



Wildlife

Research Strategy



research and development

national health and environmental effects research laboratory

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Wildlife Research Strategy

U. S. Environmental Protection Agency
Office of Research and Development
National Health and Environmental Effects Research Laboratory
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Foreword

The United States Environmental Protection Agency's Office of Research and Development (ORD) describes its research directions through a series of Multi-year Research Plans. These multi-year plans identify the principal issues facing environmental decision makers, the critical scientific uncertainties behind these issues needing resolution through research, the expected research outputs, and a projected time line for conducting this research. The plans are organized around topical areas that deal with specific program areas (e.g., particulate matter, drinking water, safe food) or more general broad-based areas such as ecosystem protection or human health research.

An issue that cuts across several of ORD's Multi-year Research Plans is the need to better understand and predict the effects of human activities on wildlife populations. EPA has historically relied upon laboratory-derived, species-specific toxicity data to protect aquatic and terrestrial species. As we face more complex environmental problems, we realize that we must integrate responses of organisms to multiple stressors as well as incorporate changing habitat conditions. To empower State, local and Tribal decision makers, we also must provide tools that can explicitly be applied to specific geographic locations. This is a challenging research endeavor that calls for an organized approach to bring together a variety of disciplines and tools.

To help meet this need, ORD's National Health and Environmental Effects Research Laboratory developed the Wildlife Research Strategy. The Strategy lays out a conceptual framework that when realized will provide the scientific basis for spatially explicit population level environmental risk assessments for application to a wide variety of environmental stressors. We recognize that solving this issue is a long-term commitment that will require the knowledge, expertise, and research far beyond the capacity of EPA alone. We welcome your insights and contributions as we undertake this challenge.

Lawrence Reiter, Ph.D.



Director
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Abstract

This document describes a strategy for conducting wildlife effects research within the U.S. Environmental Protection Agency's (EPA) National Health and Environmental Effects Research Laboratory (NHEERL). The Strategy is designed to address critical research areas and produce methods, models, and findings that the EPA Program and Regional Offices, the States, and Tribes can use to conduct wildlife population risk assessments and to develop associated criteria.

Consistent with the EPA's ecological risk assessment guidelines, the Strategy is designed to improve problem formulation, effect characterization, and risk characterization steps. Within this context, the Strategy supports a tiered approach to wildlife risk assessment and criteria development by arraying a series of assessments from most general and broadly based (screening level) to most realistic, accurate, and situation-specific (definitive level). While the sustainability of wildlife populations remains the assessment endpoint of concern throughout the tiered approach, increasingly accurate and realistic models and data are needed in higher tier risk assessments to narrow the band of uncertainty around the estimate of risk. The Strategy proposes development of a suite of methods and models with increasing realism and accuracy that will first concentrate on lower-tier risk assessment and criteria needs then on research that provides techniques and approaches for higher-tier applications. Specifically, the Strategy is focused on three major research objectives:

- 1. Develop mechanistically based approaches for extrapolating toxicological data across wildlife species, media, and individual-level response endpoints.*
- 2. Develop approaches for predicting population-level responses to stressors. Identify the responses at the individual level that have the greatest influence on population-level responses.*
- 3. Develop approaches for evaluating the relative risks from chemical and non-chemical stressors on spatially structured wildlife populations across large areas or regions.*

The proposed research across these three objectives will provide increasingly sophisticated methods and models for avian, amphibian, and mammalian wildlife risk assessments and criteria development. Further development of this Strategy, fulfilment of its goals, and its ultimate implementation require interaction among the Agency's Program Offices and Regions and collaboration within the Office of Research and Development and with other federal partners.

Table of Contents

Foreword	iii
Abstract	iv
Tables	vi
Figures	vii
Abbreviations	viii
Acknowledgments	ix
Executive Summary	E - 1
Introduction	1
Programmatic Needs	2
Major Research Needs	3
Research Scope, Objectives, and Conceptual Framework	5
Research Scope	5
Conceptual Framework	6
Research Objectives	9
Conceptual Approach to Wildlife Risk Assessment	11
Considerations about Ecological Models	11
Tiered Risk Assessment Protocol	12
Methodological Requirements of the Tiered Protocol	15
Mechanistically Based Approaches for Interspecies Extrapolation of Toxicological Information (Objective 1)	19
Statement of the Objective	19
Background	19
Research Questions	21
Research Approach	22
Modeling Approaches for Predicting Responses of Wildlife Populations to Anthropogenic Stressors From Individual-Based Information (Objective 2)	25
Statement of the Objective	25
Background	25
Research Questions	26
Research Approach	26
Spatially Explicit Modeling to Assess Relative Risks From Chemical and Non-Chemical Stressors (Objective 3)	29
Statement of the Objective	29
Background	29
Research Questions	30
Research Approach	30
Case Studies	34
References	36

Tables

Table 1.	Research and data collection activities	8
Table 2.	Example attributes of screening and definitive tiers of wildlife risk assessments ...	14
Table 3.	Types of extrapolation required by the conceptual approach of wildlife risk assessment	17

Figures

Figure 1. Ecological risk assessment framework highlighting the effects components to which NHEERL research will contribute most directly	1
Figure 2. Conceptual approach to wildlife risk assessment	7
Figure 3. Ordination scheme for ecological models	11
Figure 4. Tiered risk assessment approach for wildlife, moving from screening levels to definitive levels	13
Figure 5. Conceptualization of uncertainty in a tiered risk assessment	14
Figure 6. Decision points in a tiered risk assessment	15
Figure 7. Example life cycle diagram	26
Figure 8. Schematic representation of how a dose-response function could be used to modify a matrix model parameter	28

Abbreviations

DDT	Dichlorodiphenyltrichloroethane
ECOFRAM	Ecological Committee on FIFRA Risk Assessment Methods
EPA	Environmental Protection Agency
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FWS	Fish and Wildlife Service
GIS	Geographical Information Systems
LC ₅₀	Lethal Concentration 50
NCEA	National Center for Environmental Assessment
NERL	National Exposure Research Laboratory
NHEERL	National Health and Environmental Effects Research Laboratory
NPL	National Priorities List
ORD	Office of Research and Development
p	Probability
PATCH	Program to Assist in Tracking Critical Habitat
PBTK	Physiologically Based Toxicokinetic
PCB	Polychlorinated Biphenyls
RCRA	Resource Conservation and Recovery Act
SAB	Science Advisory Board
TCDD	2,3,7,8-Tetrachlorodibenzo-o-Dioxin
TSCA	Toxic Substances Control Act
USGS	U.S. Geological Survey

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Development of the Strategy included an initial retreat that provided valuable input from EPA Program Offices including:

Office of Air Quality Planning and Standards, Office of Air and Radiation;
Office of Emergency and Remedial Response, Office of Solid Waste and Emergency Response;
Office of Pesticide Programs, Office of Prevention, Pesticides, and Toxic Substances; and the
Office of Science and Technology, Office of Water.

Executive Summary

This document describes a strategy for conducting wildlife effects research within the U.S. Environmental Protection Agency's (EPA) National Health and Environmental Effects Research Laboratory (NHEERL). The goal of NHEERL's wildlife research is to develop scientifically valid approaches for assessing risks to wildlife populations from multiple stressors. The need to advance wildlife risk assessment methods and knowledge bases is recognized across the Agency's air, water, pesticide, toxic substances, and hazardous waste programs. Through a series of EPA's Science Advisory Board reviews and consultations, as well as other EPA peer-reviews, four key areas of research have been identified where advances in the science would be instrumental in improving wildlife risk assessment techniques and criteria methodology. These areas include the following:

1. Extrapolation research that improves the basis for predicting toxicological responses among wildlife species and exposure scenarios of concern.
2. Coordinated wildlife population biology and wildlife toxicology research to improve predictions of population dynamics in spatially explicit habitats.
3. Research to advance techniques for assessing the relative risk of chemical and non-chemical stressors on wildlife populations.
4. Research to define appropriate geographical regions/spatial scales for wildlife risk assessments.

The Strategy is designed to address these critical research areas and produce methods, models, and findings that will provide scientifically credible approaches for the EPA Program and Regional Offices, the States, and Tribes to conduct wildlife population risk assessments and to develop associated criteria.

Consistent with the EPA's ecological risk assessment guidelines, the Strategy is designed to improve problem formulation, effect characterization, and risk characterization steps. Within this context, the Strategy employs a tiered approach to wildlife risk assessment and criteria

development by arraying a series of assessments from most general and broadly based (screening level) to most realistic, accurate and situation-specific (definitive level). While the sustainability of wildlife populations remains the assessment endpoint of concern throughout the tiered approach, increasingly accurate and realistic models and data are needed in higher-tier risk assessments to narrow the band of uncertainty around the estimate of risk. The appropriate final tier for a specific wildlife risk assessment is based on a risk management analysis that weighs risk assessment uncertainties against the context of the management decision and the costs associated with a “wrong” decision compared to the costs of gathering and employing increasingly realistic and accurate data and models. The Strategy proposes development of a suite of methods and models with increasing realism and accuracy that will first concentrate on lower-tier risk assessment and criteria needs followed by research that provides techniques and approaches for higher-tier applications.

In reviewing wildlife risk assessments and criteria development, four steps were identified that are critical to completing effects characterizations. The first step involves the spatial and temporal characterization of stressors; e.g., contaminant exposure, habitat suitability, and introduced species that may adversely affect the wildlife population of concern. Based on the results of Step 1, quantitative chemical dose-response relationships and habitat-response relationships at the individual level are developed in Step 2 (e.g., relationships to fecundity and life-stage specific probability of survival). In Step 3, these demographic rates are used in population models to generate outputs describing population growth rates or other appropriate population-level endpoints. Finally, in Step 4, these relationships are “inserted” back into the landscape to determine cumulative population dynamics across the landscape and assess effects due to chemical exposure as well as other forms of habitat disturbance. As discussed previously, the level of accuracy and realism required for these four steps varies with risk assessment and management needs.

Based on the four steps required to assess effects in wildlife populations, the Strategy is focused on three major research objectives:

- 1. Develop mechanistically based approaches for extrapolating toxicological data across wildlife species, media, and individual-level response endpoints.*

2. *Develop approaches for predicting population-level responses to stressors. Identify the responses at the individual level that have the greatest influence on population-level responses.*
3. *Develop approaches for evaluating the relative risks from chemical and non-chemical stressors on spatially structured wildlife populations across large areas or regions.*

These research objectives are consistent with recommendations provided by the Science Advisory Board (SAB) and other peer-review panels and correspond to the wildlife effect characterization steps described above. Objective 1 deals with development of individual-level exposure-response relationships. The research proposed under Objective 1 will emphasize approaches for developing and extrapolating toxicity data to a broader array of species, environmental media, and response endpoints (in particular, the endpoints required as input to population response models). Objective 2 deals with extrapolating from individual-level responses up to the population. The primary approach and organizing structure of research conducted under Objective 2 will be the development, application, and evaluation of population response models. Analyses will also be conducted to identify responses at the individual level that have the greatest influence on population-level responses to help prioritize future research under Objective 1. Research addressing Objective 3 introduces issues associated with the spatial and temporal heterogeneity of populations and stressors and extends the analyses under Objectives 1 and 2 to applications in real landscapes with multiple stressors.

The proposed research across these three objectives will provide increasingly sophisticated methods and models for avian, amphibian, and mammalian wildlife risk assessments and criteria development. The projected outputs will advance techniques and knowledge bases needed to support early-tier risk assessments and a national methodology for wildlife criteria. Through the selection of prototypical compounds and landscapes of concern, the research effort will also develop methods and models that can support increasingly situation-specific risk assessments and site- and species-specific wildlife criteria.

Further development of this research strategy, fulfillment of its goals, and its ultimate implementation require interaction among the Agency's Program Offices and Regions and

collaboration within the Office of Research and Development (ORD) and with other federal partners. While development of the wildlife strategy was based in part on discussions with Program Office and Regional representatives and a review of recent wildlife risk assessment and criteria activities, this initial dialogue must be expanded to ensure that the regulatory challenges have been properly understood and that the proposed research approach addresses the associated needs. Collaboration with the National Exposure Research Laboratory (NERL) and the National Center for Environmental Assessment (NCEA) is required to ensure that approaches developed to assess effects on wildlife populations are compatible with approaches for exposure and risk characterization. Collaboration with other federal research organizations will also be essential. For example, it is not envisioned that NHEERL would conduct new mammalian and avian toxicity and physiology experiments in-house because such work can be achieved by collaborating with existing federal facilities better suited for such efforts, such as the U.S. Geological Survey (USGS) Patuxent Wildlife Research Center. In a related manner, fulfillment of research goals associated with population modeling and spatially explicit applications would benefit from collaboration with Department of Interior scientists. Finally, it will be essential to integrate research undertaken within ORD and other federal facilities with any future EPA grant initiatives to ensure ORD-sponsored research undertaken by academia complements in-house efforts.

Introduction

This document describes a strategy for conducting wildlife effects research within the U.S. Environmental Protection Agency's (EPA) National Health and Environmental Effects Research Laboratory (NHEERL). The goal of NHEERL's wildlife research is to *develop scientifically valid approaches for assessing risks to wildlife populations from multiple stressors*. Consistent with the mission of NHEERL, the emphasis is on improved approaches for effects components of the risk assessment process (Figure 1). NHEERL research will be conducted in consultation with the EPA National Exposure Research Laboratory (NERL) and National Center for Environmental Assessment (NCEA) as well as other organizations to ensure that approaches developed to assess effects on wildlife populations are compatible with approaches for exposure and risk characterization.

The purpose of this document is to describe NHEERL's strategy for wildlife research. It defines a conceptual framework for wildlife risk assessments and identifies high priority areas of research to be undertaken within NHEERL, linkages among these components, and the general types of products that could be expected over the next six years. It does not describe specific research approaches or projects. Rather, the strategy provides the foundation from which these more-detailed research plans will be developed, implemented, and integrated. It also provides a starting point for discussions with other organizations regarding uncertainties in risk assessment techniques and potential collaborative research and interactions.

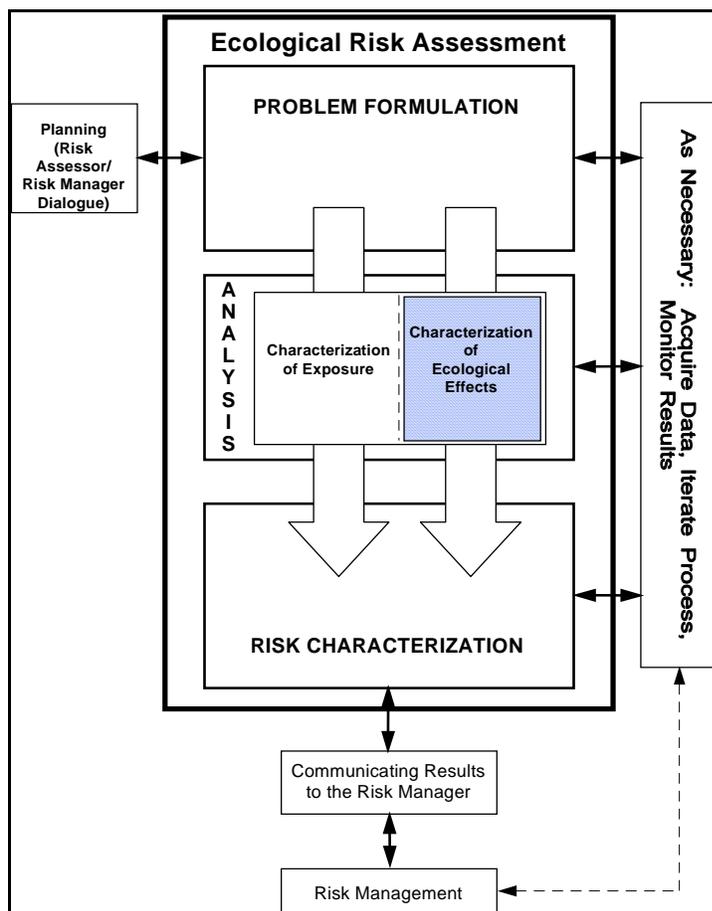


Figure 1. Ecological risk assessment framework highlighting the effects components to which NHEERL research will contribute most directly.

Programmatic Needs. Several EPA programs deal with issues associated with effects on wildlife. The need to advance wildlife risk assessment knowledge bases and methods is recognized across EPA. Immediate needs primarily concern the potential adverse effects of chemical contaminants; however, the importance of considering effects associated with multiple types of stressors is recognized.

Within EPA's toxic substances and pesticide programs, the goal of advancing probabilistic risk assessments for wildlife has been articulated in risk assessment reviews, workgroups, and advisory bodies. For example, in 1996 the Environmental Fate and Effects Division within the Office of Pesticide Programs presented two ecological risk assessment case studies for review to the Scientific Advisory Panel for the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). While reaffirming the utility of the ecological assessment process, the Panel also offered a number of suggestions for improvement. Foremost, the Panel recommended moving beyond the current single-point deterministic assessment approach and to developing the tools and methods necessary for a probabilistic assessment of risk. As a follow-up to this and other reviews and to develop specific recommendations for revising the assessment process, the Office of Pesticide Programs formed the Ecological Committee on FIFRA Risk Assessment Methods (ECOFRAM).

The Office of Water developed prototypical methodologies to assess risks of bioaccumulative chemicals to wildlife in 1995 through the Great Lakes Water Quality Initiative (U.S. EPA 1995). The wildlife criteria methodology, as well as numeric criteria for four specific pollutants (DDT; 2,3,7,8-TCDD; PCB, and mercury), were developed collaboratively by federal and state scientists and risk assessors. A draft Memorandum of Agreement among the Office of Water, U.S. Fish and Wildlife Service (FWS), and National Marine Fisheries Service (*Federal Register*, January 7, 1999) calls for development of improved approaches for wildlife criteria derivation and requires EPA to explicitly address protection of threatened and endangered species in implementation of the Clean Water Act. The draft Jeopardy Opinion for the California Toxics Rules also requires the Office of Water to derive new wildlife criteria, specifically for mercury and selenium.

The 1990 Clean Air Act Amendments require the Office of Air to consider possible effects on wildlife from airborne deposition of hazardous substances. Adverse effects from

airborne deposition of mercury are of special interest. In the Agency's Mercury Report to Congress (U.S. EPA 1997), the approaches used in the Great Lakes Water Quality Initiative (U.S. EPA 1995) were adapted to assess risks to piscivorous birds and mammals; and limitations in current techniques and databases were noted. The Office of Air is currently developing approaches to assess the significance of effects from other hazardous air pollutants on wildlife and related ecosystem components.

Finally, EPA's hazardous waste (Superfund) program is attempting to establish consistency in wildlife risk assessment approaches for organic compounds and metals, with an emphasis on terrestrial ecosystems. In the absence of a cohesive approach to wildlife risk assessment, risk assessors render decisions affecting wildlife based on variable assumptions regarding exposure and effects. Currently, an Office of Solid Waste and Emergency Response sponsored multi-stakeholder workgroup is attempting to develop scientifically sound screening levels for chemicals in soils that would be protective of mammalian and avian wildlife populations. The mammalian and avian benchmarks will be based on a hazard quotient method derived from toxicity data for higher vertebrates and a generic food chain model. In addition to generating discrete benchmark values, the workgroup is considering using methods to estimate the likelihood of wildlife effects based upon probabilistic distributions of toxicity and exposure data for some chemicals.

Major Research Needs. Underlying each of these Program Office efforts is the need for improved techniques to extrapolate effects across species, levels of biological organization, and landscapes. In consultation with external peer-review panels including EPA's Science SAB (U.S. EPA 1992, 1994, 1998), four key areas of research have been identified where advances in the science would improve wildlife risk assessments:

1. *Research that improves the basis for predicting and extrapolating toxicological responses across wildlife species and exposure scenarios of concern.* In general, toxicological data are not available for species of concern and instead must be extrapolated from a limited number of studies with "model laboratory organisms." In addition, chemical exposure data derived from monitoring studies or fate and transport models are not always reported in a medium most useful for assessing effects. Consequently, there is a need to improve experimental approaches and predictive models

to advance techniques for extrapolating toxicological responses across wildlife species using translators appropriate for estimating exposure from different media. This extrapolation requires consideration of the separate but related issues of differences among species in their exposure and differences among species in their sensitivity and nature of toxicological response.

2. *Coordinated wildlife population biology and toxicology research to improve predictions of population dynamics in spatially explicit habitats.* To establish a scientifically credible approach to assess the risk of direct chemical effects on populations, research is needed to better define those toxicological responses at the individual level that are most critical in perturbing population dynamics. In addition, there is a need to predict population responses to spatially explicit scenarios of chemical exposure.
3. *Research to advance techniques for assessing the relative risk of chemical and non-chemical stressors on wildlife populations.* Landscape characterization studies combined with experimental approaches are required to better quantify the relative effects of chemical stressors, habitat alterations, and the introduction of exotic species on wildlife populations. Associated with this effort is the need to develop and integrate predictive models so that the outcome of different management scenarios can be quantified based on chemical loading, habitat alterations, exotic species control, and other management options.
4. *Research to define appropriate geographical regions / spatial scales for wildlife risk assessments.* A significant effort is needed to define scientifically credible spatial scales for wildlife risk assessments. Habitat requirements for wildlife species associated with aquatic and terrestrial ecosystems must be established and referenced to regulatory jurisdictions to ensure coordinated implementation of risk-based decisions. A consensus on current or potential habitat ranges is needed to identify wildlife species of concern and to evaluate approaches in risk assessments that consider spatial population structure.

Research Scope, Conceptual Framework and Objectives

This research strategy is designed to address the critical research needs identified by the SAB and other peer-review bodies and to produce models, approaches, and data that would assist the Program Offices and other risk managers in conducting wildlife risk assessments.

Research Scope. The focus of the research strategy is on the effects on wildlife, in particular, amphibians, birds, and mammals. Historically, EPA ecological research has dealt predominately with aquatic biota and, to a lesser degree, terrestrial vegetation, as the basis for defining water and air quality criteria authorized under the Clean Water and Clean Air Acts. The present focus on wildlife is designed to provide techniques to help rectify this imbalance and will build on approaches developed previously for aquatic biota. Tests of new models and hypotheses will incorporate both wildlife and aquatic biota to ensure that the approaches developed are robust across taxa and ecosystem types.

The assessment endpoint of concern is effects on populations; that is, the abundance (numbers, biomass) and long-term viability of a given species within a defined geographic area. It is recognized that other assessment endpoints (e.g., at the individual or community level) may be appropriate for some wildlife risk assessments. NHEERL's research will focus on population-level effects, however, because populations represent ecologically and legislatively important endpoints of concern as expressed, for example, in the Great Lakes Water Quality Initiative (U.S. EPA 1995) and the Endangered Species Act. While mortality or injury of individuals (e.g., malformations) may cause concern, a more important question is whether these individual losses affect population growth and viability. Community-level effects, such as declines in species diversity or disruption of food webs, are important endpoints as well but are far less tangible from both a scientific and management perspective. Furthermore, information on population-level responses represents an important stepping stone towards an improved understanding of community-level responses.

EPA regulatory authorities deal most directly with limiting the release of contaminants into the environment. Wildlife populations also are affected, however, by many other stressors resulting directly or indirectly from human activities (e.g., habitat loss and alterations, introduced species, hunting pressure). The sensitivity of a population to a given contaminant, as

well as the ecological significance of a contaminant effect, is influenced by these other stressors. Thus, an important aspect of this research strategy is to develop approaches for assessing risks of contaminants within this broader context. Consistent with recommendations of the SAB (Section I), this Strategy deals explicitly with the combined effects of contaminants, habitat loss and alteration, and introduced species on wildlife populations. Other types of stressors could also be readily incorporated into the framework and models but will not be the subject of focused attention in the time frame encompassed by this Strategy.

Neither stressors nor wildlife populations are distributed uniformly within the environment. The interplay between spatial and temporal heterogeneity in wildlife population structure and spatial and temporal patterns of stressors is a major factor controlling the severity of effects on wildlife populations (e.g., Kareiva 1990; Turner et al., 1995; Hanski 1998). Thus, a critical feature of this Strategy is development of probabilistic models that deal explicitly with the spatial distribution of population and stressors over time. These models will be designed for application to real landscapes by interfacing with geographical information systems (GIS).

NHEERL's approach to wildlife risk assessment links wildlife toxicology, population biology, and landscape ecology. It is impractical for NHEERL to undertake an extensive empirical testing program for all species, contaminants, and habitats; therefore, an extrapolation approach to fill data gaps will be applied. Consequently, the Research Strategy reflects an integration of strategic laboratory and field-based studies with predictive modeling.

Conceptual Framework. Figure 2 outlines the NHEERL conceptual framework for wildlife risk assessments, focusing on the effects component of the assessment process. Step 1 involves spatial and temporal characterization of stressors, in particular contaminant exposure, habitat suitability, and introduced species, that may adversely affect the population of concern. Much of this information, especially data on contaminant exposures, would be derived from studies conducted by others (e.g., NERL exposure modeling). Results from Step 1 provide the input into Step 2, quantification of the exposure-response and habitat-response relationships at the individual level. The specific response variables estimated in Step 2 are spatially explicit demographic rates (fecundity and life-stage-specific probability of survival) of individuals within the

population. These demographic rates in turn drive population models in Step 3, generating outputs describing population growth rate or other appropriate population-level endpoints (e.g., extinction probabilities). Finally, these population dynamics are inserted back into

Conceptual Approach

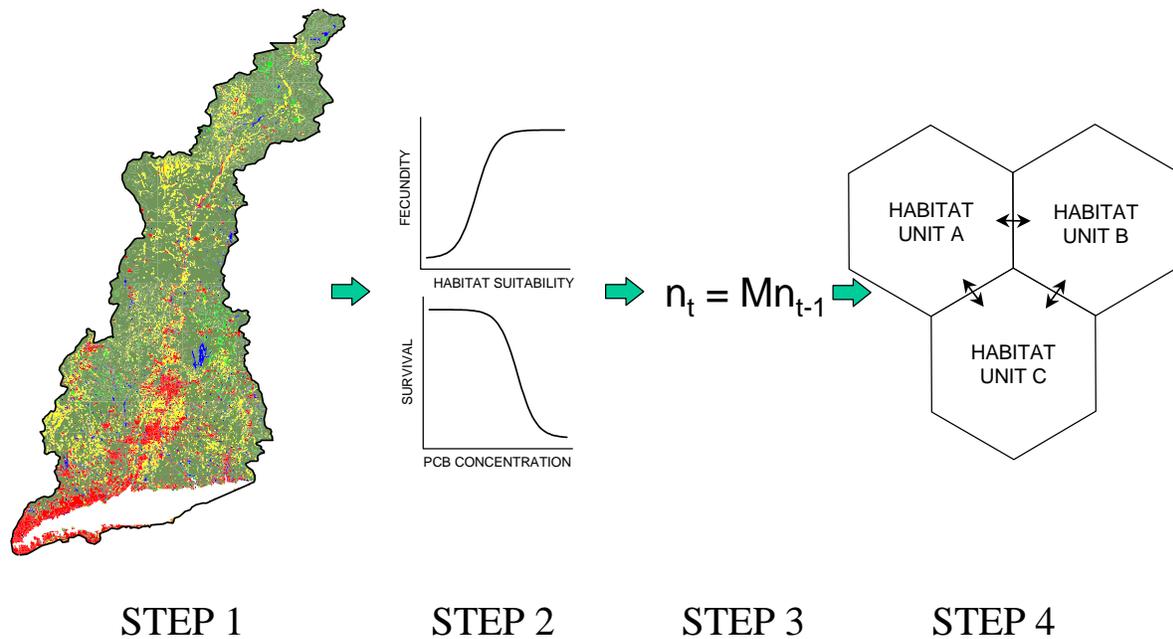


Figure 2. Conceptual approach to wildlife risk assessment. Steps 1-4 show landscape characterization, development of exposure and habitat response relationships, estimating population responses, and spatial modeling.

the landscape in Step 4 to determine habitat-specific population sources and sinks using spatially explicit modeling platforms. Analysis of the cumulative population dynamics across the landscape provides the estimates of wildlife risks from chemical exposure, habitat changes, introduced species, and other forms of disturbance in the landscape. Example research and data collection activities for each step in this process are listed in Table 1.

Table 1. Research and data collection activities for each step in the Conceptual Approach to Wildlife Risk Assessment.

Step	Research or Data Collection Activity
1. Landscape characterization	Spatial / temporal aspects of contaminant exposure Spatial / temporal aspects of habitat and habitat quality Spatial / temporal aspects of introduced species
2. Exposure / habitat response relationships	Evaluation of chemical effects on vital rates Taxonomic extrapolation of dose-response effects on vital rates Extrapolation of toxic response across media and endpoints Effects of interactions of multiple stressors on individuals Exposure-response model development Habitat-response model development
3. Population responses and modeling	Population model development Identification of species response classes Effects of interactions of multiple stressors on populations Evaluation of model outputs, parameters, and assumptions
4. Spatial modeling	Spatial model development Identification of risk classes Identification of appropriate spatial scales for assessment Evaluation of relative risks from multiple stressors and effectiveness of alternative management strategies

Research Objectives. The conceptual framework outlined above organizes the research strategy and defines three major research objectives:

1. *Develop mechanistically based approaches for extrapolating toxicological data across wildlife species, media, and individual-level response endpoints.*
2. *Develop approaches for predicting population-level responses to stressors. Identify the responses at the individual level that have the greatest influence on population-level responses for a wide range of life-history types.*
3. *Develop approaches for evaluating relative risks from chemical and non-chemical stressors on spatially structured wildlife populations across large areas or regions.*

Objectives 1-3 correspond to Steps 2-4, respectively, in the conceptual framework presented in Figure 2. Objective 1 deals with development of individual-level exposure-response relationships. We are not proposing to conduct substantial new mammalian and avian toxicity testing, in part because such work can be achieved by collaborating with existing facilities better suited for such efforts (e.g., USGS Patuxent Research Center). Rather, NHEERL research will emphasize approaches for extrapolating toxicity data to a broader array of species, environmental media, and response endpoints (in particular, the endpoints required as input to population response models). This approach is consistent with the recommendations of the SAB.

Objective 2 deals with extrapolating from individual-level responses up to the population. Development and application of population response models will be the primary approach and organizing structure. Modeling will be supplemented with targeted field and laboratory studies designed to evaluate model outputs, key assumptions, model parameters, and potential population-level compensatory mechanisms. Analyses will also be conducted to identify responses at the individual level that have the greatest influence on population-level responses to help prioritize future research under Objective 1.

Objective 3 introduces issues associated with the spatial and temporal heterogeneity of populations and stressors and extends the analyses under Objectives 1 and 2 to applications in

real landscapes. Because different stressors tend to be distributed heterogeneously in the landscape, it is under Objective 3 that we can most completely address the interactive effects of contaminants, habitat alteration, and introduced species on wildlife populations. Models and analyses under Objective 3 will both assess risks from multiple stressors and evaluate the relative effectiveness of alternative management strategies.

It is important to note that research supporting these objectives will produce results and models of value both independently and jointly. For example, screening-level wildlife risk assessments could be undertaken without applying the quantitative population and spatial models described under Objectives 2-3.

The remainder of this document is organized around the three objectives that define NHEERL's wildlife research strategy. Section III reviews concepts of ecological modeling and a tiered approach to risk assessment. Sections IV-VI describe our strategic approach to Objectives 1-3. Each Objectives section includes: (1) a brief summary of the state of the science and research needs specific to that objective; (2) a list of more detailed research questions and proposed research activities; and (3) an overview of the proposed research approach in the context of existing research and expertise within NHEERL. Section VII describes the role of and criteria for selecting case studies to be conducted jointly with others (e.g., Program Offices, Regions, NERL, NCEA, other organizations) to provide an opportunity to evaluate and demonstrate the approaches developed.

Conceptual Approach to Wildlife Risk Assessment

To understand the NHEERL strategic approach to wildlife research, it is important to consider features of ecological models and how they can be used to address different aspects of wildlife risk assessment. These features suggest an approach for optimizing the effort and costs of individual assessments based on the needs of environmental managers. The following discussion provides background concerning the methodological requirements and research needed to develop and implement a wildlife risk assessment protocol.

Considerations About Ecological Models. In his broad discussion of ecological theory and models, Levins (1968) describes a triangular scheme for ordinating ecological models that has the attributes of *generality*, *realism*, and *accuracy* (originally *precision*¹) as its apices (Figure 3). In this context, general models are those that tend to be simple, apply to a broad range of situations, and therefore are appropriate for exploring relationships among model parameters and outputs. Realistic models attempt to account for known relationships and processes in ecological systems and, as a result, can be relatively complex. Accurate models are constructed with the objective of minimizing numerical differences between model outputs and actual ecological system dynamics. Their often case-specific nature limits their use in broader applications.

Levins (1968) pointed out that any two of these attributes could be maximized at one time but that it is not possible to maximize all three with a single model. Typically, models developed for use in applied situations (e.g., conservation biology) are intended to give realistic, accurate answers; parameterization depends upon the actual conditions of the

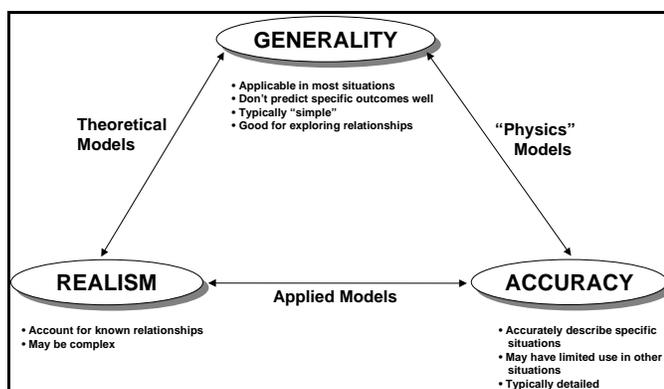


Figure 3. Ordination scheme for ecological models (modified from Levins 1968).

¹Use of the terms *accuracy* and *precision* in this plan follows their connotations in the field of inferential statistics. Accuracy refers to how well an estimate matches the true value of a particular parameter or value being estimated (in this case, ecological risk), and typically is quantified using some measure of bias. Precision refers to the amount of variation among multiple estimates made of the parameter and usually is expressed using some measure of scatter.

situation being modeled (for example, the specific life history and demographic characteristics of the species of interest). Increased generality can be achieved by expanding the range of values assumed for particular model coefficients or by assuming broad functional relationships among parameters, but such actions necessarily reduce the accuracy achievable in any particular application. Model accuracy can be enhanced by increasing the specificity of model parameterization relative to a particular species or environmental situation.

With this ordination scheme in mind, ecological models and, specifically, population models, can be used in wildlife risk assessments for at least three, arguably different purposes. The first is to detect (and perhaps diagnose) previous or ongoing adverse effects on wildlife population dynamics. Such a use typically requires sufficient high quality data to be able to detect statistical changes in population abundance and to relate those changes to variation in chemical exposure, habitat, or other forms of disturbance. The second purpose is to project the consequences of a given set of environmental conditions (or changes in conditions) to the dynamics of a population. Here the intent may be to evaluate the ramifications of particular environmental management decisions as determined by trends in population numbers or changes in extinction probabilities. The final purpose is to forecast or predict the future behavior of the population based on a understanding of environmental variability and the dynamic interactions of density and biological processes. [The distinction between projection and forecasting used here follows that given by Caswell (1986).] This last use of population models may produce the most accurate results although the generality of the analysis will suffer. While certain model formulations are more appropriately used for one of these purposes or another, all three purposes have value in the context of wildlife risk assessment.

Tiered Risk Assessment Protocol. Wildlife risk assessments are conducted with a variety of objectives in mind, including evaluation of the general consequences of environmental management actions, evaluation of the susceptibility of individual species to particular stressors, identification of classes of species that respond to stress similarly, and analysis of risks to specific populations resulting from particular combinations of stress. The quality and quantity of data available as input to risk assessment varies across assessment situations. Differences also exist in the costs (ecological, monetary, and/or societal) associated with making wrong decisions. Considering the potential range of management objectives, data requirements, and management implications, we propose development of a tiered approach to wildlife risk assessment. Just as is

used in other risk-based programs (e.g., TSCA, FIFRA), a tiered protocol for wildlife risk assessment will permit optimization of analysis effort and cost based on the objectives of the assessment.

Conceptually, the tiered approach consists of series of complete risk assessments (Figure 4) arrayed from most general and broadly based (screening level) to most realistic, accurate, and situation-specific (definitive level). Tiers in the array vary from one another in the types of models used, quality and quantity of data needed, nature of risk conclusions developed, and the degree to which results can be extrapolated to other situations (Table 2); but the assessment endpoint (sustainability of the specific wildlife population) remains constant. To illustrate, screening-level assessments would employ general models with low data requirements and would produce conclusions that can be extrapolated to a wide range of scenarios. Conversely,

definitive-level assessments would use realistic models that are accurate for particular situations (combinations of species and environmental settings) and that therefore require potentially large amounts of high quality data describing the life history and demography of the species, as well as information about the regional landscape. The risk estimates drawn from definitive assessments would be very specific to the situation evaluated and consequentially could be extrapolated to a limited number of other scenarios. The number of tiers needed for any particular risk assessment would not be prescribed; rather, assessors would cycle through increasingly more realistic and accurate assessment tiers until either the confidence associated with risk conclusions became acceptable (relative to the costs of making a wrong decision) or the availability of data and resources prevented moving to the next tier. Alternately, the process

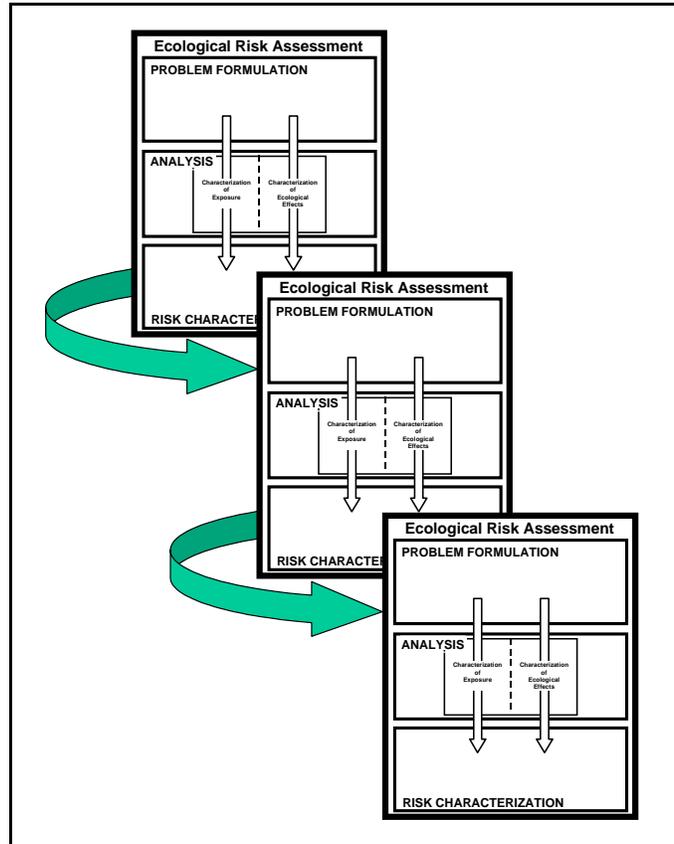


Figure 4. Tiered risk assessment approach for wildlife, moving from screening levels to definitive levels.

could be entered and completed at any single tier based on the requirements of the assessment and nature of available information.

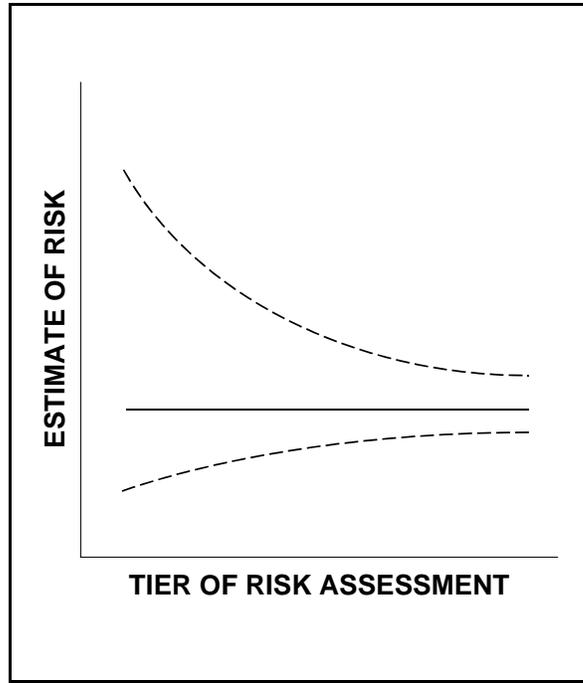


Figure 5. Conceptualization of uncertainty in a tiered risk assessment. Solid line is estimate of risk; dashed lines are uncertainty bounds.

Table 2. Example attributes of screening and definitive tiers of wildlife risk assessments.

Tier	Modeling Tools	Data Needs	Applicability	Extrapolatability
screening	general	low	robust	high
definitive	realistic, accurate	high	specific	low

Reflective of this trend from general, screening-level tiers to realistic and accurate definitive-level tiers is an expected increase in the confidence associated with the estimates of risk to the assessment population. As illustrated conceptually in Figure 5, the use of data and models that are increasingly specific to the population and assessment situation should lead to a narrowing of the bounds of uncertainty around the estimates of risk. Decisions to move from one tier to the next will be in part based on the level of confidence/uncertainty acceptable to the

risk manager. Figure 6 illustrates the decision process relative to assessment tiers; with the communication of risk estimated at each tier, the risk manager will decide whether the uncertainties associated with that tier are acceptable in the context of the decision to be made and the costs associated with a wrong decision or if next tier assessment is warranted. In practice, estimates of risk that suggest either extremely low risk or extremely high risk to the wildlife population should permit immediate decisions regarding that risk and how to manage it. Estimates of risk that are ambiguous and are associated with sufficiently high levels of uncertainty should invoke further assessment at the next higher tier. Working through the risk assessment tiers permits decisions to be made as early as possible in the process.

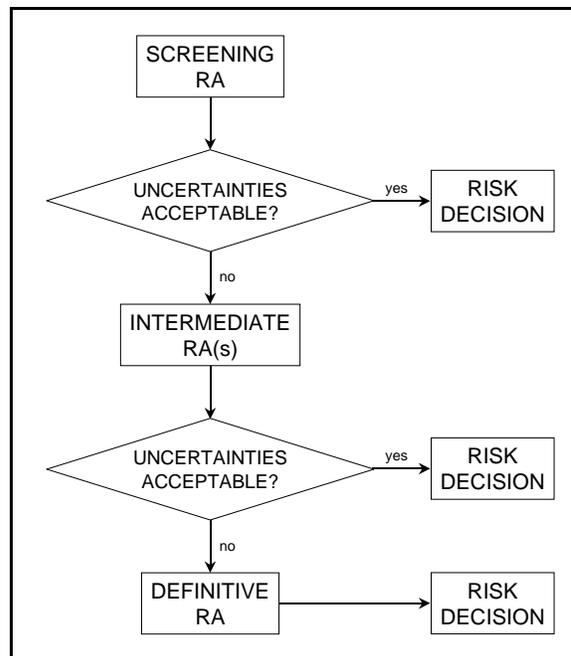


Figure 6. Decision points in a tiered risk assessment, illustrating movement to higher tiers if uncertainties and available data warrant.

Methodological Requirements of the Tiered Protocol. Full implementation of the proposed tiered protocol will require development and verification of a suite of methods, models, and data appropriate for each tier. Although the actual tools employed may vary across tiers from the general to the more realistic and/or accurate, the basic process for assessing risk is more or less constant across tiers (Figure 2). Each tier requires information regarding the habitat and stressors therein (Step 1), methods to translate habitat suitability and stressor levels to the demographic rates of survivorship and fecundity (Step 2), models to characterize population-level effects (Step 3), and methods for interpreting the consequences of spatial and temporal variation in the patterns of stressors and wildlife population structure (Step 4). In some instances, the tools to accomplish these steps may not change between tiers, but rather their use and data requirements will vary. In other instances, the tools themselves will change. Research undertaken to meet Objectives 1-3 will address the range of methodological requirements dictated by the tiered protocol.

Information and data specific to the wildlife species of concern often will be limited and will vary across tiers. New approaches will be needed to develop those data and may include

tools for habitat quantification and generation of biological response data (i.e., assays of stressor-response). In particular, issues of extrapolation (and interpolation) are likely to be critically important within any given tier and will play a role in each step of the risk assessment process (Table 3). In Step 2 of the assessment, for example, data available to describe the demographic consequences of chemical exposure to the assessment species (e.g., river otter) may be unavailable; and reproductive and survivorship rates may need to be extrapolated from those of a more commonly tested and related species (e.g., mink). Similarly, Step 3 requires extrapolation of population-level responses from changes in demographic rates. The types of extrapolation needed include taxonomic (among species), hierarchical (across levels of biological organization), spatial, and temporal. Several approaches can be employed to meet these needs, ranging from empirically-based statistical models to process-based mechanistic models; the considerations described above for ecological models also are cogent here. Much of the research described in this strategy focuses on development and verification of extrapolation methodologies.

Table 3. Types of extrapolation required by the conceptual approach to wildlife risk assessment.

Step	Type of Extrapolation	Example Use	Methodological Requirement
1. Landscape characterization	spatial	quantify habitat suitability	GIS methods
	temporal	develop chemical exposure profile	exposure models
2. Exposure / habitat response relationships	interspecific	estimate toxicological response of one species from data on another	empirical models mechanistic models
	intraspecific	estimate variability in demographic response within a population	empirical models
	developmental	estimate adult response from juvenile response	empirical models mechanistic models
	endpoint to endpoint	estimate reproductive response from survival response	empirical models
	exposure - response	estimate response at differing levels of exposure	empirical models
	lab to field	estimate response of a species in the field from laboratory data	empirical models
	hierarchical	estimate demographic response from physiological response	empirical models mechanistic models
3. Population responses and modeling	hierarchical	estimate population response from demographic response	mechanistic models
4. Spatial modeling	spatial	describe population distribution	mechanistic models
	temporal	describe population dynamics	mechanistic models

By its very nature, the tiered assessment protocol requires the exposure, ecological effects, and risk characterization methods necessary and sufficient to conduct a complete ecological risk assessment. Although this Strategy focuses primarily on critical effects research that will be

conducted by NHEERL, much of the methodological and data needs associated with wildlife risk assessment are more appropriate to the missions of NERL, NCEA, and other research partners; consequently, interaction with and the active participation of these groups will be sought.

Objective 1: Mechanistically Based Approaches for Interspecies Extrapolation of Toxicological Information

Statement of the Objective. *Develop mechanistically based approaches for extrapolating individual-based toxicity testing information to population-level effects across wildlife species, media, and individual response endpoints.* Mechanistically based approaches provide a credible basis for better understanding observed differences among species with respect to exposure-effects relationships. The focus of this research is on toxicity endpoints that can be directly related to adverse effects on populations thereby providing a linkage between Objectives 1 and 2. Critical components of this Objective include identifying and developing the capability for predicting toxicokinetic and toxicodynamic differences among species.

Background. Predictions about the potential for toxic effects on wildlife occurring from exposure to chemicals are generally made using individual-based toxicity data. Studies conducted in a controlled setting using relatively few species of common laboratory animals (e.g., rats, mice, dogs, chickens) constitute the majority of toxicity data. For many chemicals, the endpoints measured in these studies were chosen to address human health concerns (e.g., cancer) as opposed to ecological concerns. While the capability exists to test new chemicals and species when there is a need for more accurate assessments, resources available to conduct these studies will never be sufficient to test all chemicals and species of concern. A need exists, therefore, to develop approaches that can be used to extrapolate existing toxicity data from a relatively few tested species to wildlife species of concern. Additionally, there is a need to move beyond unbounded expressions of effect (e.g., no-observable-adverse-effects levels) and to better characterize the uncertainty in predicted effects.

A variety of extrapolations are commonly used to “convert” individual-based toxicity information from a particular study to information that can be used to predict effects in a species of concern. Extrapolations are performed to adjust or account for (1) taxonomic differences (interspecies extrapolation); (2) differences in dose-response relationships among different endpoints (endpoint extrapolation); (3) toxicological effects levels (e.g., lowest-observable to no-observable-adverse-effects extrapolation); (4) differences in exposure duration between the test and the actual exposure (subchronic-to-chronic extrapolation); (5) differences in exposure route between the test situation and the actual exposure (route-to-route extrapolation); (6) sensitivity differences among individuals in a population (intraspecies extrapolation); and (7) differences

between laboratory and field conditions (lab-to-field extrapolation). This list of extrapolations is not exhaustive, but it demonstrates the range of extrapolations necessary to perform effects characterizations for untested species. There are currently major uncertainties associated with the necessity, validity, precision, and accuracy of performing such toxicological extrapolations.

Approaches used to perform extrapolations across species include the application of uncertainty factors, allometric scaling, and correlative statistical models. Each of these methods assumes that the chemical's mode-of-action is similar in both the tested species and the species of concern and that a similar chemical dose at a site of action will produce a similar response. Furthermore, it is assumed that toxicokinetic differences between the two species (e.g., differences in metabolic biotransformation) do not result in substantial interspecies differences in the relationship between delivered dose and dose at the target tissue. Not surprisingly, the reliability of these methods tends to vary directly with the taxonomic relatedness of the two species (Suter 1993). While none of these approaches is inherently right or wrong, each has its limitations.

Uncertainty factors are applied to toxic effects data to account for uncertainties about the relationship between the test conditions and a "real world" situation. These factors are often applied in orders of magnitude (i.e., a factor of 10); when uncertainty exists in more than one area, the uncertainty factors are usually multiplied. Uncertainty factors may be derived from expert judgment, ratios of observed values (e.g., acute-to-chronic LC₅₀ values), or differences between observed values (e.g., difference between most sensitive and least sensitive species). Thus, they are by no means "standardized" and may or may not incorporate a mechanistic understanding of toxicity (Chapman et al., 1998). Allometric scaling functions, usually based on body weight or surface area, are used to convert the toxic dose from one animal to a toxic dose in another. This approach assumes that the toxic dose is related to kinetic factors (e.g., absorption and elimination routes/rates) which are themselves functions of body weight or surface area. The use of this approach does not require knowledge of these kinetic factors; it is assumed, however, that similar factors determine the toxic dose in both species (Travis and White 1988). Regression models are based on the assumption that two classes of toxicity data (e.g., lethal dose for two mammals) are correlated and can therefore be used predict one another. Typically, regression models for toxic effects extrapolations are statistical expressions of an observed relationship and do not consider the mechanism that underlies the relationship (Suter 1993).

Less often employed, but potentially more useful, are physiologically based toxicokinetic (PBTK) models. PBTK models provide estimates of internal (target tissue) dose in both a tested

species and the species of interest. These estimates are based on mathematical descriptions of absorption, distribution, metabolism, and elimination and require anatomical, physiological, and biochemical information for both species. Dosimetry estimates are then combined with dose-response data from the tested species to predict toxicity in the untested animal. PBTK models have several advantages, including (1) accurate estimation of target dose, (2) integration of temporal dosing dynamics, and (3) simulation of variance in target tissue dose within and across species. These models have been used extensively in human health risk assessment to extrapolate data from laboratory animals to humans and are commonly linked to biologically based models of chemical effect (Reitz et al., 1996). The greatest impediment to the development and application of PBTK models in wildlife risk assessment is the lack of kinetic data (i.e., the chemical time-course in specific tissues) for relevant/representative chemicals and species.

Toxicity extrapolations are more tenuous when the chemical mode-of-action varies among species. Under these circumstances there is a need to understand the cause of the observed differences in toxic response. It may then be possible to characterize the circumstances under which dose-based extrapolations are still possible while also identifying those cases for which additional information is needed. This information could conceivably include toxicity testing data for species of interest or studies of physiological and biochemical differences among species.

Research Questions. In the context of individual-level effects, it is possible to identify three major areas of uncertainty in wildlife risk assessments for toxic contaminants: (1) quality and quantity of existing data; (2) extrapolation of existing data to untested species and chemicals; and (3) prediction of field responses from laboratory data. From these three major areas of uncertainty come the following research questions:

- a. *To what extent and for what purposes can existing toxicity testing data be used in wildlife risk assessments? This question includes the use of toxicity data for wildlife species as well as that collected using common laboratory test animals.*
- b. *In efforts to fill existing data gaps, what types of toxicity testing (chemicals, species, duration, dosing route, etc.) should receive priority?*
- c. *How well do current extrapolation techniques serve the needs of wildlife risk assessors and under what circumstances do they fail?*

d. How can current extrapolation techniques be extended and improved?

As indicated previously, there is a need to link individual-level effects to population-level responses. This need suggests the following additional research questions:

e. What types of toxicity test data (endpoints and expressions of effect) are most useful in relating individual-level effects to effects on populations?

f. What are the relationships between common toxicity test endpoints (e.g., lethality, growth reduction) and endpoints used for population modeling (e.g., vital rates)?

Research Approach. *Critical evaluation of existing toxicity data:* Current methods for extrapolating toxicological data among species generally assume that if a chemical operates in two species via the same mode-of-action, similar doses at the site of action will produce similar effects. If this is true to some reasonable approximation, it is prudent to focus on techniques such as PBTK modeling as a basis for extrapolating dose (and by extension, effect) across species. Alternatively, physiological and biochemical differences among species may result in substantially different effects at the same tissue dose. In this case, elucidation of the fundamental basis for the observed difference in effect must precede any detailed consideration of chemical kinetics. To this end, existing toxicity testing data for wildlife species should be systematically evaluated to elucidate exposure-residue-response relationships for individual chemicals and chemical classes. Evaluation of these relationships along with toxicokinetic information will provide insight into whether toxicodynamic or toxicokinetic differences underlie apparent differences in sensitivity. When sensitivity differences are largely due to kinetic differences, PBTK models will provide the appropriate extrapolation tool. The utility of this effort for cases where the dose-response equivalence assumption is not met will be the identification of gaps in our current understanding of chemical mode-of-action and, thus, a future research need.

The focus of these efforts should be placed on species for which exposure factors have previously been determined (U.S. EPA 1993). In a manner similar to that employed in human health risk assessment, existing data should be used to derive reference doses for selected compounds and taxa. These data should also be used to evaluate techniques currently used for inter-species extrapolation (e.g., allometric scaling of toxic dose). There is a need to compile data on

chemicals' mode-of-action at the cellular, tissue, and whole animal levels to provide a basis for interspecies extrapolation and as a means of dealing with chemical mixtures. There is also a need to identify fundamental differences among taxa (e.g., oviparous versus placental reproduction) that result in large differences in toxic response. Finally, an effort should be undertaken to evaluate the suitability of data from toxicity tests with common laboratory species for use in wildlife risk assessments. Such research could coordinate with and build upon current NHEERL efforts to collect wildlife toxicity data in the TERRETOX database.

Targeted collection of toxicity testing data: Toxicity tests with selected wildlife species should be performed to complement existing information. Data gaps identified in a review of existing information will aid in planning these efforts. These studies should be designed to yield exposure-residue-response relationships for high priority chemicals under environmentally relevant exposure conditions (e.g., dosing route and duration). Chemical selection should be guided by the need to characterize adverse effects of specific chemical classes representing known or suspected modes of action. Candidates for this activity include persistent bioaccumulative toxicants, high-use pesticides, and compounds with known or suspected endocrine-disrupting activity. Throughout these efforts there is a need to evaluate effects endpoints relevant to population modeling efforts.

Extrapolation of existing data to new chemicals and species and from lab-to-field: The utility of laboratory-derived toxicity-testing data in effects assessments for wildlife should be critically examined. Existing techniques for extrapolating this information should be reviewed to identify strengths and limitations and to provide guidance for their use. Special emphasis should be placed on identification of factors that could limit the application of laboratory testing data to chemical exposures that take place in the field. A partial listing of these factors includes the chemical route of exposure, fluctuating exposures, and site-specific differences in chemical bioavailability. Where possible, characteristics of field exposures should be identified to guide future laboratory testing efforts.

Development of PBTK models for selected species: Improved techniques for interspecies extrapolation should be developed and the utility of these methods evaluated through application to specific wildlife risk assessment problems. An emphasis should be placed on the development of mechanistic models for predicting chemical disposition as a means of relating applied dose rates to chemical residues in critical target tissues. Emphasis should also be placed on the development of PBTK models for selected species. The development and use of PBTK models

for interspecies extrapolation is a philosophy as much as it is a definitive tool. Understanding the toxicokinetic and toxicodynamic processes that underlie chemical toxicity will improve all approaches currently used for interspecies extrapolation. For example, knowledge of the mechanism of action of a chemical and physiological processes critical for manifestation of toxicity will add credibility to the professional judgement used in applying uncertainty factors. An understanding of chemical toxicokinetics, combined with knowledge of physiological and metabolic parameters, will also improve the interpretation of correlative statistical models and allometric scaling efforts.

The development of PBTK models requires that necessary anatomical, physiological, and biochemical information be obtained (measured or estimated) for each new species. There is also a need to estimate equilibrium tissue partitioning coefficients for compounds of interest. Controlled exposures should be conducted to evaluate model predictions. Additional research may also be required to obtain key parameter estimates such as rates of metabolic biotransformation. It is suggested that initial efforts be devoted to the development of a PBTK model for a commonly tested species of bird. Candidate species include the mallard duck, Japanese quail, pheasant, and chicken. Additional models for amphibians and mammalian wildlife species would be developed as needed to address specific research and risk assessment needs.

Objective 2: Modeling Approaches for Predicting Responses of Wildlife Populations to Anthropogenic Stressors From Individual-Based Information

Statement of the Objective. *Integrate wildlife population biology and wildlife toxicology research to improve prediction of population responses.* There are two primary goals in this research area. The first goal is to develop approaches for integrating individual-level responses in order to extrapolate and predict the population-level effects of anthropogenic stressors. The second is to identify those responses at the individual level that have the greatest influence on population-level responses.

Background. Many Program and Regional Offices are now grappling with how to address the effects of anthropogenic stressors on wildlife populations. Questions associated with extrapolation of effects across levels of biological organization are a recurring uncertainty associated with wildlife risk assessments. From the perspective of ecotoxicology, Clements and Kiffney (1994) concluded that “[the] two greatest challenges are interpreting the ecological significance of [toxicological] effects and improving the predictive ability of [higher level] studies.” Anthropogenic stressors are not limited to chemicals, and our approach must be flexible enough to encompass other forms of anthropogenic and natural stressors. In response to the recent declines in amphibian species, Wake (1998) stressed the need for a basic understanding of population biology, as well as the need to understand the roles of natural versus anthropogenic stressors. Population models have increasingly been used to evaluate conservation measures for threatened and endangered species (Crouse et al., 1987; Doak et al., 1994; Caswell et al., 1999) and for projecting population-level effects of chemicals (Caswell 1996; Munns et al., 1997). We propose using population models to integrate individual measures of anthropogenic stress (survival and reproduction) from Step 2 to project population-level effects that will support Step 4 (Figure 4).

There are many modeling approaches to choose from including bioenergetics models (Hewett 1989), individual-based models (DeAngelis and Gross 1992), and matrix models (Caswell 1989). In order to explicitly address the goals cited above, the selected model construct must first provide population-specific models that can integrate the individual response data from Step 2. Secondly, the selected model construct should be compatible with the spatially explicit modeling framework identified in Step 4. Thirdly, the model construct must provide a basis for understanding risk classes in demographic terms. Additional desirable features of a

model type include the ability to utilize existing data (i.e., the model construct should not require a great deal of new research except where very specific needs have been identified); applicability across multiple tiers of an ecological risk assessment (from general to highly detailed and realistic [see Figure 4]); and ease of use for risk assessors to apply and interpret.

Research Questions.

- a. *Which responses at the individual level have the greatest influence on population-level responses?*
- b. *How can individual-level responses to anthropogenic stressors be integrated with and extrapolated to population-level effects? What is the most appropriate way to extrapolate across levels of biological organization?*
- c. *How effective are population models for addressing questions a and b above? Can the veracity of model results be assessed? How sensitive are model results to model parameters and assumptions?*
- d. *What is the relative importance of compensatory mechanisms (e.g., density dependence, natural selection, and adaptation) in terms of ultimate outcomes at the population level?*

Research Approach. We have chosen to focus on developing demographic matrix models as the modeling construct because they provide the best overall fit to the criteria identified in the background section. Matrix models utilize basic life history data, including life stage-specific survival and reproduction data (Figure 7). This information has been published for many species, thus reducing the need to conduct studies to collect baseline data. Matrix models provide a great deal of flexibility and are appropriate for multiple

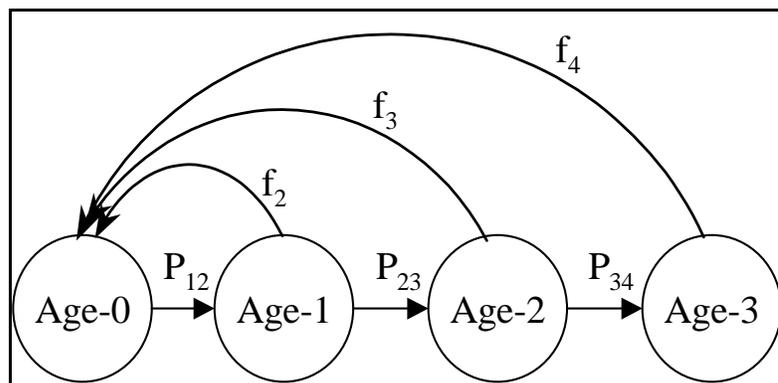


Figure 7. Example life cycle diagram, where P_{ij} represents the probability of an individual surviving from life stage i to life stage j ; and f_i represents the stage specific reproductive output. The life cycle diagram is a schematic representation of a matrix model.

tiers in a risk assessment because they can be developed across a range of complexity from very general to highly detailed. For example, simple density-independent matrix models using literature-derived life-history data could be used for screening-level risk assessments. Alternatively, stochastic and/or density-dependent matrix models could be developed for detailed site-specific risk assessments.

Matrix models can address both goals of this research objective. Matrix algebra provides analytical solutions for a suite of population-level endpoints including population growth rate, stable age distribution, reproductive value, and demographic sensitivity and elasticity (Caswell 1989). Changes in population growth rate in response to anthropogenic stress can be used as a measure of population-level effect (Munns et al., 1997). Demographic elasticity is the relative sensitivity of population growth rate to each of the matrix elements (life-history parameters) and represents an approach for identifying responses at the individual level that have the greatest influence on population-level response (Caswell et al., 1984, De Kroon et al., 1986). In addition to analytical solutions, matrix models can also be used to conduct simulations to project stochastic population growth rates and to estimate extinction and quasi-extinction risks (Ginzburg et al., 1982). If desired, it is also possible to embed other modeling attributes, such as density-dependent responses or migration between sites with different stressors, within the framework of a matrix model.

Matrix models use the same information generated by many common bioassay protocols (i.e., life stage-specific survival and fecundity) making the incorporation of these endpoints a relatively straightforward exercise (e.g., Gleason et al., 1999). Bioassay results can be used to directly modify the matrix entries. Alternatively, life-stage-specific, dose-response functions can be incorporated into the matrix entries (Figure 8). Matrix models are required for the spatially explicit modeling construct proposed in the Step 4. Additionally, this modeling construct takes advantage of existing NHEERL expertise and provides opportunities for collaborative population-level research across the Ecology Divisions. Specifically, NHEERL scientists have experience applying matrix models to habitat and conservation-related questions and incorporating bioassay data into matrix models to assess population-level effects of contaminants.

The veracity of demographic model projections can be evaluated in several ways. One approach is to evaluate the general utility of models by reviewing the success of published models. Population model results could also be evaluated against empirical results from multi-generational laboratory life-table-response-experiments. Because laboratory results do not necessarily accurately reflect the field, a third approach to model verification would be to evaluate model results in specific field assessments (see Section VII). Model evaluation in the field would be most effective for populations that have long-term demographic data sets.

Research must address the relative importance of compensatory mechanisms (density dependence, tolerance, local adaptation) because they can potentially have a significant influence on population response. Density dependence, at a minimum, requires an understanding of the functional relations between density and population dynamics (often requiring multiple years of population measurements). A potentially more intractable problem involves determining the interactions between population density and stressor effects. The costs associated with determining these interactions for specific cases may preclude such analyses for all but the most critical risk assessments. As an example of the importance of considering evolutionary processes, Nacci et al., (1999) have identified a population of a common estuarine fish species that has a specific metabolic adaptation which allows it to persist in an extremely contaminated environment. Research should address the generality of this phenomenon, as well as other compensatory mechanisms such as life history shifts, the effects of anthropogenic stress on genetic diversity, population genetics, and the potential ecological and evolutionary costs of such adaptations.

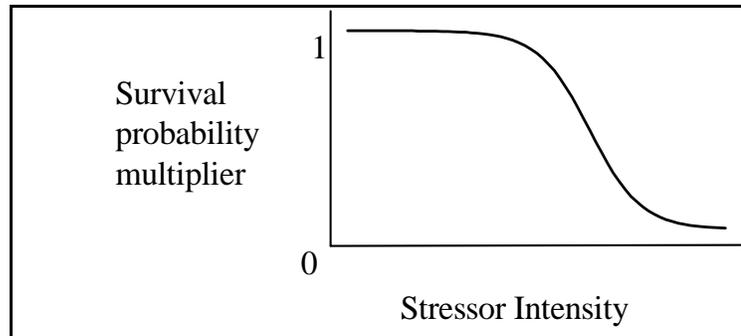


Figure 8. Schematic representation of how a dose-response function could be used to modify a matrix model parameter. The survival probability multiplier would then be used to modify the appropriate survival probability (P_i) based on stressor intensity.

Objective 3: Spatially Explicit Modeling to Assess Relative Risks from Chemical and Non-Chemical Stressors

Statement of Objective. *Develop approaches for evaluating the relative risks from chemical and non-chemical stressors to spatially structured wildlife populations across large areas or regions.* While Objective 2 addresses the potential effects of toxicants on homogeneous populations, Objective 3 specifically addresses how spatial and temporal heterogeneity in both stressor distribution and wildlife population structure influence wildlife population size, growth, distribution, and persistence through time. Results from these analyses will also provide insight into appropriate spatial scales for wildlife risk assessments.

Background. Numerous studies have documented that the spatial pattern and temporal dynamics of habitats across large landscapes play important roles in the long-term viability of populations (Doak et al., 1992; Kareiva and Wennergren 1995; Vitousek et al., 1997; Fahrig 1998). High-quality habitats serve as source areas for repopulating and sustaining populations in lower quality habitats (population “sinks”) elsewhere in the landscape. With habitat loss and degradation, these source areas become increasingly important. Contaminants or other stressors can have markedly different effects on populations depending on whether the area affected is a population source or sink. Likewise, because organisms move among habitat units within the landscape, depressed reproductive or survival rates resulting from contaminant exposure could cause population declines over fairly large areas even if the contaminant is confined to a relatively small area. Thus, assessments that ignore the influence of spatial structure and temporal dynamics in landscapes and populations could seriously under- or overestimate the risks to wildlife.

Wildlife populations are affected simultaneously by multiple stressors, both natural and anthropogenic. By understanding the relative risks from different stressors, managers can design effective strategies that will provide the greatest net benefit to wildlife populations. While EPA regulatory authorities deal most directly with the release of contaminants into the environment, the SAB and other reviewers (Kareiva 1990, Saunders et al., 1991) have identified habitat loss and introduced species as major environmental risks. Thus, NHEERL research will focus on the interactive effects of contaminants, habitat loss and alteration, and introduced species on wildlife populations. Populations adversely affected by habitat loss or introduced species may be more susceptible to additional stress from environmental contamination, but high-priced control programs to reduce environmental contamination may have little measurable benefit if

populations continue to be depressed by widespread habitat loss and fragmentation.

Research Questions. Research under Objective 3 will address the following major research questions:

- a. *Can GIS-based, time-varying models be developed that project wildlife population responses to spatially distributed stressors with levels of precision and accuracy suitable for wildlife risk assessments and evaluation of alternative management scenarios?*
- b. *Does consideration of spatial and temporal heterogeneity in landscapes and population dynamics significantly alter estimates of wildlife population risks to stressors? If so, under what circumstances is it most important to incorporate spatially explicit, time-varying models into the assessment process?*
- c.. *How do environmental contaminants interact with other landscape-level stressors, in particular habitat loss and fragmentation and introduced species, to affect population abundance and persistence? Under what circumstances are multiple stressors likely to interact synergistically or antagonistically?*
- d. *What life history characteristics, habitat requirements, and mobility/dispersal characteristics have the greatest influence on the sensitivity of different wildlife species to spatially distributed stressors? Can species be grouped into risk classes based on these characteristics?*
- e. *How does the spatial and temporal resolution and extent of analysis influence predictions? What are the most appropriate spatial and temporal scales for wildlife risk assessments?*

Research Approach. Just as for Objective 2, modeling will provide the primary approach and organizing structure for Objective 3 research. By necessity, research under Objective 3 will be largely model-based because it will integrate issues associated with population dynamics and landscape change at large spatial and temporal scales. Data and findings developed under Objectives 1 and 2 will help parameterize and evaluate Objective 3 models. Additional field and laboratory studies may be conducted to define and evaluate key model parameters, assumptions,

and outputs. For example, several ongoing NHEERL studies are evaluating amphibian population responses to multiple stressors in different regions of the U.S. (Heppell et al., 1999, U.S. EPA 1999). The case studies described in Section VII may provide other opportunities for model evaluation and demonstration. However, much of the data needed to parameterize and evaluate the Objective 3 model(s) will be derived from non-NHEERL and non-EPA sources (e.g., FWS research on habitat requirements and basic population biology). Thus, particularly for Objective 3, we will seek out opportunities to collaborate with other organizations, especially organizations with expertise and data relating to effects of habitat loss and introduced species on wildlife populations.

One of the first tasks for Objective 3 will be development of GIS-based, time-varying models that can project the population-level consequences of multiple, spatially distributed stressors. To be suitable, a model should (1) be spatially explicit, preferably through the use of digital landscape maps; (2) be probabilistic, providing a mechanism for including demographic and environmental stochasticity; (3) incorporate species vital rates in the form of a population projection matrix; (4) link species vital rates to habitat quality and the presence of contaminants; (5) simulate the movement of organisms through a landscape; (6) alter movement behavior based on habitat quality and the presence of contaminants; (7) permit habitat quality and chemical contaminant severity and distribution to change with time; (8) be general enough to work with a range of species, yet sophisticated enough to link species life histories to realistic landscape patterns; and (9) balance simplicity against generality, keeping in mind the limitations of existing and readily collected data.

The influence of landscape on populations will be mediated through the individual. The behavior and contribution of each individual to the population will be affected by its survival rate, reproductive rate, and ability to locate a suitable breeding site. Individual organisms will respond to both landscape quality and pattern which may change through time. Organisms will also respond to the presence of other individuals, which will allow the model to capture the influence of invasive species via competitive and predator-prey relationships. The presence of contaminants in portions of a landscape will likely be modeled as changes in habitat quality, which in turn lower the fertility, survival, or dispersal ability of organisms trying to utilize the affected areas. The exposure of individuals moving through contaminated areas could alter their vital rates on a temporary or permanent basis. NHEERL models will not deal with contaminant fate and transport, but could be linked with other models that do. Those models, by themselves, could be applied to address “what if” scenarios regarding the spread and attenuation of contami-

nants on the landscape, altering habitat quality according to distance from source, time of year or time since the contamination took place. However, it will be important to be aware of the inherent limitations in the ability of such models to capture the effects of contaminants. For instance, there are likely to be many consequences for wildlife of exposure to toxicants that cannot be meaningfully collapsed into an effective change in habitat quality.

Because they require information about dispersal and the effects of habitat quality on collections of individuals, spatially explicit models are more data intensive than site-specific, homogeneous population models. To be well suited for the tiered assessment approach (Section III), models selected for Objective 3 will have to accommodate a wide range of data uncertainty. The models will have to capture the generality necessary to incorporate real landscapes and multiple species without becoming so parameter rich that verification is impossible. If movement or specific habitat data are lacking, the models should permit simulations to be conducted with a simple landscape and movement rules to answer general questions about the effects of landscape heterogeneity. If data are less limiting, the models should permit interactions between species and their environments to become more complex.

Spatially explicit models will be applied to the research questions outlined above dealing with (a) stressor interactions, (b) the role of life history, habitat requirements, and dispersal/mobility characteristics in determining species sensitivity to different types of stressors, (c) identification of life-history-based risk classes, and (d) the influence of spatial and temporal resolution and extent on model results. These sorts of analyses will be conducted using both real and simulated landscapes. The use of actual landscapes will help keep the research applied and relevant. Real landscapes, however, are typically complex so simple, fabricated landscapes will be employed at times as an aid to the development of theory. An example of a theory that Objective 3 will develop is the definition of species guilds by life history traits grouped by anticipated responses to anthropogenic stressors. As noted earlier, the validity of such theoretical investigations will be examined using the proposed case studies.

Our initial research efforts will focus on modifying an existing in-house GIS model that already meets many of the above criteria. NHEERL researchers have completed a prototype model, PATCH (a Program to Assist in Tracking Critical Habitat) (Schumaker 1998), designed to track the effects of changes in habitat quality and pattern on populations territorial birds and mammals having well-defined habitat requirements. Over the next six years, PATCH will be adapted and/or new models developed that capture species interactions and address more taxa

and other stressors (in particular contaminants and introduced species).

Case Studies

As part of the NHEERL research effort, case studies will be used both to develop and verify specific methods and tools associated with Objectives 1-3 and to verify and demonstrate our overall approach for assessing risks to wildlife within a tiered assessment protocol. This section focuses primarily on the second use of case studies and describes the objectives and criteria for selection of candidate studies. Future selection of case studies and their implementation will depend on the opportunities available and on input from the Program Offices and other research partners.

To be maximally useful to development of wildlife risk assessment methods, case studies should help us accomplish several objectives. These include the following:

- 1. Evaluate the strengths and weakness of approaches to predict risks to wildlife species.*
- 2. Evaluate key hypotheses regarding risks to wildlife species.*
- 3. Demonstrate the usefulness of research products to program offices and other wildlife managers.*
- 4. Provide information useful for solving existing wildlife problems.*
- 5. Highlight additional research needs for wildlife risk assessment.*

In addition to meeting these objectives, case studies undertaken by NHEERL should combine aspects of toxicology, population biology, and landscape ecology and make optimal use of existing resources.

The approach envisioned to accomplish these objectives involves conducting a series of case studies. To maximize the immediate benefits of the research approaches and products, each case study will focus on a real problem facing wildlife managers. Although somewhat premature at this stage of research planning, some candidate case studies include the following:

- 1. Assessment of risks to a mammal or piscivorous bird species at a National Priorities*

List (NPL) or Resource Conservation and Recovery Act (RCRA) site or pesticides application site.

2. *Assessment of risks to selected amphibian populations in National Parks or in regions of known amphibian deformities and declines.*
3. *Development of a state-wide or site-specific wildlife criteria for a site or state.*
4. *Basin-wide assessment relating patterns of land use to population trends in wildlife, fish, and aquatic invertebrate populations.*

To conduct these or other case studies, NHEERL will draw on its existing strengths and involve Agency and external research partners to the extent feasible. Potential and desirable collaboration and linkages with other groups include with NERL on exposure issues; with NCEA on risk characterization methods; with the program offices and regions; and with agencies such as FWS, NOAA, DOD, DOE to identify specific cases studies, to exchange data, and to share expertise.

Potential products resulting from the case studies include the following:

1. *Verified approaches for wildlife risk assessment.*
2. *Spatially explicit modeling systems for selected wildlife species.*
3. *Support for development of guidelines for wildlife risk assessment.*
4. *Support for other program office and research partner needs, including scientifically sound methods for establishing wildlife chemical criteria and approaches for examining the relative risks of multiple stressors to threatened and endangered species.*

References

- Caswell, H. 1986. Life cycle models for plants. *Lect. Math. Life Sci.* 18: 171-233.
- Caswell, H. 1989. *Matrix Population Models*. Sinauer Associates, Sunderland, MA.
- Caswell, H. 1996. Demography meets ecotoxicology: untangling the population level effects of toxic substances. In: Newman, M.C. and C.H. Jagoe, Eds. *Ecotoxicology: a Hierarchical Treatment*. CRC Press, Lewis Publishers, Boca Raton, FL.
- Caswell, H., R. J. Naiman and R. Morin. 1984. Evaluating the consequences of reproduction in complex salmonid life cycles. *Aquaculture* 43:123-134.
- Caswell, H., M. Fujiwari and S. Brault. 1999. Declining survival probability threatens the North Atlantic right whale. *Proc. Nat. Acad. Sci.* 96:3308-3313.
- Chapman, P.M., A. Fairbrother and D. Brown. 1998. A critical evaluation of safety (uncertainty) factors for ecological risk assessment. *Environ. Toxicol. Chem.* 17:99-108.
- Clements, W.H. and P.M. Kiffney. 1994. Assessing contaminant effects at higher levels of biological organization. *Environ. Toxicol. Chem.* 13: 357-359.
- Crouse, D.T., L.B. Crowder and H. Caswell. 1987. A stage-based population model for loggerhead sea turtles and implications for conservation. *Ecology* 68:1412-1423.
- DeAngelis, D.L. and L.J. Gross. 1992. *Individual-based Models and Approaches in Ecology: Populations, Communities, and Ecosystems*. Chapman and Hall, NY.
- De Kroon, H., A. Plaisier, J. von Groenendael and H. Caswell. 1996. Elasticity: the relative contribution of demographic parameters to population growth rate. *Ecology* 67:1427-1431.
- Doak, D.F., P.C. Marino and P.M. Kareiva. 1992. Spatial scale mediates the influence of habitat fragmentation on dispersal success: implications for conservation. *Theoret. Pop. Biol.* 41:315-336.
- Doak, D., P. Kareiva and B. Klepetka. 1994. Modeling population viability for the desert tortoise in the western Mohave Desert. *Ecol. Appl.* 4:446-460.

Fahrig, L. 1998. When does fragmentation of breeding habitat affect population survival? *Ecol. Model.* 105:273-292.

Ginzburg, L.R., L.B. Slobodkin, K. Johnson and A.G. Bindman. 1982. Quasiextinction probabilities as a measure of impact on population growth. *Risk Anal.* 2:171-181.

Gleason, T.R., W.R. Munns Jr. and D.E. Nacci. 1999. Projecting population-level response of purple sea urchins to lead contamination for an estuarine ecological risk assessment. *J. Aquat. Ecosystem Stress Recov.* (in press).

Hanski, I. 1998. Metapopulation dynamics. *Nature* 396 (6706):41-49.

Heppell, S.S., H. Caswell and L.B. Crowder. 1999. Elasticity patterns of age-based models: a comparative analysis using mammal life tables with implications for conservation of life history-types. *Ecology* (in press).

Hewett, S.W. 1989. Ecological applications of bioenergetics models. *Am. Fish. Soc. Symp.* 6:113-120.

Kareiva, P. 1990. Population dynamics in spatially complex environments: Theory and data. *Phil. Trans. R. Soc. Lond. B* 330:175-190.

Kareiva, P. and U. Wennergren. 1995. Connecting landscape patterns to ecosystem and population processes. *Nature* 373:299-302.

Levins, R. 1968. Evolution in changing environments. Princeton University Press, Princeton, NJ.

Munns, W.M., Jr., D.E. Black, T.R. Gleason, K. Salomon, D.A. Bengtson and R. Gutjahr-Gobell. 1997. Evaluation of the effects of dioxin and PCBs on *Fundulus heteroclitus* populations using a modeling approach. *Environ. Toxicol. Chem.* 16:1074-1081.

Nacci, D.E., L. Coiro, D. Champlin, S. Jayaraman, R. McKinney, T. Gleason, W.R. Munns, Jr., J. Specker and K. Cooper. 1999. Adaptation of wild fish population to dioxin-like environmental contamination. *Marine Biol.* (in press).

Reitz, R.H., M.L. Gargas, M.E. Andersen, W.M. Provan and T.L. Green. 1996. Predicting cancer risk from vinyl chloride exposure with a physiologically based pharmacokinetic model. *Toxicol. Appl. Pharmacol.* 137:252.

Saunders, D. A., R. J. Hobbs and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. *Conserv. Biol.* 5:18-32.

Schumaker, N. H. 1998. A users guide to the PATCH model. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon. EPA/600/R-98/135.

Suter, G.W., II. 1993. Organism-level effects. In: Suter, G.W., II, Ed. *Ecological Risk Assessment*. Lewis Publishers, Boca Raton, FL.

Travis, C.C. and R.K. White. 1988. Interspecific scaling of toxicity data. *Risk Anal.* 8:119-125.

Turner, M.G., R.H. Gardner and R.V. O'Neill. 1995. Ecological dynamics at broad scales: Ecosystems and landscapes. *BioScience* Supplement 1995:S-29 to S-35.

U.S. Environmental Protection Agency. 1992. An SAB report: Evaluation of the guidance for the Great Lakes Water Quality Initiative. Washington, D.C. EPA-SAB-EPEC/DWC-93-005.

U.S. Environmental Protection Agency. 1993. Wildlife exposure factors handbook. U.S. EPA Office of Research and Development, Washington, D.C. EPA/600/R-93/187a.

U.S. Environmental Protection Agency. 1994. Advisory on the development of a national wildlife criteria program. Washington, D.C. EPA-SAB-EPEC-ADV-94-001.

U.S. Environmental Protection Agency. 1995. Great Lakes Water Quality Initiative technical support document for wildlife criteria. Office of Water. Washington, D.C. EPA-820-B-95-009.

U.S. Environmental Protection Agency. 1997. Mercury Study Report to Congress. Office of Air Quality Planning and Standards and Office of Research and Development, Washington, D.C. EPA-452-R-96-0003.

U.S. Environmental Protection Agency. 1998. EPA responses to SAB comments on the draft Mercury Study Report to Congress. Office of Air Quality Planning and Standards and Office of Research and Development, Washington, D.C.

U.S. Environmental Protection Agency. 1999. Final Report on the PRIMENet Ultraviolet Radiation/Amphibian Populations Research Planning Workshop. Duluth, MN. February 1-3, 1999.

Vitousek, P.M., H.A. Mooney, J. Lubchenco and JM Melillo. 1997. Human domination of Earth's ecosystems. *Science* 277:494-499.

Wake, D.B. 1998. Action on amphibians. *Trends Ecol. Evol.* 13 (10):379-380.



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