lakes Environmental Research Laboratory Salmonid Recruitment in the Muskegon. http://www.glerl.noaa.gov/res/Task_rpts/edymason09-4.html. Accessed 1/21/02.

Matthews, L.G., F.R. Homans, and K.W. Easter. 1999. Reducing Phosphorous Pollution in the Minnesota River: How Much is it Worth? Staff Paper. Department of Applied Economics, University of Minnesota, St. Paul.

Matthews, W.J. 1998. *Patterns in Freshwater Fish Ecology*. Chapman & Hall, New York.

Mayo, R. and L. O'Brien. 2000. Atlantic cod. In *Status of Fishery Resources off Northeastern United States*. http://www.wh.whoi.edu/sos/spsyn/pg/cod/. Accessed 1/03.

Mazzotta, M.J. 1996. Measuring Public Values and Priorities for Natural Resources: An Application to the Peconic Estuary System. Doctoral Dissertation, University of Rhode Island, Kingston.

McBride, R.S. 1995. Marine forage fish. In *Living Resources of the Delaware Estuary*, L.E. Dove and R.M. Nyman (eds.). The Delaware Estuary Program, Wilmington, pp. 211-217.

McCambridge, J.T., Jr. and R.W. Alden, III. 1984. Growth of juvenile spot, *Leiostomus xanthurus* Lacepede, in the nursery region of the James River, Virginia. *Estuaries* 7(4B):478-486.

McConnell, K. and I. Strand. 1994. The Economic Value of Mid and South Atlantic Sportfishing: Volume 2. Cooperative Agreement #CR-811043-01-0 between the University of Maryland at College Park, the U.S. Environmental Protection Agency, the National Marine Fisheries Service, and the National Oceanic and Atmospheric Administration.

McConnell, K.E. and I.E. Strand. 1999. Overnight Trip Choice for Marine Anglers. Report on National Marine Fisheries Service Contract Number 40ANF804203. Bockstael, McConnell, and Strand Associates, Hyattsville, MD. August 8.

McCrimmon, H.R. 1968. Carp in Canada. Fisheries Research Board of Canada Bulletin 165, Ottawa, Ontario.

McDermot, D. and K.A. Rose. 2000. An individual-based model of lake fish communities: Application to piscivore stocking in Lake Mendota. *Ecological Modelling* 125:67-102.

McEwan, D. 1992. In *California's Living Marine Resources and their Utilization*, W.S. Leet, C.M. Dewees, and C.W. Haugen (eds.). California Sea Grant Extension Publication UCSGEP-92-12. California Sea Grant Extension Program, University of California, Davis, pp. 67-70.

McFadden, D. 1981. Econometric models of probabilistic choice. In *Structural Analysis of Discrete Data*, C.F. Manski and D.L. McFadden (eds.). MIT Press, Cambridge, MA.

McLaren, J.B., T.H. Peck, W.P. Dey, and M. Gardinier. 1988. Biology of Atlantic tomcod in the Hudson River Estuary. In *Science, Law, and Hudson River Power: A Case Study in Environmental Impact Assessment*, L.W. Barnthouse, R.J. Klanda, D.S. Vaughn, and R.L. Kendall (eds.). American Fisheries Society Monograph No. 4. American Fisheries Society, Bethesda, MD.

McLean, R.I. and J.J. Dieter. 2002. State of Maryland Comments on Proposed Regulations to Establish Requirements for Cooling Water Intake Structures at Phase Ii Existing Facilities; Proposed Rule, Published Federal Register, April 9, 2002. To Proposed Rule Comment Clerk -W-00-32, dated August 5, 2002.

McMichael, R.H., Jr. and K.M. Peters. 1989. Early life history of spotted seatrout *Cynoscion nebulosus* (Pisces: Sciaenidae) in Tampa Bay, Florida. *Estuaries* 12(2):98-110.

Meadows, P.S. and J.I. Campbell. 1978. *An Introduction to Marine Science*. John Wiley and Sons, New York.

Meffe, G.K. 1992. Techno-arrogance and halfway technologies: Salmon hatcheries on the Pacific Coast of North America. *Conservation Biology* 6:350-354.

Meng, L. and P.B. Moyle. 1995. Status of splittail in the Sacramento-San Joaquin Estuary. *Transactions of the American Fisheries Society* 124:538-549.

Mercer, L.P. 1987. Fishery Management Plan for Spot. Fisheries Management Report of the Atlantic States Marine Fisheries Commission, No. 11. North Carolina Department of Natural Resources and Community Development, Morehead City.

Meredith, W.H. and V.A. Lotrich. 1979. Production dynamics of tidal creek population of *Fundulus heteroclitus* (linnaeus). *Estuaries and Coastal Marine Science* 8:99-118.

Merriam-Webster Online. 2002. Collegiate Dictionary. http://www.m-w.com/dictionary.htm. Accessed 4/1/02.

Michigan Department of Natural Resources (MDNR). 2002. Data from the 2001 Recreational Angler Survey. Charlevoix Fisheries Research Station. Received from David Clapp, Charlevoix Great Lakes Research Station, Charlevoix, MI.

Miller, E.E. 1966. Channel catfish. In *Inland Fisheries Management*. California Department of Fish and Game, Sacramento, pp. 440-463.

Miller, R.R. 1960. Systematics and biology of the gizzard shad (*Dorosoma cepedianum*) and related fishes. *Fishery Bulletin* 60:371-392.

Miller, R.W. 1995. Striped bass. In *Living Resources of the Delaware Estuary*, L.E. Dove and R.M. Nyman (eds.). The Delaware Estuary Program, Wilmington, pp. 135-141.

Milliman, S.R., B.L. Johnson, R.C. Bishop, and K.J. Boyle. 1992. The bioeconomics of resource rehabilitation: A commercial-sport analysis for a Great Lakes fishery. *Land Economics* 68(2):191-210.

Mitchell, R.C. and R.T. Carson. 1981. An experiment in determining willingness to pay for national water quality improvements. Preliminary Draft of a Report to the U.S. Environmental Protection Agency. Resources for the Future, Inc., Washington, DC.

Mitchell, R.C. and R.T. Carson. 1986. The Use of Contingent Valuation Data for Benefit/Cost Analysis of Water Pollution Control. Resources for the Future, Washington, DC. September.

Mitchell, R.C. and R.T. Carson. 1989. Using Surveys to Value Public Goods: The Contingent Valuation Method. Resources for the Future, Washington, DC.

Monaghan, P., J.D. Uttley, M.D. Burns, C. Thaine, and J. Blackwood. 1989. The relationship between food supply, reproductive effort and breeding success in arctic terns *Sterna paradisaea*. *J. Anim. Ecol*. 58:261-274.

Monteleone, D.M. 1992. Seasonality and abundance of ichthyoplankton in Great South Bay, New York. *Estuaries* 15(2):230-238.

Mood, A.M., F.A. Graybill, and D.C. Boes. 1974. *Introduction to the Theory of Statistics*. McGraw-Hill, New York.

Morey, E.R. 1999. Two RUMS Uncloaked: Nested logit models of site choice and nested logit models of participation and site choice. In *Valuing Recreation and the Environment: Revealed Preference Methods in Theory and Practice*, J.A. Herriges and C.L. Kling (eds.). Edward Elgar, Northampton, MA, pp. 65-120.

Morgan, II, R.P. 1980. Biocides and fish behavior. *Power Plants: Effects on Fish and Shellfish Behavior*, C.H. Hocutt, J.R. Stauffer, Jr., J.E. Edinger, L.W. Hall, Jr., and R.P. Morgan, II (eds.). Academic Press, New York, pp. 75-102.

Morgan, II, R.P. and E.J. Carpenter. 1978. Biocides. *Power Plant Entrainment: A Biological Assessment*, J.R. Schubel and B.C. Marcy, Jr. (eds.). Academic Press, New York, pp. 95-134.

Morse, W.W. 1980. Maturity, spawning, and fecundity of the Atlantic croaker, *Micropogonias undulatus*, occurring North of Cape Hatteras, North Carolina. *U.S. Fish. Bull*. 78(1):190-195.

Morton, T. 1989. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic): Bay Anchovy. U.S. Fish and Wildlife Service Biological Report 82(11.97). U.S. Army Corps of Engineers TR EL-82-4. February.

Mouratov, D. 2001. MarineReference.com: Marine Glossary. http://www.marinereference.com/glossary/. Accessed 4/1/02.

Moyle, P.B. 1976. *Inland Fishes of California*. University of California Press, Berkeley.

Moyle, P.B. and J.J. Cech. 1996. *Fishes: An Introduction to Ichthyology*. 3rd ed. Prentice Hall, Upper Saddle River, NJ.

Moyle, P.B., B. Herbold, D.E Stevens, and L.W. Miller. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. *Transactions of the American Fisheries Society* 121:67-77.

Muncy, R.J. 1984. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Gulf of Mexico): Pinfish. U.S. Fish and Wildlife Service FWS/OBS-82/11.26. U.S. Army Corps of Engineers TR EL-82-4. http://www.nwrc.gov/wdb/pub/0166.pdf.

Murphy, M.D. and T.C. MacDonald. 2000. An Assessment of the Status of Sheepshead in Florida Waters through 1999. Florida Marine Research Institute, St. Petersburg.

Murphy, M.D. and R.G. Taylor. 1989. Reproduction and growth of black drum, *Pogonias cromis*, in northeast Florida. *Northeast Gulf Science* 10:127-137.

Murphy, M.D. and R.G. Taylor. 1994. Age, growth, and mortality of spotted seatrout in Florida waters. *Transactions of the American Fisheries Society* 123:482-497.

Murphy, M.D., G.A. Nelson, and R.G. Muller. 2000. Florida's Inshore and Nearshore Species: 2000 Status and Trends Report. http://floridamarine.org.

Murphy, R.C. 1952. *Oceanic Birds of South America*. MacMillan, American Museum of Natural History, New York.

National Geographic Society. 1969. *Wondrous World of Fishes*. 2nd edition. National Geographic Society, Washington, DC.

National Marine Fisheries Service (NMFS). 1997-2001. Marine Recreational Fisheries Statistics Survey: MRFSS Participation Time Series Query. http://www.st.nmfs.gov/recreational/queries/participation/par_time_series.html. Accessed 8/14/03.

National Marine Fisheries Service (NMFS). 1999a. Marine Recreational Fisheries Statistics: Data User's Manual. Office of Science and Technology, Fisheries Statistics and Economics Division. http://www.st.nmfs.gov/st1/recreational/pubs/data_users/index.html. Accessed 7/12/99.

National Marine Fisheries Service (NMFS). 1999b. Our Living Oceans. Report on the Status of US Living Marine Resources. NMFS-F/SPO-41. NOAA Technical Memorandum.

National Marine Fisheries Service (NMFS). 1999c. Recovery Planning for West Coast Salmon. http://www.nwr.noaa.gov/1salmon/salmesa/pubs/recovsum.pdf. Accessed 1/03.

National Marine Fisheries Service (NMFS). 2000. Marine Recreational Fisheries Statistics Telephone Survey, includes Southeast 1997 Telephone Follow-up. Silver Spring, MD.

National Marine Fisheries Service (NMFS). 2001a. Report to Congress: Status of Fisheries of the United States 2001. Prepared by National Marine Fisheries Service, Silver Spring, MD. January.

National Marine Fisheries Service (NMFS). 2001b. Sea Turtle Protection and Conservation. Office of Protected Resources. http://www.nmfs.noaa.gov/prot_res/PR3/Turtles/turtles.html.

National Marine Fisheries Service (NMFS). 2002a. Annual Report to Congress on the Status of U.S. Fisheries — 2001. U.S. Department of Commerce, NOAA, National Marine Fisheries Service, Silver Spring, MD.

National Marine Fisheries Service (NMFS). 2002b. Commercial Landings Data Caveats. http://www.st.nmfs.gov/commercial/landings/caveat.html. Accessed 11/4/02.

National Marine Fisheries Service (NMFS). 2002c. Fishery Management Councils. National Marine Fisheries Service. http://www.nmfs.noaa.gov/councils/. Accessed 12/9/02.

National Marine Fisheries Service (NMFS). 2002d. Marine Recreational Fisheries Statistics Survey (MRFSS), Participation Time Series Query. http://www.st.nmfs.gov/recreational/queries/participation/par_time_series.html.

National Marine Fisheries Service (NMFS). 2002e. Marine Recreational Fisheries Statistics Survey (MRFSS), Snapshot Query. http://www.st.nmfs.gov/recreational/queries/catch/snapshot.html.

National Marine Fisheries Service (NMFS). 2002f. National Marine Fisheries Service. Sustainable Fisheries Act. http://www.nmfs.noaa.gov/sfa/. Accessed 12/9/02.

National Marine Fisheries Service (NMFS). 2003a. Annual Commercial Landing Statistics website. http://www.st.nmfs.gov/st1/commercial/. Accessed 8/03.

National Marine Fisheries Service (NMFS). 2003b. Marine Recreational Fisheries Statistics Intercept Survey. http://www.st.nmfs.gov/recreational/the_mrfss.html.

National Marine Fisheries Service (NMFS). 2003c. Marine Recreational Fisheries Statistics Survey. http://www.st.nmfs.gov/st1/recreational/data.html. Accessed 8/03.

National Marine Fisheries Service (NMFS). 2003d. Marine Recreational Fisheries Statistics Telephone Survey, includes 1994 Northeast Region Economic Survey. National Marine Fisheries Service, Silver Spring, MD.

National Research Council (NRC). 1993. *Managing Wastewater in Costal Urban Areas*. National Academy Press, Washington, DC.

Natural Resource Defense Council (NRDC). 2002. Glossary of Environmental Terms. http://www.nrdc.org/reference/glossary/b.asp. Accessed 3/29/02.

Nature Conservation Council of NSW. 2002. Environmental Glossary: Glossary Item: Critical Habitat. http://www.nccnsw.org.au/glossary/Criticalhabitat.html. Accessed 3/29/02.

NatureServe. 2002. Natural Heritage Central Databases. NatureServe, Arlington, VA.

Nelson, G.A. 1998. Abundance, growth, and mortality of young-of-the-year pinfish, *Lagodon rhomboides*, in three estuaries along the Gulf Coast of Florida. *Fishery Bulletin* 96:315-328.

Nelson, J.S. 1994. *Fishes of the World*. 3rd ed. John Wiley and Sons, West Sussex, UK.

New England Power Company and Marine Research Inc. 1995. Brayton Point Station Annual Biological and Hydrological Report, January-December 1994. August.

New Jersey Department of Environmental Protection (NJDEP). 2000. Fact Sheet for a Draft NJPDES Permit Including Section 316(a) Variance Determination and Section 316(b) Decision. Permit No. NJ0005622, Salem Generating Station. New Jersey Department of Environmental Protection, Trenton.

New Jersey Division of Fish and Wildlife. 2002. New Jersey Division of Fish and Wildlife. http://www.state.nj.us/dep/fgw/ensphome.htm. Accessed 3/3/99.

Newman, M.C. 1995. *Quantitative Methods in Aquatic Ecotoxicology*. Lewis Publishers, Boca Raton, FL.

New York Conservationist (anonymous). 1997. Tidal Wetlands in New York State 51 (psupp 4-5).

New York Sportfishing and Aquatic Resources Education Program. 2001. Selected Fishes of New York State. http://www.dnr.cornell.edu/sarep/fish/fish.html. Accessed 9/19/01.

New York State Department of Environmental Conservation. 2000. Unpublished Tables of Impingement Data for Steam Electric Stations in New York. Provided to U.S. EPA by Ed Radle, New York State Department of Environmental Conservation, Albany. January.

Nicholson, W. 1994. *Intermediate Microeconomics and its Application*. Sixth Edition. The Dryden Press, Fort Worth, TX.

Nitschke, P., R. Brown, and L. Hendrickson. 2000. Winter flounder. In *Status of the Fishery Resources off the Northeastern United States*. NOAA, Northeast Fisheries Science Center. http://www.nefsc.nmfs.gov/sos/spsyn/fldrs/winter/. Accessed 1/03.

NOAA (National Oceanic and Atmospheric Administration). 1993. Status of the Fishery Resources off the Northeastern United States for 1993. NOAA Technical Memorandum NMFS-F/NEC 101. National Marine Fisheries Service, Silver Spring, MD.

NOAA (National Oceanic and Atmospheric Administration). 2001a. Bay Anchovy. NOAA Coastal Service Center. http://www.csc.noaa.gov/acebasin/specgal/bayanch.htm. Accessed 10/18/01.

NOAA (National Oceanic and Atmospheric Administration). 2001b. NOAA Chesapeake Bay Office Species Information. http://noaa.chesapeakebay.net/fisheries/species.htm. Accessed 12/01.

NOAA (National Oceanic and Atmospheric Administration). 2001c. Status of the Fishery Resources off the Northeastern United States. http://www.nefsc.nmfs.gov/sos/. Accessed 11/01.

NOAA (National Oceanic and Atmospheric Administration). 2002. NOAA National Marine Fisheries Service Alaska Regional Office. Pink Shrimp (*Pandalus borealis*). http://www.fakr.noaa.gov/trawl/shr/shrimps.htm. Accessed 1/17/02.

North Atlantic Energy Service Corporation. 1999. Seabrook Station Sea Duck Entrapment Report. North Atlantic Energy Service Corporation, Manchester, NH. March 22.

North Dakota Game and Fish Department. 1986. Fishes of North Dakota. North Dakota Game and Fish Department, Bismarck, ND. Northern Prairie Wildlife Research Center. http://www.npwrc.usgs.gov/resource/tools/ndfishes/ndfishes.htm (Version 02FEB98).

Northeast Fisheries Science Center (NEFSC). 2000. Status of the Fishery Resources Off the Northeastern United States. Winter Flounder. Northeast Fisheries Science Center. http://www.nefsc.nmfs.gov/sos/spsyn/fldrs/winter/. Accessed 1/16/02.

Northeast Fisheries Science Center (NEFSC). 2001. NMFS Northeast Fisheries Science Center Presents…Fish FAQ. http://www.nefsc.nmfs.gov/faq/fishfaq2a.html. Accessed 1/16/02.

Norton, V., T. Smith, and I. Strand (eds.). 1983. Stripers: The Economic Value of the Atlantic Coast Commercial and Recreational Striped Bass Fisheries. UM-SG-TS-83-12. Maryland Sea Grant Publication, College Park.

O'Brien, L. 2000. American Plaice. http://www.nefsc.nmfs.gov/sos/spsyn/fldrs/plaice/. Accessed 6/30/01.

O'Connell, C. 1953. Life History of the *Cabezon Scorpaenichthys marmoratus* (Ayres). State of California Department of Fish and Game Marine Fisheries Branch Fish Bulletin No. 93.

Ohio Department of Natural Resources. 2001. Life History Notes. http://www.dnr.state.oh.us/wildlife/resources/default.htm. Accessed 3/20/01.

Ohio Department of Natural Resources. 2003. Life History Notes: Bluntnose Minnow. http://www.dnr.state.oh.us/wildlife/Fishing/aquanotes-fishid/bluntnose.htm. Accessed 1/03.

Olsen, D., J. Richards, and D.R. Scott. 1991. Existence and sport values for doubling the size of Columbia River Basin salmon and steelhead runs. *Rivers* 2(1):44-56.

Opaluch, J.J., T.A. Grigalunas, J. Diamantides, and M.J. Mazzotta. 1995. Environmental economics in estuary management. *Maritimes* 38(3)(Winter):21-23.

Opaluch, J.J., T. Grigalunas, M.J. Mazzotta, J. Diamantides, and R. Johnston. 1998. Resource and Recreational Economic Values for the Peconic Estuary. Report prepared for Peconic Estuary Program, Suffolk County Department of Health Services, Riverhead, NY, by Economic Analysis, Inc., Peace Dale, RI.

Oro, D. 1996. Interspecific kleptoparasitism in Audouin's gull *Larus audouinii* at the Ebro Delta, northeast Spain: A behavioral response to low food availability. *Ibis* 138:218-221.

Overholtz, W. 2002a. Northeast Fisheries Science Center. Status of the Fishery Resources off the Northeastern United States. Atlantic Herring. http://www.nefsc.nmfs.gov/sos/spsyn/pp/herring/. Accessed 1/11/02.

Overholtz, W. 2002b. Northeast Fisheries Science Center. Status of the Fishery Resources off the Northeastern United States. Atlantic Mackerel. http://www.nefsc.nmfs.gov/sos/spsyn/pp/mackerel/. Accessed 1/03.

Overholtz, W.J., R.S. Armstrong, D.G. Mountain, and M. Tercerio. 1991. Factors Influencing Spring Distribution, Availability, and Recreational Catch of Atlantic Mackerel (*Scomber scombrus*) in the Middle Atlantic and Southern New England Regions. NOAA Technical Memorandum NMFS-F/NEC-85.

Pacific Fishery Management Council. 1998. Fishery Management Plan: Coastal Pelagic Species. Appendix A: Description of the Coastal Pelagics Fishery. December. http://www.pcouncil.org/cps/cpsfmp.html. Accessed 2/03.

Pacific Fishery Management Council. 2003a. Pacific Fishery Management Council. http://www.pcouncil.org. Accessed 2/03.

Pacific Fishery Management Council. 2003b. Pacific Fishery Management Council. Background: Coastal Pelagic Species. http://www.pcouncil.org/cps/cpsback.html#fishery. Accessed 2/03.

Pacific Fishery Management Council. 2003c. Pacific Fishery Management Council Information Sheet: Groundfish. http://www.pcouncil.org/facts/groundfish.pdf. Accessed 2/03.

Packer, D.B., S.J. Griesbach, P.L. Berrien, C.A. Zetlin, D.L. Johnson, and W.W. Morse. 1999. Essential Fish Habitat Source Document: Summer Flounder, *Paralichtyus dentatus*, Life History and Habitat Characteristics. NOAA Technical Memorandum NMFS-NE-151. September. http://www.nefsc.nmfs.gov/nefsc/publications/.

Parsons, G. and M.J. Kealy. 1992. Randomly drawn opportunity sets in a random utility model of land recreation. *Land Economics* 68(1):93-106.

Parsons, G.R., P.M. Jakus, and T. Tomasi. 1999. A comparison of welfare estimates from four models for linking seasonal recreational trips to multinomial logit models of site choice. *Journal of Environmental Economics and Management* 38:143-157.

Pate, J. and J. Loomis. 1997. The effect of distance on willingness-to-pay values: A case study of wetlands and salmon in California. *Ecological Economics* 20:199-207.

Pattillo, M.E., T.E. Czapla, D.M. Nelson, and M.E. Monaco. 1997. Distribution and Abundance of Fishes and Invertebrates in Gulf of Mexico Estuaries, Volume II: Species Life History Summaries. ELMR Report No.11. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD.

Pauly, D. and V. Christensen. 1995. Primary production required to sustain global fisheries. *Nature* 374:255-257.

Pauley, G.B., D.A. Armstrong, R. Van Citter, and G.L. Thomas. 1989. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest) — Dungeness Crab. U.S. Fish and Wildlife Service Biological Report 82(11.121). U.S. Army Corps of Engineers TR EL-82-4.

Peconic Estuary Program. 2001. Peconic Estuary Comprehensive Conservation and Management Plan. Sponsored by the U.S. Environmental Protection Agency under Section 320 of the Clean Water Act. Suffolk County Department of Health Services, Program Office. http://www.savethepeconicbays.org/ccmp.

Pendleton, L. and R. Mendelsohn. 1998. Estimating the economic impact of climate change on the freshwater sportfisheries of the Northeast United States. *Land Economics* 74:483-496.

Pennsylvania. 1999. Rules and Regulations: Title 58-Recreation, Fish and Boat Commission [58 PA. Code CHS. 61 and 65]. http://www.pabulletin.com/secure/data/vol29/29-28/29_28_rr.pdf. Accessed 11/01.

Pennsylvania Department of Conservation and Natural Resources. 2002. Pennsylvania Department of Conservation and Natural Resources. http://www.dcnr.state.pa.us/wrcf/franda.htm. Accessed 3/3/02.

Pepin P., J.F. Dower, J.A. Helbig, and W.C. Leggett. 2002. Estimating the relative roles of dispersion and predation in generating regional differences in mortality rates of larval radiated shanny (*Ulvaria subbifurcata*). *Can. J. Fish. Aquat. Sci.* 59:105-114.

Pérez Farfante, I. 1969. Western Atlantic shrimps of the genus Penaeus. *U.S. Fish Wildl. Serv. Fish Bull*. 67:461-591.

Peterson, C.H. and J. Lubchenco. 1997. Marine ecosystem services. In *Nature's Services, Societal Dependence on Natural Ecosystems*, G.C. Daily (ed.). Island Press, Washington, DC, pp. 177-194.

PG&E National Energy Group. 2001. Brayton Point Station Permit Renewal Application, NPDES Permit No. MA0003654. 316(a) and (b) Demonstration. Executive Summary and Appendices. PG&E National Energy Group, San Francisco, CA. November.

Phillips, J.M., M.T. Huish, J.H. Kerby, and D.P. Moran. 1989. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Mid-Atlantic) — Spot. U.S. Fish and Wildlife Service Biological Report 82(111.98). U.S. Army Corps of Engineers TR EL-82-4.

Pierce, D.J., B. Mahmoudi, and R.R. Wilson, Jr. 2001. Age and growth of the scaled Herring, *Harengula jaguana*, from Florida waters, as indicated by microstructure of the sagittae. *Fish. Bull.* 99:202-209. http://fishbull.noaa.gov/991/18.pdf. Accessed 12/13/01.

Poe, G.L., K.J. Boyle, and J.C. Bergstrom. 2001. A preliminary meta analysis of contingent values for ground water quality revisited. In *The Economic Value of Water Quality*, J.C. Bergstrom, K.J. Boyle and G.L. Poe (eds.). Edward Elgar Publishers, Northampton, MA.

Poole, C. and S. Greenland. 1999. Random-effects meta-analyses are not always conservative. *American Journal of Epidemiology* 150(5):469-474.

Postel, S. and S. Carpenter. 1997. Freshwater ecosystem services. In *Nature's Services, Societal Dependence on Natural Ecosystems*, G.C. Daily (ed.). Island Press, Washington, DC, pp. 195-214.

PSE&G (Public Service Electric & Gas Company). 1984a. Section 6.1 — Entrainment, and Appendix I, Methods, Materials and Rationale, Volume 2 of 2, Section 5.1 — Entrainment, of the 1984 Salem Generating Station 316(b) Demonstration. Public Service Electric & Gas Co., Newark, NY.

PSE&G (Public Service Electric & Gas Company). 1984b. Spot (*Leiostomus xanthurus*): A Synthesis of Information on Natural History, with Reference to Occurrence in the Delaware River and Estuary and Involvement with the Salem Generating Station; Salem Generating Station 316(b) Demonstration Appendix VII. Public Service Electric & Gas Co., Newark, NY.

PSE&G (Public Service Electric & Gas Company). 1999. Permit Renewal Application NJPDES Permit No. NJ0005622. Public Service Electric and Gas Company Salem Generating Station. Public Service Electric & Gas Co., Newark, NJ.

QuanTech, Survey Research Center. 1998. 1997 AMES Telephone Follow-Up Survey Coding Handbook. QuanTech, Survey Research Center, Rosslyn, VA.

Quinn II, T.J. and R.B. Deriso. 1999. *Quantitative Fish Dynamics*. Oxford University Press, Oxford, UK, and New York.

Rago, P.J. 1984. Production forgone: An alternative method for assessing the consequences of fish entrainment and impingement losses at power plants and other water intakes. *Ecological Modelling* 24:79-111.

Randall, Alan. 1994. A difficulty with the travel cost method. *Land Economics* 70(1):88-96.

Raposa, K. 2002. Early responses of fishes and crustaceans to restoration of a tidally restricted New England salt marsh. *Restoration Ecology* 10:665-676. http://www.blackwell-synergy.com/. Accessed 1/9/03.

Rettig, R. and B. McCarl. 1985. Potential and actual benefits from commercial fishing activities. In Making Information More Useful for Salmon and Steelhead Production Decisions. NOAA Technical Memorandum NMFS F/NWR-8. National Marine Fisheries Service, Portland, OR.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Fisheries Research Board of Canada, Bulletin* 191.

Roberts, L.A. and J.A. Leitch. 1997. Economic Valuation of Some Wetland Outputs of Mud Lake. Agricultural Economics Report No. 381. Department of Agricultural Economics, North Dakota Agricultural Experiment Station, North Dakota State University, Fargo.

Robinette, H.R. 1983. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Gulf of Mexico): Bay Anchovy and Striped Anchovy. U.S. Fish and Wildlife Service Biological Report FWS/OBS-82/11.14. U.S. Army Corps of Engineers TR EL-82-4.

Rogers, B.A., D.T. Westin, and S.B. Saila. 1977. Life Stage Duration Studies on Hudson River Striped Bass, *Morone saxatillis* (Walbaum). University of Rhode Island, Applied Mar. Res. Group, NOAA Sea Grant, Mar. Tech. Rep. 31, Kingston.

Roman, C.T., K.B. Raposa, S.C. Adamowicz, M.-J. James-Pirri, and J.G. Catena. 2002. Quantifying vegetation and nekton response to tidal restoration of a New England salt marsh. *Restoration Ecology* 10(3):450-460.

Ronafalvy, J.P., R.R. Cheesman, and W.M. Matejek. 2000. Circulating water traveling screen modifications to improve impinged fish survival and debris handling at the Salem Generating Station. *Environmental Science and Policy* 3(1):S377-S382.

Rosenberger, R.S. and J.B. Loomis. 2000a. Panel stratification in meta-analysis of economic studies: An investigation of its effects in the recreation valuation literature. *Journal of Agricultural and Applied Economics* 32(3): 459-470.

Rosenberger, R.S. and J.B. Loomis. 2000b. Using meta-analysis for benefit transfer: In-sample convergent validity tests of an outdoor recreation database. *Water Resources Research* 36(4): 1097-1107.

Ross, D.A. 1995. *Introduction to Oceanography*. Harper Collins College Publishers, New York.

Rottmann, R.W., R. Francies-Floyd, and R. Durborow. 1992. The Role of Stress in Fish Disease. SRAC Publication No. 474. Southern Regional Aquaculture Center, Stoneville, MS. February. http://ag.ansc.purdue.edu/aquanic/publicat/usda_rac/efs/srac/474fs.pdf.

Rowe, R.D., W.D. Shaw, and W. Schulze. 1992. Nestucca oil spill. In *Natural Resource Damages*, K. Ward and J. Duffield (eds). Wiley and Sons, New York.

Rowe, R.D., W.D. Schulze, B. Hurd, and D. Orr. 1985. Economic Assessment of Damage Related to the Eagle Mine Facility. Energy and Resource Consultants, Inc., Boulder, CO.

Rozas, L.P. 1992. Bottomless lift net for quantitatively sampling nekton on intertidal marshes. *Marine Ecology Progress Series* 89:287-292.

Ruhl, J.B. and R.J. Gregg. 2001. Integrating ecosystem services into environmental law: A case study of wetlands mitigation banking. *Stanford Environmental Law Journal* 20(2):365-392.

Ruppert, D., R.L. Reish, R.B. Deriso, and R.J. Carroll. 1985. A stochastic population model for managing the Atlantic menhaden (*Brevoortia tyrannus*) fishery and assessing managerial risks. *Canadian Journal of Fisheries and Aquatic Sciences* 42:1371-1379.

Russell, B. and C.H. Hanson. 1990. Assessment of Entrainment Impacts to Rockfish at the Diablo Canyon Power Plant. Prepared for Pacific Gas and Electric Company by Tenera Environmental Services, Lafayette, CA. May 2.

Sacramento River Conservation Area Forum (SRCAF). 2002. Frequently Asked Questions. http://www.sacramentoriver.ca.gov/publications/questions_to_date.pdf. Accessed 12/8/02.

SAIC. 1994. Background Paper Number 3: Cooling Water Intake Technologies. Prepared for U.S. EPA Office of Wastewater Enforcement and Compliance, Permits Division by Science Applications International Corporation, Falls Church, VA.

SAIC. 1995. Preliminary Draft Working Paper: Biological Impacts from the Intake of Cooling Water. Prepared for U.S. EPA Office of Wastewater Enforcement and Compliance, Permits Division by Science Applications International Corporation, Falls Church, VA.

SAIC. 1996a. Background Paper Number 2: Cooling Water Use for Selected U.S. Industries. Prepared for U.S. EPA Office of Wastewater Enforcement and Compliance, Permits Division by Science Applications International Corporation, Falls Church, VA.

SAIC. 1996b. Supplement to Background Paper Number 3: Cooling Water Intake Technologies. Prepared for U.S. EPA Office of Wastewater Management by Science Applications International Corporation, Falls Church, VA.

Saila, S.B. and E. Lorda. 1977. Sensitivity analysis applied to a matrix model of the Hudson River striped bass population. In *Proceedings of a Conference on Assessing the Effects of Power Plant Induced Mortality on Fish Populations, Gatlinburg, Tennessee, May 3-6, 1977*, W. Van Winkle (ed.). Pergamon Press, NY, pp. 311-332.

Saila, S.B., X. Chen, K. Erzini, and B. Martin. 1987. Compensatory Mechanisms in Fish Populations: Literature Reviews. Volume 1: Critical Evaluation of Case Histories of Fish Populations Experiencing Chronic Exploitation or Impact. EA-5200, Volume 1, Research Project 1633-6. Final Report, May 1987. Electric Power Research Institute, Palo Alto, CA.

Saila, S.B., E. Lorda, J.D. Miller, R.A. Sher, and W.H. Howell. 1997. Equivalent adult estimates for losses of fish eggs, larvae, and juveniles at Seabrook Station with use of fuzzy logic to represent parametric uncertainty. *North American Journal of Fisheries Management* 17:811-825.

Salzman, J., B.H. Thompson, Jr., and G.C. Daily. 2001. Protecting ecosystem services: Science, economics, and law. *Stanford Environmental Law Journal* 20(2):309-332.

Sanders, L.D., R.G. Walsh, and J.B. Loomis. 1990. Toward empirical estimation of the total value of protecting rivers. *Water Resources Research* 26(7):1345-1357.

San Diego Natural History Museum. 1998. Shark Glossary. http://www.sdnhm.org/kids/sharks/glossary.html. Accessed 4/1/02.

Santos, J.M.L. 1998. *The Economic Valuation of Landscape Change*. Edward Elgar, Cheltenham, UK.

Scherer, M.D. 1972. The Biology of the Blueback Herring, *Alosa aestivalis* (Mitchill) in the Connecticut River above the Holyoke Dam, Holyoke, Massachusetts. Masters thesis, University of Massachusetts, Amherst.

Schkade, D.A. and J.W. Payne. 1994. How people respond to contingent valuation questions: A verbal protocol analysis of willingness-to-pay for an environmental regulation. *Journal of Environmental Economics and Management* 26(1): 88-109.

Schorfhaar, R.G. and P.J. Schneeberger. 1997. Commercial and Sport Fisheries for Lake Whitefish in Michigan Waters of Lake Superior, 1983-96. State of Michigan Department of Natural Resources, Fisheries Division Research Report Number 2034. June 30. http://www.dnr.state.mi.us/www/ifr/ifrlibra/research/reports/2034rr.pdf.

Schram, S.T., T.N. Halpern, and T.B. Johnson. 1998. Ecology of burbot in western Lake Superior. In *Biology and Management of Burbot*, V. Paragamian and D. MacKinlay (eds). International Congress on the Biology of Fish, Baltimore, MD, July 27-30. http://www-heb.pac.dfo-mpo.gc.ca/congress/Burbot.pdf.

Schubel, J.R., C.C. Coutant, and P.M.J. Woodhead. 1978. Thermal effects of entrainment. In *Power Plant Entrainment: A Biological Assessment*, J.R. Schubel and B.C. Marcy (eds.). Academic Press, New York, pp. 20-93.

Schultz, K. 2000. *Ken Schultz's Fishing Encyclopedia: Worldwide Angling Guide*. IDG Books Worldwide, New York.

Schulze, W.D., R.D. Rowe, W.S. Breffle, R.R. Boyce, and G.H. McClelland. 1995. Contingent Valuation of Natural Resource Damages due to Injuries to the Upper Clark Fork River Basin. State of Montana Natural Resource Damage Litigation Program. Prepared by RCG/Hagler Bailly, Boulder, CO.

Schwartz, F.J., P. Perschbacher, M. McAdams, L. Davidson, K. Sandoy, C. Simpson, J. Duncan, and D. Mason. 1979. Summary Report for 1973-77, an Ecological Study of Fishes and Invertebrate Macrofauna Utilizing the Cape Fear River Estuary, Carolina Beach Inlet, and Adjacent Atlantic Ocean. Vol. XIV. Report to Carolina Power Light Co., Raleigh, NC.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. *Fisheries Research Board of Canada Bulletin* 184.

Scott, W.B. and E.J. Crossman. 1998. Freshwater fishes of Canada. *Fisheries Research Board of Canada Bulletin* 184 ed. Galt House, Oakville, Ontario, Canada.

Scott, W.B. and M.G. Scott. 1988. Atlantic fishes of Canada. *Can. Bull. Fish. Aquat. Sci.* 219.

Seagraves, R.J. 1995. Weakfish. In *Living Resources of the Delaware Estuary*, L.E. Dove and R.M. Nyman (eds.). The Delaware Estuary Program, Wilmington, pp. 293-298.

Serchuk, F. and C. Cole. 1974. Age and growth of the cunner, *Tautogolabrus adspersus* (Waldbaum), Pisces (Labridae), in the Weweantic River Estuary, Massachusetts. *Chesapeake Science* 15(4):205-213.

Setzler, E.M., W.R. Boynton, K.V. Wood, H.H. Zion, L. Lubbers, N.K. Mountford, P. Frere, L. Tucker, and J.A. Mihursky. 1980. Synopsis of Biological Data on Striped Bass, *Morone saxatilis* (Walbaum). NOAA Technical Report NMFS Circular 433. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, June.

Shaw, M. 1998. Biology 71.125 Glossary. http://www.umanitoba.ca/faculties/science/biological_sciences/labgloss.html. Accessed 4/1/02.

Shepherd, G.R. and C.B. Grimes. 1983. Geographic and historic variations in growth of weakfish, *Cynoscion regalis*, in the Middle Atlantic Bight. *U.S. Fish. Bull*. 81(4):803-813.

Shepherd, G.R. and C.B. Grimes. 1984. Reproduction of weakfish, *Cynoscion regalis*, in the New York Bight and evidence for geographically specific life history characteristics. *U.S. Fish. Bull*. 82(3):501-511.

Sheridan, P. 1996. Forecasting the fishery for pink shrimp, *Penaeus duorarum*, on the Tortugas grounds, Florida. *Fishery Bulletin* 94:743-755.

Shirey, C.A., C.C. Martin, and E.J. Stetzar. 1997. Abundance of Sub-adult Atlantic Sturgeon and Areas of Concentration within the Lower Delaware River. Final Report, Grant No. NA66FG0326. Prepared for the Delaware Division of Fish and Wildlife, Dover.

Siegfried, C.A. 1989. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Southwest) — Crangonid Shrimp. U.S. Fish and Wildlife Service Biological Report 82(11.125). U.S. Army Corps of Engineers TR EL-82-4.

Simmonds, R.L., A.V. Zale, and D.M. Leslie. 1997. Physical and biological factors affecting seasonal double-crested cormorant densities at Oklahoma reservoirs. *Colonial Waterbirds* 20:31-40.

Singer, J.D. 1998. Using SAS PROC MIXED to fit multilevel models, hierarchical models, and individual growth models. *Journal of Educational and Behavioral Statistics* 23(4):323-355.

Smith, C.L. 1981. Satisfaction bonus from salmon fishing: Implications for economic evaluation. *Land Economics* 57(2):181-196.

Smith, C.L. 1985. The inland fishes of New York State. ISBN 0-9615433-0-2. The New York State Department of Environmental Conservation, Albany.

Smith, V.K. and L. Osborne. 1996. Do contingent valuation estimates pass the scope test? A meta analysis. *Journal of Environmental Economics and Management* 31(3):287-301.

Smith, V.K., G. Van Houtven, and S.K. Pattanayak. 2002. Benefit transfer via preference valibration: "Prudential algebra" for policy. *Land Economics* 78(1):132-152.

Snyder, D.E. 1998. Burbot — larval evidence for more than one North American species? In *Biology and Management of Burbot*, V. Paragamian and D. MacKinlay (eds). International Congress on the Biology of Fish, Baltimore, MD, July 27-30. http://www-heb.pac.dfo-mpo.gc.ca/congress/Burbot.pdf.

South Carolina Department of Natural Resources. 2001. Marine Resources Research Institute. SEAMAP Target Species website. http://water.dnr.state.sc.us/marine/mrri/seamap/species.htm. Accessed 12/12/01.

Southern Energy Delta, LLC. 2000. Multispecies Habitat Conservation Plan, Pittsburg and Contra Costa Power Plants. Draft-Revision 5, June 30, 2000. Prepared for the U.S. Fish & Wildlife Service, Sacramento, CA, and the National Marine Fisheries Service, Santa Rosa, CA.

Spigarelli, S.A., A.J. Jensen, and M.M. Thommes. 1981. An Assessment of the Impacts of Water Intakes on Alewife, Rainbow Smelt, and Yellow Perch Populations in Lake Michigan. EPA-905/3-81-001. ANL/ES-109. Prepared by Argonne National Laboratory and U.S. EPA. March.

Stanley, J.G. and D.S. Danie. 1983. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic): White Perch. U.S. Fish and Wildlife Service Biological Services Report FWS/OBS-82/11.7. U.S. Army Corps of Engineers TR EL-82-4.

State of Maine Department of Marine Resources. 2001a. Maine Division of Marine Resources. 2001. Saltwater Anglers Guide, Know Your Catch. Family Clupeidae, Herrings. http://www.state.me.us/dmr/recreational/fishes/shad.htm. Accessed 7/18/01.

State of Maine Department of Marine Resources. 2001b. Maine Division of Marine Resources. 2001. Saltwater Anglers Guide, Know Your Catch. Family Labridae, Wrasses, Tautog. http://www.state.me.us/dmr/recreational/fishes/tautog.htm. Accessed 2/6/01.

State of Maine Department of Marine Resources. 2001c. Maine Division of Marine Resources. 2001. Saltwater Anglers Guide, Know Your Catch. Family Pleuronectidae, Righteye Flounders. http://www.state.me.us/dmr/recreational/fishes/winterflounder.htm. Accessed 2/6/01.

State of New York, Department of Environmental Conservation. 2001. State of New York, Department of Environmental Conservation. List of Endangered, Threatened and Special Concern Fish & Wildlife Species of New York State. http://www.dec.state.ny.us/website/dfwmr/wildlife/endspec/etsclist.html. Accessed 3/3/01.

Stauffer, Jr., J.R. 1980. Influence of temperature on fish behavior. In *Power Plants: Effects on Fish and Shellfish Behavior*, C.H. Hocutt, J.R. Stauffer, Jr., J.E. Edinger, L.W. Hall, Jr., R.P. Morgan, II (eds.). Academic Press, New York, pp. 103-141.

Steimle, F.W. and P.A. Shaheen. 1999. Tautog (*Tautoga onitis*) Life History and Habitat Requirements. NOAA Technical Memorandum NMFS-NE-118. National Marine Fisheries Service, Silver Spring, MD.

Steiner, L. 2000. Pennsylvania Fishes. Pennsylvania Fish Commission, Harrisburg, PA. http://sites.state.pa.us/PA_Exec/Fish_Boat/fishhtms/chapindx.htm. Accessed 10/30/2001.

Stevens, D.E. 1992. Striped bass. In *California's Living Marine Resources and their Utilization*, W.S. Leet, C.M. Dewees, and C.W. Haugen (eds.). California Sea Grant, Sea Grant Extension Publication UCSGEP-92-12. California Sea Grant Extension Program, University of California, Davis, pp. 72-75.

Stevens, D.E. and B.J. Finlayson. 1978. Mortality of Young Striped Bass Entrained at Two Power Plants in Sacramento–San Joaquin Delta, California. Fourth National Workshop on Entrainment and Impingement. EA Communications, Melville NY, pp. 57-69.

Stevens, D.E., L.W. Miller, and B.C. Bolster. 1990. Report to the Fish and Game Commission: A Status Review of Delta Smelt (*Hypomesus transpacificus*) in California. Candidate Species Status Report 90-2. California Department of Fish and Game, Sacramento.

Stevens, T.H., M.K. Field, T.A. More, and R.J. Glass. 1994. Contingent Valuation of Rare and Endangered Species: An Assessment. W-133 Benefits and Cost Transfer in Resource Planning.

Stevens, T.H., J. Echeverria, R.J. Glass, T. Hager, and T.A. More. 1991. Measuring the existence value of wildlife: What do CVM estimates really show? *Land Economics* 67:390-400.

Stewart, L.L. and P.J. Auster. 1987. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (North Atlantic) Atlantic Tomcod. U.S. Fish and Wildlife Service Biological Report 82(11.78). U.S. Army Corps of Engineers TR EL-82-4. http://www.nwrc.gov/wdb/pub/1043.pdf. Accessed 6/03.

Stewart, N.H. 1926. Development, growth, and food habits of the white sucker, *Catostomus commersonii* Lesueur. *Fishery Bulletin* 42:147-184.

Stone & Webster Engineering Corporation. 1977. Supplemental Assessment in Support of the 316 Demonstration, Pilgrim Nuclear Power Station Units 1 and 2, Boston Edison Company. Stone & Webster Engineering Corporation, Boston, MA.

Stone & Webster Engineering Corporation. 1980. 316(a) and (b) Demonstration Big Bend Station — Unit 4. Volume I and Volume II, Appendices. Prepared for Tampa Electric Company by Stone & Webster Engineering Corporation, Boston, MA. August 1.

Stromborg, K. 1993. Memo re: Analysis of Band Return Data Related to 1990 Bird Kill. To Special Agent Roy Owens, Green Bay, WI. February 4.

Studholme, A.L., D.B. Packer, P.L. Berrien, D.L. Johnson, C.A. Zetlin, and W.W. Morse. 1999. Essential Fish Habitat Document: Atlantic Mackerel, *Scomber scombrus,* Life History and Habitat Characteristics. NOAA Technical Memorandum NMFS-NE-141.

Stumborg, B.E., K.A. Baerenklau, and R.C.. Bishop. 2001. Nonpoint source pollution and present values: A contingent valuation of Lake Mendota. *Review of Agricultural Economics* 23(1): 120-132.

Suddaby, D. and N. Ratcliffe. 1997. The effects of fluctuating food availability on breeding arctic terns *Sterna paradisaea*. *The Auk* 114:524-530.

Sullivan, J.R. 1979. The Stone Crab, *Menippe mercenaria*, in the Southwest Florida Fishery. Florida Marine Research Publications Number 36. Florida Department of Natural Resources Marine Research Laboratory, St. Petersburg.

Summers, J.K. 1989. Simulating the indirect effects of power plant entrainment losses on an estuarine ecosystem. *Ecological Modelling* 49: 31-47.

Sutherland, R.J. and R.G. Walsh. 1985. Effect of distance on the preservation value of water quality. *Land Economics* 61(3):282-291.

Sutter, F.C., R.S. Waller, and T.D. McIlwain. 1986. Species Profiles: Life Histories and Environmental Requirements of Coastal Fisheries and Invertebrates (Gulf of Mexico)-Black Drum. U.S. Fish and Wildlife Service Biological Report 82(11.51). U.S. Army Corps of Engineers TR LE-82-4.

Swanson, C. 1993. Economics of Non-Game Management: Bald Eagles on the Skagit River Bald Eagle Natural Area, Washington. PhD dissertation, Department of Agricultural Economics, Ohio State University, Columbus.

Swedberg, D.V. and C.H. Walburg. 1970. Spawning and early life history of the freshwater drum in Lewis and Clark Lake, Missouri River. *Transactions of the American Fisheries Society* 99:560-570.

Swee, U.B. and H.R. McCrimmon. 1966. Reproductive biology of the carp, *Cyprinus carpio* L., in Lake St. Lawrence, Ontario. *Transactions of the American Fisheries Society* 95(4):372-380.

Taft, E.P. 1999. Fish Protection Technologies: A Status Report. Presentation at Power Generation Impacts on Aquatic Resources Conference, Atlanta, GA, April 12-15.

Talhelm, D.R. 1988. Economics of Great Lakes Fisheries: A 1985 Assessment. Great Lakes Fishery Commission Technical Report No. 54. Great Lakes Fishery Commission, Ann Arbor, MI. November.

TBNEP (Tampa Bay National Estuary Program). 1992. Synthesis of Basic Life Histories of Tampa Bay Species. TBNEP Technical Publication #10-92. Tampa Bay National Estuary Program, St. Petersburg, FL.

Tenera Environmental Services. 1988. Diablo Canyon Power Plant Cooling Water Intake Structure 316(b) Demonstration. Prepared for Pacific Gas and Electric Company. April 28.

Tenera Environmental Services. 2000a. Diablo Canyon Power Plant 316(b) Demonstration Report and Appendices. Prepared for Pacific Gas and Electric Company. March 1.

Tenera Environmental Services. 2000b. Moss Landing Power Plant Modernization Project 316(b) Resource Assessment. Prepared for Duke Energy Moss Landing, LLC. April 28.

Tenera Environmental Services. 2001. Morro Bay Power Plant Modernization Project: 316(b) Resource Assessment. Prepared for Duke Energy Morro Bay, LLC, Oakland, CA. July 10.

Texas Parks and Wildlife Department (TPWD). 2003. Marine Sport-Harvest Monitoring Program, Annual Effort, Landings, and CPUE Estimates. Coastal Fisheries Division. Received from Mark Fisher, August 6.

Thomas, D.A. 2002. Memo to docket, RE: Observations of foam in discharge canals of 2 power plants. December 30, 2002.

Thomas, D.L. 1971. An Ecological Study of the Delaware River in the Vicinity of Artificial Island. Progress Report for the Period January-December 1970, Part III: The Early Life History and Ecology of Six Species of Drum (Sciaenidae) in the Lower Delaware River, a Brackish Tidal Estuary.

Thomas, M.V. and R.C. Haas. 2000. Status of Yellow Perch and Walleye Populations in Michigan Waters of Lake Erie, 1994-98. Fisheries Research Report 2054. Michigan Department of Natural Resources, Fisheries Division, Lansing. August.

Thomas, P. 2001. Thomas Research Group. Species Information. http://www.utmsi.utexas.edu/people/staff/thomas/species_information.htm. Accessed 1/30/02.

Thomson, C.J. 1991. Effects of avidity bias on survey estimates of fishing effort and economic value. In *Creel and Angler Surveys in Fisheries Management*. *American Fisheries Society Symposium* 12: 356-366.

Townsend, R.E. 1985. The right to fish as an external benefit of open access. *Canadian Journal of Fisheries and Aquatic Sciences* 42:2050-2053.

Trautman, M.B. 1981. *The Fishes of Ohio, with Illustrated Keys*. Revised ed. Ohio State University Press, Columbus.

Twomey, K.A., K.L. Williamson, and P.C. Nelson. 1984. Habitat Suitability Index Models and Instream Flow Suitability Curves: White Sucker. FWS/OBS-82/10.64. U.S. Fish and Wildlife Service.

UCMP. 2002. UCMP Glossary. University of California, Museum of Paleontology, Berkeley. http://www.ucmp.berkeley.edu. Accessed 4/1/02.

Ulanowicz, R.E. and B. Kinsman. 1978. Purgatorio–two rather different views of the same event. In *Power Plant Entrainment: A Biological Assessment*, J.R. Schubel and B.C. Marcy, Jr. (eds.). Academic Press, New York, pp. 245-253.

University of Minnesota. 2003. Gizzard shad. Photo by Konrad P. Schmidt. http://www.gen.umn.edu/research/fish/fishes/gizzard_shad.html. Accessed 10/6/03.

University of Washington. 2000. Invertebrates in the Plankton: Arthropoda. http://depts.washington.edu/fhl/zoo432/plankton/plarthropoda/plarthropoda.html. Accessed 11/19/2002.

University of Wisconsin Sea Grant Institute. 2001a. Fish of Lake Erie. http://www.seagrant.wisc.edu/greatlakesfish/LakeErie.html. Accessed 10/29/01.

University of Wisconsin Sea Grant Institute. 2001b. Fish of the Great Lakes: Fish Glossary. http://seagrant.wisc.edu/greatlakesfish/glossary.html. Accessed 3/29/02.

U.S. Bureau of Labor Statistics. 2002. Bureau of Labor Statistics, U.S. Department of Labor, Occupational Outlook Handbook, 2002-03 Edition, Fishers and Fishing Vessel Operators. http://www.bls.gov/oco/ocos177.htm. Accessed 2002.

U.S. Bureau of Labor Statistics. 2003. Consumer Price Index (CPI) data: U.S. Bureau of Labor Statistics, Division of Consumer Prices and Price Indexes. CPI-U, Not Seasonally Adjusted. http://www.bls.gov/cpi/home.htm. Accessed 2003.

U.S. Census Bureau. 2000. ss00002.uf1. ftp://ftp2.census.gov/census_2000/datasets/Summary_File_1. Accessed 12/21/01.

U.S. Census Bureau. 2002. 2000 Census, Summary File 3: United States. Prepared by the U.S. Census Bureau, Washington, DC.

U.S. Department of Energy (U.S. DOE). 2001a. Form EIA-860 (2001). Annual Electric Generator Report. U.S. Department of Energy, Washington, DC.

U.S. Department of Energy (U.S. DOE). 2001b. Form EIA-861 (2001). Annual Electric Utility Data. U.S. Department of Energy, Washington, DC.

U.S. Department of Energy (U.S. DOE). 2001c. Form EIA-906 (2001). Power Plant Report. U.S. Department of Energy, Washington, DC.

U.S. DOI. 1997. 1996 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, Bureau of the Census. U.S. Government Printing Office, Washington, DC.

U.S. EPA. 1972. Dr. Clarence Tarzwell. Pollution of the Interstate Waters of Mount Hope Bay and its Tributaries in the States of Massachusetts and Rhode Island. Conference Proceedings, Providence, RI, January 6, 1972. Volume 2. NTIS No. PB 230 572. U.S. Environmental Protection Agency, Washington, DC, pp. 591-623.

U.S. EPA. 1976. Development Document for Best Technology Available for the Location, Design, Construction, and Capacity of Cooling Water Intake Structures for Minimizing Adverse Environmental Impact. Office of Water and Hazardous Materials, Effluent Guidelines Division, U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA. 1977. (Draft) Guidance for Evaluating the Adverse Impact of Cooling Water Intake Structures on the Aquatic Environment: Section 316(b) P.L. 92-500. U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA. 1997. Guiding Principles for Monte Carlo Analysis. EPA/630/R-97/001. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, DC.

U.S. EPA. 1998a. Guidelines for Ecological Risk Assessment. EPA/630/R-95/002F. Risk Assessment Forum, U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA. 1998b. Product Performance Test Guidelines OPPT 810.3500 Premises Treatments. EPA-712-C-98-413. U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA. 1998c. Terms of Environment at http://www.epa.gov/OCEPAterms/. U.S. Environmental Protection Agency, Washington, DC. As of May 13, 1998. Accessed 1/02.

U.S. EPA. 2000. Guidelines for Preparing Economic Analyses. EPA 240-R-00-003. U.S. Environmental Protection Agency, Washington, DC. September.

U.S. EPA. 2002a. Case Study Analysis for the Proposed Section 316(b) Phase II Existing Facilities Rule (EPA-821-R-02-002). U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA. 2002b. Documentation of EPA Modeling Applications (V.2.1) Using the Integrated Planning Model. EPA 430/R-02-004. U.S. Environmental Protection Agency, Washington, DC. March.

U.S. EPA. 2002c. Indian River Lagoon National Estuary Program. Drums. U.S. Environmental Protection Agency. http://www.epa.gov/owow/oceans/lagoon/drum.html. Accessed 1/17/02.

U.S. EPA. 2002d. Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms. Fifth Edition. Section 11, Acute Toxicity Analysis. EPA-821-R-02-012. U.S. Environmental Protection Agency, Washington, DC, pp. 71-108.

U.S. EPA. 2002e. Total Maximum Daily Load (TMDL) Program: Glossary. U.S. Environmental Protection Agency Office of Water. http://www.epa.gov/owow/tmdl/pathogen/glossary.htm. Accessed 4/1/02.

U.S. EPA. 2003. Watershed Case Studies Analysis for the Final Section 316(b) Phase Two Existing Facilities Rule. Part D: The Mid-Atlantic Region, and Part G: The Great Lakes. U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA. 2004a. Economic and Benefits Analysis for the Final Section 316(b) Phase II Existing Facilities Rule. EPA-821-R-04-005. U.S. Environmental Protection Agency, Washington, DC. February.

U.S. EPA. 2004b. Technical Development Document for the Final Section 316(b)Phase II Existing Facilities Rule. EPA-821-R-04-007. U.S. Environmental Protection Agency, Washington, DC. February.

U.S. FDA. 2001. U.S. Food & Drug Administration Seafood Products Research Center. Center for Food Safety & Applied Nutrition. http://vm.cfsan.fda.gov/~frf/rfe0cb.html. Accessed 10/18/01.

U.S. Fish and Wildlife Service (USFWS). 1978. Development of Fishes of the Mid-Atlantic Bight. An Atlas of Egg, Larval and Juvenile Stages. FWS/OBS-78/12. U.S. Department of the Interior, Fish and Wildlife Service, Washington, DC.

U.S. Fish and Wildlife Service (USFWS). 1996a. The Endangered Species Act of 1973. A Summary of the ESA and Implementation Activities. Updated October 1996. http://endangered.fws.gov/esasum.html. Accessed 10/10/00.

U.S. Fish and Wildlife Service (USFWS). 1996b. Recovery Plan for the Sacramento-San Joaquin Delta Native Fishes. U.S. Fish and Wildlife Service, Portland, OR.

U.S. Fish and Wildlife Service (USFWS). 1998. 1996 Net Economic Values for Bass, Trout, and Walleye Fishing, Deer, Elk, and Moose Hunting, and Wildlife Watching. Report 91-9. U.S. Fish and Wildlife Service, Washington, DC.

U.S. Fish and Wildlife Service (USFWS). 2001. 2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation. Available at http://fa.r9.fws.gov/surveys/surveys.html#survey_reports.

U.S. Fish and Wildlife Service (USFWS). 2003. Fish Facts — Alewife. http://www.fws.gov/r5crc/fish/ze_alps.html. Accessed 10/4/2003.

U.S. Fish and Wildlife Service (USFWS). Date unknown. The Endangered Species Act of 1973. A Summary of the ESA and Implementation Activities. The Endangered Species Act of 1973. A Summary of the ESA and Implementation Activities. http://endangered.fws.gov/esasum.html. Accessed 10/10/00.

U.S. Fish and Wildlife Service and National Marine Fisheries Service. 2000. Habitat Conservation Planning and Incidental Take Permit Processing Handbook. http://endangered.fws.gov/hcp/hcpbook.html. Accessed 3/6/00.

U.S. Fish and Wildlife Service and Stratus Consulting. 1999. Recreational Fishing Damages from Fish Consumption Advisories in the Waters of Green Bay. Prepared for U.S. Fish and Wildlife Service, U. S. Department of Justice, and U. S. Department of Interior by Stratus Consulting, Boulder, CO. November 1.

USGen New England. 2001. Variance Request Application and Partial Demonstration Under the Clean Water Act, Section 316(a) and (b) in Support of Renewal of NPDES Permit No. MA 000 3654 for USGen New England, Inc.'s Brayton Point Station. May 24.

U.S. Geological Survey (USGS). 2001a. Alaska Science Center — Biological Science Office. Marine Habitat. http://www.absc.usgs.gov/research/seabird&foragefish/marinehabitat/home.html. Accessed 1/30/02.

Usher, A.J. 1987. Ontario Lake of the woods fishery: Economic and social analysis. *Transactions of the American Fisheries Society* 116:352-366.

U.S. Ocean Commission. 2002. Developing a National Ocean Policy: Mid-term Report of the U.S. Commission on Ocean Policy. September. Available at http://oceancommission.gov/documents/midterm_report/midterm_report.html.

Valiela, I. 1995. Spatial structure: Patchiness. In *Marine Ecological Processes*. Springer, New York, pp. 325-353.

Van den Avyle, M.J. and D.L. Fowler. 1984. Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (South Atlantic) — Blue Crab. U.S. Fish and Wildlife Service Biological Report USFWS/OBS-82/11. U.S. Army Corps of Engineers TR EL-82-4.

VandenBerg, T.P., G.L. Poe, and J.R. Powell. 2001. Assessing the accuracy of benefits transfers: Evidence from a multi-site contingent valuation study of ground water quality. In *The Economic Value of Water Quality*, J.C. Bergstrom, K.J. Boyle, and G.L. Poe (eds.). Edward Elgar Publishers, Northampton, MA.

Van Oosten, J. 1942. The age and growth of the Lake Erie white bass, *Lepibema chrysops* (Refinesque). *Papers of the Michigan Academy of Science Arts and Letters* 27: 307-334.

Varian, H.R. 1992. *Microeconomic Analysis*. 3rd Edition. W.W. Norton, New York.

Vaughan, W.J. and C.S. Russell. 1982. Valuing a fishing day: An application of a systematic varying parameter model. *Land Economics* 58(4):450-463.

Vetter, E.F. 1988. Estimation of natural mortality in fish stocks: A review. *Fishery Bulletin* 86 (1):25-43.

Virginia Tech. 1998. Marine and Coastal Species Information System. Fish and Wildlife Information Exchange. http://fwie.fw.vt.edu/WWW/macsis/index.htm.

Vouglitois, J.J., K.W. Able, R.J. Kurtz, and K.A. Tighe. 1987. Life history and population dynamics of the bay anchovy in New Jersey. *Trans. Am. Fish. Soc.* 116 (2):141-153.

Wahl, D.H. and L.A. Neilsen. 1985. Feeding ecology of the Sauger (*Stizostedion canadense*) in a large river. *Canadian Journal of Fisheries and Aquatic Sciences* 42:120-128.

Wainger, L.A., D. King, J. Salzman, and J. Boyd. 2001. Wetland value indicators for scoring mitigation trades. *Stanford Environmental Law Journal* 20(2):413-478.

Walburg, C.H. 1960. Abundance and life history of the shad, St. Johns River, Florida. *U.S. Fish. Bull.* 60(177):487-501.

Wallace, D.C. 1971. Age, growth, year class strength, and survival rates of the white perch, *Morone americana* (Gmelin) in the Delaware River in the vicinity of Artificial Island. *Chesapeake Science* 12(4): 205-218.

Wallus, R., B.L. Yeager, and T.P. Simon. 1990. Reproductive Biology and Early Life History of Fishes in the Ohio River Drainage, Volume I: Acipenseridae through Esocidae. Tennessee Valley Authority, Chattanooga.

Walsh, R., R.D. Bjonback, T.D. Rosenthal, and R. Aiken. 1985. Public Benefits of Programs to Protect Endangered Wildlife in Colorado Symposium on Issues and Technology in the Management of Impacted Western Wildlife. Thorne Ecological Institute, Glenwood Springs, CO.

Walsh, R.G., D.M. Johnson, and J.R. McKean. 1990. Nonmarket values from two decades of research on recreation demand. In *Advances in Applied Micro-Economics*, V.K. Smith and A.N. Link (eds.). JAI Press, Greenwich, CT.

Walsh, R.G., J.B. Loomis, and R.A. Gillman. 1984. Valuing option, existence, and bequest demands for wilderness. *Land Economics* 60(1):14-29.

Wang, J.C.S. 1986. Fishes of the Sacramento-San Joaquin Estuary and Adjacent Waters, California: A Guide to the Early Life Histories. Prepared by the California Dept. of Water Resources, the California Dept. of Fish and Game, the U.S. Bureau of Reclamation, and the U.S. Fish and Wildlife Service. Technical Report 9 (FS/B10-4ATR 86-9). Prepared for the Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. January. World Wide Web electronic publication. http://elib.cs.berkeley.edu/kopec/tr9/html/home.html. Accessed 11/01.

Wang, J.C.S. and R.J. Kernehan. 1979. Fishes of the Delaware Estuaries: A Guide to Early Life Histories. E.A. Communication. Ecological Analysts, Inc., Towson, MD.

Wapora. 1979. Impingement and Entrainment Assessment Using the Production Foregone Analysis at J.R. Whiting Plant During 1978. Prepared for Consumers Power Company. October.

Warke, G.M., K.R. Day, J.E. Greer, and R.D. Davidson. 1994. Cormorant (*Phalacrocorax carbo*) populations and patterns of abundance at breeding and feeding sites in northern Ireland, with particular reference to Lough Neagh. *Hydrobiologia* 279:91-100.

Warlen, S.M., A.J. Chester, and M.T. Boyd. 1980. Growth of larval/early juvenile spot, *Leiostomus xanthurus*, in North Carolina. In Anonymous. Annual report of the Southeast Fish Cent. Beaufort Lab., Beaufort, NC, to U.S. Dep. Energy, July 1, pp. 456-472.

Warren, R.S., P.E. Fell, R. Rozsa, A.H. Brawley, A.C. Orsted, E.T. Olson, V. Swamy, and W.A. Niering. 2002. Salt marsh restoration in Connecticut: 20 years of science and management. *Restoration Ecology* 10(3):497-513.

Washington Department of Fish and Wildlife. 1997. Washington State Forage Fish. Pacific Herring. http://www.wa.gov/wdfw/fish/forage/herring.htm.

Washington Tourist.com. 2000. Salmon Glossary. http://www.washingtontourist.com/salmon/journey/glossary.html. Accessed 3/29/02.

Waterfield, G.B. 1995. River herrings. In *Living Resources of the Delaware Estuary*, L.E. Dove and R.M. Nyman (eds.), pp. 191-197.

Water Quality Association. 1999. Water Quality Glossary. http://www.wqa.org/glossary.cfm. Accessed 3/29/02.

Weisberg, S.B. and W.H. Burton. 1993. Spring distribution and abundance of ichthyoplankton in the tidal Delaware River. *Fishery Bulletin* 91:788-797.

Welle, P.G. 1986. Potential Economic Impacts of Acid Deposition: A Contingent Valuation Study of Minnesota. Dissertation, University of Wisconsin-Madison.

Wetzel, R.G. 1983. *Limnology*. 2nd ed. CBS College Publishing, New York.

Wey, K.A. 1990. Social Welfare Analysis of Congestion and Water Quality of Great Salt Pond, Block Island, Rhode Island. Dissertation, University of Rhode Island, Kingston.

White, M.L. and M.E. Chittenden, Jr. 1977. Age determination, reproduction, and population dynamics of the Atlantic croaker, *Micropogonias undulatus*. *U.S. Fishery Bull*. 75(1):109-123.

Whitehead, J.C. and R. Aiken. 2000. An Analysis of Trends in Net Economic Values for Bass Fishing from the National Survey of Fishing, Hunting, and Wildlife-associated Recreation. East Carolina University, Department of Economics, Greenville, NC. April.

Whitehead, J.C. and G.C. Blomquist. 1991a. A link between behavior, information, and existence value. *Leisure Sciences* 13:97-109.

Whitehead, J.C. and G.C. Blomquist. 1991b. Measuring contingent values for wetlands: Effects of information about related environmental goods. *Water Resources Research* 27(10):2523-2531.

Whitehead, J.C. and G.C. Blomquist. 1992. Ex ante willingness to pay with supply and demand uncertainty: Implications for valuing a sea turtle protection programme. *Applied Economics* 24:981-988.

Whitehead, J.C. and P.A. Groothuis. 1992. Economic benefits of improved water quality: A case study of North Carolina's Tar-Pamlico River. *Rivers* 3:170-178.

Whitehead, J.C., G.C. Blomquist, T.J. Hoban, and W.B. Clifford. 1995. Assessing the validity and reliability of contingent values: A comparison of on-site users, off-site users, and non-users. *Journal of Environmental Economics and Management* 29(2):238-251.

Whittington, D., G. Cassidy, D. Amaral, E. McClelland, H. Wang, and C. Poulos. 1994. The Economic Value of Improving the Environmental Quality of Galveston Bay. GBNEP-38, 6/94. Department of Environmental Sciences and Engineering, University of North Carolina at Chapel Hill.

Wild, P.W. and R.N. Tasto (eds.). 1983. Life History, Environment, and Mariculture Studies of the Dungeness Crab, Cancer magister, with Emphasis on the Central California Fishery Resource. Fish Bulletin 172. California Department of Fish and Game.

Williams, A.B. 1958. Substrates as a factor in shrimp distribution. *Limnological Oceanography* 3:283-290.

Williamson, K.L. and P.C. Nelson. 1985. Habitat Suitability Index Models and Instream Flow Suitability Curves: Gizzard Shad. U.S. Fish and Wildlife Service Biological Report 82(10.112).

Wilson, M.A. and S.R. Carpenter. 1999. Economic valuation of freshwater ecosystem services in the United States: 1971-1997. *Ecological Applications* 9(3):772-783.

Winkelmann, R. 2000. *Econometric Analysis of Count Data*. Springer, New York.

Wisconsin Sea Grant. 2003. Rainbow Smelt. http://www.seagrant.wisc.edu/greatlakesfish/rainbowsmelt.html.

Woodward, R.T. and Y.S. Wui. 2001. The economic value of wetland services: A meta-analysis. *Ecological Economics* 37:257-270.

Wyda, J.C., L.A. Deegan, J.E. Hughes, and M.J. Weaver. 2002. The response of fishes to submerged aquatic vegetation complexity in two ecoregions of the mid-Atlantic bight: Buzzards Bay and Chesapeake Bay. *Estuaries* 25(1): 86-100.

Yoshiyama, R.M., E.R. Gerstung, F.W. Fisher, and P.B. Moyle. 1996. Historical and present distribution of chinook salmon in the Central Valley drainage of California. In Status of the Sierra Nevada: Sierra Nevada Ecosystem Project Final Report to Congress, Volume 3: Assessments, Commissioned Reports, and Background Information. Regents of the University of California, Davis, CA. http://ceres.ca.gov/snep/pubs/v3.html. Accessed 8/29/01.

Zastrow, C.E., E.D. Houde, and L.G. Morin. 1991. Spawning, fecundity, hatch-date frequency and young-of-year growth of bay anchovy *Anchoa mitchilli*, in mid-Chesapeake Bay. *Mar. Ecol. Prog. Ser*. 73:161-171.