Economic Impacts of Aquatic Invasive Species Workshop
Washington, DC, July 20-21, 2005

Co-hosted by EPA Office of Water and Office of Policy, Economics and Innovation

Workshop Agenda and Participants

Workshop Goal

The goal of this Workshop is to obtain Workshop participants' individual views on potential conceptual frameworks and bioeconomic tools for use in the subsequent development of national and regional estimates of the market and non-market economic impacts of aquatic invasive species.

Disclaimer

These proceedings are being distributed in the interest of increasing public understanding and knowledge of the issues discussed at the workshop and have been prepared independently of the workshop. Although the proceedings have been funded in part by the United States Environmental Protection Agency under Contract No. 68-W-01-055 to Alpha-Gamma Technologies, Inc., the contents of this document may not necessarily reflect the views of the Agency and no official endorsement should be inferred.

Workshop Agenda

Wednesday, July 20th

8:00 – 8:30 am	Registration and Continental Breakfast
8:30 – 8:45 am	Welcome
8:45 – 9:00 am	Statement of Workshop goal and expectations for Workshop
9:00 – 9:30 am	Keynote Address by Dr. David Lodge
9:30 – 10:00 am	Keynote Address by Dr. Jason Shogren
10:00 – 10:30 am	Discussion with Keynote Speakers
10:30 – 10:45 am	Break
10:45 am – 12:00 pm	**Breakout session I – Discussion of key impacts of aquatic invasive species**

Obtain Participants' individual input on economically and ecologically significant impacts of aquatic invasive species.

Charge to breakout groups:

1. *Brainstorm— provide each member of the group an opportunity to state his or her views on what are the most important impacts of aquatic invasive species, including the importance of aquatic invasive species impacts relative to other environmental issues facing the nation's ecosystems.*
2. *List the ideas with short explanations and summaries of all opinions.*
3. *Submit lists to EPA Workshop Steering Committee.*

12:00 – 1:00 pm — Lunch
EPA Workshop Steering Committee will review and consolidate lists over lunch.

1:00 – 2:30 pm — **Breakout session II – Consider relative priority of impacts of aquatic invasive species**

Obtain Participants' individual input on the relative priority of listed items for developing estimates of the *market and non-market economic impacts of aquatic invasive species and provide plain language explanations for opinions.*

Charge to breakout groups:

1. *Provide Participants' individual views on what are the appropriate criteria for prioritizing impacts. These could include significance to the environment; significance to the economy; feasibility of measurement; etc.*
2. *Individual participants should rank the list of economically and ecologically significant impacts of aquatic invasive species according to the prioritization criteria he or she feels are most appropriate.*
3. *Submit individual participants' ranked lists and descriptions of prioritization criteria to EPA Workshop Steering Committee.*

2:30 – 3:15 pm	**Plenary session** Reports of criteria and prioritized lists to full Workshop and discussion.
3:15 – 3:30 pm	Break
3:30 – 4:45 pm	**Breakout session III – Potential methods for measuring impacts of aquatic invasive species**

Now that consideration has been given to the most ecologically and economically significant impacts of aquatic invasive species, obtain Participants' individual input on the best/most appropriate methods for measuring the economic costs of those impacts.

Charge to breakout groups:

1. *Provide Participants' individual views on what analytic tools are needed to estimate the economic costs of the impacts identified above.*
2. *Provide Participants' individual views on the appropriate scale of analysis (geographic, taxonomic, etc) for estimating/measuring the economic costs of these impacts.*

4. *Provide Participants' individual views on how diverse local or regional estimates of impacts could be aggregated to a regional or national level.*

5. *Consider the extent to which risk assessment and uncertainty is (or should be) explicitly or implicitly considered in each approach.*
6. *Provide hypothetical examples for how ecological and economic tools could work together.*
7. *Prepare a description of the ecological and economic tools discussed and their relationship with one another and submit to EPA Workshop Steering Committee.*

4:45 – 5:30 pm — **Plenary session**
Reports on initial discussion of analytical tools.

The first day should provide Participants' individual views on significant economic and ecological endpoints that are potentially appropriate for use in determining the market and non-market economic impacts of aquatic invasive species. The various viewpoints will be summarized and reported by the EPA Workshop Steering Committee at the beginning of the second day.

6 pm -? — **Informal Happy Hour at Aria's or other nearby location**

Thursday, July 21st

8:00 – 8:30 am — Breakfast

8:30 – 9:00 am — **Plenary session**
Reconvene with summary of previous day's reports and discussion.

9:00am – 10:15am — **Breakout session IV – Consider shortcomings in available methods/tools.**

Obtain Participants' individual input on the shortcomings of available methods/tools for measuring economic impacts and how these shortcomings can be addressed.

Charge to breakout groups:

1. *Provide Participants' individual views on significant impacts for which there are no readily available analytic tools.*
2. *Brainstorm about possible tools and tool development.*
3. *Provide Participants' individual views on shortcomings or problems with existing tools/methods.*

4. *Brainstorm about possible improvements to existing tools/methods.*
5. *Provide Participants' individual views on data needs for possible and existing tool/method development.*
6. *Provide Participants' individual views on the most promising tools/methods or areas for research with plain language explanations for these views.*

10:15 – 10:30 am	Break
10:30 – 11:30 noon	**Continuation of Breakout session IV**
11:30 am – 12:30 pm	**Plenary session** Reports on additional discussion of analytical tools and general discussion.
12:30 – 1:30 pm	Lunch *EPA Workshop Steering Committee will summarize Workshop over lunch*.
1:30 – 3:00 pm	**Plenary session** EPA Workshop Steering Committee will present summary of various views obtained at the Workshop and present provisional outline of research and development needs.
3:00 pm	Workshop adjourns for non-Federal participants.
3:30 – 5:00 pm	Following break, Federal participants stay to evaluate Workshop and plan next steps.

Workshop Participants

Name	Affiliation
Patrick Baker	University of Florida
Allen Basala	EPA
Erik Beck	EPA
Nick Bouwes	EPA
Katherine Bruce	EPA
Joan Cabreza	EPA
Dorn Carlson	NOAA
Sarah Carr	EPA
Ruby Cooper	EPA
Joel Corona	EPA
Brad Crowder	EPA
Stan Daberkow	USDA Economic Research Service
Robert Dieterich	EPA
Liz Fairey	NOAA
Linda Fernandez	University of California- Riverside
David Finnoff	University of Wyoming
Richard Fristik	Army Corps of Engineers
Mike Fritz	EPA
Michael Grodowitz	Army Corps of Engineers
Sharon Gross	USGS
Benjamin Grumbles	EPA
Erik Helm	EPA
Erin Henderson	Fish & Wildlife Service
Rick Horan	Michigan State University
Brooks Kaiser	Gettysburg College
Marilyn Katz	EPA
Henry Lee	EPA
Brian Leung	McGill University
David Lodge	University of Notre Dame
George Loeb	EPA
Sabrina Lovell	EPA
Laura Meyerson	Heinz Center
Whitman Miller	Smithsonian Institute
Susan Millsap	USGS
Mark Minton	Smithsonian Institute
Steve Newbold	EPA
Lars Olson	University of Maryland
Dick Park	Eco Modeling
Bivan Patnaik	Coast Guard
Judith Pederson	MIT Sea Grant
Gina Perovich	EPA
John Powers	EPA
Myra Price	EPA

Dave Redford	EPA
Tony Ricciardi	McGill University
Christine Ruf	EPA
David Secord	University of Washington
Anne Sergeant	EPA
Jay Shogren	University of Wyoming
David Simpson	EPA
Susan Stone	EPA
Craig Vogt	EPA
Marge Wellman	EPA
Erin Williams	Fish & Wildlife Service
Robert Wolcott	EPA

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Workshop Summary

Workshop Goal

The goal of this Workshop is to obtain Workshop participants' individual views on potential conceptual frameworks and bioeconomic tools for use in the subsequent development of national and regional estimates of the market and non-market economic impacts of aquatic invasive species.

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Workshop Summary

Background and Workshop Goal

Aquatic invasive species (AIS) are organisms introduced to marine or freshwater ecosystems to which they are not native and whose introduction causes harm to human health, the environment, or the economy. The environmental and economic damages caused by AIS are a growing concern to policymakers, natural resource managers, scientists, and members of the general public.

To effectively manage the risks posed by AIS, it is important to evaluate AIS economic impacts and the economic costs and benefits of actions that may be taken to reduce AIS risks. Unfortunately, developing estimates of AIS economic impacts is difficult, and few attempts have been made to develop comprehensive estimates. The most prominent estimates of the economic impacts of invasive species on the United States have focused on the cumulative impact of all invasive species. A study conducted by the Office of Technology Assessment in 1993 estimated the *cumulative* cost of invasive species to the United States from 1906 to 1991 to be $97 billion.[1] A later study conducted by Cornell University biologist David Pimentel and colleagues estimated the cost of invasive species in the United States to be $120 billion *per year*.[2] The fact that these figures are so far apart tends to confirm what the studies themselves state- that their estimates are preliminary, incomplete, and speculative.

The goal of EPA's July 2005 Workshop was to move beyond preliminary and incomplete estimates of the costs of invasive species by holding discussions about conceptual frameworks and bioeconomic tools that could be used to develop national and regional estimates of AIS economic impacts.

Importance of Developing Estimates of AIS Economic Impacts

Most currently-available estimates of the economic impacts of invasive species combine the impacts of aquatic and terrestrial invasive species. Several Workshop participants stated that since approaches and resources for preventing and managing terrestrial and aquatic invasive species are substantially different, it would be appropriate and beneficial to develop separate estimates of their impacts.

Numerous participants also stated that having credible, comprehensive estimates of AIS economic impacts is important because those estimates would give policymakers a sense of the scale of AIS impacts and the level of resources needed to prevent or mitigate those impacts. Participants noted that currently-available estimates of the economic impacts of invasive species

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[1] United States Congress Office of Technology Assessment (1993). *HarmfulNon-Indigenous Species in the United States*. OTA-F-565. Washington, DC.

[2] Pimentel, D., Zuniga, R., Morrison, D. (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* 52: 273-288.

are incomplete because they do not adequately incorporate economic theory and do not fully account for non-market economic impacts.

Participants also noted that having comprehensive estimates of AIS economic impacts could help prevent market failures which are often associated with AIS impacts. In cases where the impact of an AIS on individuals is relatively minor but a large number of individuals are affected, the cumulative impact of an AIS may be large. Individuals are unlikely or unable to implement effective prevention, eradication, or control actions, and government action may be warranted.

Types of AIS Impacts

Participant breakout groups were asked to list and prioritize the most significant AIS impacts. Workshop organizers used breakout group lists to compile the following master list. Impacts are not listed in order of importance because the lists varied in nature across breakout groups. Some groups listed broad categories of impacts (e.g. alterations to biodiversity or food webs) while others listed very specific impacts (e.g. alterations to commercial fisheries). In some instances, groups used different terminology to describe the same impact or used the same terminology to describe different impacts.

Important AIS Impacts

Alterations to:

Habitat
Food webs
Commercial and recreational fishing, including aquaculture
Water supplies (e.g. drinking, industrial, agricultural)
Genetic resources
Flood control
Storm protection
Erosion control
Water purification
Disease regulation
Weed/pest control (effects on transportation, property values)
Recreation (e.g. boating, swimming)
Aesthetics
Cultural, spiritual, religious, inspirational, and sense of place values
Monitoring/detection costs
Prevention costs
Education costs
Eradication/control costs
Restoration costs

Participants noted that since many of these impacts can not be quantified directly, it will be necessary to establish endpoints for them that can be quantified and valued. An example of quantifiable endpoints for alterations to habitat would be changes in water clarity or nutrient levels.

Several participants pointed out that other groups have established frameworks for ecosystem goods and services which can be used to value economic impacts of ecosystem alterations. These participants stated that using an ecosystem goods and services framework would help focus discussion on the value of ecosystems and help identify impacts that can be measured. They noted that using an ecosystem goods and services framework is particularly important for determining the economic impact of AIS on biodiversity. Some participants noted that concentrating on biodiversity as a stand-alone service may be unproductive because the importance of biodiversity to human welfare is not widely appreciated. They suggested instead that future efforts focus on the goods and services (including cultural) that species provide to society.

Criteria for Determining Which Impacts to Value

Participants generally believed that the full range of AIS impacts is too large for all impacts to be valued in a single study. Two criteria for prioritizing impacts to value were suggested. The first criterion would be the potential severity of the impact on human well-being. This could be determined by a variety of factors, including the areal extent of the impact, the number of people affected, the degree to which ecosystem functioning is affected, the type of areas affected (e.g. sensitive, pristine, degraded), the degree to which people are affected, which people are affected (i.e. if some populations are affected disproportionately), and the ability of economic and ecological systems to adapt to the impact. The second criterion would be the feasibility of addressing the AIS impact, including the feasibility of attributing the impact to AIS, valuing the impact, and preventing, mitigating, or remediating the impact.

Methods of Determining AIS Economic Impacts

Estimating AIS economic impacts requires estimating AIS ecological impacts then estimating the value of these impacts to society. Statistical and mechanistic approaches are the two main approaches for developing estimates of AIS ecological impacts. Statistical approaches use data on a given invasion to predict the impact of another invasion, possibly of a different species, at a different time, or in a different location. Mechanistic approaches involve developing dynamic models of ecosystem interactions and comparing the results of simulations with and without AIS.

Valuing AIS impacts on market goods and services is generally more straightforward and less controversial than valuing non-market goods and services because the prices of goods or services can serve as proxies for their value. For example, if an invasive species harms a commercial crop, the market value of the crop loss can be used as a measure of the economic loss due to the invasive species. In other cases, however, economic losses are more difficult to measure and must be inferred from estimates of the increased cost of production or decreased value of fixed assets resulting from an invasion. Approaches taken to estimating losses vary in breadth and sophistication. Relatively simple “partial equilibrium” analyses estimate or simulate the effects of invasive species in a single market. More elaborate computable general equilibrium (CGE) models capture effects that arise in multiple markets as a result of invasive species.

Participants discussed non-market values, which can be separated into use and nonuse (i.e. existence) values. Use values can be determined by either revealed or stated preference approaches. Revealed preference approaches are based on actual economic decisions made by consumers and are generally preferred to stated preference approaches such as surveys, interviews, or simulation exercises. Nonuse values leave no "behavioral trail" to relate them to economic decisions, however, and are often estimated through stated preference approaches.

Some participants suggested that AIS ecological and economic impacts could be determined simultaneously by linking ecosystem and CGE models. The output of such models could be used in "green accounting," which incorporates natural resources into calculations of regional or national income and product accounts.

Developing Credible and Timely Estimates of AIS Economic Impacts

Many participants stated that to be credible, estimates of AIS impacts will first have to be developed at local/regional levels (e.g. waterbody or watershed) because ecosystem goods and services, AIS impacts on ecosystem goods and services, and the value of ecosystem goods and services vary regionally. In addition, both economic and ecological models that would be used to estimate AIS economic impacts generally work better at regional levels. Finally, stakeholder interest in and potential management responses to AIS often occur at a regional level. Participants believed that a national estimate of AIS impacts could be developed by aggregating regional estimates but cautioned that care should be taken to avoid double-counting impacts because of overlap in regional estimates.

Participants emphasized the need for developing timely estimates of AIS impacts because human activities that promote aquatic invasions, such as international trade and travel, are increasing AIS impacts on the United States. To develop timely estimates, participants suggested that researchers be pragmatic and opportunistic. Specific suggestions for developing timely estimates included looking at impacts from a subset of AIS in each region; focusing on regions, species, and impacts that are already well-studied; using existing market and non-market valuation techniques rather than developing new ones; and using initial studies to develop a standard approach/framework that could be used to build additional estimates.

Participants also stressed several other points. They warned against stretching data and/or tools past the point of credulity, stating that "a credible under-estimate" would be more useful than "an incredible total." Some participants also stressed the need to incorporate ecological and economic uncertainty into estimates through the development of appropriate confidence intervals. Additional research could then be directed at areas with the greatest uncertainty. Several participants suggested that future damages should be considered when developing estimates because minor invasions can have large impacts over time.

Some participants stated that both positive and negative AIS impacts should be included in estimates because ecological changes can be valued differently by different stakeholders. One example of differing stakeholder value of AIS impacts is the case of zebra mussel filtration of the Great Lakes. This filtration has led to an increase in water clarity and aquatic vegetation which benefits bass and pike fishermen but harms walleye fishermen. Participants also stated that human behavior in response to AIS impacts should be incorporated into bioeconomic models because responses can mitigate ecological changes (e.g. a response could be an effective control measure) or societal impacts (e.g. a response could reduce society's dependence on the affected resource). Finally, many participants stated that estimates of AIS economic impacts would be most useful if they enabled policymakers and natural resource managers to determine the most cost-effective management and policy actions, including prevention.

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Summaries of Breakout and Plenary Sessions

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Breakout Sessions I and II

Breakout Session I – Discussion of key impacts of aquatic invasive species

Objective: *Obtain participants' individual input on economically and ecologically significant impacts of aquatic invasive species.*

Charge: W*hat are the most important impacts of aquatic invasive species, including the importance of aquatic invasive species impacts relative to other environmental issues facing the nation's ecosystems?*

Breakout Session II – Consideration of the relative priority of impacts of aquatic invasive species

Objective: *Obtain participants' individual input on the relative priority of listed items for developing estimates of the market and non-market economic impacts of aquatic invasive species and provide plain language explanations for opinions.*

Charge: *What are the appropriate criteria for prioritizing impacts? (e.g., significance to the environment, significance to the economy, feasibility of measurement) Individual participants should rank the list of economically and ecologically significant impacts of aquatic invasive species according to the prioritization criteria he or she feels are most appropriate.*

***NOTE:** The following summaries combine the breakout groups' discussions regarding the charges for the first two sessions. All of the groups found that addressing the Session I and Session II charges naturally evolved into an intermingled, all-encompassing discussion. Also, each group summary is a compilation of the group's individual discussions along with the group's wrap-up plenary presentation for that session. Although we refer to what was discussed by groups, EPA did not call for each group to reach a consensus; each participant was requested to share his/her own views. For ease of summarization, when the majority of group members expressed similar views, we refer to their comments as "the group's comments."

Group 1

The members of Group 1 repeatedly stated that the *total* impacts of aquatic invasive species are really what is important—a combination of both the direct market impacts and the direct non-market impacts. Most felt that in the long run the non-market impacts would end up outweighing the direct market impacts by several orders of magnitude, potentially. The group advanced directly to the Session II charge of identifying the ranking criteria and came up with the following list:

- The universe of the impact

- The time horizon (i.e., whether short-term or long-term, because in the short-term something might not be particularly important to deal with but in the long-term it could result in great costs)
- The uncertainty involved (How well can we measure this? How well do we understand it?)
- Subjective vs. objective damages (A lot of this has to do with: How well can we convey this to the public and educate them and make people understand these various types of impacts?)
- The equity of the distribution of the impacts (*Everybody* doesn't want invasive species but *nobody* doesn't want them enough to put much money toward the problem because the impact to individuals *themselves* might not be very big. So, there's probably a bigger role for community oversight—some sort of governmental decision—when you have something with more diffuse costs and benefits.)
- Transferability (Can we take information that we have from some specific cases and transfer that to other cases to be able to predict what types of impacts there might be? How informative have invasions in the past been for us to be able to predict the future?)
- The "action-ability" (In other words, can we actually do anything about a particular problem or is it something that we're not really, ultimately, ever going to be able to have any effect on?)

Those are the criteria identified. Then, as the group went through the process of trying to identify the most important impacts and prioritize them, they found that many could actually be nested within others. For example, habitat quality entered into not only the major category of biodiversity but it also played a role in fisheries and others. The group ultimately ended up with the following five categories (listed in order of importance):

1. Biodiversity (captures a lot of the ecosystem services)
2. Fisheries (capture part of the ecosystem services)
3. Industrial costs (water quality and water supply, flood control, aquaculture, etc.)
4. Community values (whether it's cultural heritage, property values, water quality, recreation, or what have you)
5. Navigation (water quality and water supply, etc. affecting both the commercial and recreational navigation of our waterways)

It's interesting to note that biodiversity, which involves mostly indirect costs and impacts which are much harder to quantify, was a clear #1 choice. This reflected the discussion that the group had at the very beginning—basically that these long-term, non-market costs are really important and need to be part of the equation because in the long run they promise to be several orders of magnitude greater than the direct market costs.

Group 2

This group also went about the task "backwards," focusing first on the ranking criteria and then on identifying important impacts. They established two levels of criteria, the first being that there should be likely potential damage—in other words, the probability of severity. Secondly, they established the criterion that it should be possible to do something about the situation, both from a measurement perspective (to have knowledge about the consequences of invasive species regarding particular damages) and from a policy perspective, so that it is actually possible to moderate impacts that are deemed important.

To give a point of reference on the participants' thinking, one of the impacts that was excluded as a primary category was transportation. Although the group felt that the value of transportation was important, they didn't feel that there were very many species that would impact transportation or navigation. Therefore, they didn't see it as a "top-five" area of focus for invasive species impacts. They also felt that a lot of the impacts to navigation would also apply to recreational boating, so that would be subsumed under it, as would water quality.

Their five categories, not in order of importance (but chosen because they determined that if a species would impact a lot of the category components, then it would be possible to measure an economic valuation for them and implement policies to preserve them):

- Degradation of physical capital (navigation, transportation, industry, commercial fishing)
- Recreation (recreational fishing, boating, swimming)
- Biodiversity (actually very similar to the degradation of natural capital, listed below)
- Public health (incorporating such factors as bioaccumulation and food safety)
- Degradation of natural capital (Here, the group is referring to environmental stocks such as fish stocks, habitat stocks, things that influence habitat and food chains, etc. Habitat degradation is also subsumed here.)

Other impacts that were excluded from major status because they were deemed "too narrow" include water supply changes and water quality, which is important and is a component of a lot of these primary categories. They also excluded a whole list of impacts that had to do with "costs," because that was one of the criteria for inclusion and so they felt it was not in and of itself an impact.

To clarify the focus of this category (i.e., degradation of natural capital), the group was really looking at the criterion of economic net benefits, not social benefits. That can include things such as uncertainty, the likelihood of spread of organisms, and things of that nature.

Group 3

This group reversed the Session I and Session II charges also, ranking the impacts first, then addressing criteria. However, they did then go back and revisit the impacts to see if the original rankings held up in light of the criteria discussions. The impacts that they felt were the most important were:

- Biodiversity
- Fisheries
- Public health issues
- Industrial costs
- Governmental control costs

- Habitat degradation and existence of native ecosystems

By biodiversity, they specify that they are talking about "native biodiversity"—that is, the diversity of life forms co-evolved with the natural environment in the region being studied. They made it clear that they're not interested in exotic biodiversity. By way of explanation, they clarified that fisheries don't necessarily come under the umbrella of biodiversity because the fish could be exotic species.

When the group was ranking the impacts, they needed something to go by other than the criteria (which they hadn't really articulated yet), so they compared the impacts to other stressors, including habitat alteration through river water diversion, pollution, etc. Given that, they decided that under certain situations the impacts to public health can be great (such as with the introduction of a disease vector or when an exotic pathogen flares up), but in most cases other stressors will have a greater immediate and widespread impact on public health. This is not considering what could happen in the future, however—it's concerned only with what is happening currently. That's why public health is ranked among the highest but not *the highest*—the group made a distinction between the criteria and the actual situation.

After deciding *what* was the most important, the group then discussed *why* they had selected that list to help them identify the pertinent criteria. (NOTE: The fact that a criterion was important didn't necessarily correlate into an equal importance for the associated impact. For example, although almost everyone in the group agreed that human health was a really important criterion, not everyone agreed that aquatic invasive species have a high impact on public health.) They generated the following list of criteria:

- The effect on human health was the top criterion.
- Ecosystem services (The group felt that, all other things being equal, if you're looking at the impact of ecosystem services as opposed to the impact of something else, commercial services for example, the ecosystem services trump all other kinds of services.)
- The scale and extent of the impact. That's why the group assigned a relatively high priority for ecosystem-level impacts, because anything that changes fundamental ecosystem properties affects the rules of existence for everything else in it, and that could include biodiversity or fisheries, etc. So, something that had the potential to affect multiple levels of an ecosystem's food web would be considered a more important criterion than some of the other ones.

Group 4

The group performed a "semi-quantitative" ranking of impacts after deciding that after doing so they would revisit the question of criteria in light of the data. In other words, they went about the task backwards, (i.e., addressing the Session II charge before completing the Session I charge) but it seemed to work for them.

Their top five impacts:

1. Biodiversity
2. Public health
3. Habitat degradation
4. Existence value of native ecosystems
5. Water quality

This preliminary listing and ranking was followed by an involved discussion of why certain things that everyone thought were really important (e.g., fisheries) didn't show up in the top five. That led to the idea that it might be prudent to do some "lumpings," since a lot of the categories seemed really very similar to each other. For example, combining biodiversity with the existence value of native ecosystems would enable fisheries or recreation to move up on the list.

Another issue discussed quite extensively was the notion of ecosystem services. The way it was phrased on the impact list as "natural capital and productivity" perhaps didn't capture the ecosystem services concept for some of the group members, but some particular elements of ecosystem services, such as flood control, were on the list and received some individuals' votes.

As far as criteria to drive the rankings, the group came up with the following list:

- Severity—impacts and damages, whether environmental health or usage
- Probability—whether something is a low-, medium-, or high-probability event, and how to establish this
- Knowledge—the costs of collecting and not collecting data and the feasibility of measurement (An interesting difference arose between an economist's view that if something *can* be measured, then the cost of measuring would be lower so more of that *should* be measured—as opposed to a biologist's viewpoint, which seemed to represent more of an inverse relationship that the harder something is to measure, the more critical it is to do so—in other words, the harder problems are the ones to attack.)
- Costs and tractability of doing something. Again, there was an inverse relationship, with economists holding the viewpoint that if something had high benefits and low costs it should be done, and biologists advancing the viewpoint that even if costs are high it should be done anyway. The biologists' rationale was that if something really does have high benefits, then the costs might decrease if the issue is addressed.
- Adaptability. For example, we've all adapted to dandelions in one way or another. Likewise with invasive aquatics, adaptation is one way of dealing with them as opposed to doing something about them. Of course, just because you *can* adapt to a specific situation doesn't necessarily mean that it is *desirable* to adapt.

Group 5

This group began by brainstorming and developing a rather long list of impacts, and as they did so, they attempted to lump issues that were related. Their initial list:

- Water supply changes and drinking water quality

- Existence of native ecosystems, biodiversity, impacts on native species, homogenization
- Habitat degradation, degradation of natural capital and productivity
- Fisheries, food web

After looking at the list, the group set about the task of developing some criteria to guide the prioritization of the impacts. In doing so, they talked about some scalar issues and decided that for the criteria to be valuable, it had to be clear what it was that you were looking for. For example, a criterion that affected a broader area, or more people, or more sectors was deemed more important than a criterion with lesser reach. Their list of ranking criteria:

- As for areas, the more sensitive and more pristine were judged to be more important.
- The extent to which the ecosystem function is changed (again, the more change effected, the more important the impact).
- Human well being
- Potential leveraging (the extent to which different regulatory agencies would have the opportunity to collaborate and pool resources to work on certain issues)
- Irreversibility (the more irreversible the effect, the more important the impact; an associated issue is the availability of practical, reasonable alternatives for reversing degradation.)
- The degree to which an effect is caused by invasives (again, the greater the degree the more important the impact.)
- Politics —the existence of feasible options for action (in other words, what can EPA do about it? How will people react to it [the remediation]? How well developed is the science? Can we actually prevent the spread or worsening of the impact?)

Realizing that their original extensive list of impacts wasn't very practical, they went back and did some individual ranking and tabulation and developed the following group list, which is listed in order of importance:

1. Biodiversity/bio-homogenization
2. Habitat degradation (tie for 2nd)
3. Water quality and quantity (tie for 2nd)
4. Food web, including fisheries
5. Costs (detection, prevention, education, control, regulatory costs, industrial costs, eradication, and restoration)

Wednesday Afternoon Plenary Session

It was remarked that all of the groups saw biodiversity as an important criterion, valued for its own sake, not as part of some other category—yet, how do you go about establishing the value of biodiversity? A follow-on remark was that many of the criteria selected by the different groups are very difficult to measure—yet, despite that fact, the groups chose these as the most important criteria for assessing the impacts of invasive aquatic species. One person clarified that the real issue is not an inability to measure these things—there are a number of ecological models that measure biodiversity on a number of scales—the real difficulty is in associating costs with the measurements.

Another person commented that there was some disappointment voiced in his group that cultural values didn't rank higher. He added that there is currently in conservation biology circles a growing tendency to admit that biodiversity and people are not separate and that people are part of the natural world. In this view, a broader way of thinking about biodiversity includes cultural diversity, linguistic diversity, and various other kinds of human diversity. In fact in some parts of the world, we're losing these biodiversity features also—and some segment of those cultural values associated with organismal existence has to do with invasives.

Another person spoke up and questioned whether the over-riding concern for biodiversity among the workshop participants—primarily highly educated ecologists and economists—reflects the value of biodiversity in the population as a whole. As a follow-on comment someone else agreed that the average citizen is probably unaware or unconcerned about the issue of biodiversity. She felt a need to educate the populace and articulate exactly why biodiversity is important.

An ecologist spoke up and said he is actually *not* in favor of having biodiversity be a placeholder for a set of issues. He felt that it would be far more helpful to flesh that out with some more specific and measurable terms that we actually care about. He asserted that it's really not the number of species that anyone actually cares about, it's the goods and services, cultural or otherwise, that are provided by those species. There was a concern that the focus on biodiversity is leading us down an unproductive path, especially in this context of valuation. It would be more productive to focus on why it is that we value items and to identify the measurable things that we value.

Another participant clarified that more is not *a priori* better when it comes to biodiversity, and she stated that she has heard people assert that invasives actually add to the biodiversity of an ecological community, at least in the short term. She agreed that coming up with a better definition of biodiversity will help counter such simplistic assertions. She added that different individuals value the same things differently—some prefer the beach while others prefer the mountains, and what that means is they value the plants and animals they see in those locations differently—so, we need a more unifying definition of what biodiversity really is.

Someone else added that what really matters in the context of biodiversity is the local abundance of a given organism—not just that it exists, but that it exists in such a state that it can provide goods and services that people value.

Another gentleman offered this clarification of why biodiversity keeps coming into the picture in discussions of the impacts of invasive species. He said the first reason is that regardless of what definition of biodiversity is used—number of species, number of families, whatever—they're disappearing at an alarming rate. We don't know the consequences, but we know that it's happening. Couple that with the knowledge that one of the primary contributing factors to this phenomenon is invasives. He asked rhetorically: Do you throw biodiversity off the list because you can't quantify the consequences or do you put it on the list because there is an abundance of data that show that some invasive species are driving other species extinct?

Someone added that one of the problems with focusing on biodiversity as the catch-word is that by the time a species becomes endangered, the goods and services that it provided, that people care about, have long since disappeared.

Another participant added that the most convenient things to put on the criteria list are things that have easy measures, things easily quantified. With the more difficult criteria, such as biodiversity, the issue is how to valuate 300,000 years of co-evolution and the genetic information that's associated with that and the way these ecosystems and communities function. Once non-indigenous species are introduced, the integrity of the ecosystem or the evolutionary history is broken, gone, in much the same way an extinct species is gone. We don't have very good measures of the value of that ecosystem integrity, but it is valuable and important. It's the reason a lot of pharmaceutical companies go to the rainforest—they're trying to capitalize on the evolutionary history and co-evolution of the plants in that ecosystem.

Someone else stated that a lot of the services will be indirect. For example, there's been a great debate over the past 20 years about how biodiversity contributes to ecosystem stability. It can't be rendered immediately as a dollar value—it's more subtle and complicated than that—but it is still very real. There are things that biodiversity seems to do that do not lend themselves to immediate valuation, and that's been one of the primary problems with this concept in the context of economic valuations.

Another workshop participant agreed that biodiversity is something that would be difficult to sell to the public, but she clarified that the groups were not charged with identifying issues that should be taken to the public. The charge was to rank what the group members thought were important issues. She also added that ecosystem services, just as with biodiversity, can mean different things in different situations—it depends on what you're looking for.

Breakout Session III and Plenary Reportout

Breakout Session III – Potential methods for measuring impacts of aquatic invasive species

Objective: Obtain participants' individual input on the best/most appropriate methods for measuring the economic costs of the impacts of aquatic invasive species.

Charge:

1. *What analytical tools are needed to estimate the economic costs of the impacts that have been identified?*
2. *What is the appropriate scale of analysis (geographic, taxonomic, etc.) for estimating/ measuring the economic costs of these impacts?*
3. *How can diverse local or regional estimates of impacts be aggregated to a regional or national level?*
4. *To what extent should risk assessment and uncertainty be explicitly or implicitly considered in each approach?*
5. *Provide hypothetical examples for how ecological and economic tools could work together.*
6. *Prepare a description of the ecological and economic tools discussed and their relationship with one another.*

Impromptu Charge: *How can we best articulate why the impacts selected yesterday are important?* The Workshop Steering Committee believes that quantification—coming up with numbers or numbers within ranges—is a good way to articulate why the impacts are important.

Group 1

The group wrestled with the fact that in trying to establish values for the various ecological impacts of invasives, uncertainty necessarily rises with increasing scale. They felt that whatever methodology is selected or created, it will have to address all of the ecological and economic uncertainty. Nevertheless, there was a general consensus that some number is better than no number, so they felt that it is well worth the effort.

They tried to work through a zebra mussel example, thinking about the various ecological and economic impacts and what methodologies might be useful in helping perform valuations. The group identified an obvious hole, or incapacity, within existing methodologies: the case of multiple interdependent species. This merely adds to the pre-existing uncertainty, especially as results are scaled up to attempt to establish regional or national values.

Group 2

This group began by acknowledging that statistical and mechanistic are really the only two viable approaches. A statistical approach would require looking at historical information (of some species or related species) and seeking some sort of correlation between a measured common impact. The group felt that it would be important to incorporate feedback between the human components and the environmental component, which can be done through a corollary equation or by adding a prompt to insert this information in an existing system.

An alternative statistical approach would be to look at different species on a broader scale, looking for how well they correspond or how well certain measures might be able to predict the effect of a new species in a new area.

Using a mechanistic approach, you could start building potential community models, but there's a whole host of problems associated with that stemming from the fact that integrating information from a wide variety of sources creates a high degree of uncertainty.

Another equation can be added to the mix to process the interactions between the feedbacks for economics, etc, with humans basically behaving as just another species within the community model.

Group 3

The group first reviewed the optional tools for valuing ecological benefits: revealed preference, stated preference, and linked ecological/economic modeling. However, they quickly dropped this line of pursuit and began to focus the discussion on more basic underlying questions such as: Is a credible national number possible? Would such a number be truly meaningful and useful? Pimental numbers were noted as possible values that could be aggregated up, but the economists in the group stated that such numbers don't measure social welfare, the issue of concern. No consensus was reached on the proper scale—whether it is better to focus on small, localized studies that generate data characterized by high uncertainty, and then aggregate up. They also spent some time discussing general equilibrium and the importance of direct influences and how to capture them, but came to no conclusion.

The group also considered developing a particular framework, such as Longfield's Equation, which says that a natural impact on a defined regional scale is equal to the range size of the organism at any given time multiplied by the abundance multiplied by some per capita effect, eating fish for example. The economists in the group felt that the per capita effect could not be easily translated to an economic effect that accounted for welfare. Once again, this led to a discussion of all the challenges associated with gathering data at lake level (or a series of lakes) and scaling up to a regional or national estimate of costs.

They addressed the question of how to scale up. One idea was to start with a probability distribution of impacts across a range of habitats. Ultimately, however, impacts are context-dependent—they vary across systems—so, scaling up will remain a problem.

Economists in the group also expressed some concern about seeking a single Pimental-like number. They are more accustomed to thinking in terms of confidence limits or best/worst-case scenarios.

Group 4

Although the group agreed that incorporating feedback is always a good idea, they also believe it's important always to explore first whether it is necessary to integrate the models and whether feedback actually matters in every case.

The second major topic of discussion was the appropriate level, i.e., watershed, regional, national. They felt it was good and necessary to have credible regional numbers, but cautioned then against the use of *incredible* aggregation methods, raising once again the whole issue of scaling up while staying real.

The group agreed that perhaps the CG models would be at least worth exploring, but there is the issue of not knowing a lot of the problematic invasive species beforehand.

The group also felt that it is important to provide confidence intervals, which policymakers can then use or not, as they see fit. Another factor to consider in modeling is that the risk preference of the decision maker might matter. The same is true of time preferences. Today's decision makers might not be too concerned about latent invasives that might become a problem in 100 years.

The group also felt it's important to focus on the best-studied species. Then, in trying to consider the same species across different places, it's important to understand what rules can be generalized, and it's important to cross-validate the model between regions.

The group also discusses what they called the "ticking time bomb" issue—the case in which a non-indigenous species arises in an ecosystem but exists for years, perhaps decades, without any real effects, and then suddenly its population explodes and it becomes a problem. It's possible that the trigger could be another invasive species and the synergistic effects that follow. They wondered whether some historical analysis of instances of this occurrence could help predict future "flare-ups."

Group 5

After establishing a common terminology and understanding of the various ecological and economic methods, the group explored the possibilities for combining methods to achieve the desired valuations. As a working example, they considered the New Zealand mud snail and its impact on water quality. Scale up was not addressed in this initial discussion, but they acknowledged that it would have to be addressed eventually.

Two water quality effects they recognized were the translocation of nutrients and water flow, observable and measurable most obviously through taste and odor impacts. AQUATOX was identified as a potential appropriate ecological model, which with the proper inputs can produce valuations on a local scale. Surveys can be used to collect stated valuations of drinking water quality to fuel the modeling. Another possible method is observing averting behavior (e.g., purchase of bottled water). A third way would be to establish replacement cost—establishing the value of a service provided by a natural ecosystem as the equivalent of a man-made counterpart that provides the same service.

Thursday Morning Plenary Session

Steering Committee input: The discussions that have begun regarding issues of scale and issues of aggregation should go a long way in helping to articulate the importance of the impacts that we are focusing on. One way to establish quantitative estimates that help explain the importance of biodiversity might be to shift the focus to the various sub-component services that support biodiversity, which can then be valued.

One person commented that because ecological systems are so diverse, it is perhaps too daunting and confusing to separate out the associated functions and services. An alternative approach might be to imagine the results or effects of having biological systems that were *not* diverse, perhaps focusing on just a specific example or two.

Another participant shared his personal realization that it is necessary to present the importance of invasive species issues, such as loss of biodiversity, in terms of factors that are important to the target audience (typically, those who control sources of funding). He said that he recognized only two of these "communicating" factors, the first being dollars or money. The other factor he classified as "votes" or public opinion, a currency that resonates with anyone who has stakeholders to answer to, and he surmised that there is a way to quantify that factor apart from money.

Someone else mentioned the Framework for Ecological Economics that the EPA established in 1998 as a useful, though perhaps imperfect, springboard or tool to help guide and inform the current discussions related to interfacing ecology and economics—no need to reinvent the wheel, in other words.

Another workshop participant identified an issue important to ecologists but perhaps less than compelling to politicians and people with purse-strings: the potential vs. the realized biological information that is contained in natural ecosystems, and he is unsure how that hidden potential can be evaluated. Someone questioned whether he was speaking of potential pharmaceuticals. His response was that he was referring not just to pharmaceuticals but to all sorts of information that we have not yet figured out how to tap into because we don't really have a thorough understanding of how ecosystems work. Asked whether he or his group had any ideas about how to address that problem he essentially said no and stated that the services and functions of ecosystems that have been monetized to date represent only the tip of the iceberg and going further is difficult.

Someone else related how his group discussed the issue of scale and their conclusion that the ideal would be that which works biologically, economically, and politically all at the same time. Realistically, it seems that economic models tend to work better at a regional as opposed to a national scale. This holds true for biological models as well, and for the most part in the political realm also, as congressional representatives are concerned primarily with issues within their districts. So, in our efforts to create an ecosystem services framework to which dollars can be attached and to make a convincing case, we should focus our attention on getting good stories backed up by good numbers for each of our major regions where there's a clear link between species, a particular ecosystem service, and dollars. That still leaves the challenge of building up to a national aggregate, but it provides a good, reasonably sound basis from which to work.

Another person reiterated the existence of unrealized and unrecognized ecosystem benefits. There are unknown ecosystem components that can help start new industries and provide real benefits. Nobody recognizes these as ecosystem services until they're discovered, but they are there and should factor into our valuation discussions. Taxol was offered as an example.

Another participant referred to an article from the Millenium Assessment entitled, "Ecosystems and Human Well Being: Biodiversity Synthesis." He felt that this completed work might provide a starting off point for categorizing all the costs and benefits associated with ecosystems.

Someone else related that the U.S. Army Corps of Engineers (U.S. ACE) is forming a team of leaders to meet annually to look at the invasive species problem. He noted that the Corps did not mention biodiversity as one of the underlying issues—they're focusing on criteria that impact their mission of transportation, navigation, and water resources. Once again, the disconnect is obvious.

Another person added that some federal agencies *do* have biodiversity as part of their mission and could provide a different perspective of its importance and how to "market" it.

In response to these comments, which seem to emphasize only that people care about their mission (i.e., they care about what they care about), another participant said that a tiered set of arguments that will hit multiple audiences is what is needed. He believes that the ecosystem services framework might provide that because it relates on one end to the conception of biodiversity but on the other side it can also be tied to the monetary, pragmatic sides of peoples' missions. This may be the one framework that could reach the multiple target audiences for this discussion.

In response to the comment that the U.S.ACE isn't concerned with biodiversity, another representative from the U.S. ACE referred to the Corps' Environmental Operating Principles that were put out a few years ago, and which list sustainability as one of the core principles. He felt that the U.S. ACE's conception of sustainability certainly encompasses biodiversity. He also supported previous comments that we should be taking what has already been done and building upon that, with the belief that there is abundant information out there regarding the value of maintaining biodiversity.

Another participant said that the Clean Water Act clearly defines protecting biological integrity as part of EPA's mission and that, in his view, EPA has evaded that issue. He sees it as a challenge to the EPA OW leadership to step up and assert the Agency's authority in fulfilling that mission to protect the biological integrity of the waters of the U.S.

Someone else agreed but said he sees the other side of the issue also. In working with the Armed Services Pest Management Board, he said it is patently clear that for all branches of the armed services, the primary concern is their mission and they address issues that interfere with the successful achievement of their mission. Public health issues are often high on their list—eradicating mosquitoes to protect the health of the troops, for instance. Here again, the issue is talking the language of the people you're trying to sell. Biodiversity might get mentioned in the end, as a PC thing to do, but oftentimes the bottom line issue is public health.

Another person who works for the Fish and Wildlife Service said that biodiversity is an element of their mission but in reality it plays out across the agency in various programs, such as invasive species, habitat restoration, etc. She added that most of their efforts to address invasive species issues have been directed toward State programs as opposed to Federal. This is generally easier and more effective than fighting for cooperation and support at the Federal level in the midst of all the budget cuts.

A member of the Workshop Steering Committee broadened the discussion away from a narrow focus on biodiversity and identifying the services it provides. She challenged the group to have productive discussions and to bring all their diverse expertise to bear on the mission of the workshop: determining the economic impacts of aquatic invasives.

Another workshop participant thought it would be useful to describe the limitations on quantifying the services provided by biodiversity and articulating this information in economic terms. There is a universe of relevant information and description dealing with moral aspects and other unquantifiable matters associated with biodiversity. Perhaps we need to acknowledge that any complete treatment of this issue, any view of the total services provided by biodiversity, will necessarily involve a combination of quantitative measures and qualitative descriptions.

Someone else said that there are a lot of ways to persuade the people who need to be persuaded. It can work if we just keep talking about it and are quietly persistent about it. If people hear about something enough, eventually they believe it was their idea in the first place, and then a lot can happen. Also, every individual has a unique hook related to invasive species that can be consciously exploited to open lines of discussion and thought. These strategies can help create from-the-ground-up, word-of-mouth "buzz" about the issues we care about, and that's another way to accomplish our goals. Releasing *some* report from this workshop, though it will by no means be a complete treatment of the issues, will help achieve this—it will get people thinking about how to make it even better, and it will increase the number of people who are aware of the issues.

Someone from academia questioned what their role is in all of this. He commented that over the last 20 years vast amounts of intellectual energy has been spent on trying to figure out how to value non-market resources for environmental economics. He said that there are reams of information on valuing ecosystem services, although it is more likely to be couched in terms of endangered species rather than invasive species. He suggested that a worthwhile activity at this workshop would be to come up with an accurate definition of invasive species that normal people can understand—then they could try to articulate what they think about it.

There was a suggestion to make a list of already existing pertinent documents, some of which had already been mentioned in the discussions, and the information they present so that the workshop can go forward and break new ground and not get stuck rehashing already-covered territory.

Another participant stated that although she agreed with all the comments made, she felt that the goal of assigning values to ecosystem services had already been attempted in other endeavors (including the Millennium Report) and didn't fit with the objective of this workshop. She urged the participants to focus on how to assign values with the invasive species issue—Do we want to do it on a regional or national level? Do we want to do it on a species level? If so, species by species by species or biodiversity, travel, habitat degradation, etc.? Once we identify the most appropriate method behind it and develop the proper framework, we can then leave it up to economists to assign values. She added that from her perspective things are tending toward a regional perspective. Most people seem to believe that a national number is currently unattainable. However, she urged the participants to consider a timeframe for developing the number---i.e., do we want this number next year?—in 10 years? (Someone commented, "We want it tomorrow," which brought laughter.)

Another person admitted that he came to the workshop with a rather naïve fantasy that we actually would be able to get a national number for all invasive species. He added that he has come to realize that we probably can't and to claim so would be non-credible because there are no ecological data on the impacts of many non-indigenous species. So, the only viable strategy is to focus on the species for which there are reasonably sufficient data and make the best economic estimates based on those—then project to some aggregation of these regional impacts without getting overlaps that take away from the credibility of the results. He summarized by saying that what we really want is "a credible under-estimate rather than an incredible total."

Someone else cited her experience with a particular study of marine invasive seaweeds along the Pacific Coast from Canada to Mexico and the challenge they faced in trying to collect adequate ecological data and carry out proper valuation procedures for that entire area. She emphasized that the scaling issues do matter.

Responding to the previous comment that we don't have adequate ecological data for many of the species of concern, one participant clarified that although we don't have data on the *impacts,* we do have some ecosystem simulation models and other tools that can be used to help predict what some of those impacts are. These efforts would need to be supplemented with some general bioenergetics/life history kind of data. It's important to distinguish between not knowing enough about a species to predict its economic impacts and simply not knowing what the impacts are.

Someone else clarified that non-indigenous species are not necessarily invasive species. The number of invasive species is a quite small subset of all non-indigenous species, and that fact might help make it a little easier to come up with some of the numbers that have been talked about.

Another person identified what she sees as two separate emerging goals: One is a quick-and-dirty number that EPA people can use to present their case to managers and explain why we really need to pay attention to the impacts of aquatic invasives. The other goal involves actually generating good data that are peer reviewed. The problem at EPA is that there is no invasive species regulation that requires a cost-benefit analysis—that's what drives action at EPA, doing regulatory analysis. She felt that both are really needed for this issue to be dealt with effectively. She closed by saying the Office of Water simply has no money to support the necessary benefits assessment or ecological assessment, but she challenged NCEE to put this into their budget.

A member of the Workshop Steering Committee responded that NCEE has very limited resources to those types of studies on the scale that would be necessary, but they are increasingly able to designate small amounts of money toward this issue.

As follow-on to the preceding comments, someone said that it is important to focus on what's possible with a small amount of resources and to work to maximize the impact of that. He suggested focusing some of the workshop discussion on identifying some of the regions where a lot of the baseline ecological and financial information already exists. Urging the group to use the tools and timely syntheses that already exist, he mentioned once again the Millennium Assessment as a valuable source of information on ecosystem services. He added that hundreds of scientists and social scientists spent four years thinking about these issues and we should take advantage of this. He said that we should just use the existing market and non-market techniques opportunistically as they can be applied. This person also remarked that just the fact that this workshop is being held is a positive sign that the issue of invasives has been gradually elevated over the past few years at both the state and federal government levels. He asserted that dollar values *do* talk and conjectured that 90% of the people in attendance have quoted Pimental's Number, albeit reluctantly. He said that probably more than any other one thing *that* number got the attention of policymakers, despite its limitations. He closed by suggesting that although policymakers have begun to appreciate the costs associated with invasive species, perhaps action has been slow in coming because the cost arguments haven't been coupled with credible suggestions of what can be done to address the problem. He acknowledged, however, that pursuing this discussion would be beyond the scope of this workshop.

A representative from the Office of Water said he appreciated the goals set out for this workshop, and he encouraged the participants, as they work to come up with national figures, to develop models and methodologies that will be useful not just in the current effort but that will also be broadly applicable in future circumstances.

Breakout Session IV and Plenary Reportout

Breakout Session IV – Consider shortcomings in available methods/tools

Objective: Obtain participants' individual input on the shortcomings of available methods/tools for measuring economic impacts and how these shortcomings can be addressed.

Charge:
1. *Are there any significant impacts for which there are no readily available analytical tools?*
7. *Brainstorm about possible tools and tool development.*
8. *What are the shortcomings or problems with existing tools/methods?*
9. *Brainstorm about possible improvements to existing tools/methods.*
10. *What data are needed for possible and existing tool/method development?*
11. *What are the most promising tools/methods or areas for research?*

Impromptu Charge: *How can we best articulate* <u>*why*</u> *the impacts selected yesterday are important?* The Workshop Steering Committee believes that quantification—coming up with numbers or numbers within ranges—is a good way to articulate why the impacts are important.

Group I

One reason that members of this group felt that the regional approach is the way to go is because as the numbers [i.e., economic benefits values related to ecological goods and services] become available, the confidence intervals are going to be huge, especially early on, and scaling up too quickly before shrinking the confidence intervals will quickly create a situation where the limits are likely to range from zero to infinity. Nevertheless, they acknowledged that it is useful and important to get a number to work with, even though it's likely to be an underestimate. They felt that, initially, this will be easier than shrinking the confidence interval to a meaningful range, which will probably be done most effectively by strengthening our understanding of the ecological processes involved.

Since *what*, *where*, and *how* a number is derived is going to depend to a large extent on the timeframe, the group felt that in the short term it will be most useful to focus on places that are better understood (e.g., the Great Lakes, Chesapeake Bay, Hawaii). It became clear to the group that controlling an aquatic invader is a lot different situation than controlling a terrestrial; in an aquatic environment, it's almost impossible to get away with just killing the species of concern. They also felt that there may be some rules of thumb specific to aquatic invaders that could be very useful in thinking about establishing values and how to go ahead with policy. For example, they suspected that the benefit cost of *prevention* of zebra mussels may be several hundred times higher than even the best control mechanism for them once they've become established. So, thinking about not only a number, but also the expected benefit cost is probably going to be useful, especially with aquatics.

As an important short-term objective, they identified the need to concentrate on meshing the existing ecological data and economic methodology, focused specifically on invasives. In the long run, they felt that focusing on improving the quality and quantity of ecological data is going to go a long way toward making the existing economic methodology yield narrower confidence intervals. This will also help clarify the critical ecosystem linkages that we need to understand to create and implement effective solutions to invasives. Also, it will be important to improve and hone non-use methodology as we go along.

The group felt that a critical element to the path forward will be getting ecologists and economists "working on the same page and the same wave-length." Economists need to better understand how ecological processes need to be modeled and refrain from making assumptions about linear relationships or forcing data through linear modeling. Ecologists can help by making the ecology clear to economists and making them aware of all the feedback effects, etc. Another advantage of getting ecologists and economists working closely in tandem is that they'll be better able to identify the "holes" that need to be filled. The group believed that monitoring, in terms of early detection and rapid response, is probably one of the biggest holes right now.

Group II

Group II began by acknowledging that despite obvious gaps in data and limitations involved, it was necessary to "dive in" to help chart a way forward. They set it among their tasks, however, to highlight where these data gaps might arise and to suggest potential solutions.

The group decided on a multi-step approach. The first step involves focusing at a regional level and selecting a certain number of species for which data are readily available regarding species distribution and impact on the effects of concern. These data would then be used to come up with an estimate of the consequences of the invasive species and their interaction with the human component of the ecosystem.

Because there may be insufficient data for an analysis of particular areas of concern or species of concern, the group identified their second step as: extrapolating from the regional and specific species data gathered in the first step to a broader look, both in terms of geographic area and species. The discussion of how best to accomplish this extrapolation led to the ideas of meta-analysis and benefits transfer.

They acknowledged that there are different levels of benefits transfer for which we have different levels of confidence. This is fine as long as it is always understood what the limitations are and where errors might occur. For instance, when extrapolating from one species to another, it is most likely that the species for which data are most accessible will also be the ones that are most damaging. To prevent sampling bias, then, it is important to take into account the distribution of the universe of damages of interest rather than just the ones measured for the most problematic species.

The question becomes: How do we begin parameterizing all these things to actually get estimates? Generally, the options are a statistical approach versus a mechanistic dynamical approach, with a statistical approach associated with less uncertainty. This group focused on the economic model of green accounting, which encompasses a combined approach, part statistical, part dynamic. Despite the uncertainty associated with the dynamical component of the value, they felt this was preferable to leaving those factors out of the estimates. Using this approach, non-market values (e.g., changes in the productivity of the habitat) can be established using some existing models, basically as a shadow value of a price derived from the models.

Group III

First off, most of the members of this group thought that a regional approach is the way to go, and they felt that there are a number of regions that could be fruitfully examined, where the extensive catalog of existing work could be used to leverage future efforts (e.g., San Francisco Bay area, Great Lakes region, Chesapeake Bay area, Florida Everglades). As a way forward in this regard, they thought that a useful way to proceed would be to: (1) identify the most important ecosystem services provided by the watershed in a particular region; (2) identify the impacts of invasive species on those services (focusing on the set of invasive species that had the most significant impact on the target services in that region); and then (3) use existing valuation methodologies to assign values to changes in those services.

In discussing how to go about getting any worthwhile information that could be used to prioritize impacts or help inform policy decisions, this group realized that it would be necessary to develop a standard approach that could be used to build up a reliable estimate or series of estimates. They proposed this simplistic approach, which would require close collaboration between ecologists and economists:

After identifying categories of impacts and, within each category, specific impacts with societal importance (e.g., human health, blocking of water supply systems, blocking of navigation), find the change in ecosystem function produced by exotic species in a given system. After the change is measured, let economists conduct an economic evaluation of what that change implies, thus translating an ecological impact into a societal impact, be it a cost or benefit. This is done per impact, per system, for all the systems for which it is possible in a given region. Over time, this can be revised as the number of systems increases and the confidence limits close around some value. Also, over time the way things are measured or the method of evaluation may change, but at least it will all be guided by an established, standard approach.

The group felt that once ecologists and economists get together and translate the measured change in ecosystem function to a measured cost or benefit, they can then also apply models of human behavior that will help predict what the effect of a societal response could be (e.g., a mitigation that could involve the reduction of a species or some adaptation to the effect). So, this approach would allow not only evaluation of something that is not immediately controlled, but also an evaluation of any control strategy imposed. This per impact-per system-approach is tractable because it does not deal with all impacts and all exotic species within a system, but rather only those that affect the impacts of interest or which are easily measured. Although that means that the estimate generated will have some error bars around it, this can be refined over time through adding more systems or refining the measurements of the impacts.

This approach acknowledges the fact that important services vary between regions, as do the impacts of invasive species on those services. It also helps ecologists and economists identify the most important missing data that are needed to help better inform the process. Finally, they felt that a regional approach that encompasses multiple jurisdictions (e.g., various states) can be beneficial in terms of providing more numerous and diverse opportunities for acquiring funding for these types of efforts.

Group IV

This group explored the idea of building a regional computable general equilibrium (CGE) model for valuing the economic impacts of aquatic invasives. A CGE model is traditionally used for assimilating all relevant factors (e.g., industries' supply and demand) within a specified region and then "shocking" the system with some input and looking at what happens to presented change in GEP. It is currently the most popular model for estimating economic damage, so it might be just the thing to use as an indicator or the impact of invasive species on a particular regional ecosystem. An advantage is that these tools are pretty well developed, and they have the aggregation capabilities built into them to enable going back and forth between regions, etc. Limitations include: they don't do dynamics very well and they have no corollary for the resource stocks associated with green accounting. The biggest advantage, perhaps, is that they can generate a number—and quickly.

Using these models would require inputting how much the costs to each "industry" (i.e., spending entity, whether it be industry, government control, recreators) increased due to the presence of the invasive species—in other words, species-specific impacts, in terms of dollars, on industry in a given region. It should be noted that this addresses only market effects.

Expanding the discussion to consider green accounting and its concern with resource stocks, change in biodiversity, water quality issues, etc., the group began to look for green, regional CGE models. Indeed, these have been developed for climate change modeling, but unfortunately invasive species and their effects aren't homogeneous and consistent across environments as carbon molecules are. In fact, there is a huge literature regarding the application of CGE models to the environment, but none with an invasive species focus.

In discussing how to actually do green accounting and how to price shadow values, the group touched primarily on the issues of stated preference and revealed preference. They addressed the problematic stated preferences contingent valuation, choice experiments, etc.—basically, all the strategies for determining willingness-to-pay. This discussion also dealt with the current incredibly tight bottleneck getting surveys, focus groups, pilot studies, etc. approved through OMB and the unreasonable time horizon this process creates. This led back to a consideration of benefits transfer—it it's difficult or practically impossible to conduct the studies to derive new numbers, can we take old, existing numbers and apply/adapt them to help answer new questions? Ultimately, however, this always leads back to extrapolating from one species or risk to another, and that is difficult to achieve with any confidence.

The group also cautioned that unless an analysis is set up correctly, it's possible to end up with the misperception that you can save a lot of money by letting invasive species run amok, basically not spending anything to regulate/control them.

Another advantage to a CGE framework is that you can begin an analysis by including only those sectors of impact for which the best information is available—you don't need a comprehensive list. The same is true for species. Another advantage is that as an organizing framework, it does force a consideration of all the interactions between the industries and the economy. To reiterate, this type of model is dependent upon the initial input of credible cost values that represent an invasive species' effects on the industries in the focus region.

As an example of a possible strategy forward at some point, the group cited the DOE's efforts to address global climate change by convening an Energy Modeling Forum, which met annually and ran a common set of parameters through the various existing models to generate an array of predictions. The associated annual report that was released gave people powerful information that could be compiled to produce global numbers as well as data relevant to more regional, individual concerns. This strategy is also one way of eliminating some of the uncertainty associated with individual modeling assessments.

Group V

This group saw the value of developing something that could be applied on a regional scale to generate information that could then be aggregated to present a broader picture. They ended up discussing a species-specific approach that focused on the ecology and relevant economic issues. As a developmental case study, they centered their discussion around hydrilla, a well-studied southern freshwater plant. Although this plant offers some advantages in its native habitat, it has a tendency to produce monocultures, which qualifies it as an invasive in terms of its effect on biodiversity, habitat degradation, food webs, water quality, etc.

In looking at the issue of biodiversity, the group found that there were actually some positive values to account for: 1) hydrilla serve as food for manatees, an endangered species, and 2) the abundance of fish in benthic communities is actually augmented by the presence of hydrilla.

Regarding water quality, there were also mixed effects: negative in terms of dissolved oxygen (and the associated long-term effects on nutrients) but positive with regards to clarity, taste and odor. Indeed, hydrilla grows so thick as to interfere with the EPA fishable/swimmable standard by preventing boat passage and swimming. The group also noted that to capture some of the taste and odor effects on peoples' consumption of drinking water through a standard survey approach. Other effects, including those related to recreational values, could also be tracked through a survey approach or travel cost method. In a survey approach, the questions posed could also deal with the future.

The group also noted that there was a probable property value change related to this invasive species. People who buy lakefront properties seem to value looking out on a smooth, reflective water surface that doesn't have hydrilla sticking up from the surface. There is probably also a recreational element to this value.

The discussion then turned to costs that are more easily measured. The plant can be washed up during floods to cause additional damage potentially affecting hydropower and irrigation ditches. Of course, there are the associated costs of control: eradication, removal, restoration, education, monitoring, detection, regulation, etc. Many of these impacts could actually be characterized through market price. When this isn't workable or appropriate, the averting expenditures approach or the replacement cost approach can often be utilized.

The group noted that when adequate data are not available to fuel the models or when the time and/or financial resources are inadequate to generate the information, the referenda approach can be an option. In other words, the public's responses to environmental-oriented voting propositions can sometimes be used to derive values for certain ecological goods and services.

Economic Impacts of Aquatic Invasive Species Workshop
Washington, DC, July 20-21, 2005

Co-hosted by EPA Office of Water and
Office of Policy, Economics and Innovation

Reports from Academic Participants

Order of Reports

Linda Fernandez - University of California-Riverside

Report on EPA Economic Impacts of Aquatic Invasive Species Workshop Held July 20-21, 2005, Washington, DC

Economic impacts of aquatic invasive species in the U.S. must be measured with a temporal and spatial perspective on existing and future impacts at local and regional levels. Tracking the continued pathways of invasion (shipping, aquaculture, aquarium trade) helps to project wider spatial and dynamic impacts. Ruiz and Carlton (2003) identify vectors (pathways) for aquatic invasions. Regions have different impacts due to differences in volume and frequency of intentional and unintentional pathway introductions.

Known techniques for nonmarket valuation should help quantify monetarily various impacts from invasive species (averting expenditures, contingent valuation, factor income method, hedonic pricing, replacement cost, travel cost, etc.). Currently, most estimates utilize the market price for quantifying costs of controlling invasive species and for goods transacted in a market (such as hydroelectric power reduction due to zebra mussels).

Besides the impacts in the EPA White Paper the following paragraphs offer some examples of site-specific impacts in the U.S. Pacific region such as foregone economic output, costs of controlling invasive species, biodiversity loss, health effects, etc. due to invasive species from shipping ballast and hull fouling, aquaculture and aquarium trade. Some examples are drawn from Murray, Fernandez, Zertuche (2005).

I. Control Costs

I.I Abatement of Hull Fouling

Cost of abatement of hull fouling is in terms of wetted surface area of hulls with shipping traffic. This value can then be entered into an estimate of cost (market price) per square meter of treatment (e.g., coating, manual removal, labor). Collection and containment of fouling organisms is treated not only by applying antifouling coatings but also by water blasting and scrapping biomass from wetted ship hulls and surfaces (Johnson and Miller 2002, 2003, 2004).

I.II Increased Fuel Costs of Hull Fouling

Hull fouling growth creates enough friction, or “drag” to slow boats and increase fuel consumption, in some cases by 30% (Younqlood et al. 2003). The market price of fuel can be multiplied by the volume that constitutes 30% of ordinary consumption. Eventually, fouling growth leads to damage to hull and vessel deterioration (Rolland and DeSimone, 2002).

I.III Ballast Water Treatment

Taylor et al. (2002) estimate costs from a direct market price for ballast water exchange according to varied ship speed, and ballast pumping capacity. A rule of thumb is 30 % of boating capacity (weight) is devoted to ballast water (Langevin 2003).

Additionally, there are cost estimates based on the market price for alternative options to ballast water exchange (Taylor et al. 2002, Tamburri et. al 2002). Alternatives include: 1) heat in-transit practices, 2) ultra violet treatment, 3) filtration, 4) ozonation, and 5) deoxygenation. These alternatives to ballast water exchange may overcome the spatial limitations and incomplete effectiveness of ballast water exchange.

I.IV Early Response Abatement Costs: *Caulerpa taxifolia* in California

California's reaction to the marine alga *Caulerpa taxifolia* constitutes rapid response. Within 17 days of the June 2000 infestation of *C. taxifolia* in Agua Hedionda Lagoon near San Diego, the Southern California *Caulerpa* Action Team (SCCAT) responded with containment and chemical treatments with tarp and chlorine injections there and at a second invasion site in Huntington Harbor. The cost of the initial eradication, management, and surveillance programs totaled US$4.1 million from July 2000 through July 2002 (Padilla and Williams, 2004). Since *Caulerpa taxifolia* spreads by vegetative growth and fragmentation, chemicals and tarping were chosen instead of mechanical control efforts to prevent dispersal during treatments. In September 2001, a ban on the sale and possession of *Caulerpa* and eight other species was passed by state legislation.

I.V. Undaria pinnatifida Eradication in California

Estimates from current efforts to eradicate *Undaria pinnatifida* conducted over more than 1 year in Monterey Bay can be obtained from marine biologist, S. Lonhart who is managing manual cutting and scrapping programs and via scuba diving under boat hulls and 400 boat slips (Lonhart, personal communication). The manual removal of *U. pinnatifida* fronds involves labor and cutting equipment. In Monterey Bay, average percent cover of *U. pinnatifida* before removal was 47.2 % and the average man-hours for removal were 3.75 hours per 0.25 m^2 quadrat. The mean biomass removed was 5,385.6 grams m^{-2}. Regrowth data showed that *U. pinnatifida* thalli returned in 64.9 % of the plots after four months. In order to derive the costs of this eradication effort, a wage rate per hour can be multiplied by the labor quantity in hours for continuous removal.

I.VI Restoration Costs

The cost of restoring tidal marshland affected by invasive species is US$7,500 per acre (US$18,533 per hectare) in terms of construction costs only (Zentner et al. 2003). Such efforts would be needed in combating invaders such as the oyster drills occurring in aquaculture marshland locations in the Pacific Northwest. Clearly, any land acquisition costs and costs of labor derived voluntarily from nonprofit organizations involved in restoration would need to be added in order to provide full cost estimates.

II. Benefits from Controlling Invasive Species

II.I Valuing Native Species

Codium fragile, Caulerpa t*axifolia* and *Undaria pinnatifida* are invasive seaweeds that, like other aquatic invaders, compete for light and space with native species and thereby can exclude and displace them. These native species have commercial, recreational, and existence value. For commercially marketed ocean flora and fauna, commercial values would be derived from a direct market price, while recreational fishing values would be derived from travel cost or contingent valuation.

Species potentially affected would need to be identified in order to access such values in the U.S. from the Pacific States Marine Fisheries Commission database on commercial and recreational fisheries values for the rest of North America's Pacific coast (California, Oregon, Washington, and Alaska).

II.II Food and Pharmaceutical Value of Invasive Species

The values for invasive seaweeds for direct consumption (e.g., *Undaria pinnatifida* for wakame) and for chemicals (e.g., alginates, agars, and carageenans) would be accounted for as plausible revenue generation from ongoing harvesting of these seaweeds. Estimates such as those from Dawes (1998) of US$100 million for alginate harvest in the U.S.. Abatement costs, therefore, could turn into financial earnings by selling the harvested species from abatement.

Bryostatin, a pharmaceutical cancer remedy is developed from the bryozoan, b *U. pinnatifida* thalli that is commonly associated with hull fouling. The production of 18 grams of bryostatin resulted from 14 pounds of *Bugula neritina* collected from hulls (Marsa, 2002). The pharmaceutical value can be derived from a market price.

II.III Restoration Impacts

The restoration of tidal wetlands and associated abatement efforts stimulate economic activity. For example, in Humboldt County California, 300 jobs and US$14.5 million in 2002 were directly tied to restoration of coastal marshes. This was about twice the value of commercial fishing in the area during that same year (Little 2004). Between 1995 and 2002, restoration activities generated more than US$65 million in Humboldt County (Little 2004).

II.IV Recreational Impacts

A direct connection of the recreational activities and impacts of aquatic invasive organisms has been made by Settle and Shogren (2002) using contingent valuation in Yellowstone National Park. *Caulerpa* t*axifolia* invasions potentially reduce enjoyment gained from recreational diving, ecosystem aesthetics, and biodiversity, and hinder boating and fishing by fouling nets, lines, hooks, and buoys in marine environments and such impacts should be valued (Meinesz 1999). It is unclear what method was used by Pimental et al. (2000) to derive the sportfishing recreational value.

II.V Coastal Property

A study that related coastal property to invasive seaweed impacts is by Cesar et al. (2002). Cesar et al. (2002) estimates show that algal blooms on the Kihei coast of Maui, distributed over a 16.1 km length of study area, resulted in US$21 million in potential revenue loss annually. This total can be disaggregated in terms of US$9.4 million from reduced property values, US$10.8 million from reduced occupancy rates at hotels, and US$1.8 million from tax loss.

II.VI Port Commerce

Lost economic activity at shipping ports due to any constraints induced by management invasive species could be costly. For example, the 2002 labor dispute that led to the shutdown of ports along the west coast cost the U.S. economy US$10 billion per day (Montaigne 2004). Due to this very high value, most shippers and manufacturers voice willingness to comply with tougher security measures according to Christopher Koch, CEO of the World Shipping Council (cited in Montaigne, 2004). The value of ports in parts of the U.S. can be derived through input-output analysis of annual economic activity with income and jobs (Rust 2004). Of course, this will require compiling data from all ports. From available data in California, the most recent survey of all ports shows that US$57 billion (and 1.16 million jobs) were added to U.S. Gross Domestic Product (GDP) for 2000 (Rust 2004). Six percent of the US$57 billion was attributed to the recreational boating use of ports (Rust 2004).

Caution

Promoting more bioeconomic models and research efforts to correlate invasive species with impacts should be emphasized in order to avoid erroneous aggregation and extrapolation that does not properly account for variations across the U.S. in all categories of impacts. Research that explores the cost of meeting existing policies such as the IMO ballast water limit (IMO, 2004) has been conducted by Fernandez (2004, forthcoming).

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Report on EPA Economic Impacts of Aquatic Invasive Species Workshop Held July 20-21, 2005, Washington, DC

This report first provides notes following the program of the workshop. The notes are followed by some personal recommendations given the outcomes of the breakout sessions. The first breakout session was intended to discuss the key impacts of aquatic invasive species. Through some give and take amongst the group, a list of the general categories by which to categorize the impacts of AIS was generated to be:

1. Severity of invasion – the magnitude of damage caused by the AIS, including both human and ecological damage.
2. Probability of invasion – the chance the damage occurs.
3. Knowledge and feasibility of measurement – does society know the potential damage the invader can cause before the fact, and if not can this be assessed through further research?
4. Costs and feasibility of measurement – are the costs of dealing with the consequences of invasion known before the fact, and if not can they be assessed through further research? This mainly dealt with a policy manager's perspective, in that to include AIS as a component of their budget they have to know what the agency may need to acquire funding for.
5. Adaptability – can the economic and ecological systems simply adapt to the invader and proceed without intervention?

In addition to this list, another useful method to categorize the key impacts from AIS could be:

i. Risks to human health
ii. Risks to ecological health
iii. Risks to human use values (consumptive and non-consumptive)
    a. Risks to commercial economic activity
    b. Risks to recreational economic activity
iv. Risks to human non-use values (non-consumptive)

The second breakout session consisted of the workshop steering committee combining each group's list from the first breakout session to provide a generalized categorization of the key impacts of invasive species. Each group then voted as to the most pertinent of the key impacts, providing a subjective ranking of the key impacts. While the voting provides some use in eliciting the collected experts' opinions, it was rather difficult as the list had many components that seemed to overlap with one another, such that some key issues lost votes to others.

The third breakout section revolved around the potential methods for measuring impacts of AIS. The basic economic tools of revealed preference methods, stated preference methods, and newer linked economic/ecological simulation models were discussed in some detail amongst the group. There was an issue here, as the economists had to present the tools at an introductory level, and argue for their justification. The time spent on this may have been better spent given the amount of effort the economic profession has placed in non-market valuation since the early 1970's (largely with EPA funding). Further, throughout the methodological discussion it became apparent that any discussion over tools (that have been shown to be useful in policy making) was simply too early for many of the group participants. Several key issues needed to be resolved in the first place, namely:

1. What is the scale of the valuation exercise? If at the national level, is a national estimate of the value of damages from AIS reasonable, measurable and policy relevant? Further, current national level estimates (i.e. Pimental et al, 1999) have been called a "serious underestimate of infinity" (Thoman, 1998) and while they have put the issue on the table, they do not appear to be credible. In discussion, national estimates were seen as "back of the envelope" and as AIS have already been shown to be a problem, another number lacking credibility was seen as unnecessary and potentially dangerous. Regional, species or outcome specific studies were seen as more accurate and preferable (i.e. the tools do well at smaller scales).

2. If regional level valuation exercises are accepted as a preferable scale, then is it possible to aggregate up to the national level? This issue caused a significant amount of debate in the group. But, as this issue is similar to the benefits transfer argument, which continues to be thoroughly investigated throughout the academic and policy arena (given the costs of valuation exercises), the debate again delved into an area other than where effort might have been best spent.

3. If a national estimate is deemed necessary, is it possible to create a generalized index for each AIS that can be valued (left to the economists) and used to evaluate the tradeoffs among emerging threats from AIS? Ricciardi suggested using Landsdales's equation as a measure of impact to create this index.

This breakout session ended largely unresolved.

The first breakout session on the second day began with a focus on answering four major questions (related to the above three):

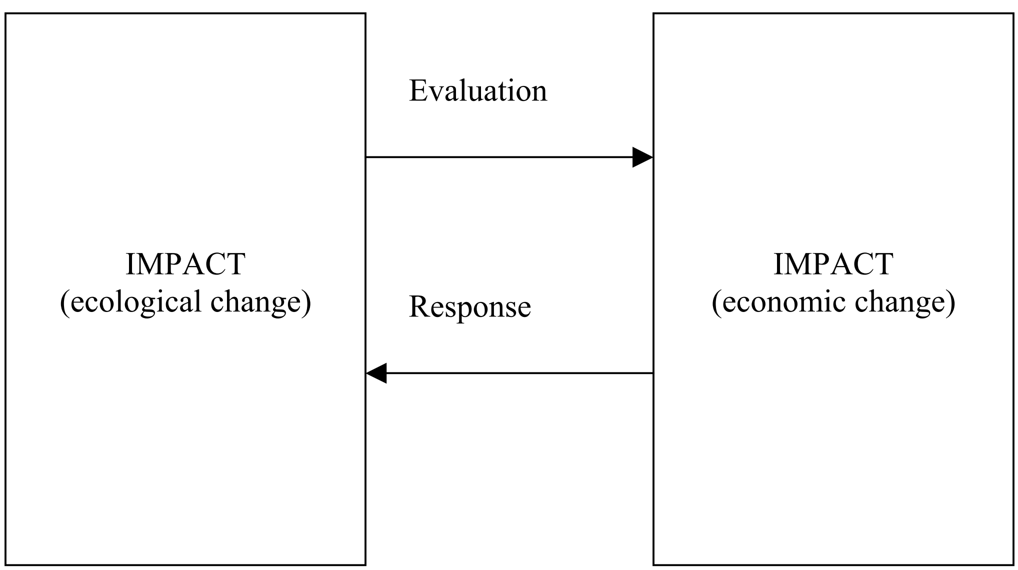
1. The appropriate scale of the analysis: national or regional?
2. Are currently available tools and data sufficient or is it necessary to gather / generate additional data and / or tools?
3. If at a regional level analysis, should the focus be the total effect (across AIS threats) or species specific effects?
4. How do policy makers evaluate a control strategy, and what information do they need to collect?

In the discussion following these questions, the economists stated that there are a standard set of tools available and how you answer a question depends on the situation being studied – there is probably not a single appropriate method for all situations. Perhaps the most important point generated in the discussion is that the important services the ecological and economic systems provide one another have to be clearly identified (i.e. all links between the systems such as ecosystem services and water regulation) and then the impacts on these linkages from the AIS quantified and understood. This discussion seemed again to go down many paths where battles had already taken place (i.e. over valuing ecosystem services).

During this session, the group's resident invasion expert, Anthony Riccardi was asked to identify what he believed to be the most critical issues with regards AIS in general. His priorities were:

1. Synergies – between species after introduction – does the combination result in an amplified or attenuated effect?
2. Does the rate of invasion matter? At what point are there thresholds and irreversibilities?
3. Are impacts predictable? Do certain functional groups of species cause certain types of impacts? If so, can we use an analogy to "benefits transfer" to predict the impacts of an AIS?

Following the debate, the group came together to develop a framework to advance. The approach revolved around a regional systems approach where the system experiences some shock (AIS introduction). From the shock a description of the ecological impacts / changes would be made, with a corresponding description of the ecological linkages to the economic system. The economic impacts would then be translated into the economic system through the ecological linkages. Further, following the economic impacts if human behavior were to be altered then the consequences of this behavioral change must be fed back through the ecological linkage to account for the joint response. At a highly abstract level the following diagram presents this circular process:



Of course if this approach is to be followed, not only must the ecological and economic changes be well specified, but just as important are the linkages between the two systems. If incorrectly specified, the results of the analysis will be biased, and provide no useful information.

While the above description of the workshop breakout sessions is not complete, our finalized approach does offer a structure that may be useful for valuing the impacts of AIS. What it implies is that to accurately predict and evaluate these impacts, the researcher must have a clear understanding of the ecological system, the economic system, the key linkages between the two systems, and how the systems respond to shocks such as an AIS. There are several methods that one may use in this situation, but one promising predictive and policy evaluation tool employs linked general equilibrium systems modeling of both ecological and economic systems. What follows is a general description of the method, which has been applied in Finnoff and Tschirhart (2003a,b, 2005a,b).

From an economist's point of view, our discipline has demonstrated a growing awareness of the vital role ecosystems occupy in economic activity. There are two themes that recur in the literature: 1) ecosystems and economies are jointly determined, and 2) both systems are general equilibrium in nature. Regarding 1), joint determination was emphasized early on by Daly (1968), and more recently Crocker and Tschirhart (1992), Nordhaus and Kokkelenberg (1999) and Settle and Shogren (2002) among others have pointed to joint determination as a key ingredient in introducing biological issues into economics. To this end, some authors have admitted considerably more ecological detail to capture the interplay between the systems (e.g., see Brown and Roughgarden, 1995, Carpenter et al., 1999, Brock and Xepapadeas, 2003, or Tilman, et al., 2005).

Regarding 2), general equilibrium theory has been referred to as the most important development in economics in the twentieth century (Sandler, 2001). The theory has been applied using computable general equilibrium (CGE) models that investigate alternative public policies (Shoven and Whalley, 1992). The CGE modeling approach would explicitly incorporate how invasive species impacts are transmitted throughout the economy through changing prices and incomes, altering regional demands and supplies, and impacting regional welfare. The CGE approach explicitly incorporates the interconnectedness of the economy, and the feedbacks that occur from one economic sector to another. Thus both direct and indirect linkages to the impact of a species are quantified. With multiple and inter-related impacts throughout the ecological system and the economic system in question, a complete description of the impact of an invasive species on the economic system (versus isolated components) is required. Because both ecological and economic systems constantly change in response to changes in the other, the general equilibrium approach that accounts for these feedback loops is necessary.

Although CGE models have been used to address natural resource issues, they usually give short shrift not just to invasive species but to the whole ecological systems in which economies are embedded. An application of CGE models will instead integrate general equilibrium modeling of the ecological system (through a general equilibrium ecosystem model, GEEM, see Finnoff and Tschirhart 2003a,b and 2005a,b) into the CGE economic model. The impact of invasive species could be quantified through direct impacts on individual human behavior (through production and consumption), and through indirect impacts on price and income. The linked CGE / GEEM would allow the ecological consequences to be weighed in economic terms through quantifiable economic impacts on welfare.

In the GEEM model, ecosystems are subject to the same reality that economies are: "They are,…, highly nonlinear complex adaptive systems with extensive interconnections among components" (Arrow, et al., 2000). Plant and animal organisms interact to form trophic structures, diversity-production relationships and nutrient flows that feedback to influence the development of the interactions (Levin, 1998). Including ecological variables in economic analyses without recognizing the general equilibrium nature of ecosystems can introduce errors for the same reasons that partial equilibrium compared to general equilibrium economic analyses can introduce errors in measuring welfare (Kokoski and Smith, 1987).

The methodology proposed for use in assessing the impacts of AIS addresses both themes of ecosystems and economies being jointly determined, and both systems being general equilibrium in nature. The method provides ecosystem service values and corrects the biased welfare values from standard economic analyses. A dynamic economic computable general equilibrium (CGE) model would be linked to a dynamic general equilibrium ecosystem model (GEEM) to quantifiably assess the tradeoffs inherent from the impacts of AIS and policies directed toward either the economic and ecological systems (i.e. assessing the impacts of AIS on ecological and economic systems).

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Report on EPA Economic Impacts of Aquatic Invasive Species Workshop Held July 20-21, 2005, Washington, DC

The goal of the July 20-21, 2005, EPA-sponsored Economic Impacts of Aquatic Invasive Species Workshop was to provide recommendations for valuing the economic impacts of invasive species that have already been introduced into U.S. waters. Here, I summarize my views on the development of an approach to accomplish this goal. Specifically, I focus on an analytical framework or model that can be used as a basis for deriving values for these impacts. As pointed out during the workshop, the theory of valuation is well-developed and so we can apply existing methods to the current problem. But to do this correctly, it is critical to have a model to help us understand what economic and ecological processes need to be estimated, and also how these processes combine to generate economic values. This ensures that all possible values can be accounted for, and that they can be computed correctly.

Green Accounting

Green accounting is a well-established approach for valuing environmental services (Hartwick 1990, Mäler 1991, Weitzman and Löfgren 1997). It has been applied by the UN and others to develop "green" estimates of NNP for many nations – that is, to incorporate the value of changes a nation's natural capital stocks and environmental services into traditional measures of NNP.

Green accounting can also be applied to the invasive species problem. To illustrate this, consider a simple model, starting with the ecological component. Suppose a lake contains an indigenous species of fish whose population level is denoted by N. For simplicity, N is taken to be a scalar, although in principle it could be a vector to represent many fish species. N grows naturally *in situ* according to the density-dependent growth function, $G(N,S,I)$, where S is a stock of habitat that provides environmental services that aid in net fish population growth (i.e., $\partial G/\partial S > 0$), and I denotes the stock of an invading species. The invader is assumed to adversely affect growth via predation or competition for resources (i.e., $\partial G/\partial I < 0$), although some invaders may benefit some species. Finally, growth is diminished by human harvests, h, that might be made for commercial or recreational purposes. Given this specification, the equation of motion for the fish population is

(1) $$\dot{N} = G(N,S,I) - h$$

The habitat S is not harvested, but it is assumed to grow according to the ecological relation $F(S,N,I)$. For instance, S may represent submerged aquatic vegetation (SAV) in the Chesapeake Bay, which provides oxygen, spawning grounds, and a nursery for striped bass and other aquatic creatures. But SAV may be diminished by some invasive species, i.e., $\partial F/\partial I < 0$. The habitat stock does not provide any direct economic benefits (rather, the benefits are indirect via the positive impact on the growth of the economically valuable fish stock), and so it is not harvested. Given this, the equation of motion for the habitat stock is

(2) $\dot{S} = F(S, N, I)$

Finally, to complete the ecological model, invasive species grow naturally after they are introduced. The equation of motion for invaders is

(3) $\dot{I} = A(I, N, S) - z$

where *A* represents net growth and *z* represents the harvest or other control applied to manage this population.

Now consider the economic component of the model. Harvests of indigenous fish yield recreational benefits (a non-market use value) and/or commercial benefits (a market use value) of *B*(*h*), while the costs of harvesting are denoted *C*(*h,N*). The indigenous fish may also be valued for intrinsic purposes – a non-market, non-use or existence value, *U*(*N*).

In contrast, the invaders have no recreational or commercial value, although there is a cost of controlling the *in situ* population, denoted *W*(*z,I*). There could also be disutility associated with the existence of the invader, denoted *V*(*I*). Finally, the invader may cause other economic impacts, such as depreciation of capital or more direct losses in the economic benefits accruing to industry or some other sectors. Denote the net economic benefits to some industrial sector by *M*(*K,I,y*) (with $\partial M / \partial K > 0, \partial M / \partial I < 0$, and $\partial M / \partial y < 0$), where *K* is capital and *y* is investment. Capital accumulation is represented by the equation of motion

(4) $\dot{K} = y - \delta(I)K$

where $\delta(I)$ (with $d\delta/dI > 0$) represents the depreciation rate, which is increased under the presence of an invader.

Given this specification, we can define economic net benefits at any point in time to be

(5) $NB = B(h) - C(h,N) + U(N) - W(z,I) - V(I) + M(K,I,y)$

Note that these benefits represent a combination of market and non-market values, as well as use and non-use values. Some values depend directly on the invader, while other values may only depend indirectly on the invader – specifically, on the level of the invader in the previous period as this would affect the current value of the other state variables (similarly, note that the indirect economic impacts of current invaders will be realized in the future).

The expression given by equation (5) only represents a *partial* value of (use and non-use) economic activity in the lake at a particular point in time. Equation (5) does not account for the intertemporal effects of current period decisions, and the value of these intertemporal effects must be accounted for to provide an accurate estimate of the *total* value of economic activity at a point in time. Green accounting can be used to value both current activity and the associated intertemporal effects. The approach involves deriving "prices" for the intertemporal effects and adding these prices multiplied by the changes in the state variables to equation (5). But in order to derive the appropriate intertemporal prices, assumptions must be made about how economic choices are made. For simplicity, assume all choices are made efficiently, so that we can focus on the social planner's problem. Economic efficiency is a strong assumption, and I discuss relaxing it below. But the concept is useful in that it provides an estimate of the maximum welfare that can be generated. When we discuss invasion costs, the efficiency assumption means that we are deriving the efficient level of social costs, although these are not necessarily minimized as we demonstrate below.

An economically efficient allocation of resources solves the following problem

$$(6) \qquad \max_{h,z,y} \int_0^{\infty} [B(h) - C(h,N) + U(N) - W(z,I) - V(I) + M(K,I,y)]e^{-rt}dt$$

s.t. (1) – (4)

where ρ represents the discount rate. The associated Hamiltonian is

$$(7) \quad H = B(h) - C(h,N) + U(N) - W(z,I) - V(I) + M(K,I,y) + \lambda_N \dot{N} + \lambda_S \dot{S} + \lambda_I \dot{I} + \lambda_K \dot{K}$$

where λ_i represents the co-state variable or shadow price associated with the state variable *i* (λ_i>0 for *i*=*N*,*S*,*K*; λ_i<0 for *i*=*I*). The Hamiltonian is the value of economic activity at time period *t*, accounting for current economic activity and the value of the intertemporal impacts of this activity. Denote $H^* |_{I>0}$ to be the optimized value of the Hamiltonian in the invaded state (*I* >0) and denote $H^* |_{I=0}$ to be the optimized value of the Hamiltonian in the non-invaded state (*I*=0). As economic welfare must be greater in the non-invaded state, the total costs of the invader (including damages and control costs) are

$$(8) \qquad TC = H^* |_{I=0} - H^* |_{I>0}$$

(note: the marginal value of an invasion is $\partial H^* / \partial I |_{I>0}$). Clearly, all of the relations defined above must be estimated and plugged into the Hamiltonian (7) and the corresponding solution process in order to derive the costs in (8).

In reality, resources are not allocated efficiently. Therefore, it may be appropriate to develop second-best green accounting measures that try to derive the co-state values based on how resources are actually managed (e.g., Aronsson and Löfgren 1998; Horan et al. 2000). It is important to note, however, that costs might be lower in an inefficient world. For instance, if the indigenous fishery is operated under open access, then society would apply a shadow value of zero to the indigenous stock ($\lambda_N = 0$) and there would be no value to invader-induced intertemporal changes in the indigenous stock!

Implementation

The model can be implemented nationally or regionally. For instance, Hrubovcak et al. (2000) develop a national model to analyze agriculture's environmental impacts. However, significant ecological details may be lost at the national level. Even a regional analysis can be highly complex, involving many indigenous and non-indigenous species, and many economic sectors. A computable general equilibrium (CGE) model is often used for dynamic regional economic analysis, and it can be modified to incorporate resource stocks (including invaders) for the purposes of green accounting. Considerable estimation might be needed to parameterize the economic and ecological components of a regional model. A benefits transfer approach might be useful for this. I am not an expert in benefits transfer or CGE modeling, so I leave it to other Workshop participants to present their views on what is required.

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Brooks Kaiser - Gettysburg College

Report on EPA Economic Impacts of Aquatic Invasive Species Workshop Held July 20-21, 2005, Washington, DC

Current aggregated estimates of invasive species damages (e.g. Pimentel et al., 2000) do not adequately incorporate economic theory, in part because economists did not prepare them. One major difficulty with the lack of theory is that it is almost impossible to know if the widely cited figure of approximately $137 B/year for invasive species damages in the U.S. is an underestimate or an overestimate of the true damages. A second difficulty presented by the lack of a comprehensive bio-economic framework for calculating the damages is that human factors, as well as the imperfections of markets surrounding the imposition of invasive species damages, are not made an explicit contingency in the damage estimates. In seeking a quantification of damages from aquatic invasive species in the U.S., the Environmental Protection Agency (EPA) has a chance to remedy these problems.

There are several points upon which economists and ecologists seem to agree regarding the assessment of invasive species damages. First, regional assessments will provide better insights into damages and appropriate policy than a national figure. This is due both to the wide variability of ecosystems (natural capital stock) and their services (flows from the natural capital stock) and to the amount of uncertainty surrounding both ecological linkages and economic damages, particularly non-market damages. Second, losses from the degradation of existing ecosystem stocks and services are likely to be significant in magnitude, though difficult to measure compared to market damages. Third, the problem of invasive species is vast and almost amorphous, encompassing a variety of economic and ecological activities.

There is, in addition to this broadness and uncertainty of scope, an awareness that time is of the essence since the human activities that promote aquatic invasive species damages, such as international trade or leisure and commercial activities that promote aquarium or aquatic garden releases, are increasing at an increasing rate as global economies expand, and the rate of ecological change appears to be accelerating dramatically as well. As such, with limited resources to address the growing problem, we should focus on analyzing the cases that will most effectively inform decision-making in a timely manner. Thus, quality estimates of regional damages from well-studied invaders should be the first step in assessing the damages.

Quality estimates are ones that use the existing information in a clear and realistic manner, including both ecological and economic uncertainty through appropriate confidence intervals. With respect to economic tools, quality estimates will meet two standards. First, they will be calculated within a framework that addresses the human dimension of the damages, such as a green accounting measure that allows for economic as well as ecological feedback mechanisms, dynamic linkages, and policy assessment of any control measures. Second, estimates will clearly address their limitations, in so doing creating error bounds that can, by further ecological and economic research, be shrunk over time. The error bounds should serve both to underscore the uncertainty of the damages as well as to direct research into areas most likely to reduce this uncertainty.

While market damages such as clogged pipes from zebra mussels should not be particularly controversial across constituencies and should be used to help determine a lower bound for damages, reductions in ecosystem services are likely to generate, on average, at least as much damage, if not considerably more, than market goods, and need to be included. When addressing non-market valuation, it may be useful to remind oneself that the marginal benefits of a good or service reflect both the willingness and the ability to pay (in the sense of relinquishing its opportunity cost) for this good or service. To wit, two distinct approaches to valuing non-market services have considerable merit, and for results that best advise policy, should probably be developed simultaneously and iteratively.

The first is to create extremely solid estimates of the ecological linkages between an invader or set of invaders to the expected change in an ecosystem and to the expected change in values derived from that ecosystem. An example of this might be to first establish clearly the interactions between zebra mussels, native isopods, and whitefish populations in the Great Lakes. Then, with this connection well understood, to add the economic dimension by assessing the change in behavior of whitefish fishermen associated with the change in the whitefish population and the associated change in social welfare. A complete model would include the cyclical effect of the change of the human's behavior on the whitefish populations (See Shogren and Settle, 2002, for a comparable example). Notice that an invader might enhance some aspects of economic activity as well as detract from them. These benefits should be included in any comprehensive assessment. In targeting projects within this subset, priority should rest on those cases where damages are expected to be highest a priori.

The benefits of modeling and assessing the damages in this way is that the estimates are well-founded in the ecology and economy under investigation, and thus any resulting estimates will fairly accurately reflect the economic damages in dollars that might easily be compared for policy purposes. The costs include the obvious limitation that the research can only address a small portion of a much larger problem, and also the limited transferability of the estimate to other cases. Given the consideration of timeliness, this technique will best be used in cases where the ecological and economic research is well underway. There appears to exist, however, a considerable amount of basic ecological research that could be tied to invasive species activity and then connected to existing economic methodology, so this approach could result in a good foundation for lower-bound estimates of regional damages. In particular, one might imagine that this methodology best uncovers the actual opportunity cost of fighting invasive species vs. accommodating them.

The second approach is to attempt to address the broadness and uncertainty of scope directly through generalization, and to leave the assessment of opportunity cost in the hands of the citizen-voter. In this strategy, values are determined for the natural state of things in a broad sense by soliciting willingness-to-pay estimates for marginal changes in the quality of generic environmental stocks and their associated ecosystem services. Since the ecological linkages and economic services associated with invasive species are often only minimally understood even by the experts, this methodology speaks more to addressing the wants of the citizenry, and the values solicited may bear little if any relation to the experts' opinion of the losses, particularly losses from change to complex ecological processes. The values, however, will reflect the willingness of the taxpayers to bear the burden of fighting invasive species vs. accommodating them, as they understand it.

I would expect these results to vary greatly with the level of information held by those whose opinions are solicited, and this expectation of information bias again highlights the importance of directly incorporating the human factor into damage estimates. Our choices already reveal values; values may conflict across constituencies as well. Wide divergence between values obtained in the first method vs. the second method would suggest that one important goal in the calculation of damages (which will be used to formulate policy) be to initiate improved public debate regarding the actual nature of damages from invasive species so that the choices regarding invasive species policies are not made by default, by a single constituency's preferences, or in ignorance.

Additional criteria that should be considered in targeting the direction of regional estimates and scientific research include the way in which the burden of damages is expected to be divided; the more diffuse the burden, the more important a comprehensive estimate, since individual actions to reduce the damages will be less likely. Additionally, research on invasions that are at the beginning of their impacts, or that present a high likelihood of spreading to other regions, should be a priority. This is particularly important for aquatic invaders, where control once an invasion is past an early stage of establishment is extremely difficult, if possible.

In summary, the lessons of the workshop seem to be: (1) work with what we know, first, at the regional level, then expand; (2) keep in mind feedback, human interactions, and endogeneity; (3) allow for both benefits and costs of change wrought by invasive species, and allow for them to differ across constituents; and (4) account for uncertainties and institutional and market structures explicitly and use them to guide research and estimation.

Brian Leung- McGill University

Report on EPA Economic Impacts of Aquatic Invasive Species Workshop Held July 20-21, 2005, Washington, DC

The objectives of this workshop were to determine methods of estimating the cost of invasive species at the national and regional levels. This type of "brain storming" session is useful for providing general directions for the types of analyses and research that might be useful. However, we should recognize that for any suggestions made, there will be gaps and subtle logic errors that will need to be overcome.

As the first step, there was a call to identify the major components of damage that might be used to measure the impact of invaders. This could be useful to focus our efforts, as estimating each component will be time consuming and costly. In all likelihood, it will not be feasible to measure or know about all the effects invaders have on society and the environment. The selection of impacts was based on several criteria including the importance to society, the likelihood that AIS would affect that component, and the feasibility to measure the component of interest and the damage caused by the AIS. Although the most important components of damage differed slightly between groups, some of the commonly chosen ones included biodiversity, human health, damage to natural and physical capital, recreation, etc. In reality, the importance of each of these components will differ depending on species, geographic region, and stakeholder group.

There was some discussion about how to measure the value of these factors. I will leave the discussion of valuation primarily to the economists, except to highlight the suggestion to use the large body of existing reports and research that have already been developed that either already provides cost estimates and/or identify the societal importance of each component (e.g., the Millennium Assessment on the relevance of biodiversity).

There was general agreement that starting with a national estimate of the cost of AIS may not be as useful as obtaining regional estimates. Firstly, the presence and consequences of a given species will be likely regional. The interest of stakeholders in the impacts is likely more pronounced at a regional scale as well. The national estimate of the cost of invasions would then be the sum across regions.

This leaves the large unanswered question of how to actually measure the effect of AIS on metrics of interest (e.g., biodiversity or the abundance of a commercial fish stock). The important components included effect of AIS on ecosystems, feedback between ecosystems and AIS, human feedbacks with AIS presence and with changes in ecosystems, cost-benefit analysis of different strategies for managing AIS. There were several ways that estimation could be approached, but it would generally fall into two categories: statistically using historical data on previous invasion impacts of a given species, and the construction of mechanistic models that capture the interaction between AIS, other species of interest, the environment, and the human interactions. Neither of these approaches is without flaws.

The statistical approach would be based on historical damage in measured areas to extrapolate to a wider geographic region where impacts have not been estimated. Relations that might be obtained could include ecosystem values before and after invasion, invaded sites compared to a number of "reference" sites, and correlations between invader abundance and a metric of interest (e.g., biodiversity, fish stock). Each approach has limitations. Temporal correlations (i.e., some other factor changed at the same time as the invader was introduced) may confound the before and after paired comparison. The identification of reference sites may be difficult. There is the implicit assumption that the reference site differs from the invaded ones only in terms of the effects of invasion. This might not be true given that we would not experimentally control for site selection.

The conditions in the new, unmeasured, area could be different from the original area such that the damages may differ from historical levels. The degree of damage should be viewed as a distribution, the value of which is conditional upon various factors. Thus, there is inherent uncertainty in the level of damage that might occur. Part of the job of scientists would be to identify the factors (statistically) that influence the magnitude of damage. If there is only a single estimate of damage, the distribution would need to be from a Prior distribution (i.e., Bayesian statistics). In addition to uncertainty, there is a potential problem of bias. It is conceivable and possibly likely that the sites measured are not representative of the universe of sites that are of interest (e.g., one might choose the highest impact sites or the sites that are of special interest to society).

Human responses could be incorporated if there were a few data points where human behavior could be matched to invasions status, or state of an ecosystem (e.g., changes in fishing pressure when fish stocks decrease due to an invader). If multiple data points exist, this relation could be fit in the same way as for the effect of invaders (e.g., another dimension in a multiple regression model). The major problem with statistical techniques is that they only provide static estimates of the effects of invaders and the response of society. In reality, these interactions are likely dynamic.

Despite the problems mentioned above, statistical techniques may provide us with our best option of estimating damages across a wide geographical range, given available information. As such, there may be several levels that are worth considering, each with different levels of uncertainty. 1) Provide a cost of invaders estimate for measured sites. 2) Provide a cost of invaders estimate extrapolated to an entire basin (e.g., damage estimates within the Mississippi Basin, extrapolated to the whole basin). 3) Provide a cost estimate across geographical regions. 4) Provide a cost estimate of different unmeasured AIS, based on characteristics of measured AIS. The degree of uncertainty obviously increases, but these options may still provide the best estimate in the absence of intensive sampling, or until intensive sampling can be conducted. With option 2, there is the implicit assumption that the sampled points are representative of the universe of interest (i.e., the basin). This seems unlikely for options 3 and 4: a single basin will provide a single point in the universe of basins, the species measured will provide a single point in the universe of species. The basins or species chosen may not be randomly chosen from all basins or species of interest. Therefore, the distributions (or universes) need to be considered (this is related to the base rate effect).

Predictions could be validated in a number of ways. 1) by subdividing the data, building the model with a subset and trying to predict the remainder (e.g., cross-validation). 2) by empirical studies, choosing specific sites where the damage is not currently known but will provide the most information. The degree of damage would be compared to those predicted by the statistical model.

Another method may be to develop detailed mechanistic models of species interactions and species/environment interactions. Given available data, these will be difficult to parameterize convincingly. Data will likely come from heterogeneous sources, some laboratory experiments, and some field studies. Further, they will likely represent only a single point estimate of a parameter value. Given the expected heterogeneity between sites and environments, this will be problematic for the same reasons discussed above. Thus, we may have little confidence in the parameter values or their interactions that we put into a model.

The advantage of the mechanistic approach, however, is that temporal dynamics and feedbacks are more naturally incorporated. Changes in human behavior could be incorporated in terms of rates of resource usage (or protection, etc).

Potentially a hybrid approach may be useful. The statistical approaches could be used to estimate the current static costs, the mechanistic approach may provide a rough estimate of future costs, when we are trying to determine optimal management strategies or expected cost benefit relations over time. Despite the limitations of each approach, the appropriate question is whether the analysis is better if the information is excluded from the analysis or the imperfect analysis is used.

David Lodge - University of Notre Dame

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A focus on aquatic ecosystems is appropriate and strategic because of the unique challenges present in aquatic (vs. terrestrial) ecosystems. The benefit:cost of management, especially prevention, of aquatic ecosystems is likely to be extremely high because impacts are

- often irreversible locally because killing the target species kills lots of non-target species—especially for animals (plants are easier to kill selectively);
- without management, species and their impacts spread and get worse;
- the clear boundaries of many aquatic ecosystems make prevention of spread from one water body to another possible with modest investments (e.g., in inspection stations).

A review of zebra mussel impacts to-date and their continuing spread across the U.S., might provide a useful case study to develop in the introduction of a report that provides the rationale for your recommendations within EPA. It illustrates several important features of the general issues, including various pathways (ships to the Great Lakes, canals, natural rivers, and cross-country recreational boaters beyond the 100th meridian), and both market and non-market costs.

My overall recommendation would be to work toward a competitive grants program to stimulate regional analyses of the costs of invasive species using existing ecological information and existing tools of economic valuation, including willingness-to-pay (WTP) valuation methods. Such analyses must go beyond the price X quantity approach of earlier studies, to generate more sophisticated estimates that also include explicit attention to uncertainties. Some studies should incorporate cost estimates into regional computable general equilibrium economic models (CGE) in order to explore the economy-wide impacts and potential economic feedbacks of invasive species.

A focus on regions, pathways, and species where direct, market-measured impacts are large will be most compelling. Nevertheless, regional—or even national—WTP surveys should complement regional market-based valuations. It is very important to call for greater inclusion of non-market valuation in invasive species studies because for many (perhaps most) species the non-market impacts will be greater than the market impacts.

Policy-makers will be more compelled by impacts on explicitly identified ecosystem goods and services (rather than on "biodiversity" *per se*). For most non-ecologists, "biodiversity" means number of species, and the number of species is not what usually matters to people. What usually matters to people, especially in terms of the provision of ecosystem goods and services, is the local and regional availability of species that are sources of goods or that provide services.

Do not encourage investigators to create new frameworks for ecosystem goods and services. Rather encourage the use of the Millennium Ecosystem Assessment's approach. See the first MA volume entitled "Ecosystems and Human Well-being: a Framework for Assessment," Ch. 2 ("Ecosystems and their services"). Figure 2.1 in this chapter (attached) has the list of a manageable number of ecosystem services that became the standard list that all the rest of the MA exercises. This and other MA volumes/chapters are available to download at www.millenniumassessment.org

Investigators should be encouraged to be opportunistic/pragmatic, rather than comprehensive (impossible). That is, rather than extend data and methods to the point of incredulity, investigators should base analyses on ecological data from those pathways and species for which the most appropriate data exist. In addition, use of ecological models to generate plausibly bounded scenarios of ecological impacts for input into economic models should be encouraged where good data exist for some foodweb components but not for others.

To maximize their impact, studies on impact costs should be couched in terms of potential management and policy responses. If studies don't at least suggest which management alternatives might lower damages, then the desired result (greater investments in cost effective management like prevention) will not be achieved.

Lars Olson – University of Maryland

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Aquatic ecosystems encompass both freshwater and coastal waterways and include lakes, rivers, ponds, streams, estuaries, and wetlands. These ecosystems provide a vast variety of valuable services to society including water for drinking, municipal, industrial and agricultural uses, fishing, recreation, shipping, flood control, nutrient recycling, habitat, and aesthetic amenities. The introduction of aquatic invasive species can have adverse effects on these and other valuable services that people derive from aquatic environments. Determining the economic impact of these effects is important both to improve our understanding of the consequences of invasive species and to develop better management policies.

In evaluating the economic impacts of aquatic invasive species it is useful to distinguish between their impacts on ecosystem services and ecosystem functions. The distinction between ecosystem services and functions is made nicely by Boyd and Banzhaf (2005) who define ecosystem services as "the end products of nature that yield human well-being." In contrast, ecosystems functions are the biological, chemical and physical interactions that make up an ecosystem. Because economic impacts of invasive species are those impacts that affect human welfare, valuation of the impacts must necessarily focus on the effects of invasive species on aquatic ecosystem services.

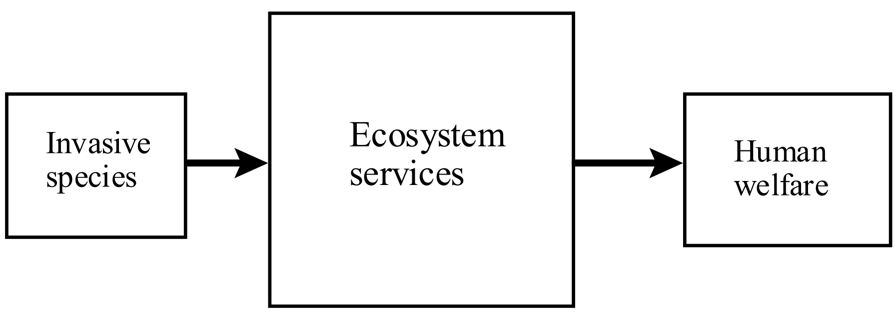

Figure 1.

One way to evaluate the impacts of aquatic invasive species is to take a species up approach that first identifies all invasive species of concern, then measures the impact of each species on ecosystem services, and last, evaluates the economic consequences of the impacts. This species up approach seems best suited to local, small-scale situations where there are few invasive species, where the interactions between invasive species are minor, and where aggregation of the impacts across species does not pose problems.

A second approach is to start by identifying the ecosystem services that are impacted by invasive species, and then measure and evaluate the impacts of invasive species on these services. This can be thought of as an ecosystem services down approach. It has the advantage that there is no need to associate impacts with individual species. Instead, an ecosystem services down approach focuses attention the cumulative impacts of invasive species on ecosystem services regardless of whether they are caused by one organism or the combined effects of many.

Another consequence of this approach is that attention is naturally focused away from all non-native species onto the subset that is invasive in the sense that they have an impact on ecosystem services. This approach seems better suited to evaluation of impacts on a larger scale, where the number of invasive species involved may preclude analysis on a species by species basis, and where there multiple invasive species have non-additive, joint impacts on ecosystem services.

There exist well established methodologies to value aquatic ecosystem services. These include production function approaches that can be used to measure the how aquatic invasive species impact ecosystem services that are inputs to the production of goods and services with market value, travel cost methods that can be applied to measure how aquatic invasives impact the recreational value of ecosystem services, hedonic pricing approaches to measure how changes in ecosystem services induced by invasive species affect real property values, as well as contingent valuation methods that can be used to measure non-market changes in the value of ecosystem services caused by invasive species. A recent National Research Council report Valuing Ecosystem Services: Toward Better Environmental Decision-Making (NRC, 2004) provides a thorough discussion of the methods that have been developed to measure the value of aquatic ecosystem services, how they can be applied, and their advantages and disadvantages. There are a number of significant challenges that must be confronted in developing methods for evaluating invasive species impacts. One challenge arises from the fact that invasive species impacts are intertemporal in nature. This is because a marginal increase in the invasion size today has two effects on the social cost of an invasion. It raises damages today and, ceteris paribus, it results in a larger invasion in future periods, thus increasing future damages. The lifetime impact of an increment to the invasion today is the discounted stream of future (marginal) damages compounded by the growth in the invasion associated with that increment, or

$$D_x(x_0) + \sum_{t=1}^{\infty} \delta^t D_x(x_t) \prod_{j=0}^{t-1} f_x(x_j)$$

, where x_t is the size of the invasion in period t, $D_x(x_t)$ is marginal damages, $f_x(x_t)$ is the growth rate in the invasion and δ is the discount factor.

Thinking about the economic impacts of invasions in this way highlights three related issues. First, a simple evaluation of current damages underestimates the true impact of an invasion. Future damages must also be considered. Second, small invasions can have large impacts when these impacts are measured over a long time horizon. Third, while it may be possible to estimate current marginal damages and current invasion growth rates, accurate estimates of future marginal damages and growth rates may be more difficult to obtain.

A second important challenge is to separate invasive species impacts from other factors that damage environmental services. The Chesapeake Bay ecosystem provides a useful context for this discussion. It provides most of the valuable environmental services listed in the introduction. In 2001, the Invasive Species Workgroup of the Chesapeake Bay Program identified and ranked a number of invasive species that have significant impacts on the Bay, or are expected to impact it in the near future. But invasive species are not the only source of environmental change for the Chesapeake Bay. The Bay is also affected by nutrient loading, increased development in the watershed and many other factors. Because invasive species and these other factors affect the environmental services provided by the Bay in complex ways, this complicates the task of measuring the economic impacts of invasive species.

A third challenge is that it is necessary to define the state of the environment relative to which the impacts of aquatic invasive species are being evaluated, both in the present and in the future.

A fourth challenge is that uncertainty characterizes many aspects of the problem of evaluating invasive species impacts. There is uncertainty about the potential for invasive species to become established, uncertainty about their rate of growth and spread, and uncertainty about their economic consequences. The fact that uncertainty exists does not mean we should not attempt to confront the problem. It is important to recognize that uncertainty exists, and whenever possible, to incorporate it into the analysis of invasive species impacts.

A fifth challenge is that the impacts of an invasive species are likely to be a nonlinear function of the invasion size. This means that it is important to not only measure the total impact, but also the marginal economic impact. Knowledge of the marginal impact provides valuable information that can be used to evaluate and prioritize different management alternatives, and determine their appropriate size.

Finally, it must be recognized that, in spite of the negative connotation of the term "invasive", not all impacts of invasive species are negative. A careful evaluation of the economic impacts of aquatic invasive species should consider positive impacts as well as the negative ones. In conclusion, there are both positive and normative reasons to improve our understanding of the economic impacts of aquatic invasive species. The methodological foundation in both ecology and economics exists to begin this process. At the same time, there are a number of significant challenges. Future research that addresses these challenges can improve our ability to measure the impact of aquatic invasive species on ecosystem services and our ability to evaluate the economic consequences. This, in turn, will lead to better management of invasive species problems.

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Richard Park - Eco Modeling

Report on EPA Economic Impacts of Aquatic Invasive Species Workshop Held July 20-21, 2005, Washington, DC

As a sequel to the discussions held July 20-21, 2005, in Washington DC, I am providing additional discussion and clarification of ecological issues raised at the Economic Impacts of Aquatic Invasive Species workshop. My perspective is offered as an ecological modeler who has some experience in simulating the impacts of invasive species.

Group 5 identified the following endpoints in their order of importance: biodiversity, habitat degradation, water quality/quantity, food web (including fisheries), and costs. I suggest we narrow these down, in one or more pilot studies, to the following more readily simulated and monetized endpoints:

- biomass of desirable recreational and commercial fish
- biomass of commercial shellfish in saltwater ecosystems
- biomass of rooted and periphytic vegetation (aquatic "weeds")
- water quality
  - water clarity as Secchi depth
  - biomass of taste- and odor-producing algae.

Additional regulatory water quality endpoints could include dissolved oxygen, nitrogen and phosphorus, and chlorophyll *a*.

All these can be simulated by any one of several ecosystem models. Because I am most familiar with AQUATOX, I will use it as an example. The AQUATOX model is a general ecological risk assessment model that represents the combined environmental fate and effects of conventional pollutants, such as nutrients and sediments, and toxic chemicals in aquatic ecosystems. It considers several trophic levels, including attached and planktonic algae and submerged aquatic vegetation, invertebrates, and forage, bottom-feeding, and game fish; it also represents associated organic toxicants. The model was first developed in 1987 and has been continually expanded and enhanced since then (Park et al. 1988, Park 1990, Park et al. 1995, U.S. Environmental Protection Agency 2000, U.S. Environmental Protection Agency 2001, Park and Clough 2004). Release 3, which is in beta test now, is capable of simulating estuaries as well as linked segments such as river reaches. The model has been used to simulate the impacts of *Corbicula*, the Asian clam, *Potamopyrgus*, the New Zealand mud snail, and *Hydrilla,* an aquatic weed. I will use the latter two as examples.

The New Zealand mud snail (NZMS) is prolific and spreading quickly throughout the West. Density can be 750,000/m^2, with biomass near 30 g/m^2 (Hall, www.uwyo.edu/bhall/snails.html). The exponential increase in numbers at given sites and geographic spread both downstream and upstream are well illustrated with data from the Lower Boise River, Idaho (Figure 1). Sufficient data were available from Hall et al. (2003) to parameterize AQUATOX for this exotic species. In particular, when compared to native snails, it is characterized by:

- higher fecundity
- lower predation pressure
- higher consumption rates
- lower assimilation rates

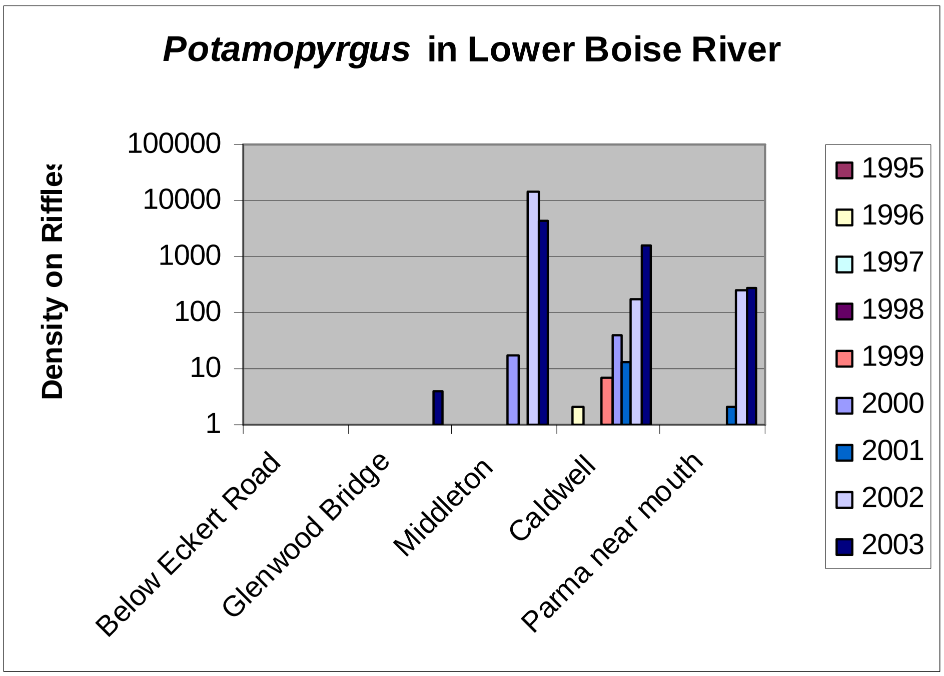

Figure 1. Exponential increase and spread of the New Zealand mud snail observed in the Boise River ID (data from MacCoy, 2004). Downstream is from left to right in the diagram.

Comparison of simulations of the upper Cahaba River, Alabama, suggest the tremendous impact of this invasive species. In the control simulation without NZMS we see abundant periphyton and *Corbicula*, an invasive clam that is well established in that ecosystem (Figure 2).

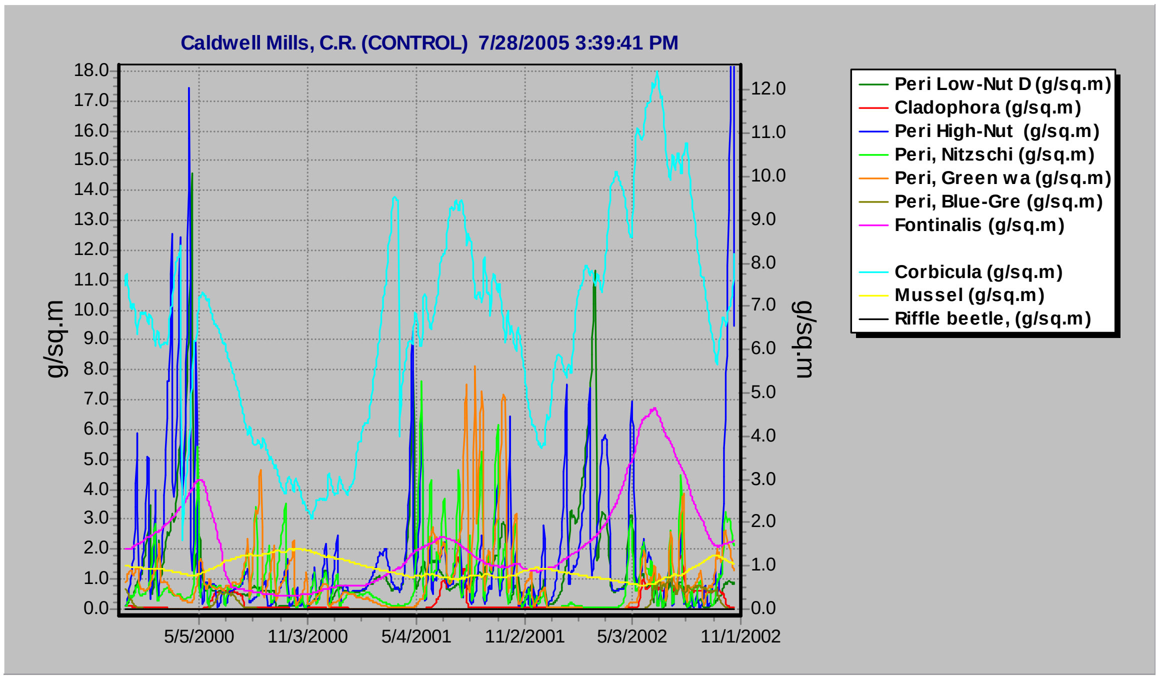

Figure 2. A calibrated simulation of the Cahaba River AL ecosystem showing predicted biomass of various organisms.

In the perturbed simulation, with NZMS added, we see loss of periphyton and considerable biomass of NZMS and *Corbicula* (Figure 3).

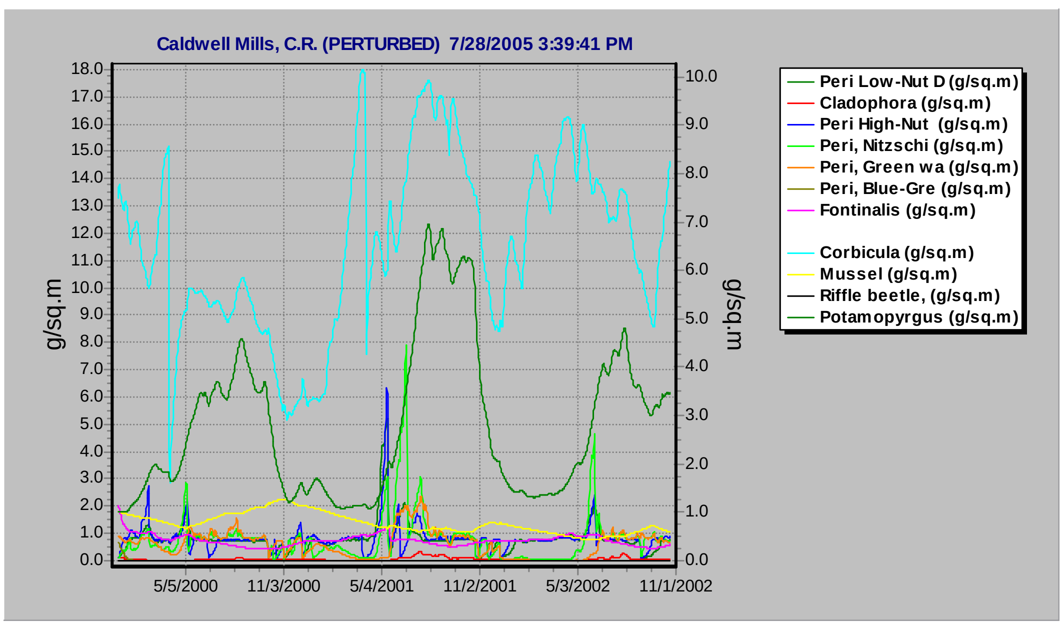

Figure 3. A simulation of the Cahaba River AL ecosystem with the same conditions as Figure 3 but with the addition of the New Zealand mud snail *Potamopyrgus*.

Difference graphs that portray the percent difference between the perturbed and control simulations (Figure 4) indicate that periphyton, moss (*Fontinalis*), and mussels decline. *Corbicula* actually increases because of the increased detritus.

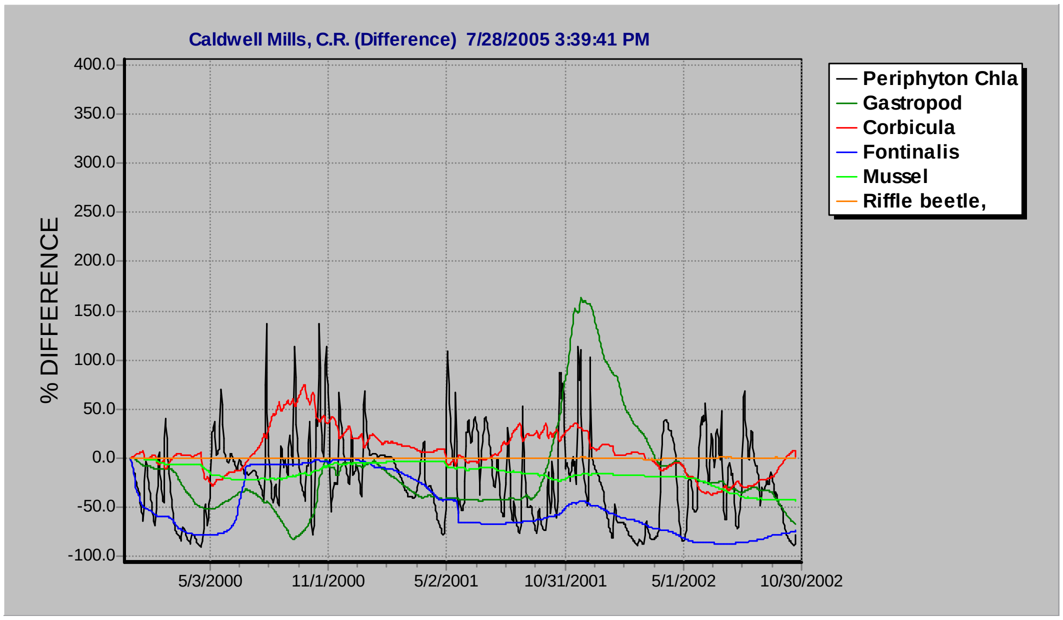

Figure 4. A difference graph showing the predicted relative decline of periphyton, moss, and various invertebrates with a hypothetical invasion of the New Zealand mud snail in the Cahaba River AL.

The greatest abiotic effect of the NZMS is in the increase of labile and refractory detrital sediments and the fluctuating ammonia. This detritus is partially recycled through the snails and *Corbicula* and in part it is swept downstream to impact lower reaches.

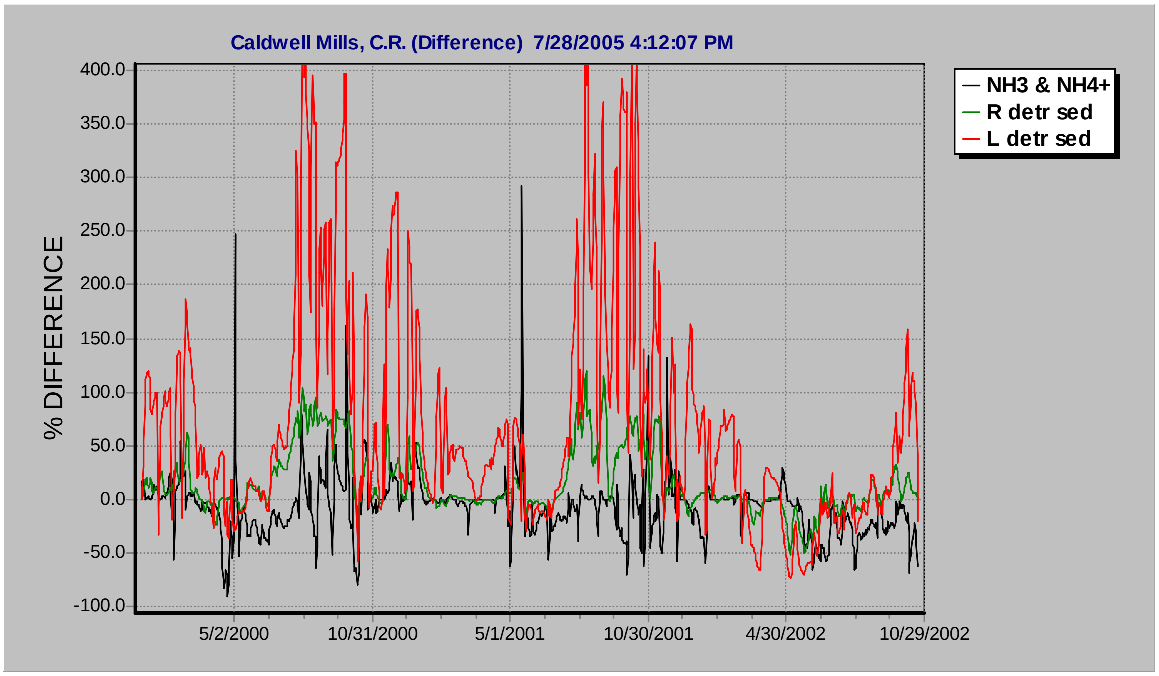

Figure 5. A difference graph showing the predicted relative increase in detritus and fluctuating ammonia with a hypothetical invasion of the New Zealand mud snail in the Cahaba River AL.

The biggest impact is on the fish, as seen in a Steinhaus similarity plot (Figure 5). A difference plot shows that young and adult bass are affected the most (Figure 6).

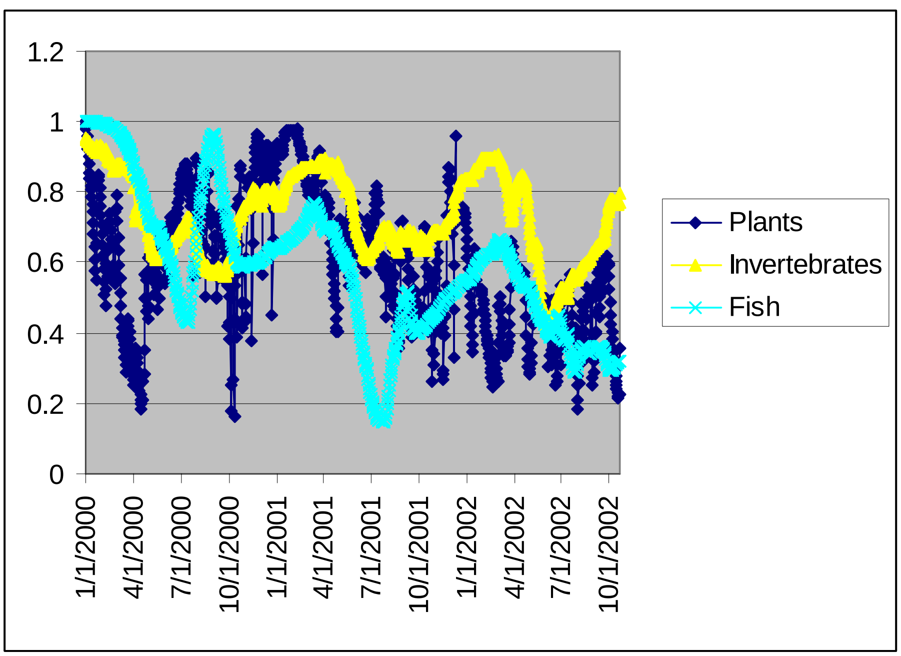

Figure 6. A plot of the Steinhaus community similarities with and without the New Zealand mud snail.

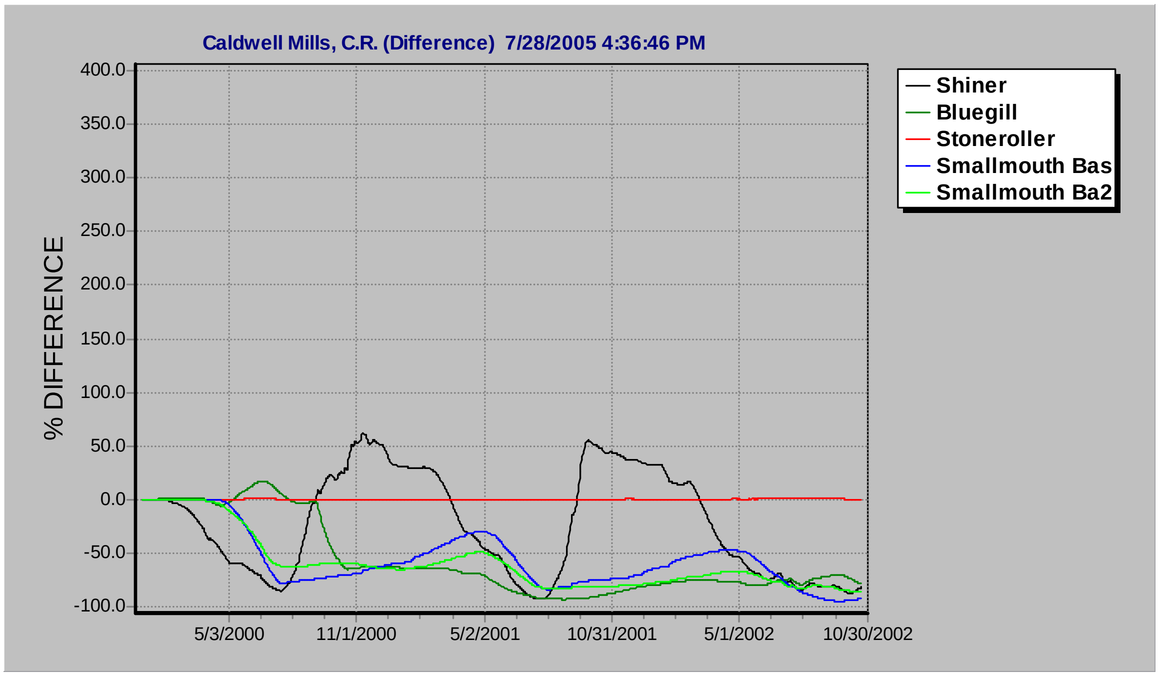

Figure 7. A difference graph showing the predicted relative decline of various fish with a hypothetical invasion of the New Zealand mud snail in the Cahaba River AL.

A second example involves the invasive aquatic weed *Hydrilla.* As Best and Boyd (1996) write: "*Hydrilla* is considered a nuisance aquatic plant in parts of the United States, since it may interfere with human utilization of freshwater resources, become aesthetically displeasing, or displace desirable indigenous community. From a shoreline perspective, the biomass in a dense 'mat' of submerged weeds appears to be enormous." The macrophyte was first noted in Clear Lake, a large lake in northern California, in 1994 (Suchanek, 2002). In the last several years there has been a fairly successful effort to eradicate it from that lake.

In part for this paper, AQUATOX has been used to analyze the possible impacts of *Hydrilla* on the Clear Lake ecosystem and to forecast the recovery following treatment with the aquatic herbicide Sonar™ (fluridone). The model had already been calibrated to represent Clear Lake for the period of 1970-1972, so *Hydrilla* was symbolically added to that simulation, although its actual introduction was twenty years later. As seen in Figure 8, high predicted biomass of *Hydrilla* (to 210 g/m^2) could suppress the usual blue-green algal blooms and could cause a decline in the excellent bass fishery. In essence, nuisance algal blooms would be replaced by nuisance weed growths.

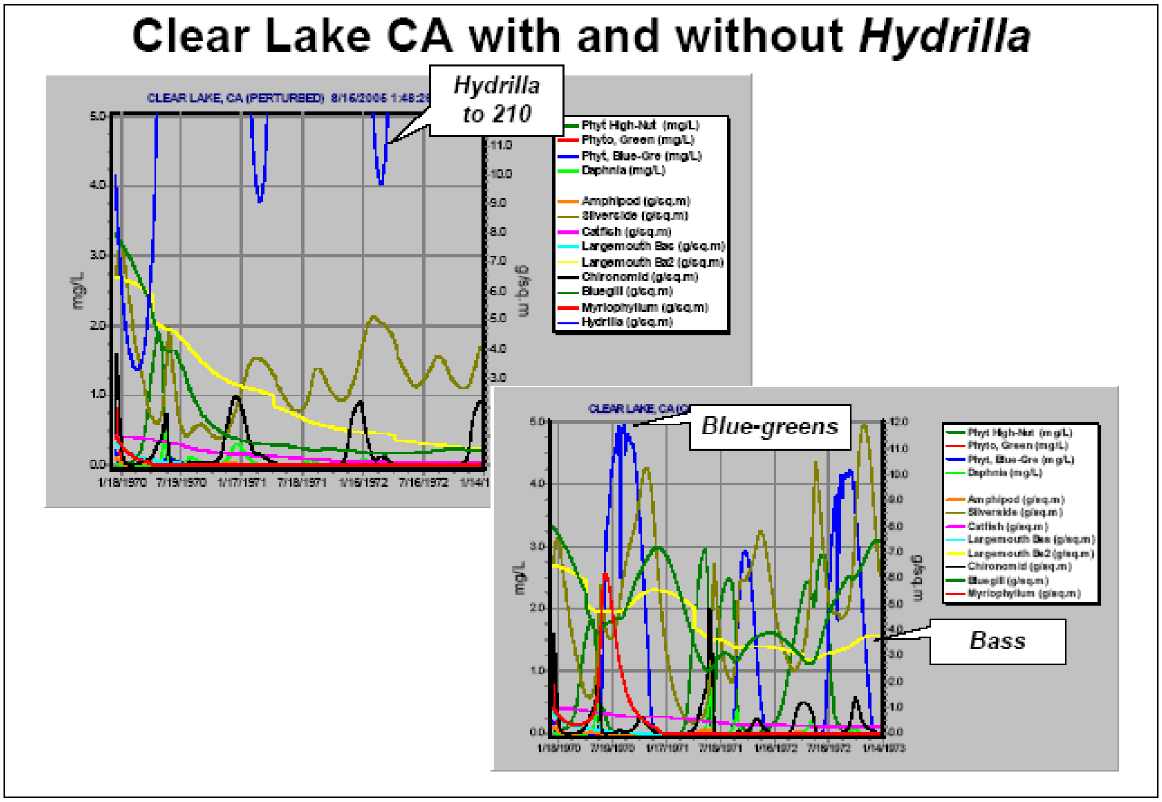

Figure 8. A comparison of biomass of selected organisms in Clear Lake CA with the invasion of *Hydilla* (upper left) and without the invasion (lower right) as predicted by AQUATOX. The axes use the same scale.

The impacts of *Hydrilla* are better shown by a difference graph (Figure 9) where it can be seen that fish would decline in the perturbed simulation with *Hydrilla* when compared with the control simulation. Note that detritus-feeding amphipods and chironomids (a midge that can form nuisance swarms) are predicted to be favored by the growth of *Hydrilla*. The less invasive macrophyte *Myriophyllum* is not well adapted to low light conditions so it would not grow as well.

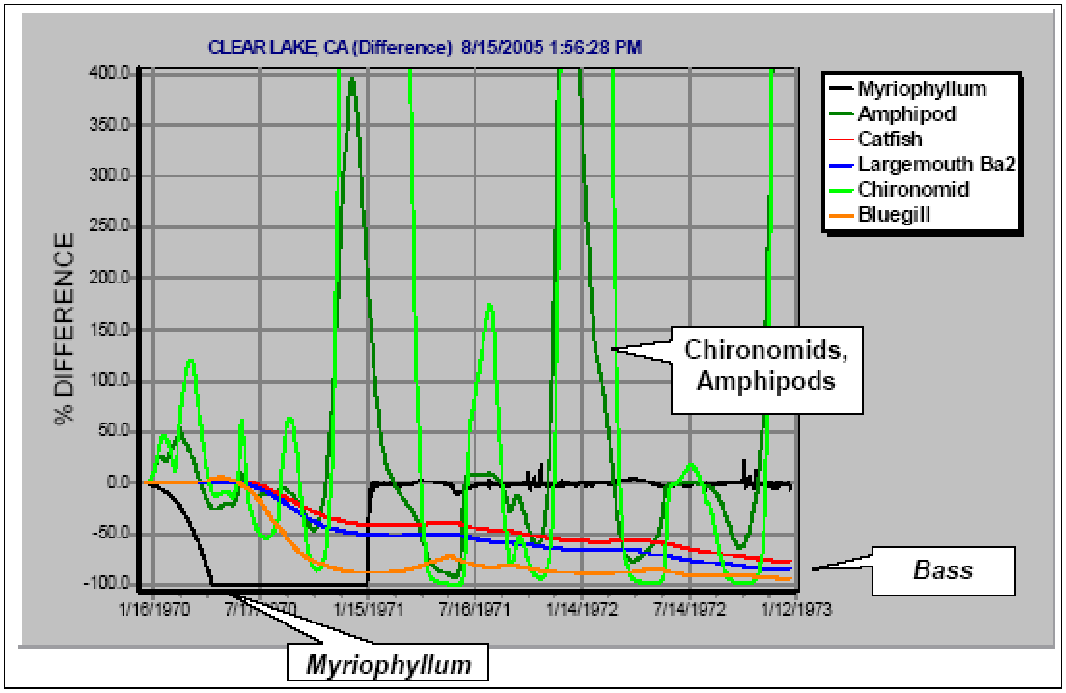

Figure 9. A difference graph showing the predicted relative decline of various fish and the relative increase in detritus-feeding invertebrates with the invasion of *Hydrilla* in Clear Lake CA.

Sonar™ (fluridone) is being used to eradicate *Hydrilla* in Clear Lake. Parameters to characterize the degradation and toxicity of fluridone permit simulation of the fate and effects of the herbicide by AQUATOX. Degradation in water is primarily by photolysis, necessitating multiple applications. Six biweekly doses of 20 ug/L of fluridone near the beginning of the growing season mimic the applications being performed in Clear Lake—applications that are constrained by water quality standards for irrigation water. The model predicts the rapid disappearance of fluridone and the equally rapid demise of *Hydrilla* (Figure 10). It also predicts that dissolved oxygen levels, affected by decomposition of plant material, would not drop below 8 ug/L, which is suitable for a warm-water fishery. Furthermore, the model predicts that fluridone would not have a deleterious effect on non-target organisms, including blue-greens and other planktonic algae. The predicted recovery of the fish following the fluridone application is well illustrated by the difference graph (Figure 10).

In conclusion, a simulation model such as AQUATOX can provide quantitative analyses of the ecosystem impacts of invasive species. Analyses can include both the potential impacts of future invasions and the current impacts at sites that have already been invaded. Output can include biomass of important recreational and commercial species and of nuisance algae and aquatic weeds, which can be monetized and/or compared with water quality standards. The impacts of control methods, such as herbicide application, also can be analyzed and presented in forms to be suitably monetized and/or compared with water quality standards.

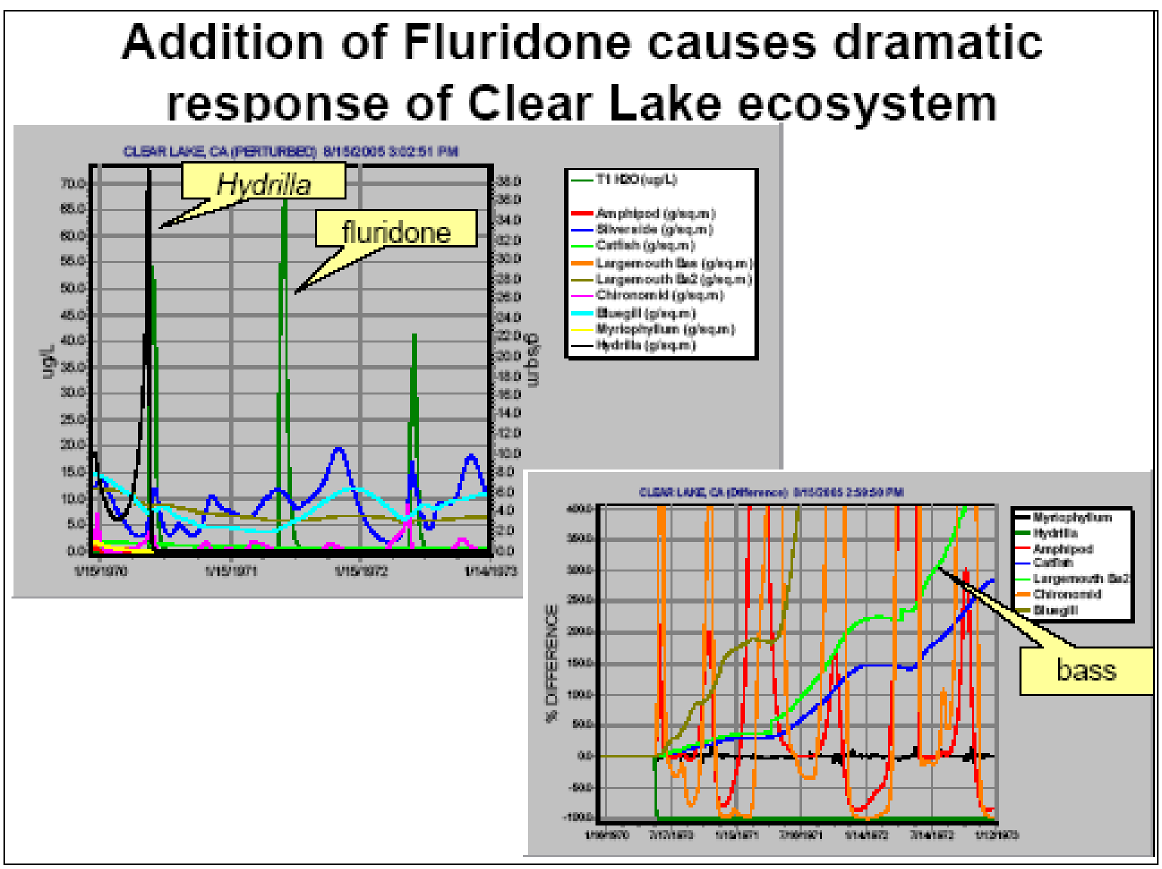

Figure 10. Simulation of the addition of fluridone to control *Hydrilla* is shown in the upper left graph, which plots fluridone concentration and biomass, and in the lower right difference graph, which shows the predicted recovery of the fish.

Acknowledgments

Development of this version of AQUATOX and of the examples was funded under U.S. Environmental Protection Agency Contract 68-C-01-037 with AQUA TERRA Consultants. The assistance of Jonathan Clough and Marjorie Coombs Wellman is gratefully acknowledged.

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Judith Pederson - MIT Sea Grant

Report on EPA Economic Impacts of Aquatic Invasive Species Workshop Held July 20-21, 2005, Washington, DC

As a marine ecologist, the lack of data on the economic costs of introduced invasive species (i.e., those species that cause harm) is inadequate for communicating with the public, other scientists and policy makers. For better or worse, economic valuations serve as the common currency for communicating ecological and human health impacts of introduced species to the various interested (and sometimes disinterested) parties. Although we tend to discuss the costs of invasive species, the value of interest will be the difference between the benefit of the introduced species and the harm caused by the introduction.

From an ecological perspective, I am concerned about impacts to biodiversity or ecological services, both of which are difficult to quantify for the purposes of demonstrating "cost". The net cost of an introduced species would include the benefit (e.g. of an introduced aquaculture species) and the cost (e.g. loss of native species, introductions of hitchhikers, etc.). Estimation of costs for (a) pathways of introduction (b) through establishment of populations, and (c) dispersion may be derived from associated management options of (1) prevention, (2) early detection and rapid response, and (3) control and management. It is the marriage of these two components that will permit improved valuation of invasive species.

The economic valuations include market values and non-market values. Market values are easiest to estimate and validate, however, they often represent a small fraction of the total costs (and benefits) associated with introduced species. Non-market values are estimated from a variety of methodologies (e.g. contingency valuation, referenda, property values, etc.). Because human preferences change, the cost estimates may also change over time reflecting acceptance of invasive species.

At its simplest, an ecological/economic model includes the sum of the costs minus the sum of the benefits. Populating a model with reliable data would use a diversity of approaches and provide a template for assessing or estimating initial costs that may be extrapolated to other situations. As new information is gained, it can be added to the model. If too general an approach is the goal, such as economic evaluation for the country, the error bars from estimating costs will be large and the end results are more likely to be criticized. Thus, a preferable approach is to calculate costs on a regional scale and extrapolate these to larger scales. This has the advantage of allowing a suite of invasive species to be identified for an area and provide specific targets for the analysis.

There are a number of approaches that could be (and from the non-economist perspective) should be used to provide ranges of valuation. From the ecological perspective, spending money to prevent introductions is probably the most effective approach. In marine ecosystems it is extremely difficult and often impossible to eradicate established and dispersing populations. Control costs are often high and in the long term cost more – ecologically and economically than prevention. From a human perception perspective, however, funding prevention is more challenging. Budgets to prevent introductions are more difficult to adopt, fund, and sustain than ones for managing species once they are here. A list of impacts of interest will include ecological issues (loss of biodiversity and homogenization of ecosystems, shifting of food webs, water quality, etc.) and human related impacts (property values, loss (and benefits) to recreation such as boating and fishing, and adaptations of humans to new ecosystems, etc.). Each impact can be viewed as suitable for market valuations (e.g. direct and indirect costs to power plants from zebra mussels) or non-market valuations (e.g. the value of the loss of an ecological service).

Assessing the values on a regional scale will necessitate defining the spatial scale and the temporal component (e.g. fast versus slow dispersing invaders with corresponding time-related changes). Other criteria that could be used to identify what to include in valuations include: the extent of the areas impacted, which sectors are impacted (including equity issues), the types of areas impacted, leveraging to existing aquatic invasive species efforts, irreversibility of impact and practical alternatives, human health impacts, and political importance. Other factors that should be considered are the total cost, whether it is possible to eradicate and/or control, feasibility of measuring success, and significance to the economy. One of the issues raised during discussions was to use the gross domestic product (GDP) as the metric for measuring impacts from invasive species, which is an interesting idea.

My group appreciated the higher level generic models as necessary for framing the problems. However, as a group, we tended to focus on specifics. We used *Hydrilla* sp., a highly invasive fresh water plant as an example to identify specific ecological and human perception issues and identify ways in which an economist would "value" these factors. Although it is considered a nuisance species by fresh water ecologists and agencies, in the south it serves as a food source for manatees. In addition it is valued by humans and fishermen for serving as a refuge for various species finfish.

For this one species, a variety of economic valuations would be needed to assess the full benefits and costs of the invasion. A few of these include fish costs (calculated as $/lb), property values in the vicinity of the invasions, travel costs (e.g., to new recreational areas), contingency values (e.g. loss of threatened and endangered species, loss of biodiversity, etc.), etc. Some data would be easy to obtain, some would be reasonable to estimate, and others require extensive surveys that together provide a value with greater or lesser levels of uncertainty. In the Northeast, the various states are interested in preventing *Hydrilla* from becoming established because it is not grazed and impacts recreation, and water quality. The difference in perception of *Hydrilla* by recreational fishermen between the north and south highlights regional differences in perception for the same species.

What was apparent throughout the discussions were the importance of understanding the ecosystems and the impacts of the invading species as a basis for economic valuations. Articulating why we care is challenging. Loss of biodiversity is often a high priority for scientists, but not necessarily embraced as a compelling reason to fund prevention projects by the public. Ecological services may be more easily understood by the public, but often is a double edged-sword. Introduced species may provide beneficial ecological services, e.g. production of oxygen but not support native species. In the northeastern U.S., the invasive green alga *Codium fragile* ssp. *tomentosoides* (introduced in 1957) inhabited a portion of the niche that was occupied by the native eelgrass *Zostera marina*. Eelgrass beds were lost during the 1930s when a fungus caused wilting disease, but the eelgrass has not fully recovered and revegetated previous areas. The *Codium* community does not support native bay scallops, it has closed beaches with excessive beach wrack and associated decaying alga odors, and forms a monoculture with a less diverse associated community over extensive areas of the sea floor.

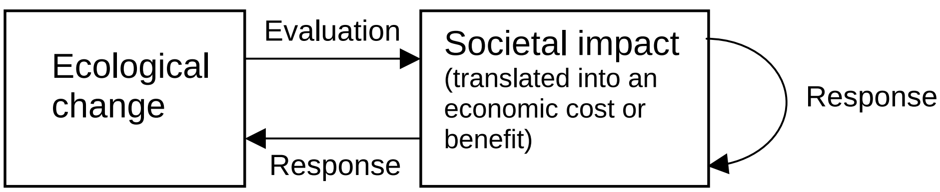
For me, the workshop helped to define the limitations of economically assessing the ecological and human health/wellbeing impacts of invasive species. Continued multidisciplinary interactions will greatly improve our current cost estimates. Reliable ecological and economic data are need for developing models that in turn can be used to identify data gaps. The next step should be to convene a multidisciplinary group that works through the details of initiating an improved economic cost estimate of invasive species impacts, refines models, and validates them with data. A product would be improved valuations for a region and a suite of species that will reduce uncertainty. This in turn may be used for public and political support.

Anthony Ricciardi - McGill University

Report on EPA Economic Impacts of Aquatic Invasive Species Workshop Held July 20-21, 2005, Washington, DC

I propose a broad conceptual framework for assessing the economic impacts of invasions. This framework applies to all invaders, not only aquatic species. It was developed in consultation with my breakout group.

The approach is to identify regions or ecosystems (lakes, river basins) whose history of invasions has been well documented. Within each ecosystem, we identify invaders which are highly abundant and known to cause at least some significant changes to components of the ecosystem that have economic or societal value (e.g. fisheries; water quality). Using whatever ecological models are available, we evaluate the positive and negative effects of each measurable ecological change on society and translate these effects into economic costs and benefits. Obviously, this is no simple task. But the task is made more tractable if a standard method can be developed to relate ecological changes to societal effects.



Changes in human behavior in response to these effects can be integrated into a model. These responses can feed back to mitigate both the ecological change (e.g. if the response is an effective control measure) or the societal impact (e.g. if the response is to reduce society's dependency on the affected resource).

This procedure can be done for each major ecological change, with costs and benefits added up over as many ecosystems or regions that have sufficient data. One might choose to focus on only a small set of ecological changes associated with a particular category of societal impact, and produce an estimate of cumulative costs or benefits over a limited set of regions or ecosystems. It is not necessary, nor possible, to account for all of the ecological changes produced by every invader in the region. In fact, a major benefit of this approach is that it does not require complete knowledge of all these changes to produce a useful estimate. It requires only knowledge of one or more ecological changes that have societal importance, e.g. those changes impacting technological systems (such as navigational systems, or water supply systems), natural resources (e.g. fisheries; tourism), or human health (e.g. waterborne diseases, or bioaccumulation of toxins in food webs). These impacts will involve only a small percentage of invaders, especially those that reach high abundances compared with native species in the ecosystem. A hypothetical result could be a cumulative cost of aquatic invaders to, say, recreational boating in the nation's major reservoirs as a result of changes to weed growth. Thus, while a single reliable indicator cost of all impacts is probably unrealistic, specific estimates (perhaps of interest to a particular constituency or group of stakeholders) are attainable.

A major caveat for this approach is that it will always underestimate negative societal impacts because (1) many ecological changes associated with invasions may not be recognized as such; (2) cumulative small ecological changes by multiple invaders (which may not be documented) may add up to significant societal impacts; (3) most of these impacts will be unanticipated, uncontrollable, and will likely interfere with the planned use of the waterbody, and thus will be negative. But at least we know on which side the estimate errs.

It should also be noted that a change in the *frequency* of ecological change (e.g. caused by an increasing rate of invasion) may be important from an economic standpoint. A high frequency of disruptive changes would make an ecosystem increasingly unmanageable, with scarce time to develop adaptive responses to mitigate societal impacts. Time is important; even when particular invasions are unavoidable, a delay caused by prevention efforts may allow sufficient time to develop a response to lessen the economic cost.

Additional comments:

- Ecological changes, and thus the economic impacts, caused by introduced species are context-dependent (largely because the ecological effects of an invader are a function of its abundance, which varies across environmental gradients). The same economic impact cannot be assumed to occur in every ecosystem invaded by the same species.

- The same invading species could produce both positive and negative economic costs. This could be due to the generation of multiple ecological changes. It may also be due to a single ecological change that is valued differently by different stakeholders: for example, the increased lake transparency and prolific growth of aquatic weeds caused by zebra mussel filtration provokes changes in fisheries that benefit one group (sport fishermen that prefer bass, pike and other fishes associated with weedy lakes) instead of another (walleye fishermen). Hypothetically, the net economic cost of an ecological change could be zero even when there is a large negative impact to one stakeholder group, if it is balanced by an economic benefit to another stakeholder group. Therefore, the *net economic cost* alone is not very informative.

- It is well documented that synergistic ecological changes may be produced by the interaction of two or more exotic species – including species that, when acting alone, produce no significant changes. This interaction is analogous to two benign chemicals forming a toxic mixture. It implies that previous invaders, even if they had originally caused no ecological change of significance, can suddenly become problematic in the presence of a newly introduced species. Previous invaders may thus act as "sleepers"; they may not figure prominently in any prior economic evaluation, but can suddenly provoke significant costs. This being the case, economic costs can change dramatically over time. Given that the number of potential synergistic interactions will rise disproportionately with every new invasion, economic costs should increase nonlinearly over time in highly invaded ecosystems.

David Secord - University of Washington

Report on EPA Economic Impacts of Aquatic Invasive Species Workshop Held July 20-21, 2005, Washington, DC

Our two-day workshop in Washington, DC was not nearly enough time to come to any real conclusions about economic valuation of invasive species impacts, but it was absolutely useful to start (or continue) interdisciplinary conversations on this issue. What follows are some very nascent musings (from one ecologist's perspective) on some of the issues we discussed, which will probably need to be considered as we form valuation methods – and ultimate new policies and research priorities – on bioinvasions.

I found it very stimulating to interact with economists for two days on invasive species issues that I have thought about for a long time, and I gained a new appreciation for some of the ways value is assigned to ecological conditions and events by economists. In particular, "low probability, high severity" events in the context of human behavior present an unusual management challenge, outside the typical time scales of government budgets and university-based research projects. While ecology and economics share an etymological root and many shared assumptions and perspectives, any universal common parameters we should use in evaluating economic costs of current and potential bioinvasions remain somewhat elusive.

One large challenge lies in defining "harm" such that ecologists, economists, and the general public see it in the same way. For example, ecologists tend to see harm in terms of modifications to the structure or function of ecological communities, where the outcome variables are changes in population size or reproductive parameters of native species, and in the details of interspecific interactions. To translate such changes wrought by invasive species into terms relevant to economists or the public, they would need to be quantified in monetary terms either directly (e.g. fewer harvestable mussels or lobsters taken to market) or indirectly (e.g. value placed by various user groups on native intertidal biodiversity in New England). Despite economists' valiant efforts so far, it is measuring the value of these non-market changes that remains intangible or fuzzily defined, for me at least, after our two days of discussions.

We may need to accept that some values are absolutely real to at least some large groups of people (e.g. wilderness, aesthetics, education) but that those can be monetized only partially and approximately. For example, the wilderness value of the Arctic National Wildlife Refuge can be measured narrowly, as in the value of the ecotourism industry that flies or rafts visitors to that remote location, or the value of meat taken by subsistence caribou hunters. Similarly, the educational value of an intact native lake or intertidal community could be measured in terms of the costs of taking students to more remote and pristine sites that lacked invasive species. These valuation measures are a start, but they are necessarily incomplete. For example, key groups of users (ardent conservationists, some indigenous peoples) will always argue that wilderness or aesthetic or spiritual values are "priceless", and I am skeptical about the reliability of economic data that would result from asking people to quantify how much they would accept (in dollars) for the removal of such resources, or pay for the creation of them.

That said, I think we can actually get a handle on some market impacts to fisheries, tourism, real estate value changes, etc. due to invasive species. We can probably also get some valuation data for some simpler non-market effects of invaders, e.g. surveys on how much farther people are willing to travel to avoid clear visible impacts of invaders on aesthetics of local parks. However, I suspect that we will always be getting an *underestimate* of the actual costs of invasive species, because some elements of the losses, such as those discussed in the above paragraph, are by their very nature not reliably quantified.

Given the assumption that our measurements of economic costs of invasive species will always be underestimates, two other considerations come to mind. First, the biological data that inform our economic models of impacts (e.g. just how many zebra mussels are there in Lake X and what are they actually doing to whom?) are almost always limited. In a few well-understood systems such data do give us a good estimate of what's really going on ecologically, but in many others our information is really pretty sketchy (and our error factors here could be in either direction). Second, there is the possibility that some people consider the arrival and activities of invasive species – in select cases – to be positive rather than negative. It is not at all clear that survey data for non-market impact valuation adequately sort out the different perspectives that people in a complex (and often divided) society might have. For example, what if 50% of the people in a given coastal county feel that it is a travesty for Rapa whelks to be in Virginia, but 20% see them as a potential (if not actual) economic boon, and 30% don't know or don't care? How shall these different perspectives and percentages, and the -values and prior-knowledge variation that might underlie them, figure into an estimate of overall costs? The answer seems to lie more in the realm of policy frameworks and their underlying values than in the details of methodologies for collecting market or non-market (or biological) data about species and their impacts.

Another critical aspect of this issue is the notion of biological time lags that often characterize invasion trajectories, and prevention of new species arrivals in the first place. This is key because significant investments often must be made to prevent (or lower the chances of success of) new invasive species arrival. How we feel about future impacts – perhaps based on current impacts of other species or impacts of a specific invader in other areas – directly determines how much we're willing to invest in prevention. This suggests that we should invest more on developing our predictive ability with respect to ecological and economic impacts of invaders, much as we have with predictive climate science. For example, we now know that short-term weather, long-term climate changes, and large-but-rare events such as Hurricane Katrina have lots of market impacts, as well as non-market ones. The market impacts alone are enough for many people and businesses to rely on prediction (and concomitant preparedness or insurance investments), much more now than even a decade ago.

So, if we had a better biological ability to predict what specific invaders might do in a region – and what larger aggregate numbers of invaders might do as numbers of non-native species increase in a given region – we might have a better-informed grasp on the question of how to value impacts. That is, even very rough estimates of what prevention investment might reduce fisheries or tourism losses would give us a handle on the costs of those losses of "clearly" market-valued resources. For example, how much are different constituencies in US urbanized estuaries are willing to pay a tax that supports ballast water treatment?

I continue to struggle with how to value the millions of years of (co)evolution embodied in most natural, native communities. In increasingly homogenized bioregions of Earth, these are increasingly rare (and thus more valuable?) resources. Such conservation arguments are somewhat market-based (e.g. predictable provision of ecosystem services) but equally non-market based (e.g. scientific, educational, ethical value of intact ecosystems full of native species that evolved, in place, together). For many people, these values fall into the "priceless" category that must be a nightmare for economists to collect data on, and brings us back to our collective societal values. Moreover, what we value collectively (or on average) as human societies may not precisely mirror what an evolutionary biologist, or an environmentalist, or a fisherman would value. For example, if everyone had a nuanced understanding of ecological and evolutionary dynamics, would they come to the same conclusions as many scientists that there is scientific and educational value in native ecosystems? And are there other pathways to the same conclusion, e.g. protection (and valuing) of creation, derived from a religious rather than a natural-science way of knowing? Or of the cultural values of preserving a way of life for centuries-old coastal fishing communities? And just what common foundation in knowledge should give us confidence in reliability of survey data on non-market values, anyway? Would the same information narrow the range in people's conclusions? Would decreasing the average level of ignorance or knowledge of sampled populations promote even a little convergence in views?

As an ecologist, I clearly see the need for more biologists to understand how policy, values, and economic thinking and methods are relevant to the issues they study. This workshop has convinced me that more frequent collaborations involving actual systems of human society, native ecosystems and invasive species will help us work out the methods we need to address the valuation question. Both ecologists and economists now have some tools to address these questions, and some collaboration in particular systems (e.g. zebra mussels) have been going on for years. But I think on average ecologists and economists have a long way to go before they collectively understand each other's disciplines in a sophisticated way, let alone consistently speaking a common language and measuring common variables. The only ways to improve this situation will be to increase substantive, rigorous interdisciplinary analysis in our K-12, popular/informal, undergraduate and graduate educational systems, and to create many more specific research projects that involve not just academic and agency ecologists and economists, but that also directly involve the general (voting, valuing) public.

Jason Shogren - University of Wyoming

Report on EPA Economic Impacts of Aquatic Invasive Species Workshop Held July 20-21, 2005, Washington, DC

The challenge is to estimate the non-market values of ecosystem impacts and incorporate them into general risk analyses. Because nonindigenous species spread across landscapes, people should develop a framework that can accommodate large scale, heterogeneous, interacting landscape units (lakes and connecting waterways). A general framework should be applicable to any species in any ecosystem, and should thus constitute a major contribution to the science and policy of invasive species.

Example of questions that need to be asked: If forecasts of zebra mussel invasions had been taken seriously, how much would it have been worth society spending to prevent the introduction into North America? How much is it worth expending to slow or prevent the spread of already established nonindigenous species? These questions need to be answered for many existing and predicted future invaders because they have clear implications for the allocation of society's resources to best protect environmental and economic interests.

To collect data on the non-market values discussed in concept in a previous section, one needs to develop a stated preference valuation survey to assess how people value different levels of reduction in the risks posed by exotic aquatic species. Our goal is to produce an econometric "valuation surface" that covers most of the range of potential risks from existing and future exotic invaders. This valuation surface will then be used in the bio-economic modeling to reflect preferences for alternative risk reduction levels (and associated policies).

The stated preference valuation method has the common feature that it is based on surveys in which people are directly questioned about their willingness to pay (WTP) for certain hypothetical changes in environmental risk, or about choices between differently-priced "lotteries" of environmental quality. The stated preference method, e.g., contingent valuation (cvm), is the most common of these approaches in practice. Survey work like CVM is widely used in government decision-making and legal damage claims in the US (e.g., by the USFWS) and elsewhere.

In principle, the method is simple. A survey asks respondents how they would behave if a market in nonindigenous species risk reduction existed. Respondents are a random sample of the relevant population, which might comprise the general public, local residents or visitors to a recreation area. The important point about the survey is that respondents are asked what they would be WTP for a hypothetical increase or decrease in environmental quality.

In practice, there are several important design features of a questionnaire aimed at invasive species: people are provided a reason for why they might pay for something that they currently do not pay for; a payment method should be proposed that is credible; the payment question should be asked in a way that minimizes incentives for people to behave strategically; people should be given adequate, unbiased information on the environmental good and its hypothetical market; and the researcher should determine why someone has a zero WTP (is it because they truly do not value the change or because they do not believe the survey).

Surveys are prone to several types of potential biases (e.g., strategic, design hypothetical, non-response, sampling frame biases) that one needs to work hard to avoid. For example, hypothetical bias exists when surveys elicits values that are inflated relative to what consumers would actually pay because consumers take hypothetical scenarios less seriously than real-life situations. This and other biases arise from the reliance on consumers' subjective responses. The task is to make the survey believable so that respondents would respond as if the scenario was actually taking place.

Risk poses special challenges for survey valuation work. Different respondents interpret risk concepts and levels differently, depending upon probability and characteristics of the event, and previous risk training. For example, people often inflate small risks, while ignoring larger risks. Three factors problematic to accurate risk communications are: the multidimensional nature of risk, the difficulty in quantifying risk, and the subjective nature of risk. Nonindigenous species risks may be especially daunting to people because these risks are unfamiliar and are diffused in time and space. To minimize the severity of this, one should provide unbiased information about the risks of nonindigenous species.

Following methods we developed earlier to value non-market goods like water quality and wildlife, one could consider using a seven-step process for determining non-market values. 1) Create a set of *nonindigenous species risk lotteries*, that combine four key impacts created by exposure to nonindigenous species: risks to human health (e.g., ballast-borne pathogens), risks to native biodiversity (e.g., extirpation of native clams by zebra mussels), risks to recreation activities (e.g., boating, fishing), and risks to aesthetics (e.g., change in shoreline appearance by *Phragmites*). One would define each of the four risks, which will be represented as probabilities (between 0 and 100 percent threat). They would need to create a randomized design over the potential levels of the four risks to create a four-dimension lottery, and the valuation surface that covers the full range of risks. This will allow one to capture the likely lotteries created by current and future policy, and current and future nonindigenous species.

2) Define the *valuation question* that captures the idea behind a "nonindigenous risk lottery." A question might ask what the respondent would be WTP to avoid a scenario with a 20% increase in risks to human, a 5% increase in risks to native biodiversity, no risk to recreation, and a 50% increase in risks to local aesthetics? The percentages would be generated randomly for each individual. Alternatively, One needs to consider using a discrete choice question, in which a person says "yes or no" to a given $ value. A range of $ values would be selected and randomized across risk lotteries.

In this survey people will have to know what **invasive species** really means. One definition comes from the Executive Order:

- An "invasive species" is defined as a species that is
  - 1) non-native (or alien) to the ecosystem under consideration *and*

- 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health.

- Invasive species can be plants, animals, and other organisms (e.g., microbes). Human actions are the **primary** means of invasive species introductions.
-

In the survey they will make decisions about different scenarios involving water bodies either being **Invaded** or **Not Invaded**.

- A water body is **Invaded** if two conditions exist:
  - (1) non-native (or alien) species exists in the ecosystem under consideration *and*
  - (2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health.

- A water body is **Not Invaded** if either condition (1) or (2) above does not hold:
  - No non-native species exists *or*
  - A non-native species exists but whose introduction has not caused economic or environmental harm or harm to human health.

More specifically, a water body is **Invaded** if the lake or river has a non-native species and if the species:

- disrupts natural ecosystems and causes irreversible ecological harm
- gets rid of native plants, fish, and other aquatic life, or
- damages the economy

A water body is **Not Invaded** if the lake or river either does not have a non-native species or if it has a non-invasive species that:

- does not disrupt natural ecosystems and cause irreversible ecological harm
- does not get rid of native plants, fish, and other aquatic life, and
- does not damage the economy

3) Run *focus groups* with people each to make sure they understand both the risks posed by nonindigenous species in the project area, and the valuation question. We propose to use a mental models approach to examine how CVM survey respondents evaluate risk reductions. The approach has been widely used as a qualitative research technique to improve the effectiveness of communication materials by understanding how individuals perceive a problem, what they know about the problem, the structure of their beliefs, how they make decisions about the problem, and the differences between lay peoples' and experts' problem solving procedures.

4) Once the valuation question has been refined, one needs to use standard *statistical experimental design* procedures to determine the sample size needed to estimate the econometric valuation surface with the degree of desired statistical precision. Participants will be residents contacted via 1,200 to 1,500 randomly selected residence telephone numbers from the areas surrounding the Great Lakes.

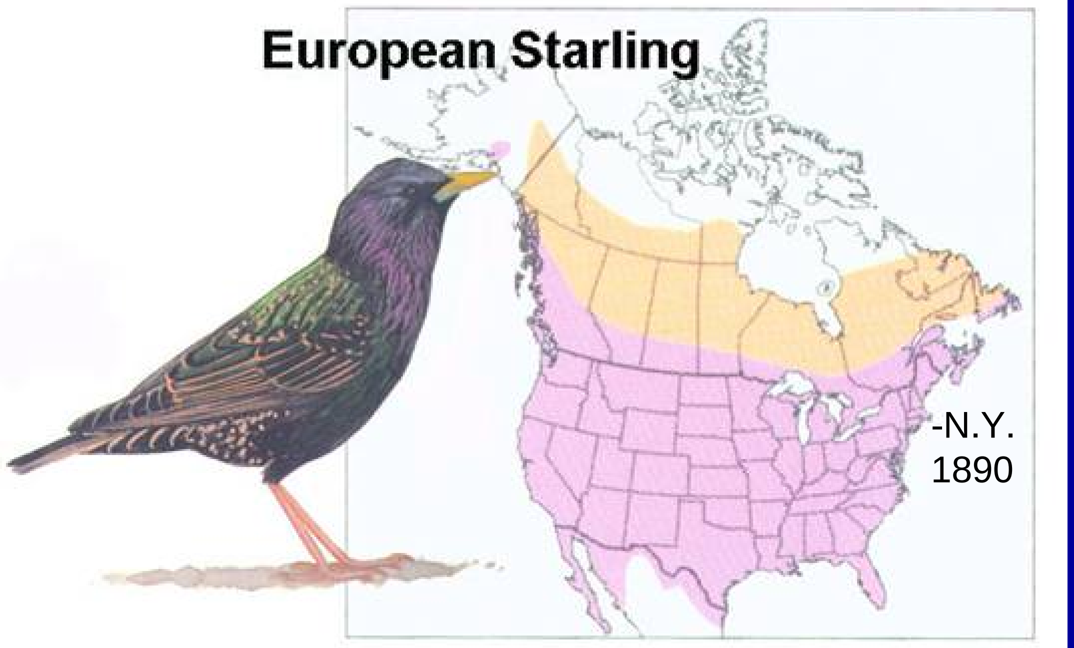
5) *Administer* the regional valuation survey with the risk questions following standard survey methods. Depending on the focus group in-put, the valuation survey could be done over the web and in-person around areas like the Great Lake region, where people have some experience with well published invasive species. For an example of our web survey applied to valuing wildlife lotteries for lake trout invasion into Yellowstone Lake, see http://uwacadweb.uwyo.edu/arb/.

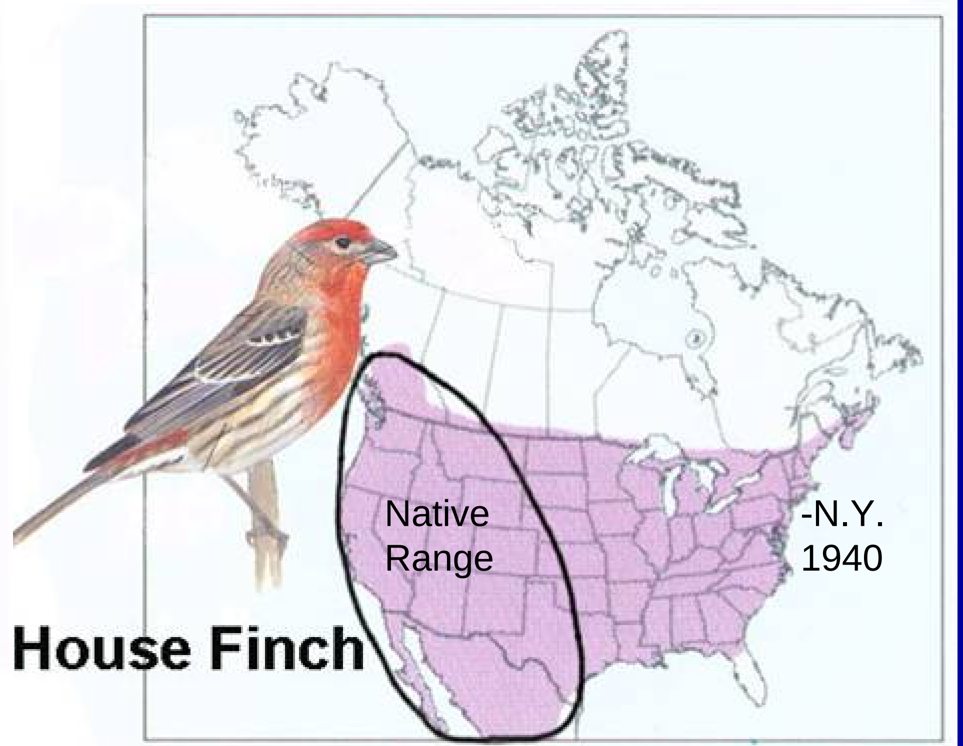
6) Use the appropriate *maximum likelihood* econometric methods to estimate the valuation surface for the exotic species lotteries. One could examine the external validity of these values through comparisons with previous research. One needs to examine their internal validity by examining whether responses are consistent with rational choice theory and behavioral models of choice under risk.

7) Finally, one would need to introduce the estimated values for reduced risks into the bio-economic model to capture how the *representative individual* reacts to policies that alter the level of risk from nonindigenous species.

In summary, valuing aquatic invasive species will be a challenge to the EPA for three main reasons. First, people have little understanding or familiarity with many species, especially invasions that have yet to occur. In some cases, some people might even like the invasive species. Second, the lag time between actions and spread complicate the temporal dimension, and complicate the nature of the ecosystem externalities. Finally, the spatial spread of invasions would need to be understood by scientists and then effective communicated to people trying to value the reduction in risk.

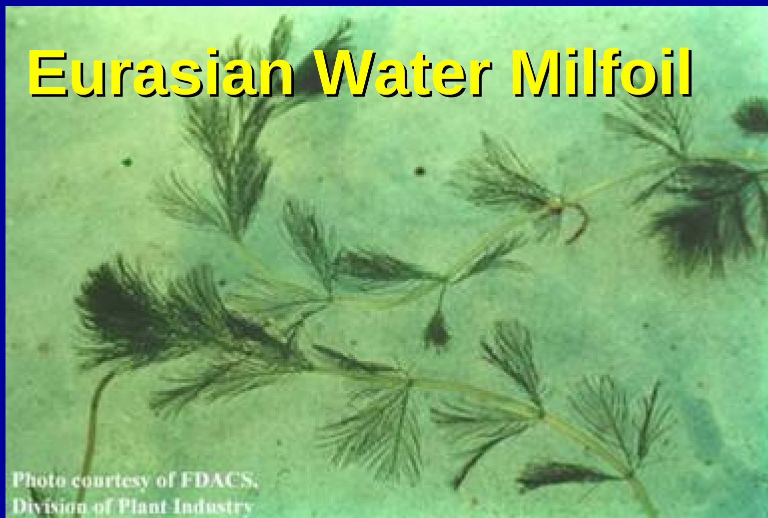
The most common birds in my backyard in South Bend, IN





Desirable Alien Species

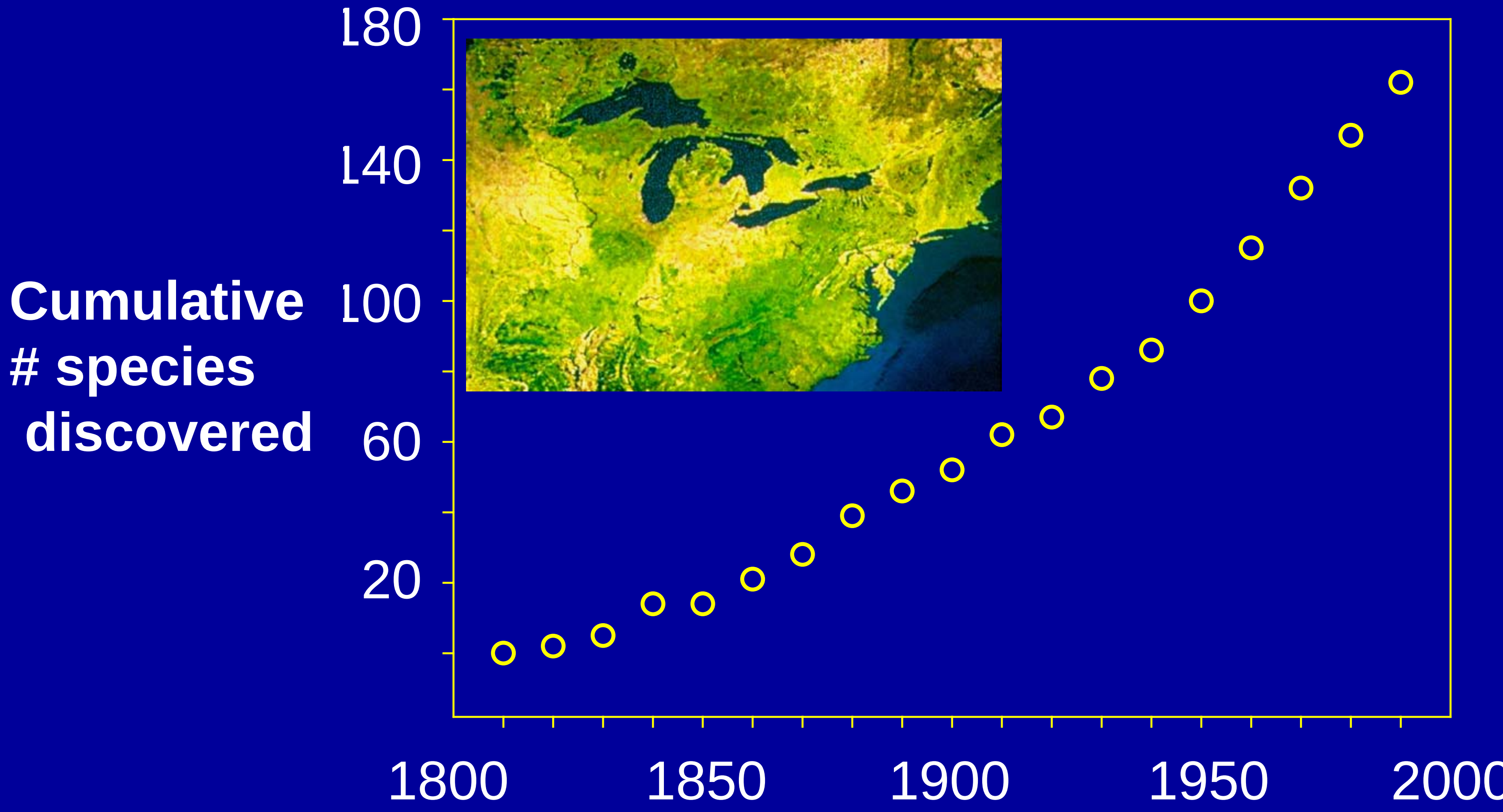
Undesirable Alien species



Sea Lamprey in the Great Lakes

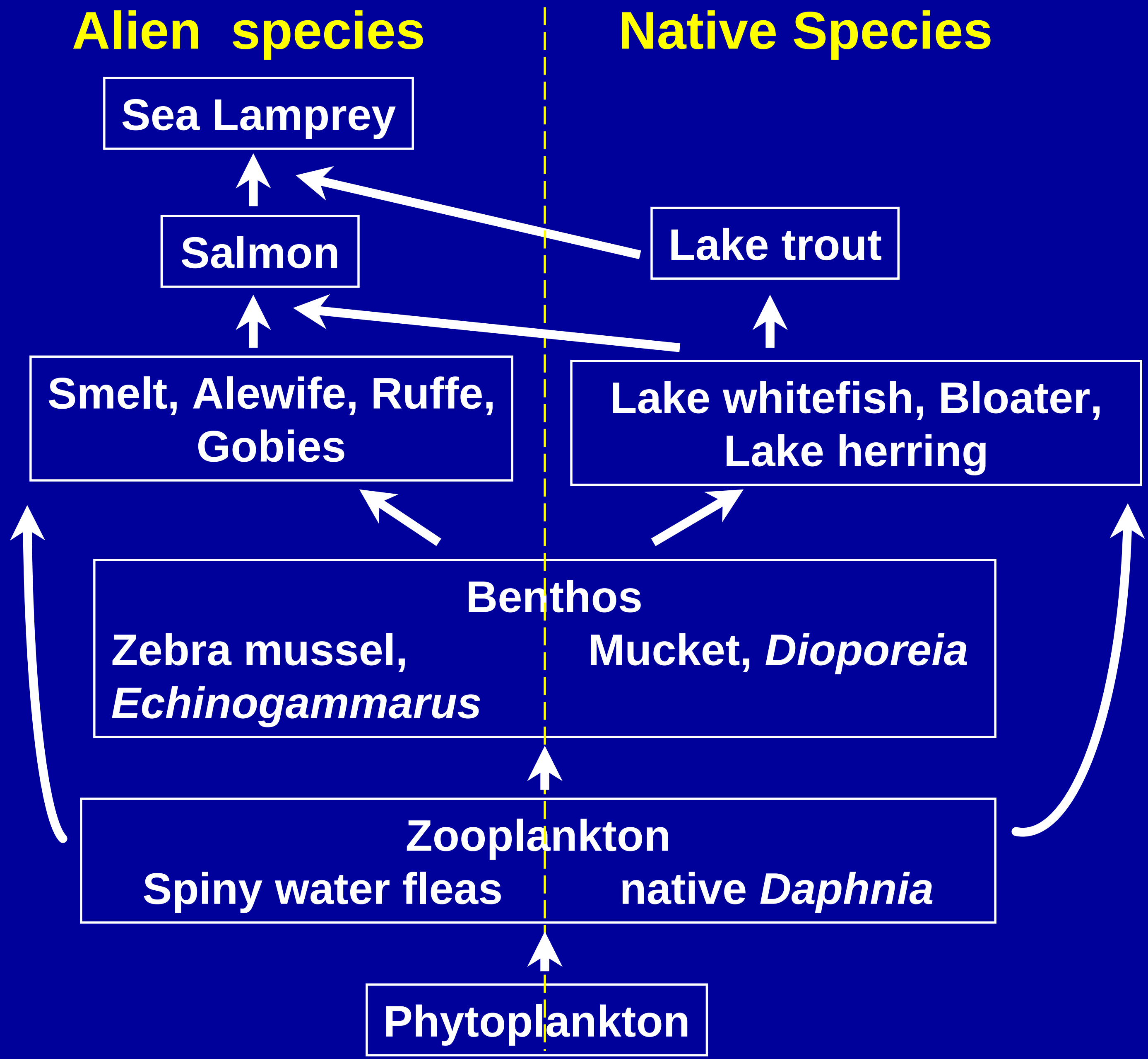
U.S. + Canada:
$15 million/year since 1956

Alien Species Established in the N.A. Great Lakes



(from Ricciardi 2001)

Transformation of Great Lakes Foodweb



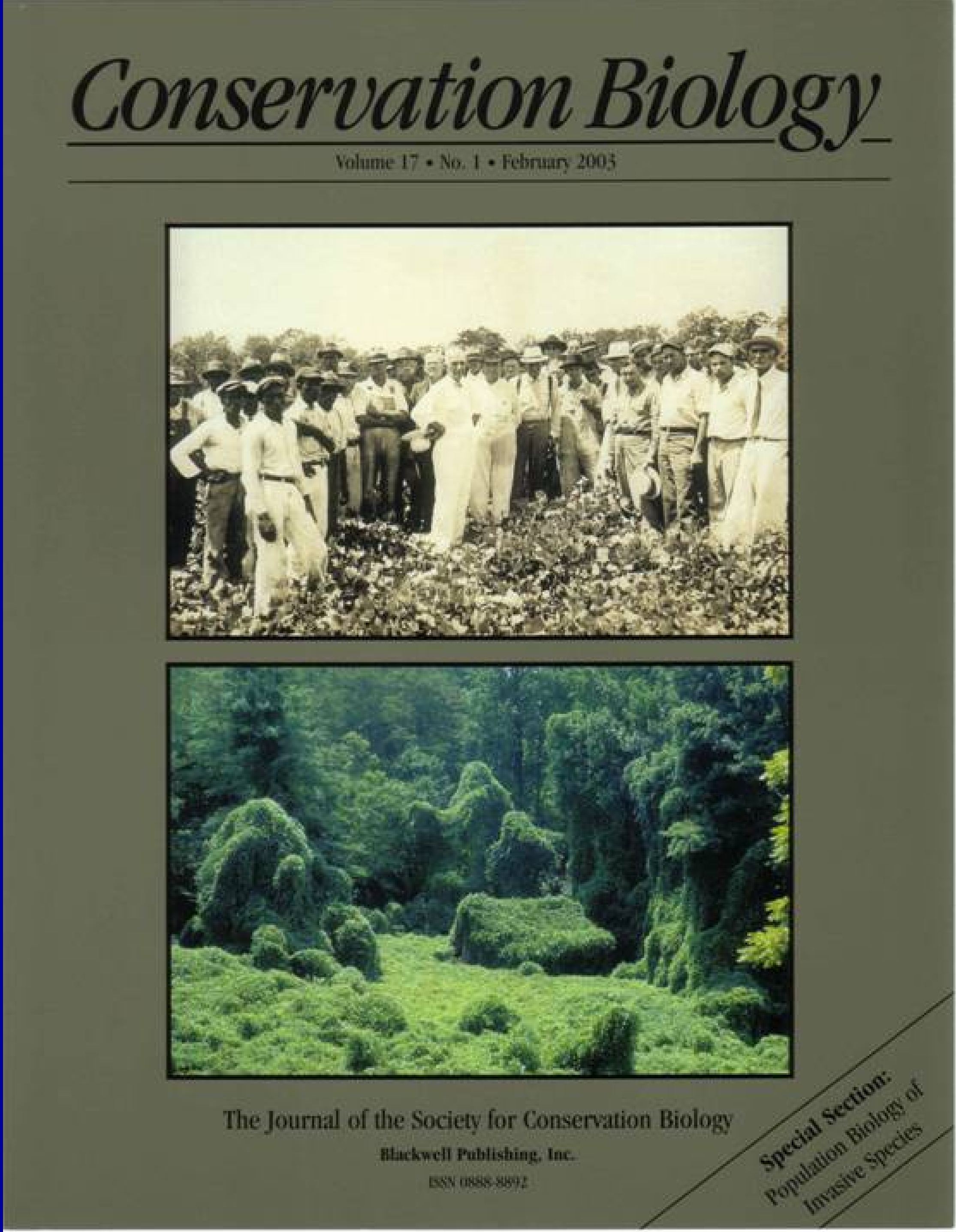
1000s of species, far-reaching impacts

- Cause large local and regional losses of ecosystem goods and services
- Contribute to 46% of imperiled species in US
- 1 of top 5 contributors to biodiversity losses globally, in all ecosystems
- Zebra mussels alone cost $100-200 million per year in Great Lakes region
- Alien agricultural weeds—millions per year, e.g., leafy spurge costs at least $4 million/year in only 4 states
- Costs at least $137 billion per year in US

Difficult Cases

Net Effect = Benefit – Harm

But **harm often develops slowly, is distributed among millions of people, and human values differ & change.**



Definitions

Alien = exotic =
nonindigenous
= nonnative

Invasive =
spreads and
causes (net)
harm

Invasive alien
= focus of
concern

www.invasivespecies.gov

Invasive Species:
Ecology and Economics

David M. Lodge

University of Notre Dame,

ISIS and projects

Risk Assessment: what harm has or is likely to result from a species under given assumptions of current human behavior?

Risk Management: what alternative management scenarios exist and which are likely to be cost-effective?

Research collaborators

Biologists: John Drake (NCEAS), Reuben Keller (UND), Cindy Kolar (USGS), Gary Lamberti (UND), Brian Leung (McGill), Hugh MacIsaac (Windsor)
Mathematician: Mark Lewis (Alberta)
Economists: Jason Shogren (U Wyo) David Finnoff (U Wyo)

Funding

EPA, Great Lakes Fisheries Commission, National Science Foundation, NOAA Sea Grant, US Department of Agriculture, US Fish & Wildlife Service, NCEAS

Invasion process

Species in Pathway

↓

Transported and Released Alive

↓

Population Established

↓

Spread

↓

Ecological, Human Health, or Economic Impact

Invasion process

Species in Pathway

Transported and Released Alive

Population Established

Spread

Ecological, Human Health, or Economic Impact

General Policy and Management Options

Prevention

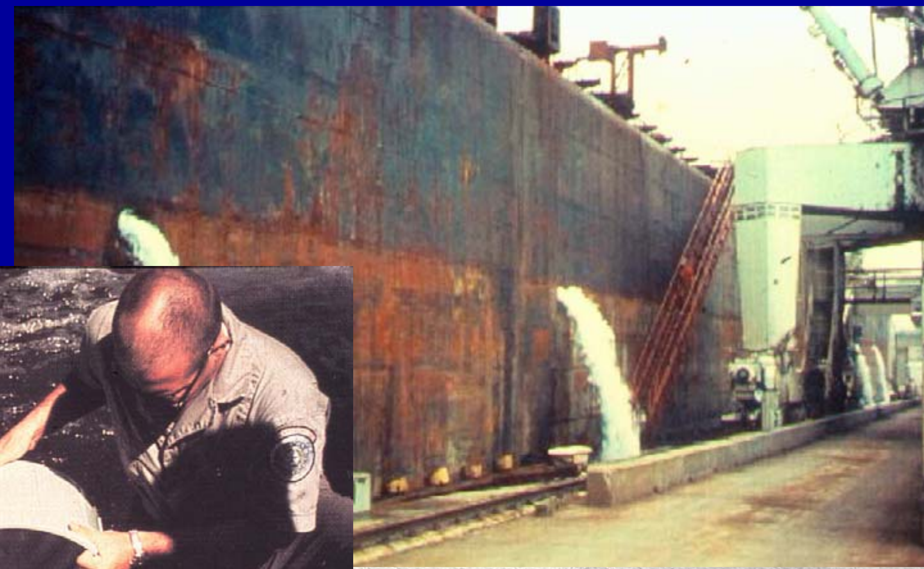
Early Detection, Rapid Response & Eradication

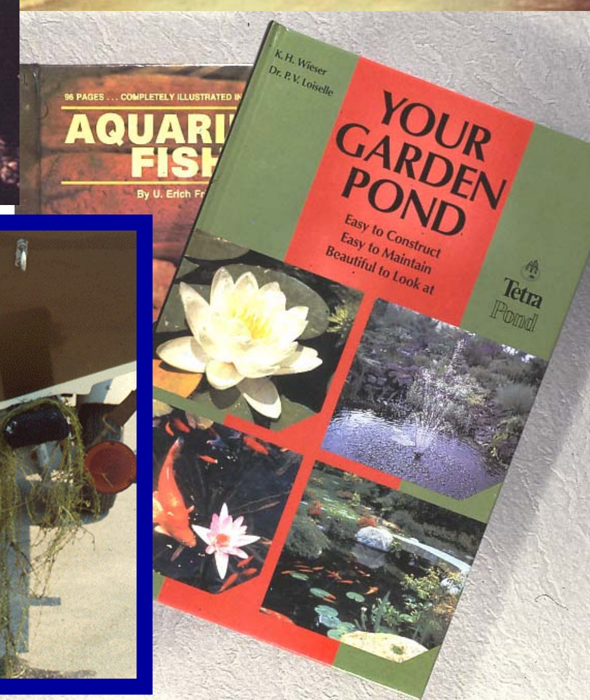
Control, & Slow the Spread

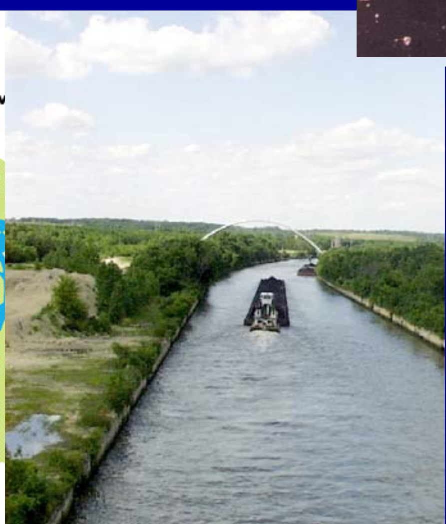
Human Adaptation (change behavior, bear the costs) or Restoration

Pathways

seedman.com
Seeds From Around the World
Jim Johnson, Seedman, 3421 Bream St., Gautier, MS 39553
Phone: 800-336-2064 Fax: 228-497-5488

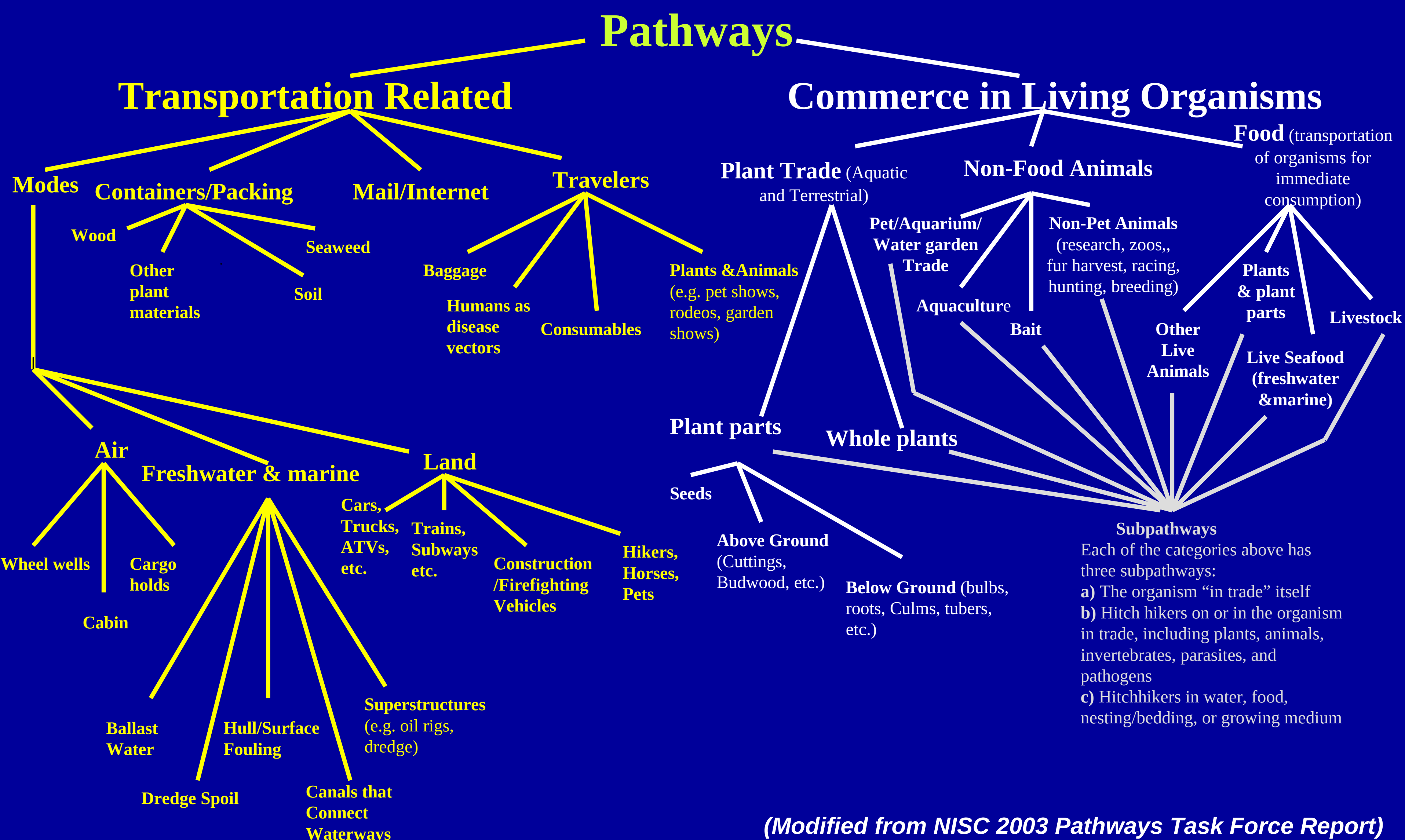







Hydrilla on boat
Hydrilla verticillata
Photo by Jeff Schardt
Copyright 2001 Florida D.E.P.

Pathways of Nonindigenous Species in the US



(Modified from NISC 2003 Pathways Task Force Report)

Invasion process

Species in Pathway

Transported and Released Alive

Population Established

Spread

Ecological, Human Health, or Economic Impact

General Policy and Management Options

Prevention

Early Detection, Rapid Response & Eradication

Control, & Slow the Spread

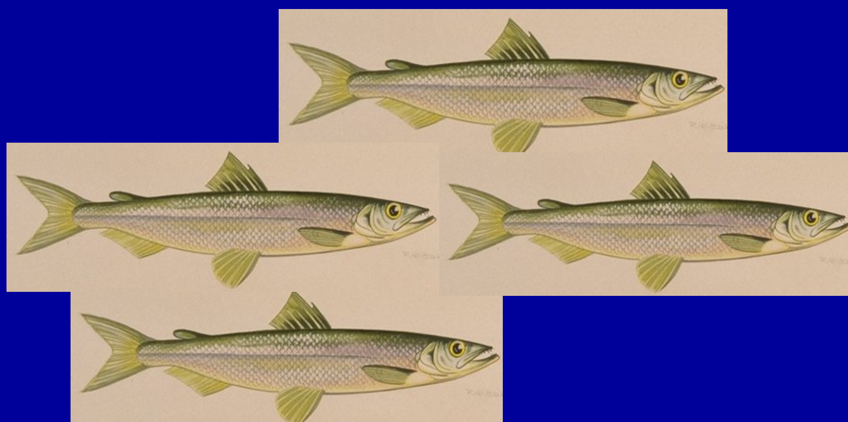
Human Adaptation (change behavior, bear the costs) or Restoration

How is risk of pathway related to . . .

- Identity and characteristics of species?
- Number of organisms released?

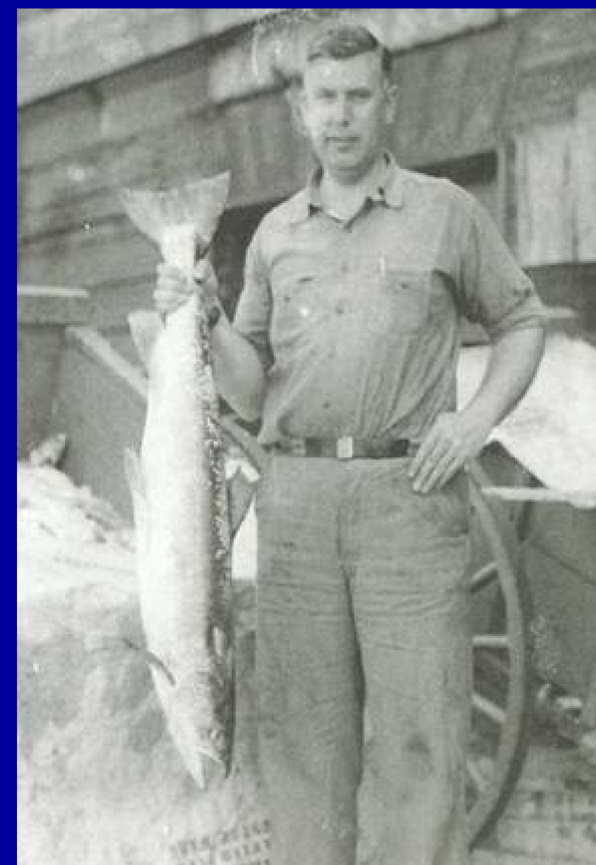
How is risk related to species traits? Successful vs. failed fishes

Successful (24 species)



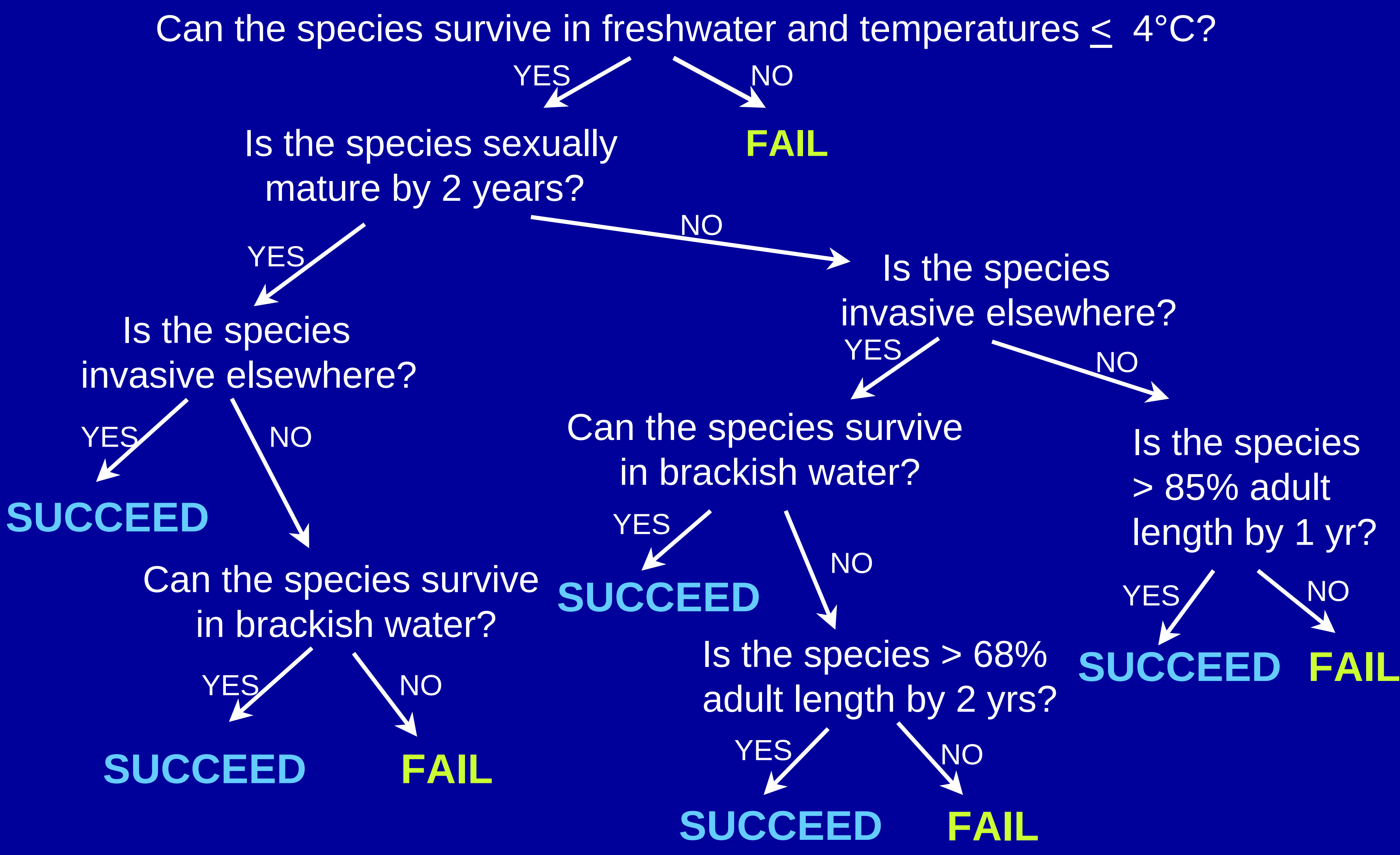
***e.g.*, rainbow smelt**

Failed (21 species)



***e.g.*, Atlantic salmon**

Results: Decision tree for establishment



(Kolar & Lodge 2002)

Overall correct classification rate 91%

Invasion process

Species in Pathway

↓

Transported and Released Alive

↓

Population Established

↓

Spread

↓

Ecological, Human Health, or Economic Impact

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How is risk of pathway related to . . .

- Identity and characteristics of species?

- Number of organisms released?
  - How many individuals are released?

Pathways


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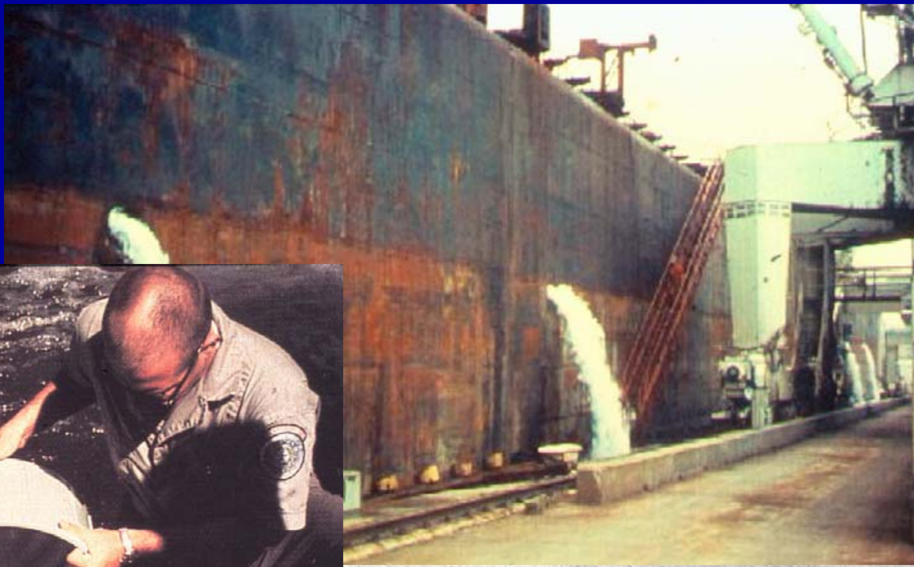
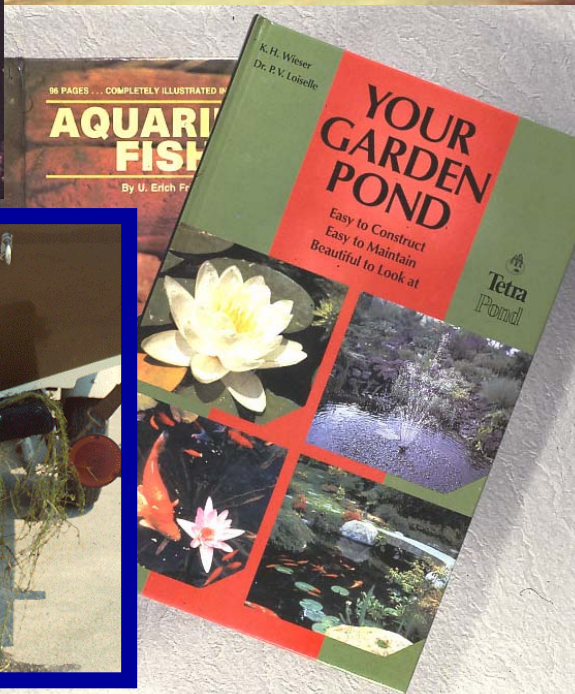



24 HOUR
BAIT&TACKLE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Lake Michigan
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Hydrilla on boat
Hydrilla verticillata
Photo by Jeff Schardt
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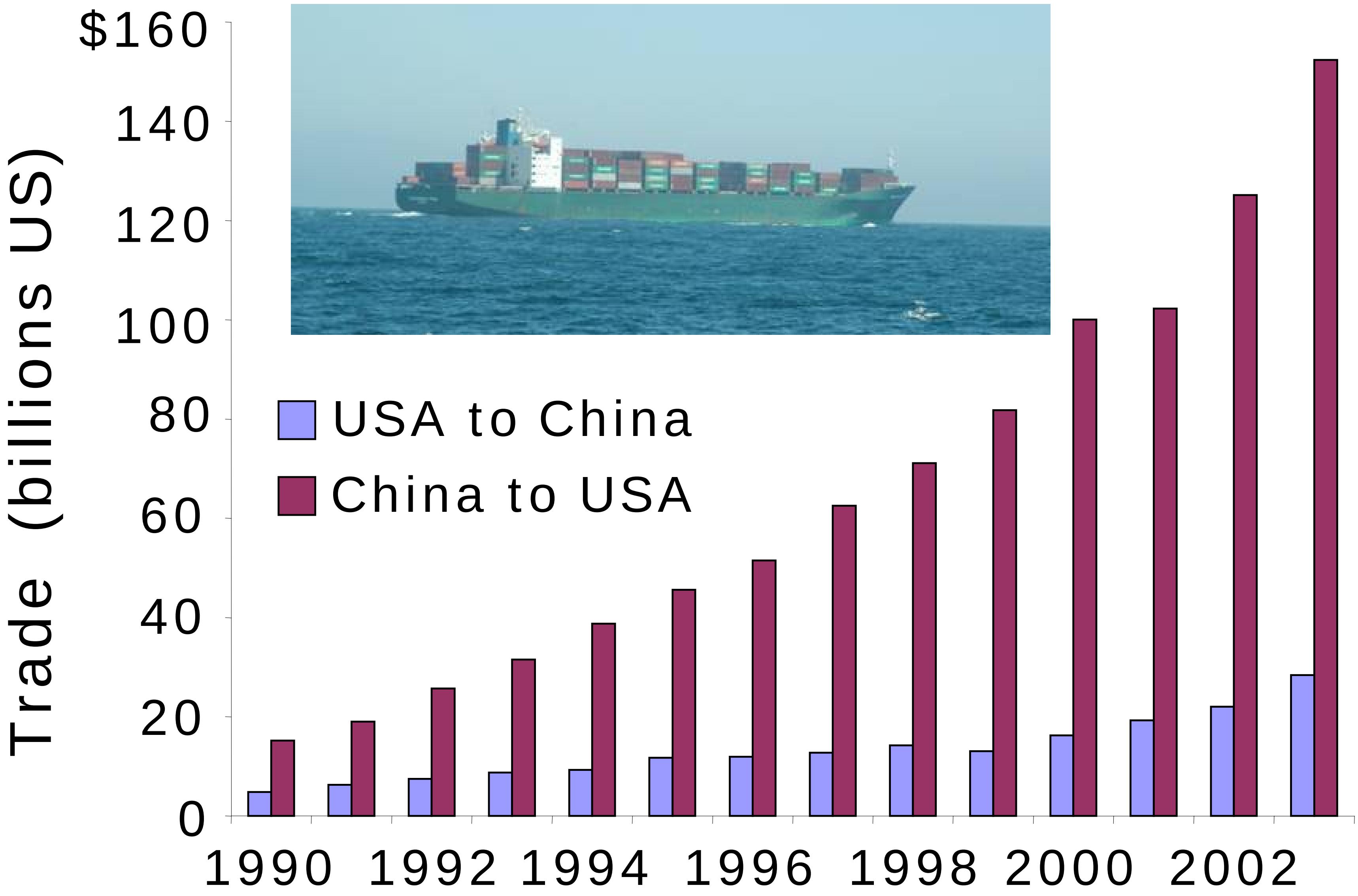
Total Trade Between China and USA



http://ese.export.gov/SCRIPTS/hsrun.exe/Distributed/ITA2003_NATIONAL/MapXtreme.htx;start=HS_Page4Chart

Invasion process

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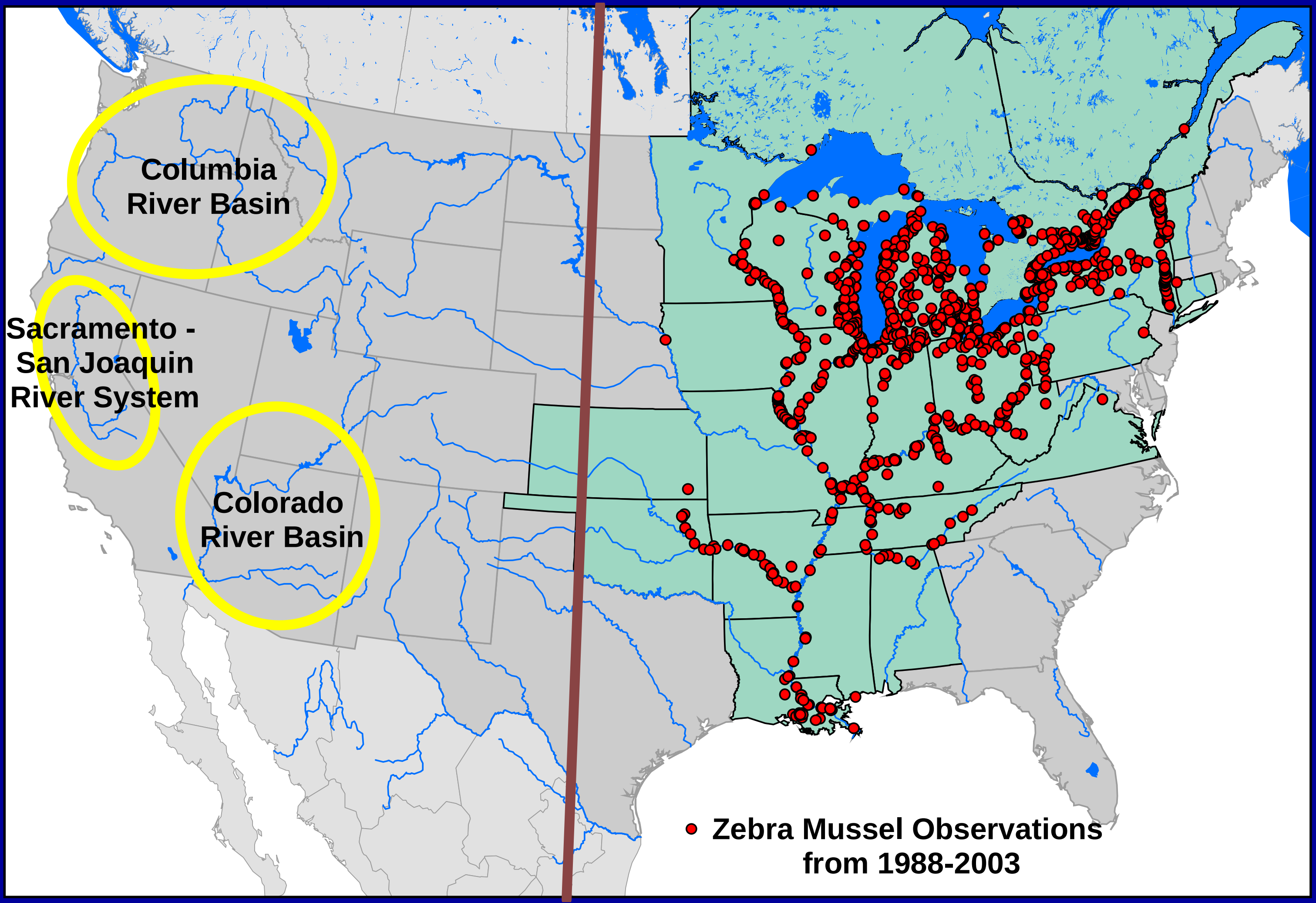
How is risk of spread related to . . .

- Suitable habitat?
- Post-establishment pathways?
- Human perception of risk of impact?

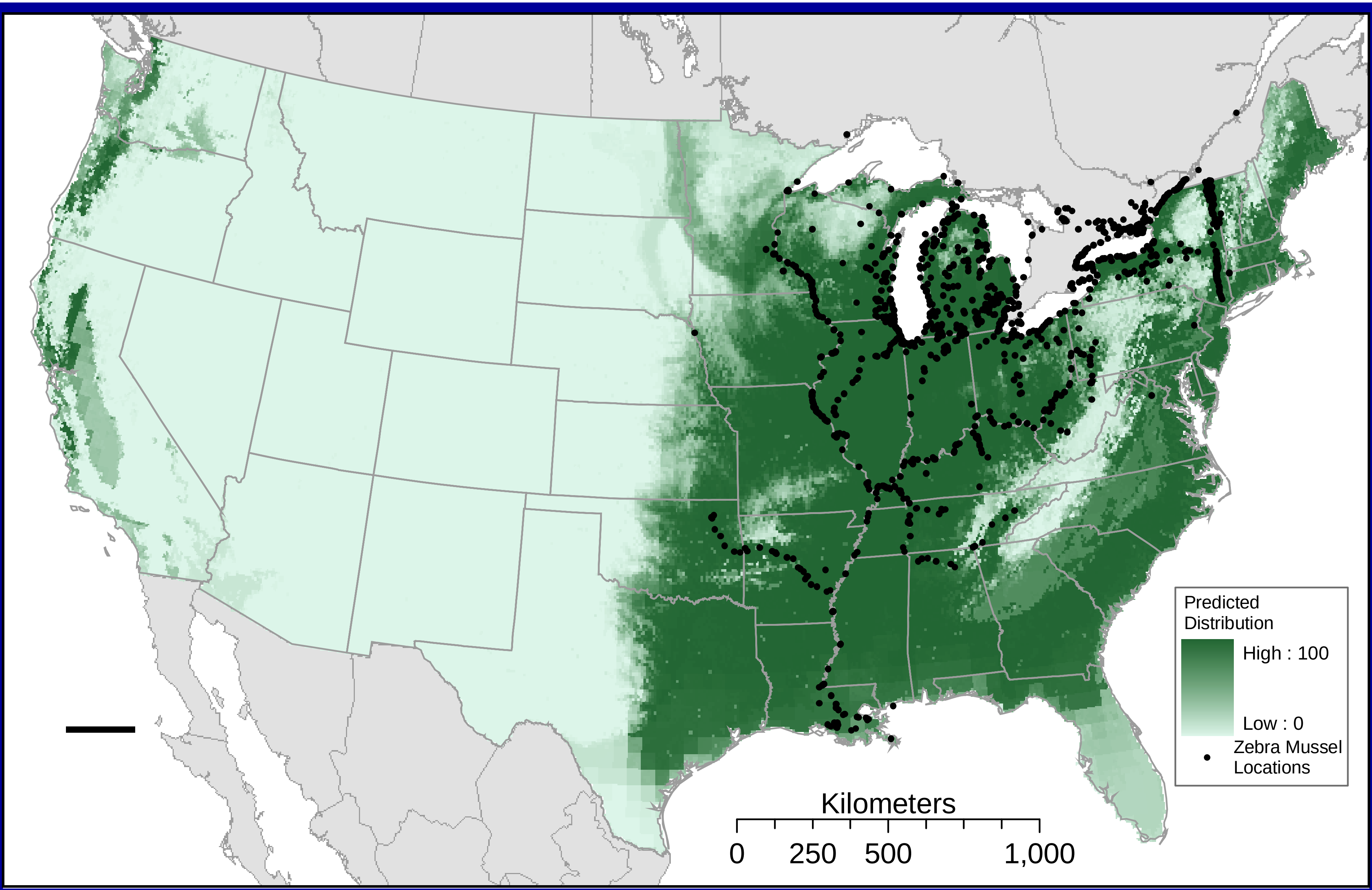
On-going Zebra Mussel Invasion: What's the Value of the 100th Meridian Initiative?



Goals

- Estimate pathways & potential habitat of ZM in the West
- Determine biota & economic services at risk
- Calculate cost & effectiveness of education and control efforts

GARP Prediction: Potential Distribution of Zebra Mussel



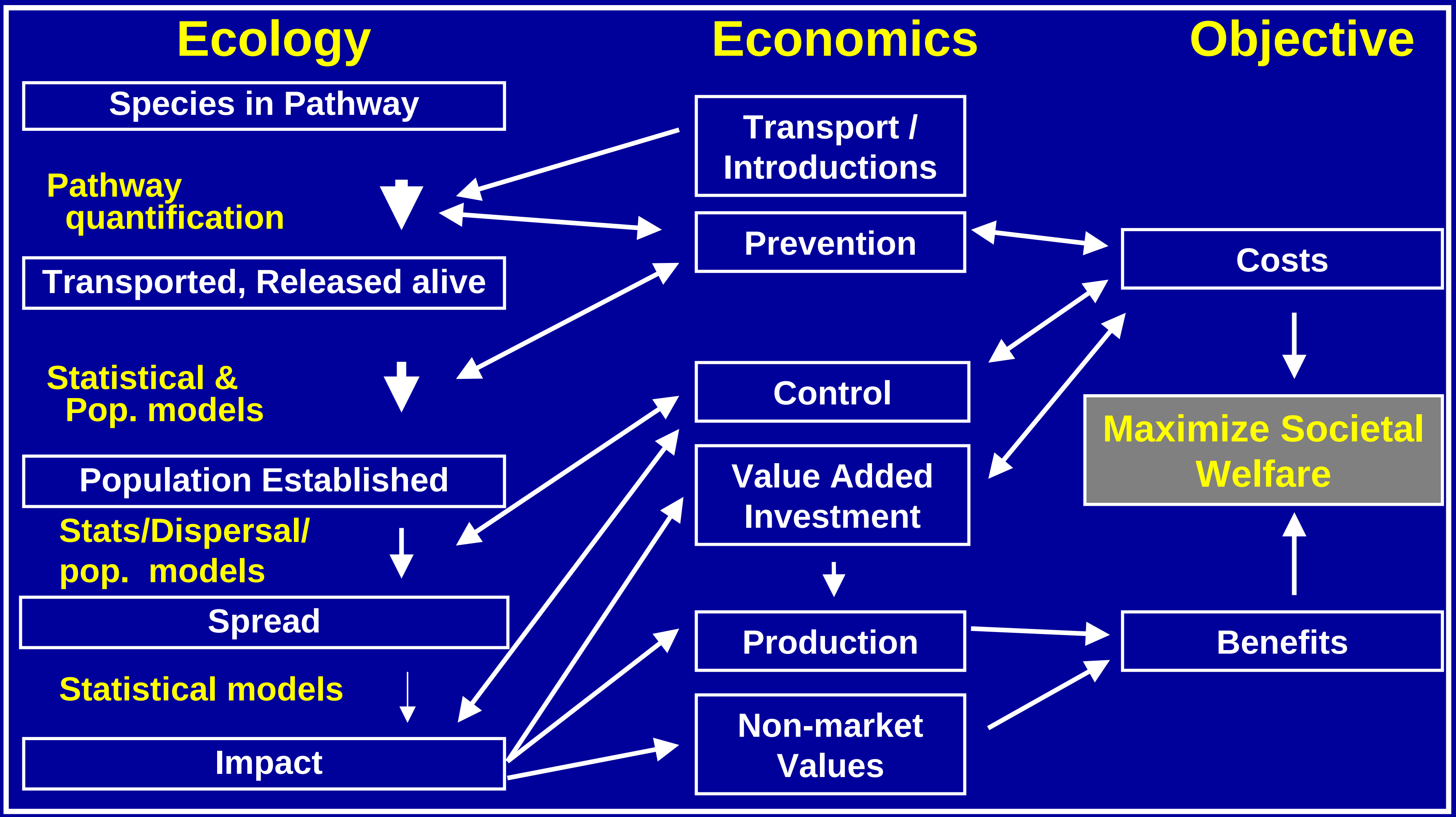
(From Drake & Bossenbroek 2004 BioScience)

Zebra mussel damage

Non-market costs: extirpation of native clams and other undesirable environmental changes

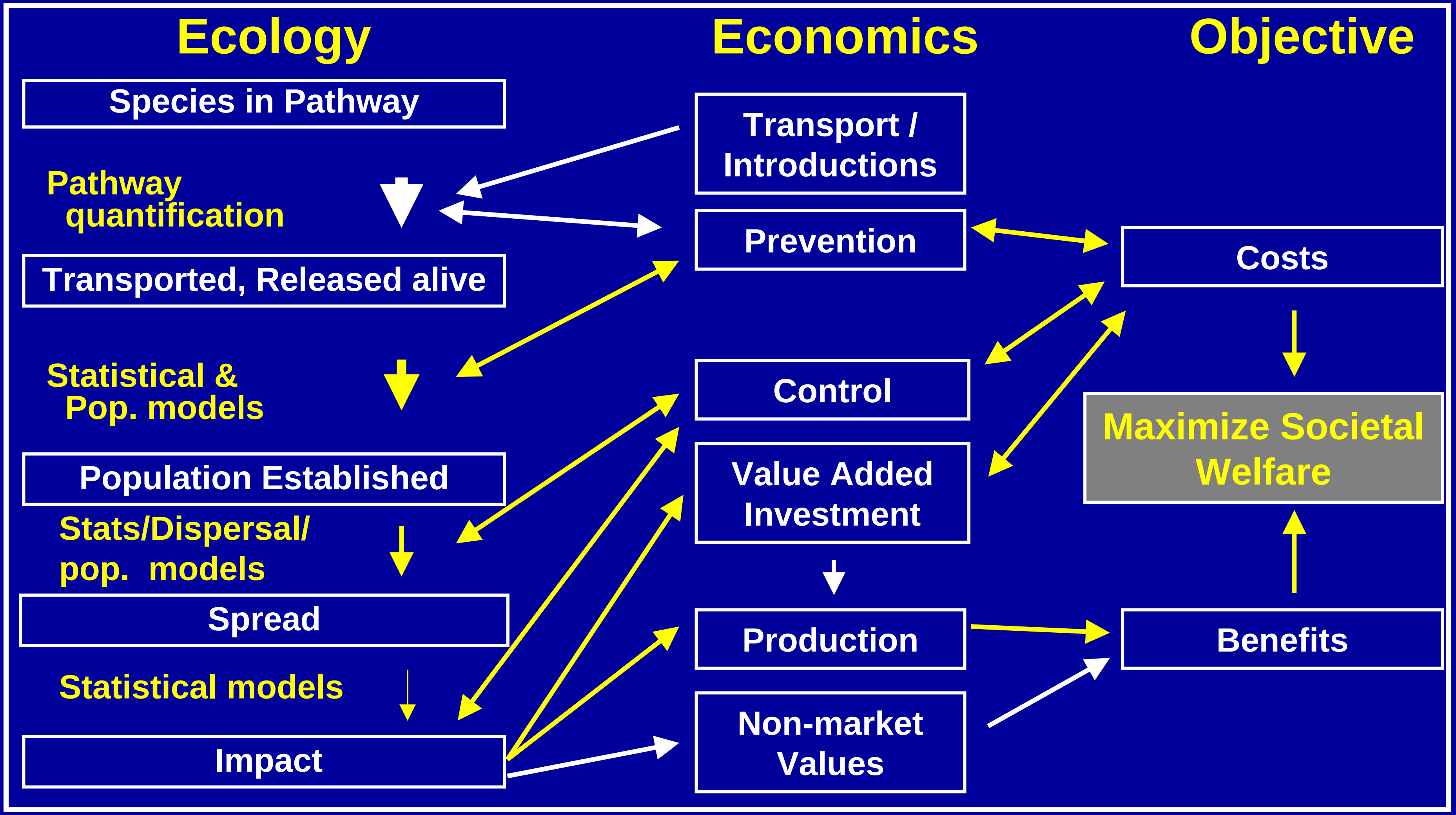
Market costs: clog water intake pipes, at a cost of millions annually around Great Lakes

Conceptual Approach



(From Leung, Lodge et al. 2002. Proc Royal Soc London B 269: 2407-2413)

Zebra Mussels: Conceptual Approach



(From Leung, Lodge et al. 2002. Proc Royal Soc London B 269: 2407-2413)

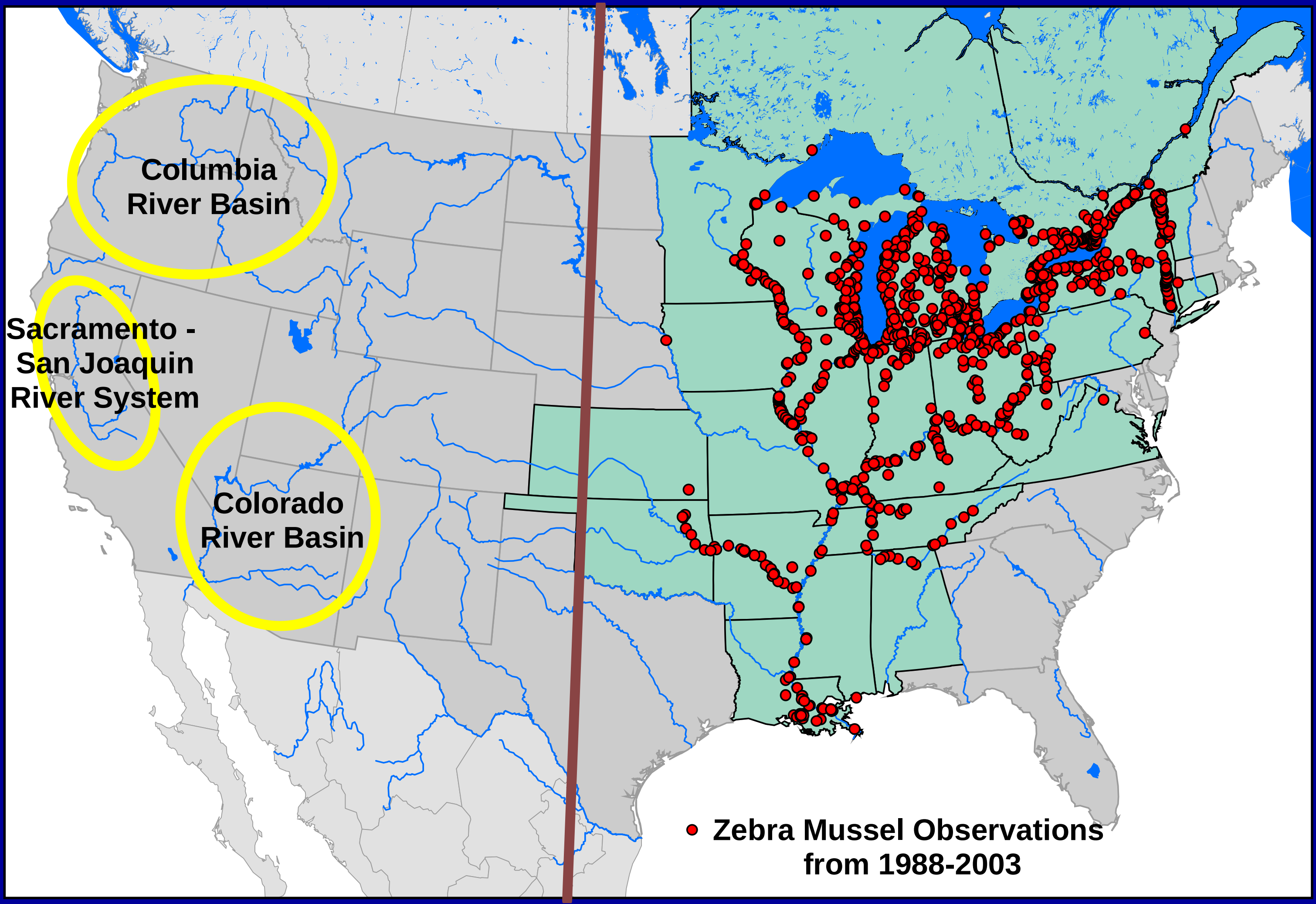
The Value of Prevention: What's it worth to keep zebra mussels out of the next lake?

Up to $324,000 per year *per lake* to prevent invasion —to protect power plants alone.

For comparison, in FY2001, the USFWS distributed to the States $825,000 in response to *all aquatic invasive species in all lakes in all states*.

(From Leung, Lodge et al. 2002. Proc Royal Soc London B 269: 2407-2413)

On-going Zebra Mussel Invasion: What's the Value of the 100th Meridian Initiative?



Goals

- Estimate pathways & potential habitat of ZM in the West
- Determine biota & economic services at risk
- Calculate cost & effectiveness of education and control efforts

How is risk related to . . .

- Human desires for trade

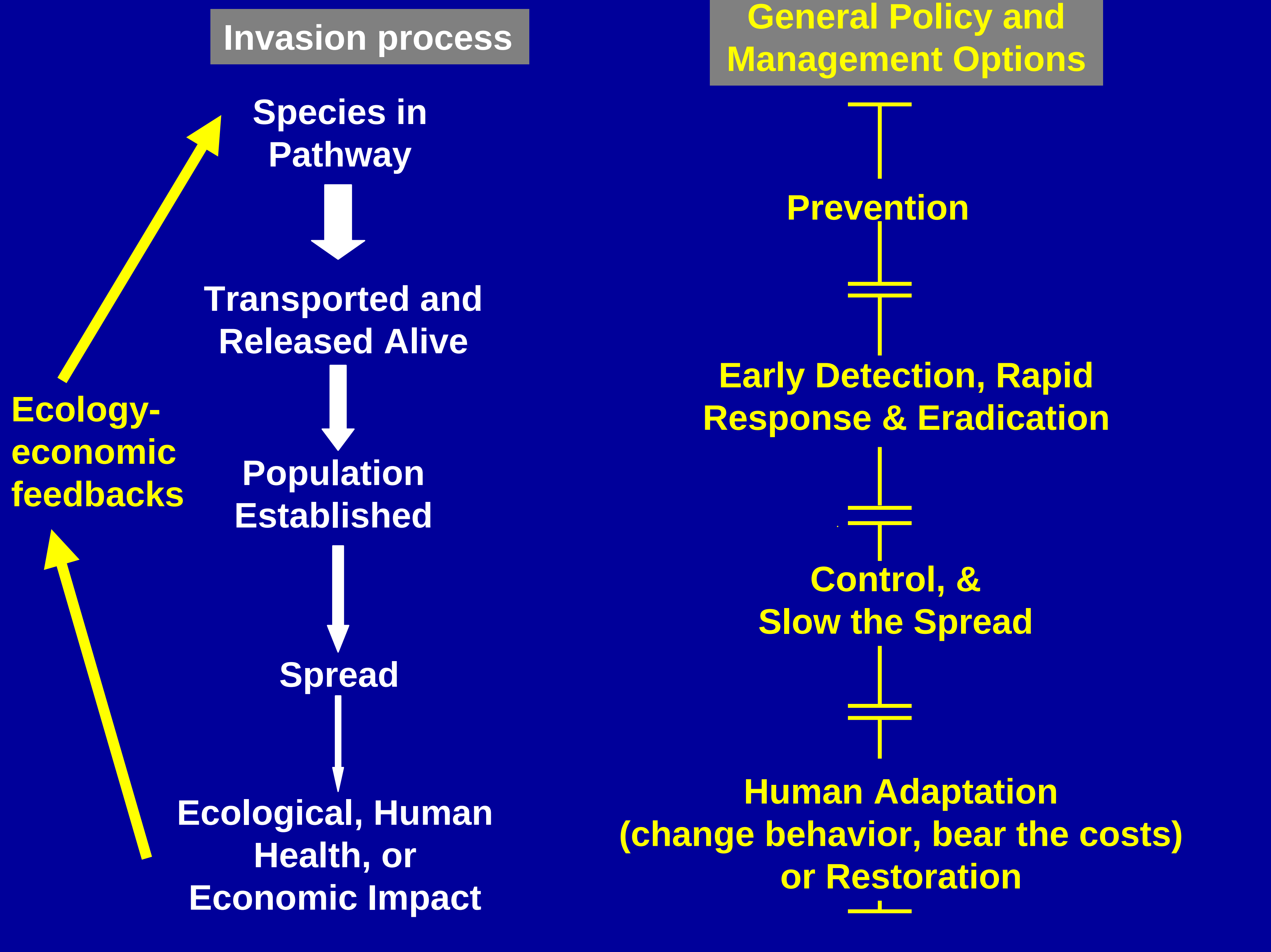
↓

- Suitable habitat?
- Population biology?
- Secondary spread?

↓

- Human perception of risk

Ecology-economic feedbacks



Invasion process
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Frontiers in economic analysis of invasions

			Net costs		
			Market	Non-market	Total
	Pathway	Species			
Current	Ships	1			
		2			
		. . .			
	Pet industry	1			
		2			
		. . .			

Frontiers in economic analysis of invasions

				Net costs	
			Market	Non-market	Total
	Pathway	Species			
Trajectory of existing species – Current	Ships	1			
		2			
		. . .			
	Pet industry	1			
		2			
		. . .			
Future					

- Ecological forecasting
- Bioeconomic modeling approaches
  - General Equilibrium Models (GEM)
  - Endogenous Risk Optimization (SDP, OCT)
  - Real Options

Frontiers in economic analysis of invasions

			Net costs		
	Pathway	Species	Market	Non-market	Total
Trajectory of existing species — Current	Ships	1			
		2			
		. . .			
	Pet industry	1			
		2			
		. . .			
Future					

- Ecological forecasting
- Bioeconomic modeling approaches
  - General Equilibrium Models (GEM)
  - Endogenous Risk Optimization (SDP, OCT)
  - Real Options

Frontiers in economic analysis of invasions

		Pathway	Species	Net costs: Market	Net costs: Non-market	Net costs: Total
Trajectory of existing species	Current	Ships	1			
			2			
			. . .			
		Pet industry	1			
			2			
			. . .			
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Economic issues & invasive species

EPA
July 2005

J Shogren
University of Wyoming

On-going research with:

- Ed Barbier, Wyoming
- Michael Margolis, Oberlin
- David Lodge and colleagues, Notre Dame
- David Finnoff, Wyoming
- Greg Parkhurst, Mississippi State
- Chad Settle, Tulsa
- Brian Leung, McGill
- Jean-Daniel Saphores, UC-Irvine
- Chris McIntosh, Wyoming
- Xiufen Wu, Wyoming

Issues

- Risk
- Incentives
- Valuation
- Prosperity
- Mindsets

Risk

- “Best practice” measures—prevention, eradication, and control
- Bioeconomics & joint determination
- Behavioral considerations

Endogenous risk

$$Max_{x,Q}\int_a^b [\,p(Q;\theta)V_0(m-c(x,Q))$$

$$+(1-p(Q;\theta))V_1(m-D(x;\theta)-c(x,Q))]dF(\theta;\beta)$$

Key notions:

- Risk and its consequences
- Bioeconomic risk assessment
- Portfolio of risk reduction mechanisms
- Mitigation and adaptation and insurance
- Prevention and control
- Stocks and flows can be added

- Captures risk-benefit tradeoffs and feedbacks

- Stresses that management priorities depend on:

  ***Tastes** of the manager

  - over time and risk bearing

  ***Technology** of risk reduction

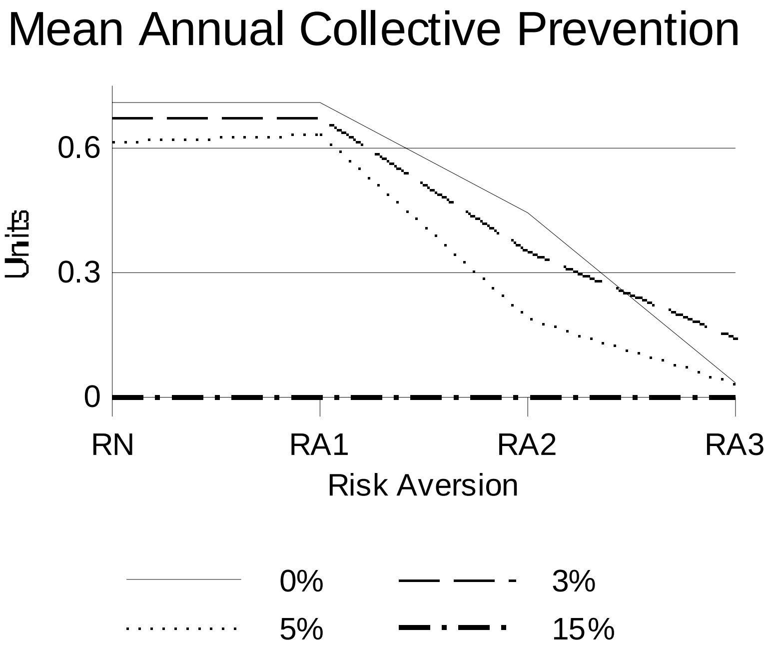
  - prevention, control, and adaptation

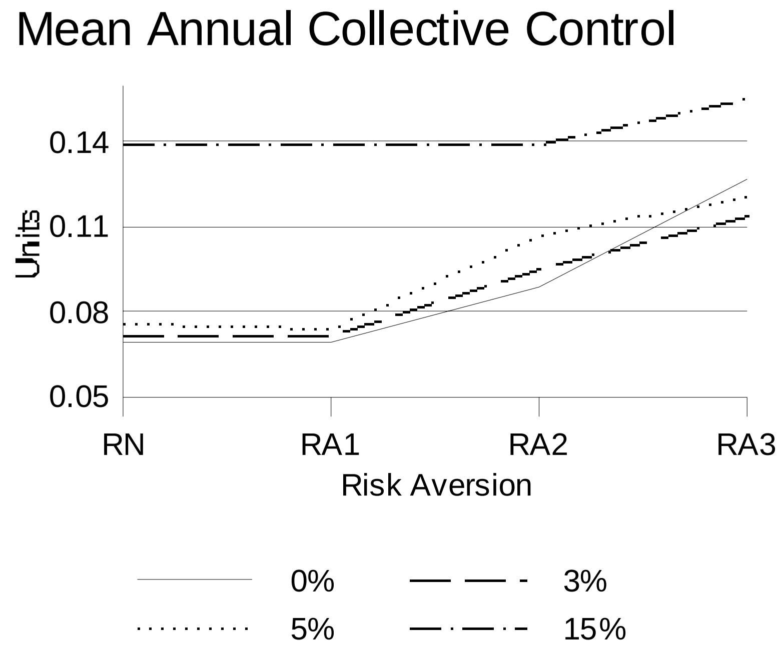
- Precautionary principle
  - To economists, we hear PP and we think *risk aversion*.
  - It is an assumption on how people might reaction to risk
  - To biologists, PP not an *assumption* rather it is an *outcome—long term protection of the environment*
  - PP: to look forward with purpose

Zebra mussel example

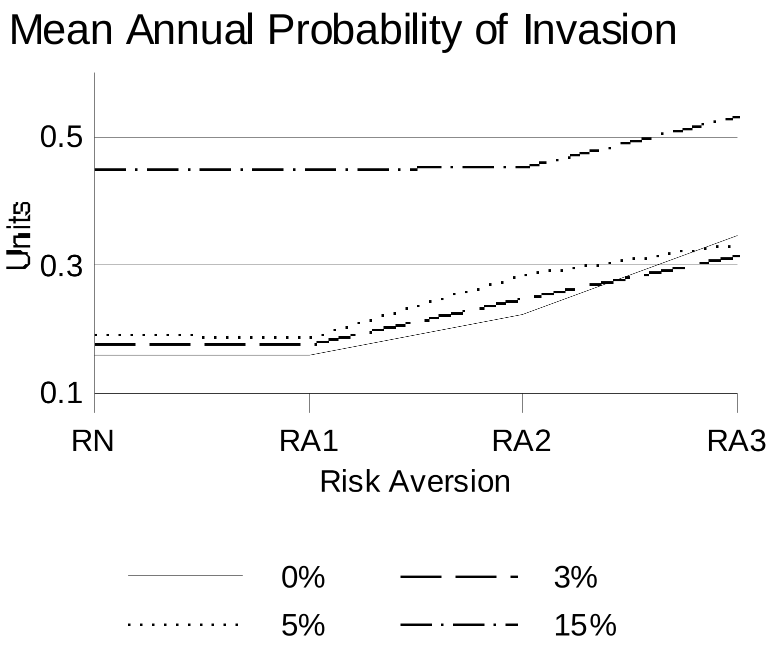
- Four managers who differ by risk preferences (RN, RA1, RA2, RA3)
- Choice of prevention or control or both
- Probability of invasion
- Welfare
- Ambiguous comparative statics

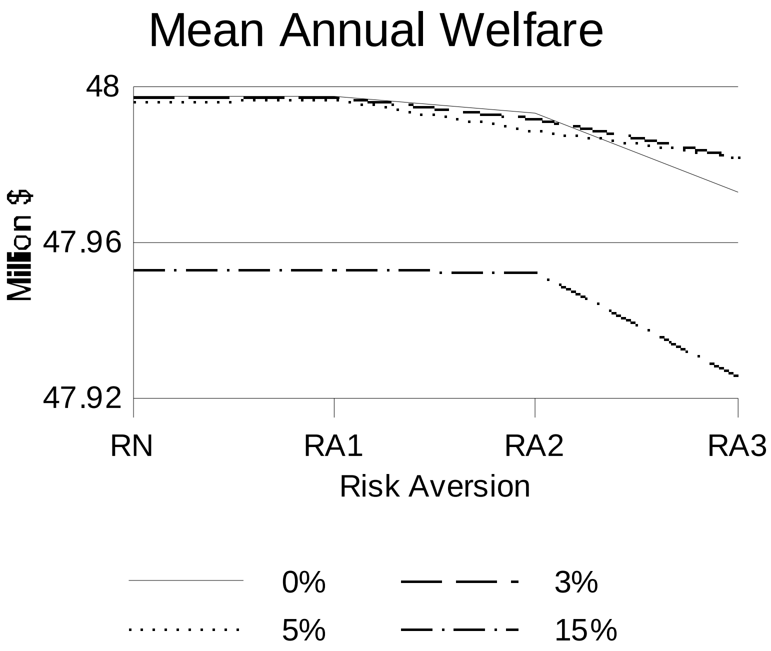
Simulation Results 1



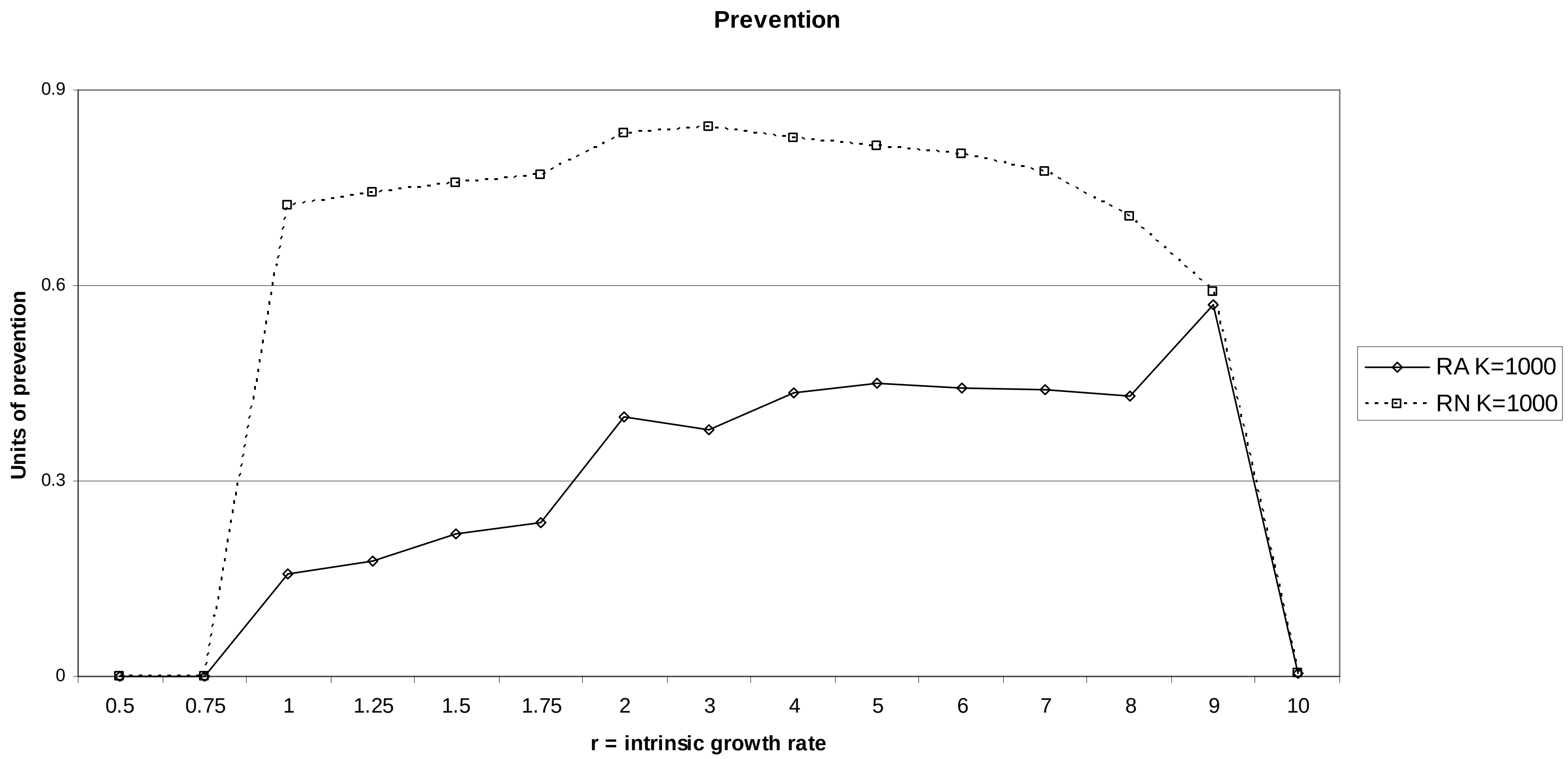


Simulation Results 2

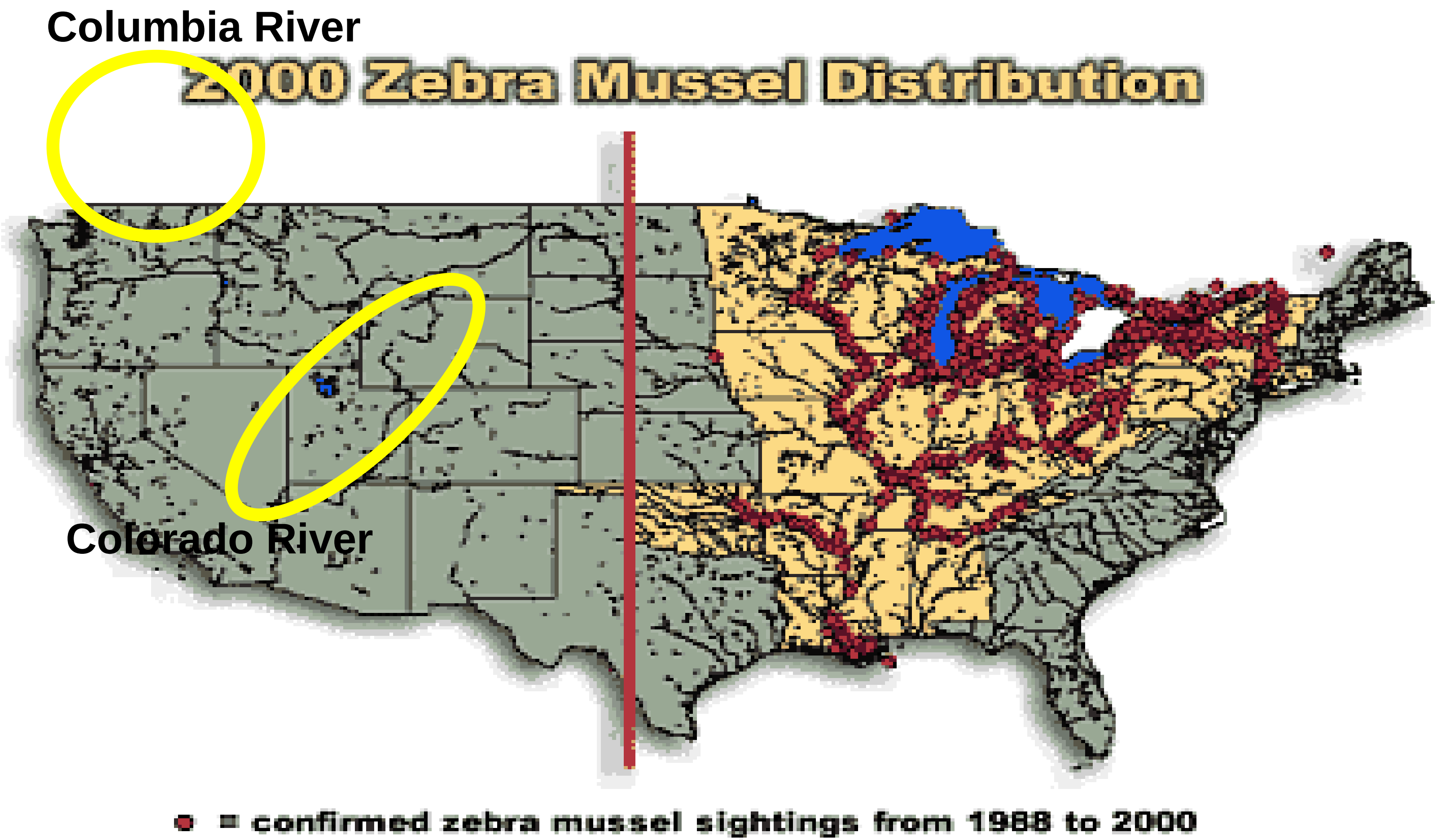




Prevention by growth rate



Value of preventing spread?



Real Option Theory

- Most investment decisions share 3 characteristics:
  - *Irreversibility*.
  - *Uncertainty*.
  - *Flexibility in selecting the timing of the investment.*
- The real options framework (see Dixit and Pindyck 1994) models investment decisions as **call options** (as in finance), that give the right (but not the obligation) to invest in a particular action.
- Such an approach has the potential for widespread applications to problems in resource and environmental economics.

GEEM

- General Ecosystem equilibrium Model
- Food web style model with Arrow-Debrue style structure
- Finnoff, Tschirhart, and students
- Cows, native grass, leafy spurge
- Lamprey eels in Lake Michigan

Other bioeconomic models

- Horan & Lupi, MSU
- Washington State
- PREISM (ERS/USDA)
- Hawaii group
- Perrings, ASU
- Olson, Maryland
- others

What seems to matter

- Feedbacks
- Defining the baseline as target
- Opportunity costs of risky inputs
- Prevention vs control
- Preferences—whose values count?
- Uncertainty & irreversibility

Behavioral considerations

- Low probability, high severity events
- Loss aversion
- Self-control problems
- Discounting issues

Incentives

- Markets
  - One person deal maker
- Coordination
  - One person deal breaker

Incentives

- Price rationing
  - Knowler and Barbier, EE 2005
  - “introducer pays” principle
- Quantity rationing
  - Horan and Lupi (EE, 2005)
  - No first best trading market that would be operational
  - Market price is overdetermined for two reasons
    - 1:1 trades inefficient.
    - Probability of invasion still public good
  - Second best trading set up
- Liability
  - Bonding requirements
  - Citizen suits

Coordination of private actions

- Coordination and the Compensation Question
- Incentive design to achieve both voluntary participation & biological targets

Target Habitat
Weak link public goods problem

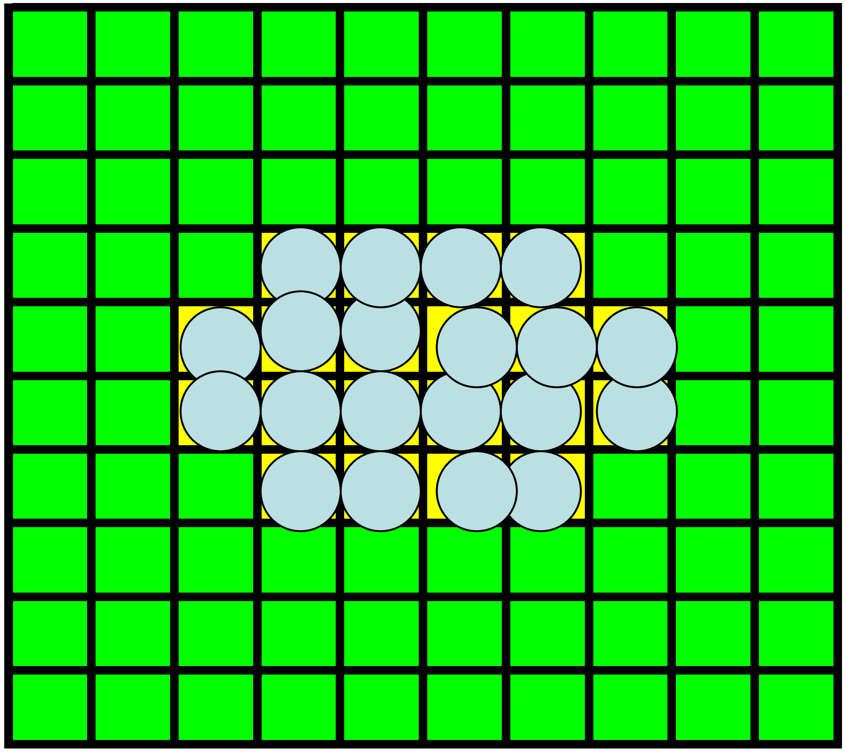


Figure C. Illustrative Example—No Subsidy

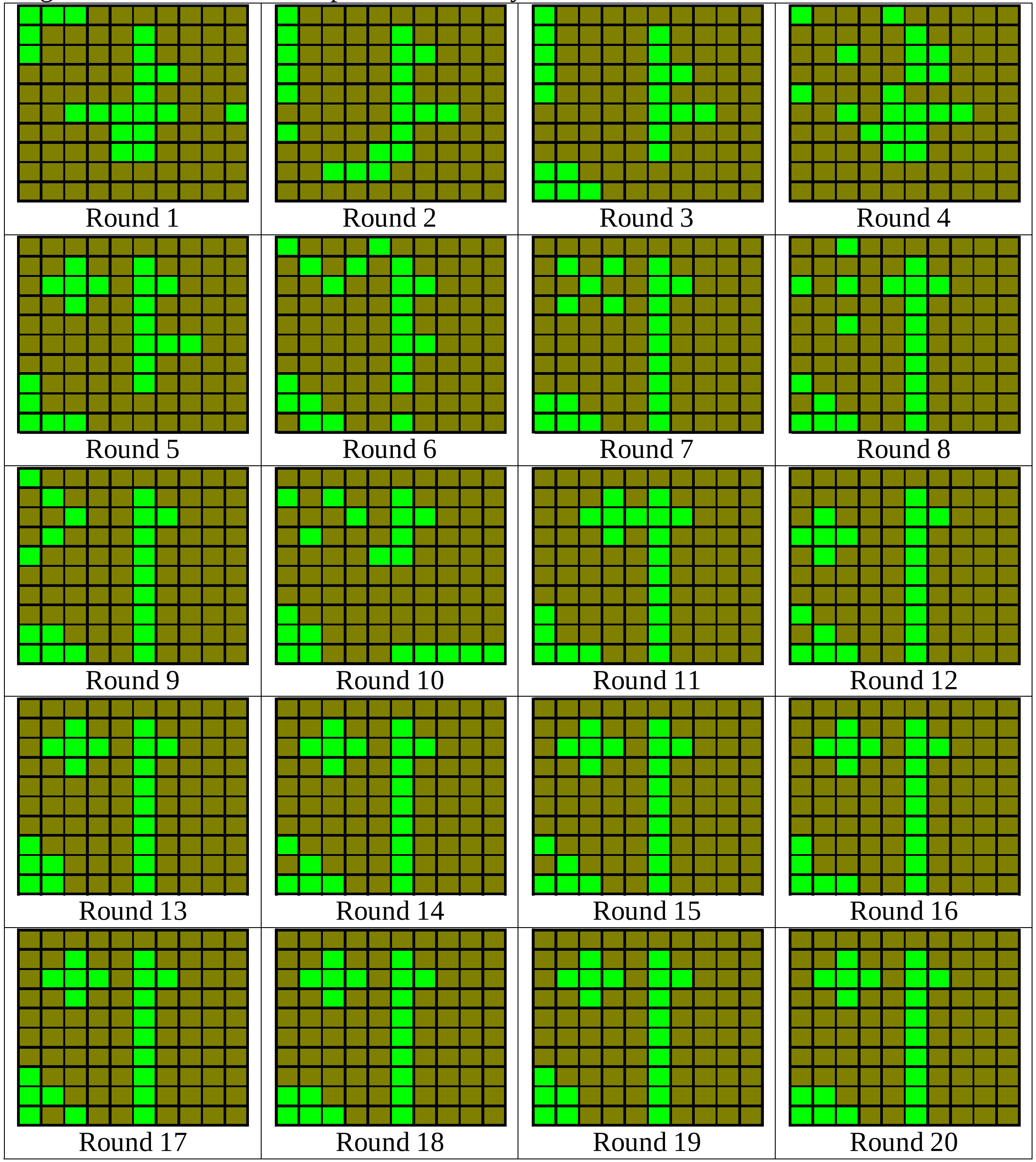
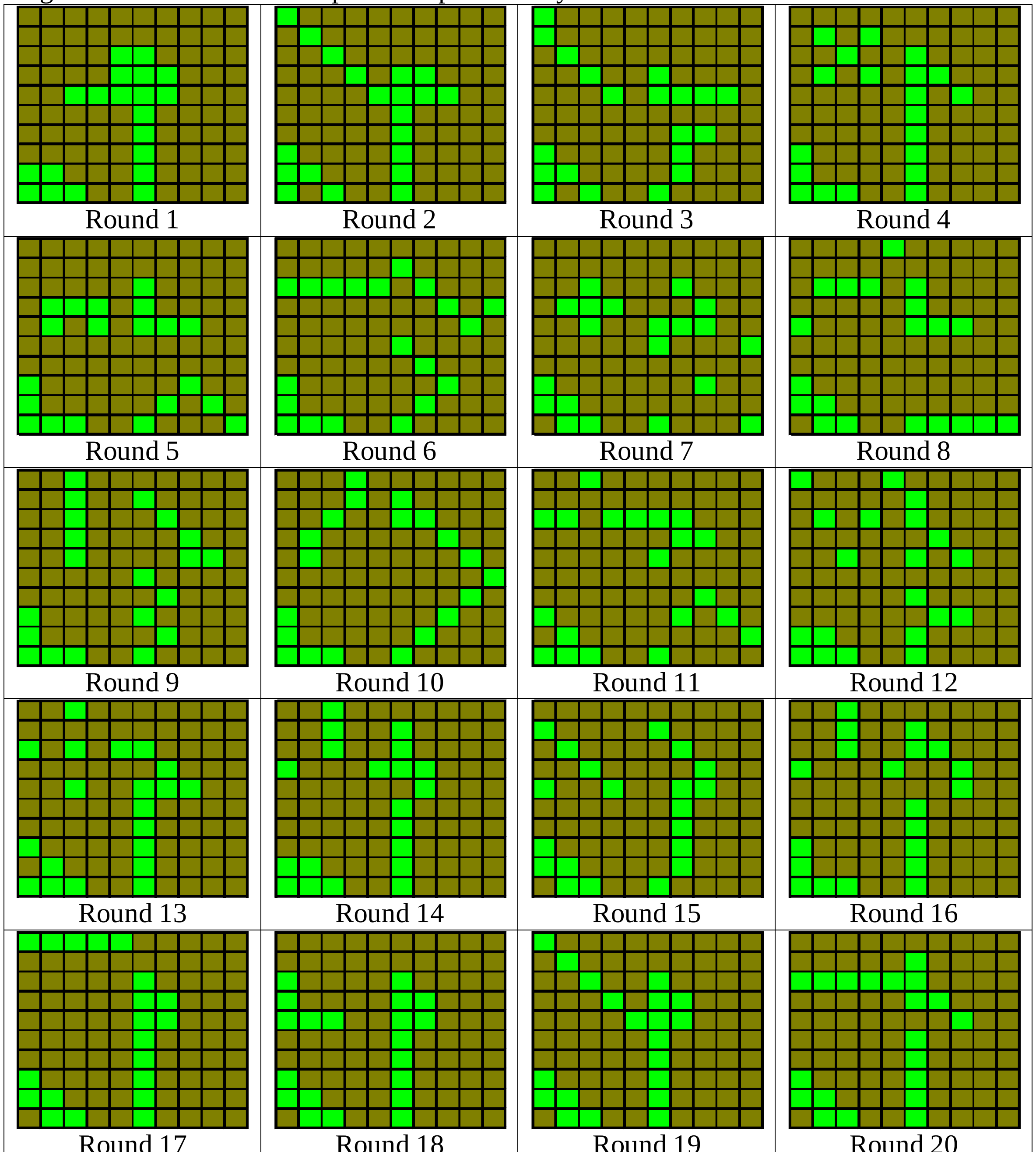
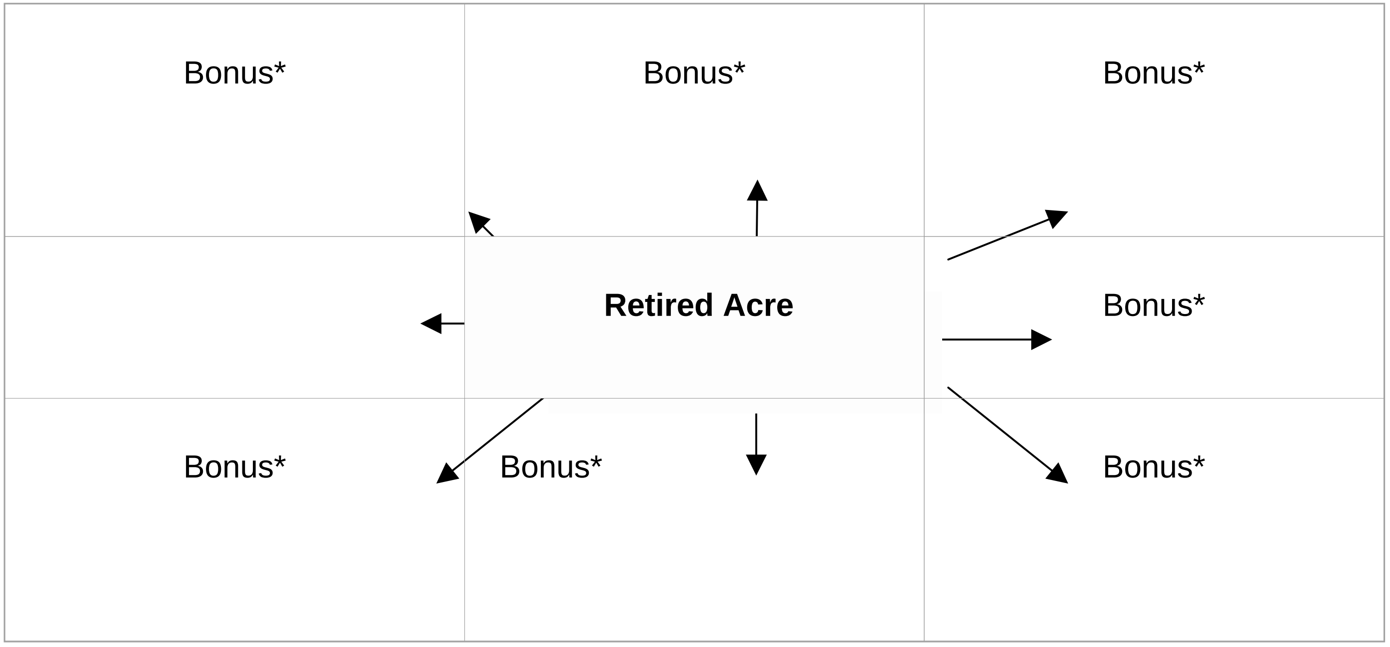


Figure D. Illustrative Example—Simple Subsidy



Agglomeration Bonus

- e.g., Oregon—river bank acreage retirement program



Subsidy system

- Four subsidies within the subsidy menu mechanism:
  - Per conserved habitat acre subsidy;
  - Own shared border
  - Row shared border subsidy
  - Column shared border subsidy
- Subsidies = + or – (or 0)

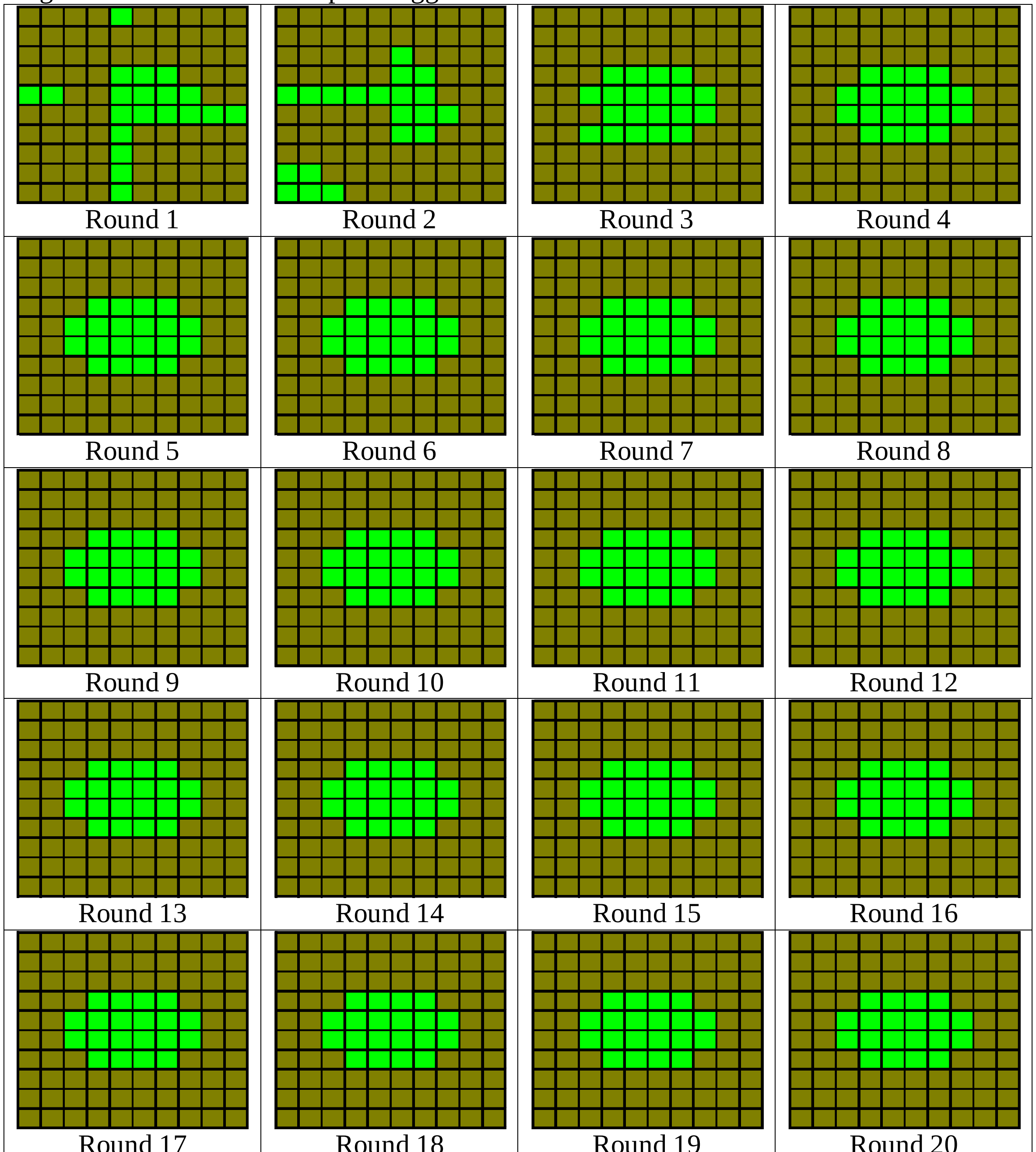
Coordination Game

Multiple Nash equilibria exist

– ("A Beautiful Mind")

- Equilibrium I—High risk, high reward
- EQ II—Safest bet, low reward
- EQ III—all those between I and II

Figure E. Illustrative Example—Agglomeration Bonus



Trading Spaces

- Set up a market to trade invasive species control responsibility

Figure 3. Illustrative Example—TSARs

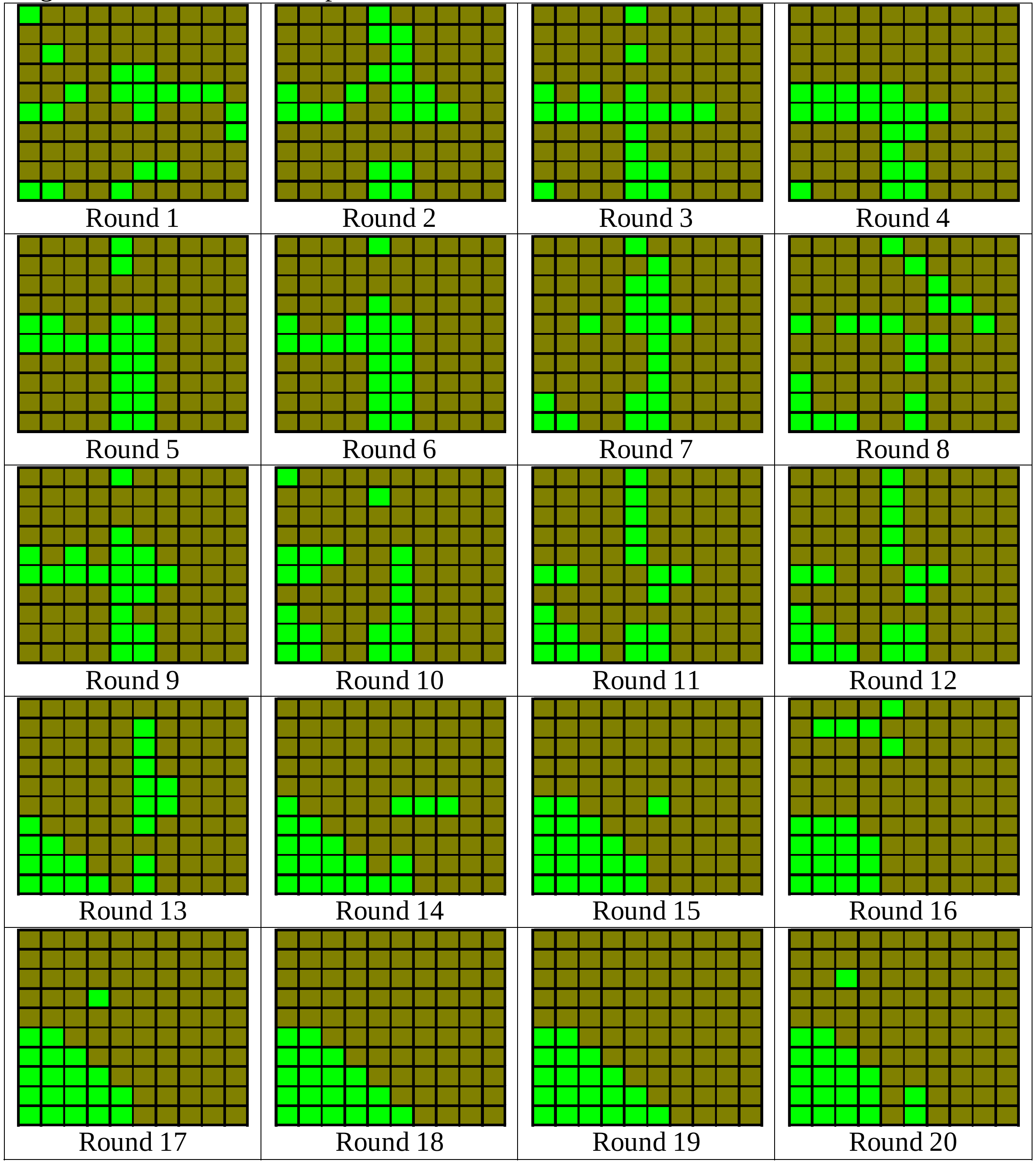
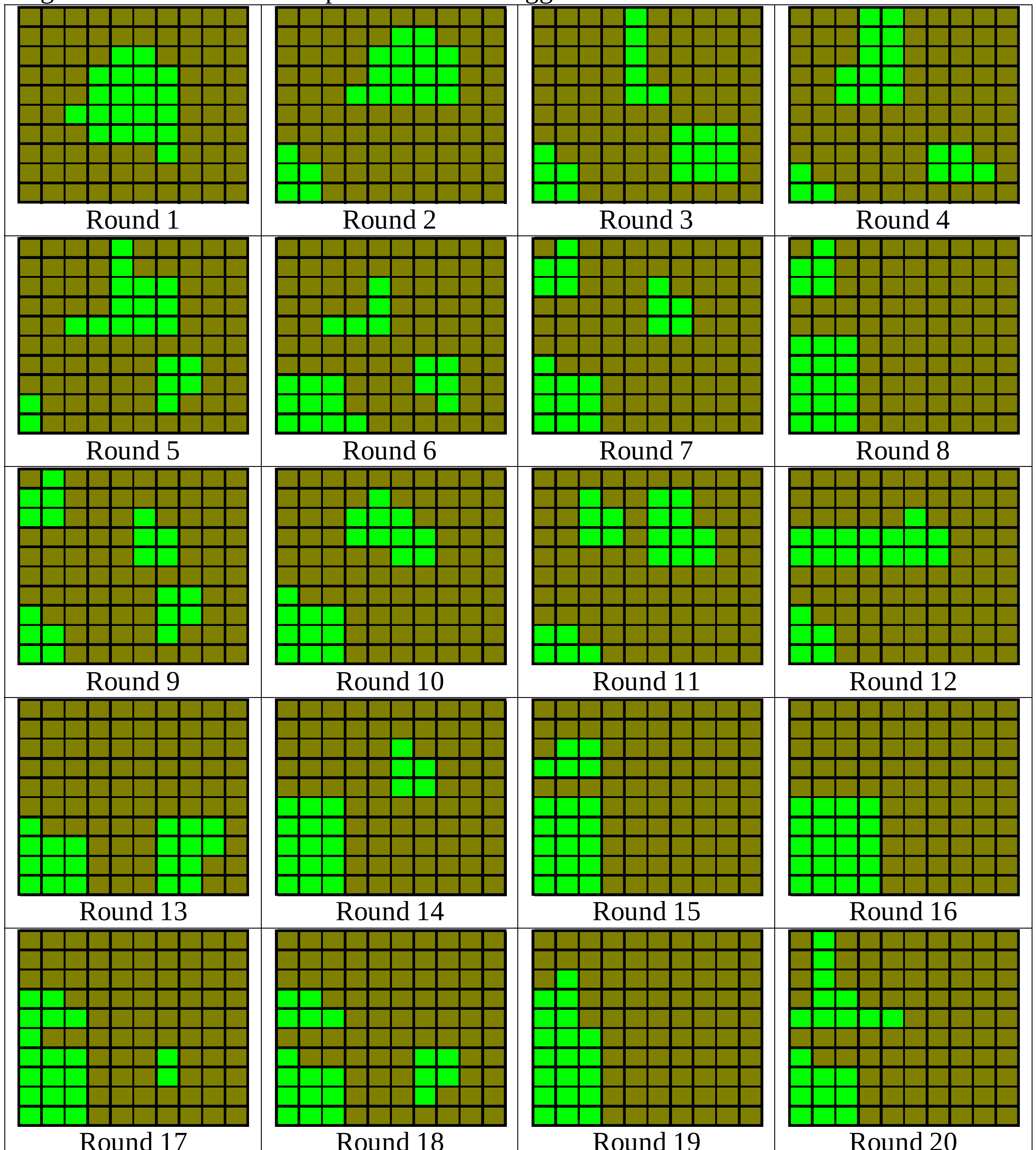
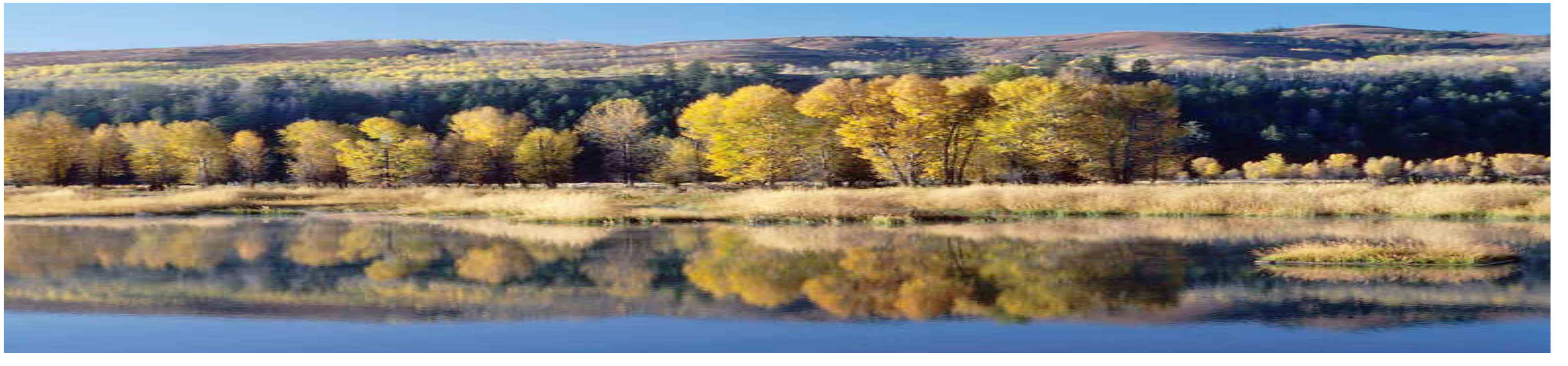


Figure 4. Illustrative Example—TSARs w/Agglomeration Bonus



Valuation

- Half-full, half-empty
  - Value of protecting baseline biodiversity?
  - Value of delaying some inevitable change from the baseline
  - What is the baseline by the way?
  - What if regular folks like the invader?



Definitions

- A water body is **Invaded** if a non-native species exists in a lake or river.
- A water body is **Harmfully Invaded** if that causes 'measurable' harm to some ecosystem attribute.
- A water body is **Not Invaded** if a lake or river is populated with only native species or **Not Harmfully Invaded** non-harmful invasive species.

More specifically, a water body is **Invaded** if the lake or river has a non-native species; and **Harmfully Invaded** if the species
- disrupts natural ecosystems and causes irreversible ecological harm
- gets rid of native plants, fish, and other aquatic life, or
- damages the economy

A water body is **Not Invaded** if the lake or river either does not have a non-native species or **Not Harmfully Invaded** if it has a non-invasive species that
- does not disrupt natural ecosystems and cause irreversible ecological harm
- does not get rid of native plants, fish, and other aquatic life, and
- does not damage the economy

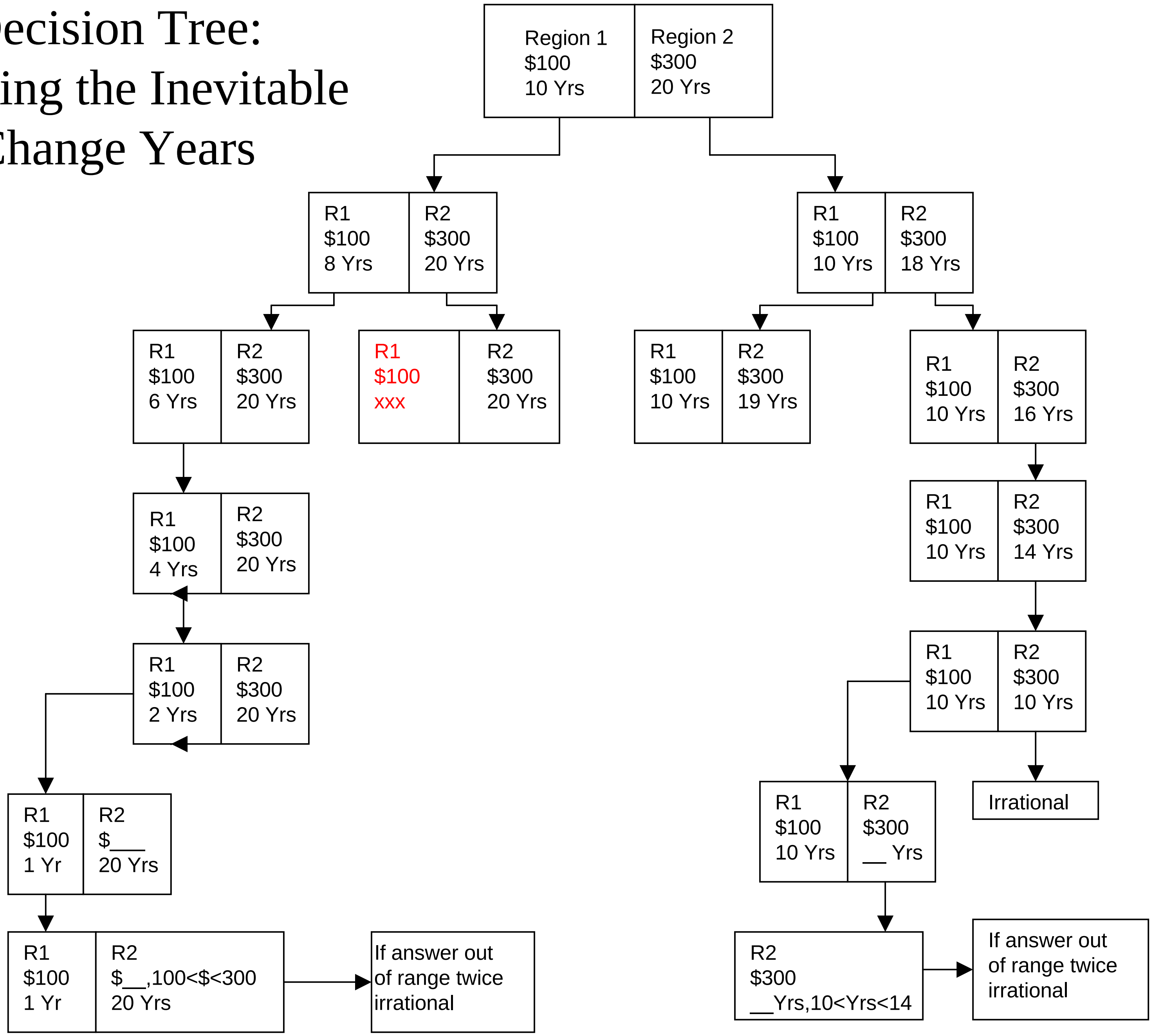
We would like to ask you some more questions like these. However, in these questions, one region will have a lower annual cost of living and the other will have higher percent of lakes and rivers that are not invaded. You must either choose between the two options or that you have no preference. No preference indicates that you are indifferent between the two options not that you dislike both options.

	Region1	Region2	
Increase in annual cost of living:	$100 More Expensive	$300 More Expensive	
Percent of lake acres and river miles that are not invaded in given amount of time from today:	40% Not Invaded Today	60% Not Invaded Today	
Which region do you prefer?	Region1	Region2	No Preference

Delaying the Inevitable

	Region1	Region2	
Increase in annual cost of living	$100 More Expensive	$300 More Expensive	
Percent of lake acres and river miles that are not invaded in given amount of time from today:	100% Invaded in 10 years	100% Invaded in 20 years	
Which region do you prefer?	Region1	Region2	No Preference

Decision Tree: Delaying the Inevitable Change Years

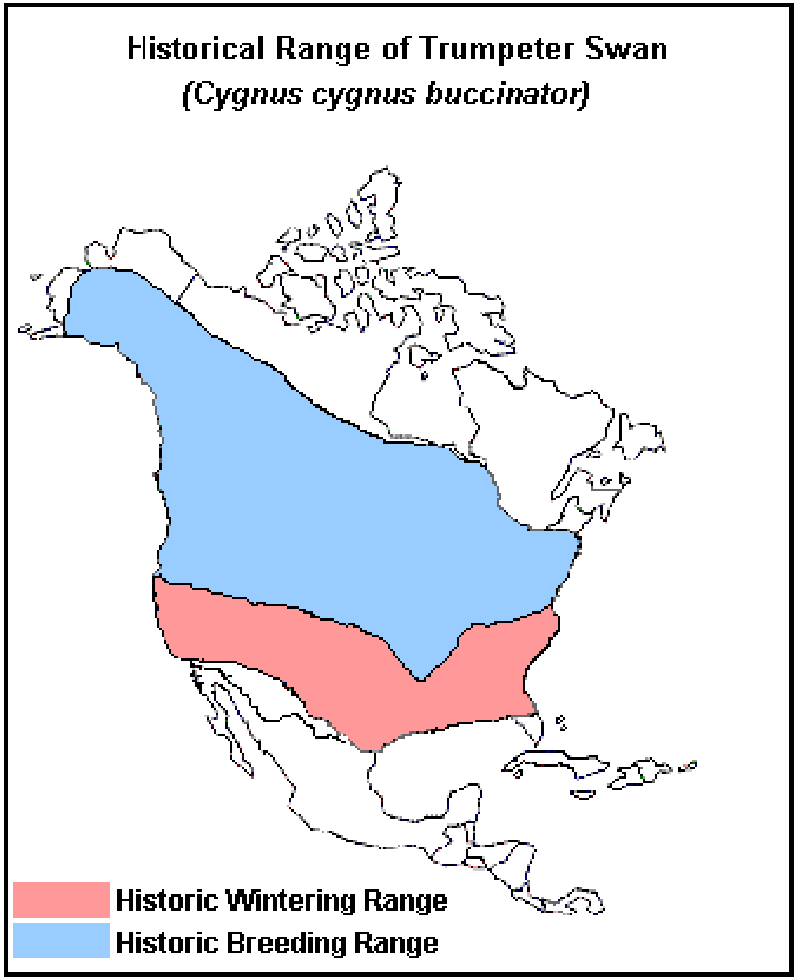


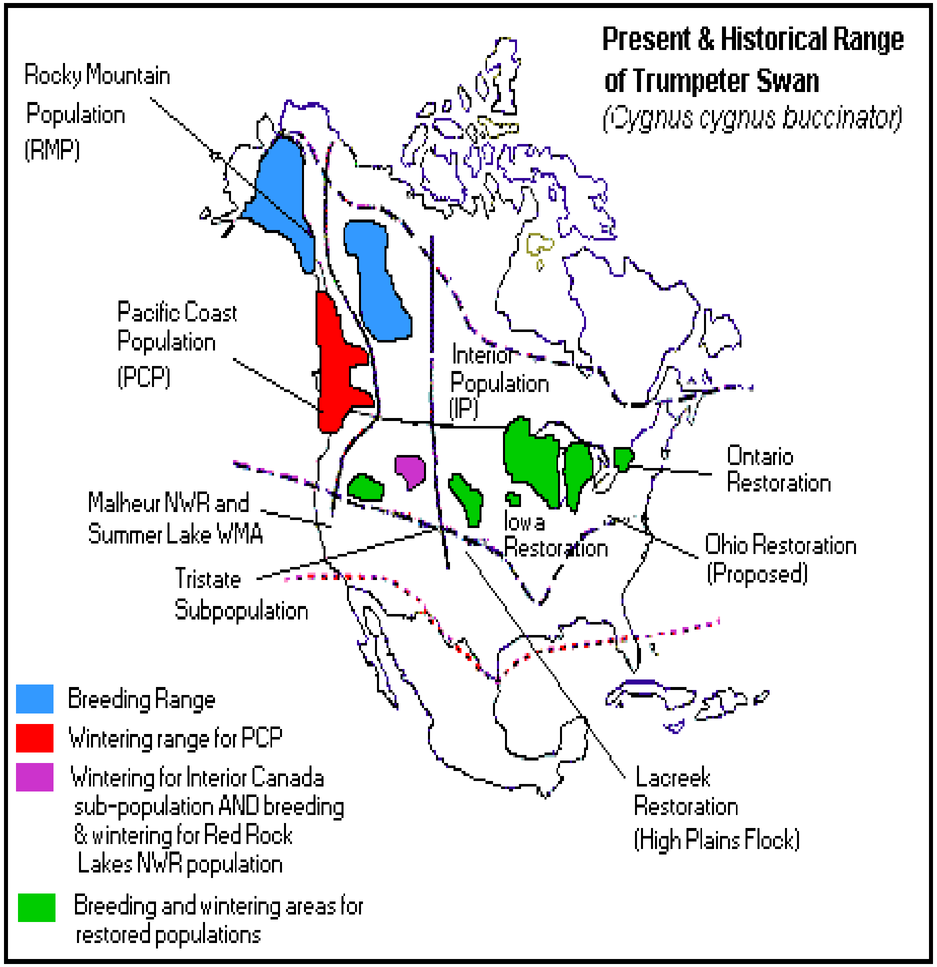
Ambiguity

How do we or should we assign value to invasive species we find aesthetically attractive?

What if the species has some good points and bad points?

How much are you willing to pay to let this bird live?



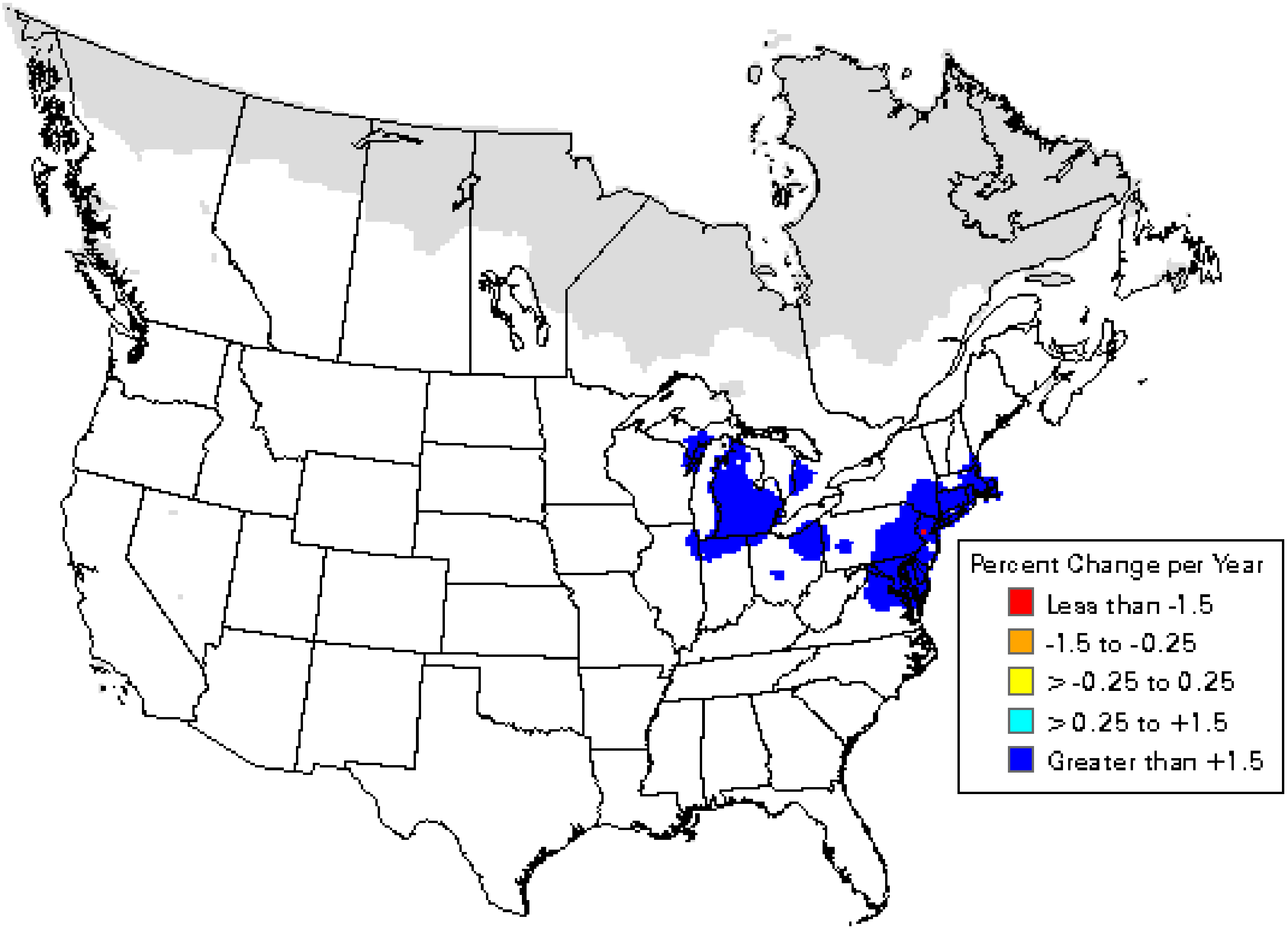


From the Defenders of Wildlife

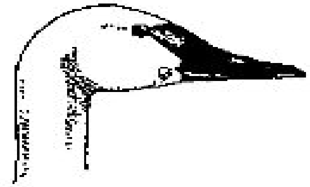
How much are you will to pay to kill this bird dead?

Mute swan

In 2002, the Maryland General Assembly urged the USFWS to act with expedience to craft and conduct appropriate regulatory processes to let Maryland establish a method to control the mute swan population and to mitigate the its impact permanently and statewide.



Mute Swan BBS Trend Map, 1966 – 2003
USGS Breeding Bird Survey

 Trumpeter	 Tundra (Whistling)	 Mute
Native to the northern U.S. Endangered Species	Native to the U.S. Population exceeds 10,000 Protected Species	Not native to the U.S. Population exceeds 6,000.
Wingspan: 7-8 feet **Weight:** 21-30 pounds **Height:** 4 feet	**Wingspan:** 6-7 feet **Weight:** 13-20 pounds **Height:** 3 feet	**Wingspan:** 7-8 feet **Weight:** 25-30 pounds **Height:** 4 feet
Often has a red border on lower mandible. Eye indistinct from bill.	Often has a yellow spot in front of eye. Eye distinct from bill.	Distinct black knob
Bill: broad, flat black bill with fine tooth-like serrations along the edges.	**Bill:** black in color	**Bill:** orange in color
Profile/Posture: Straight, sloping profile with bill is heavy and somewhat wedge-shaped in proportion to its large angular head. Holds neck erect.	**Profile/Posture:** Curving profile with bill is slightly dish-shaped or conclave and is small in proportion to its smoothly rounded head. Holds neck erect.	**Profile/Posture:** Arches wings over their backs and position their necks in a graceful "S" curve with the bill pointed downward.
Voice: resonant, deep and loud, sonorous and trumpetlike.	**Voice:** high pitched, often quavering OO-OO-OO, WHO-HO, or variations.	**Voice:** often silent, but may hiss, grunt, or snort at low volume.
	Behavior: congregate in large flocks during migration.	**Behavior:** often carry their young on their backs.

Ambiguity

- Currently, it is unknown exactly what percentage of lakes are not invaded in Region 2 so an estimate was made. The actual percentage could be anywhere in the range given with equal probability for each percent. That is, if you are given a range of 1-10% there is a 10% chance that each percent is the actual percent.

Ambiguity (Aversion)

	Region1	Region2	
Increase in annual cost of living:	$100 More Expensive	$300 More Expensive	
Percent of lake acres and river miles that are not invaded in given amount of time from today:	40% Not Invaded Today	50-70% Not Invaded Today Equal Chance of each Probability	
Which region do you prefer?	Region1	Region2	No Preference

Mindsets

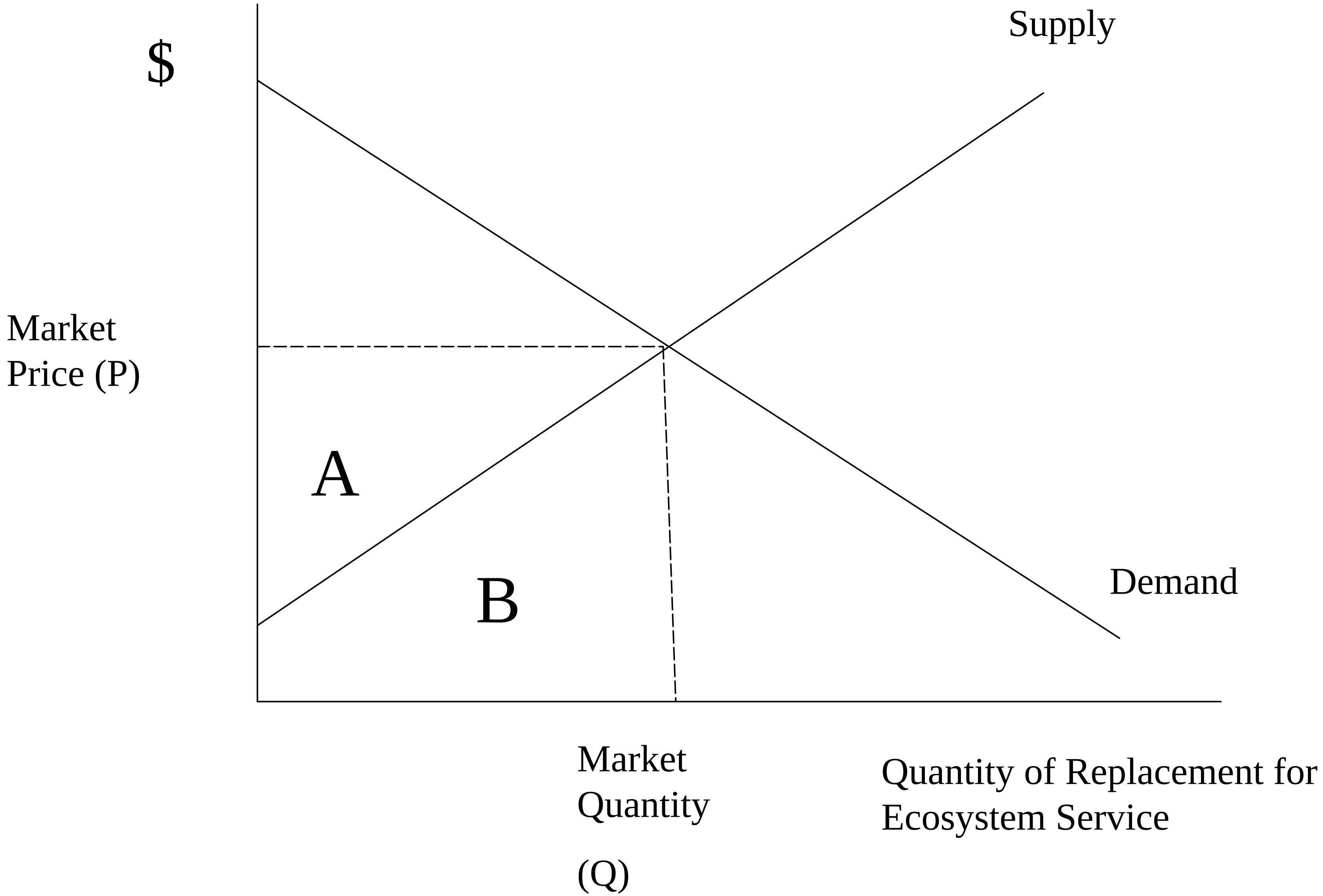
J Roughgarden’s Guide to Diplomatic Relations with Economists

Joan’s rules of engagement:

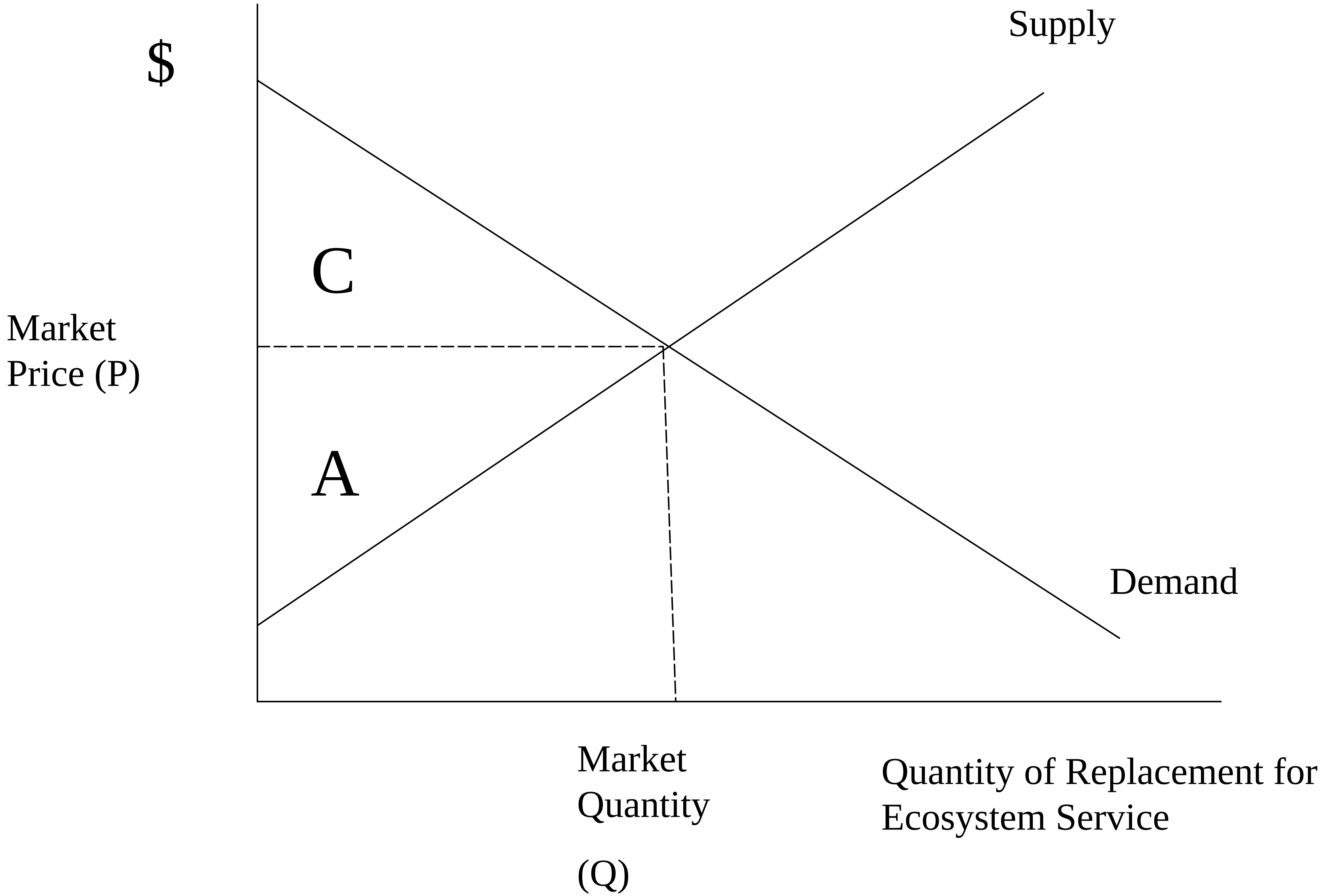
- Know who economists are
- Don’t assume the higher moral ground
- Don’t underestimate them
- Explain how ecology promotes economic growth
- Get used to their idea of valuation

Example—Pimentel et al. #s on invasive species

- $139 billion in “economic” damages done to US due to invasive species
- This $# is the #
- Economists cringe
- Why?



$
Supply
Market
Price (P)
A
B
Demand
Market
Quantity
(Q)
Quantity of Replacement for
Ecosystem Service



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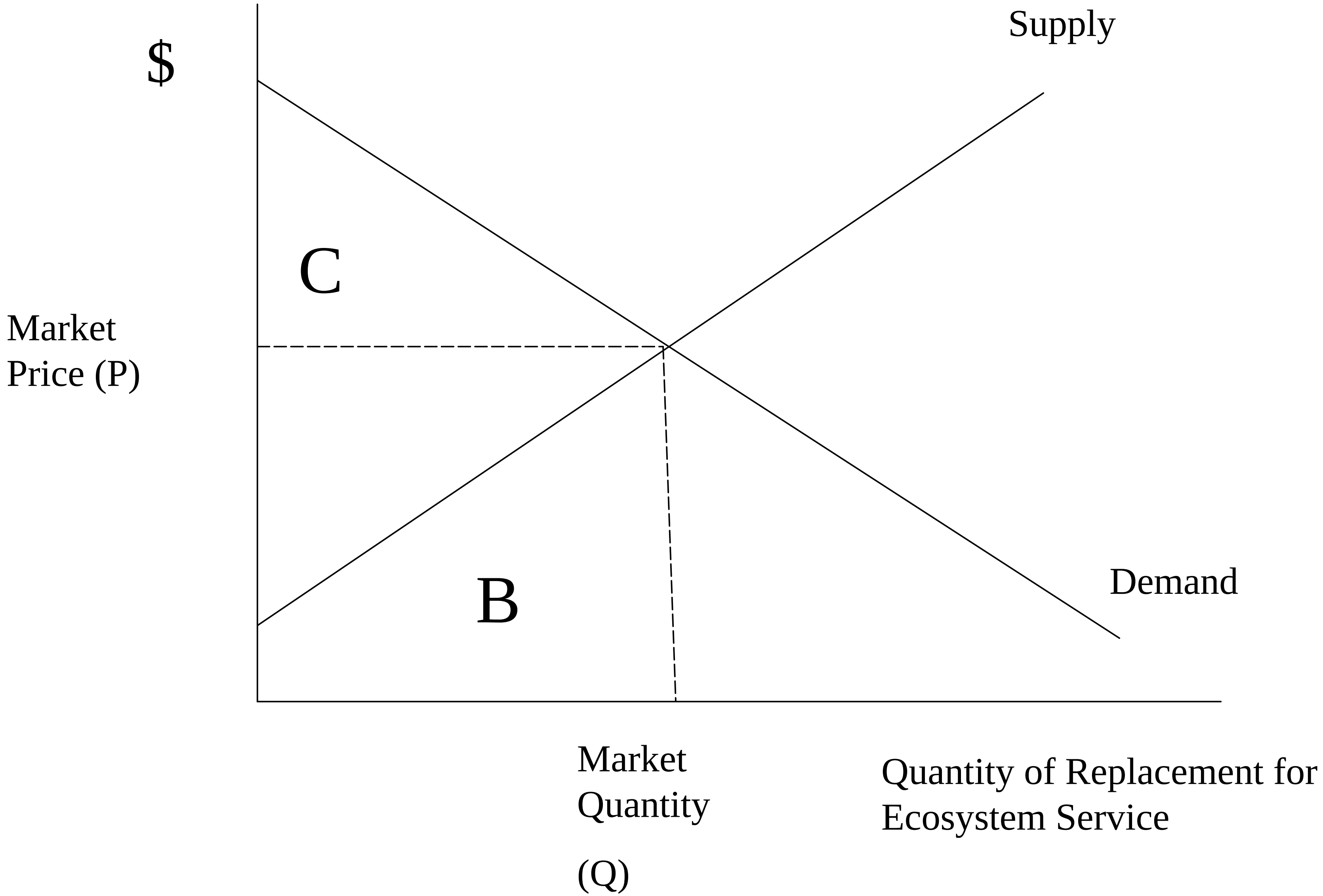
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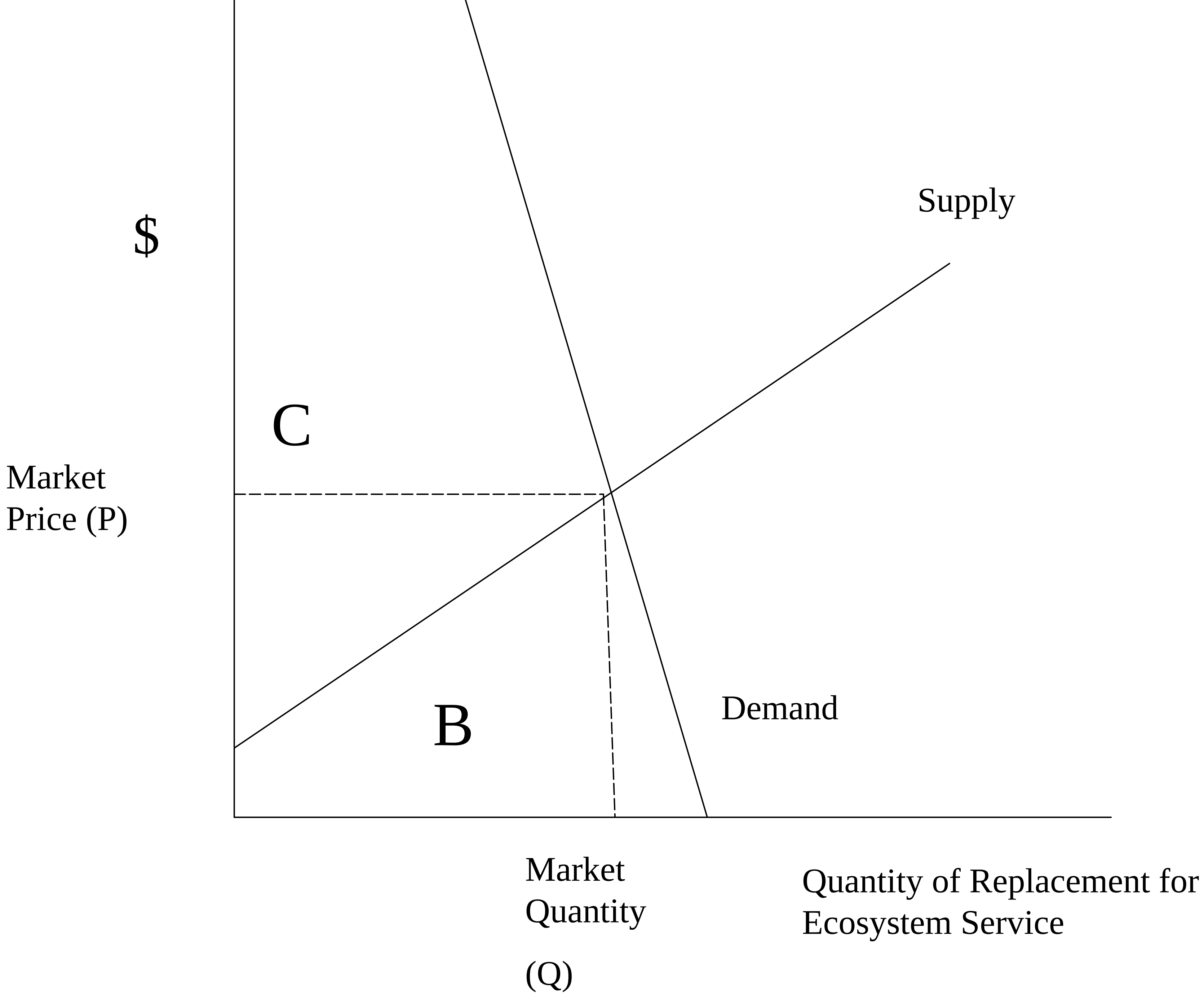
Supply
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Market
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B
Demand
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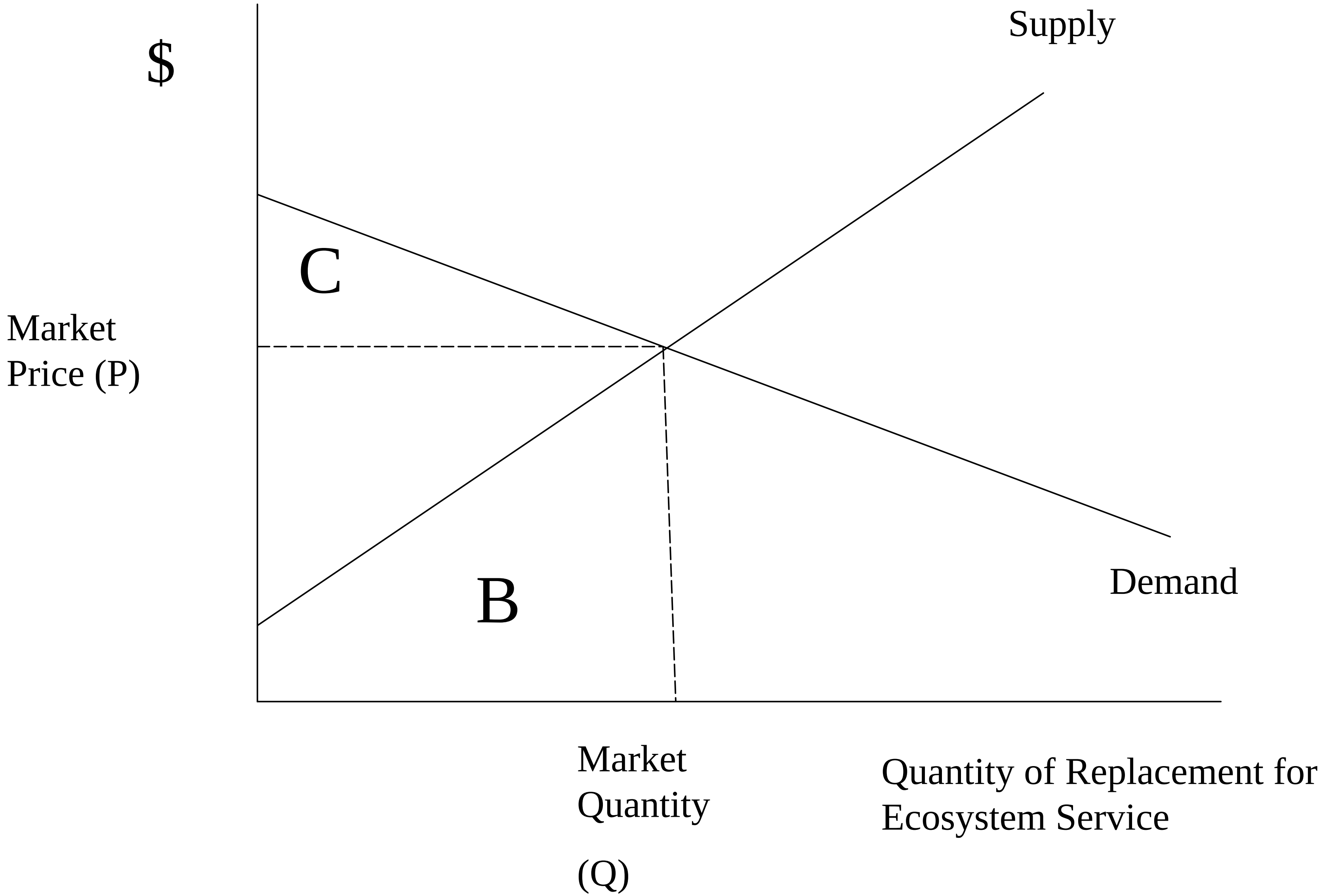
Quantity
(Q)
Quantity of Replacement for
Ecosystem Service

- “A serious underestimate of infinity”
    - – Michael Toman


$
Supply
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Market
Price (P)
B
Demand
Market
Quantity
(Q)
Quantity of Replacement for
Ecosystem Service

- So who will be the economist(s) willing to put another national number on the table based on welfare theory?
- Food safety—driven by COI estimates
- Invasive species—driven by COD estimates

Review

- Risk
  - Prevention and control
  - Joint determination
- Incentives
  - Markets
  - Coordination
- Valuation
  - Delay the inevitable
  - ambiguity
- Prosperity
  - Trade
  - Growth
- Mindsets
  - More protection at lower costs
  - Defining the target baseline