Developing a Decision Support Tool for Improved Aquatic Invasive Species Management

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Dedication

For my parents, Jane Marinsky and Daniel Sharpe.
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Abstract

Aquatic invasive species (AIS) are a serious problem with adverse ecological, economic, and social impacts. These wide-ranging impacts mean similarly wide ranges of affected and interested parties (stakeholders) and of knowledge and data types being involved in AIS decisions. Decision support tools (DST) can be powerfully effective methods for helping to simplify complex decisions, incorporating different types of knowledge, and assisting in clear communication between involved parties. Developing a useful DST, however, requires understanding the needs, priorities, and concerns of broader stakeholders as well as the managers responsible for making the decisions. It also requires understanding the legal and policy context for these decisions. This dissertation reports the results of research conducted to understand stakeholders' attitudes and concerns about genetic biocontrol (a new AIS control technology currently under development), understand the strengths and weaknesses of the current decision-making process used by AIS managers, and examine the effectiveness of the National Invasive Species Act, the key piece of federal AIS legislation regarding management of AIS. Together, these results form building blocks for developing a DST for improved management of AIS.

Information on stakeholder perspectives on development of new AIS control technologies, involving genetic manipulations, was gathered in a series of focus groups in the United States Great Lakes and Lake Champlain regions. Stakeholders were enthusiastic about the potential inherent in these new technologies but remained deeply concerned about potential unintended consequences. Key concerns related to ecological impacts, the cost of development, and the possibility that this research will detract from other, ongoing control work. Stakeholders also had a number of recommendations for development of these new technologies that have implications for broader AIS management. These recommendations included engaging stakeholders throughout the

development process, employing clear go/no-go reasoning, and using a transparent decision-making process.

A series of interviews with natural resource managers was undertaken to improve understanding of the current decision-making environment and identify its strengths and weakness. These interviews illuminated the priorities and concerns underlying managers' decision-making processes, their perceptions of existing strengths and weaknesses of these processes, and the issues that a decision support tool could help them to better address. In their work, managers must balance a wide range of priorities competing with one another for limited resources (e.g., prevention and containment efforts, research into new control tools, control and eradication efforts). The existing decision-making environment succeeds at facilitating coordination between agencies and communication with the broader public. This process, however, currently lacks several principles of robust decision-making including sufficient scientific basis, structure, documentation, and an adaptive element. The results indicate that AIS decisions could be strengthened by explicitly incorporating these principles into the decision-making process and that use of a decision support tool would be an effective way of carrying out such incorporation.

Finally, I analyzed the National Invasive Species Act, arguably the most important federal policy dealing with AIS, using peer-reviewed and grey literature, as well as natural resource manager interviews to assess whether or not the Act had met its stated goals. The results indicate the Act has had limited success in achieving its objectives, especially in preventing introductions of new invasive species and limiting the spread of invasive species already present, but has been effective in organizing national and regional coordination via the Aquatic Nuisance Species Task Force and its regional panels. Results suggest that reauthorizations of the Act should grant additional authority to regulate introductions via pathways other than ballast water to a federal agency and that the Aquatic Nuisance Species Task Force should be granted additional authority and resources to allow it to further increase regional coordination of control and containment efforts.

Together, these results allowed me to design a blueprint for a DST responsive to the needs of stakeholders, managers, and federal level policy. I developed a simplified sample of the DST to illustrate how it combines spatial data with manager experience and stakeholder priorities to determine key areas for management actions (i.e. monitoring, quarantines, and control efforts).

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Introduction

Invasive species are one of the greatest threats currently facing ecosystems. Human behaviors are responsible for increasing the rate of invasions far beyond the historical environmental norms (Mack et al. 2000) and some of these invasions have devastating effects, both ecologically and economically. Environmental managers are presently ill equipped to decide whether and how to actively control an invasive species, once it has become established in their jurisdiction. Control efforts are often *ad hoc* and primarily in reaction to public pressure instead of resulting from a systematic appraisal based on ecological reasoning.

Over a decade ago invasive species were deemed the second greatest threat to biodiversity with up to 46% of the plants and animals federally listed as endangered species in the United States negatively impacted by invasive species (Wilcove et al. 1998). Invasive species negatively affect evolutionary pathways (Mooney and Cleland 2001), ecosystem function (Mack et al. 2000), and the quality and quantity of outdoor recreation opportunities (Eiswerth et al. 2005). Pimentel et al. (2005) estimated that the economic cost of invasive species to Americans is approximately $120 billion per year. Invasive fish have been shown to harm native species through predation, competition, hybridization, and introduction of new diseases (Allendorf 1991). Concerns about aquatic invasive species led to federal legislation in 1990 that used ballast water regulations to limit invasive species introductions and established an Aquatic Nuisance Species Task Force. The Task Force was charged to create and implement a national plan for preventing, monitoring, and controlling unintentional introductions of nonindigenous species (Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990). Most recently, the Convention on Biological Diversity's Strategic Plan for Biodiversity 2011-2020 listed control and eradication of invasive species as one of its twenty key targets (Convention on Biological Diversity n.d.).

Management of aquatic invasive species is challenging because of the wide range of issues that must be considered in making management decisions and the wide range of interested and affected parties (stakeholders) who want to be involved in making those decisions. Aquatic invasive species and efforts to control them have impacts on the environment (e.g. water quality, biodiversity), economy (e.g. commercial fisheries, utility companies), and society (e.g. recreational opportunities, aesthetics). Thus, decisions about them necessarily involve a wide range of stakeholders including natural resource managers, conservation groups, anglers, and commercial interests.

Further complicating the issue is the number of agencies and policies influencing management decisions. The plethora of involved parties and policies at the federal level is overwhelming even before attempting to sort through the various management responsibilities and priorities. Multiple agencies (e.g. U.S. Fish and Wildlife Service, the National Oceanic and Atmospheric Administration, the U.S. Coast Guard, the Animal and Plant Health Inspection Service, U.S. Environmental Protection Agency) have all been involved in aquatic invasive species management under various authorities and policy instruments. This situation is exemplified by the existence of two separate national-level invasive species coordinating groups, the Aquatic Nuisance Species Task Force and the National Invasive Species Council, created by different policy instruments and producing different national management plans.

Given the wide range of issues being considered and the number of involved parties, use of decision support tools could assist managers in their decision-making process (Fedra 1995). Decision support tools (DSTs) are designed to allow information from a variety of sources to be integrated and viewed together, a critical benefit when dealing with decisions that incorporate elements that cannot be directly compared or combined (i.e. social elements with ecological ones). DSTs can also help make the decision-making process transparent. A transparent, well-documented DST can also be an effective tool for communicating decisions, a critical asset in AIS management. DSTs allow for decisions to be made systematically and uniformly and provide documentation of the decision-making process. This allows decisions to be explained and defended more easily. Appropriately designed DSTs can also be used as part of a collaborative decision-making process, facilitating involvement of stakeholders. A DST that provides documentation allows decision-makers to return to past decisions and determine whether new information would have altered the decision reached, providing a clear pathway for updating and improving the decision-making process.

My dissertation research identified and analyzed three sets of data that are important building blocks for designing a decision support tool that is most salient for the actual management context. This dissertation is made up of three chapters, each of which is written for publication in a peer-reviewed journal, and a conclusion laying out future work. The first chapter analyzes a series of focus groups held around the Great Lakes and Lake Champlain that were designed to explore stakeholder perspectives on development of new aquatic invasive species control technologies. The second chapter identifies and examines natural resource managers’ perspectives of the current aquatic invasive species decision-making environment: priorities and concerns influencing their decisions, strengths and weaknesses of extant decision processes, and aspects that could be improved by a decision support tool. The third chapter is a policy analysis focused on the National Invasive Species Act, examining both its intent and its actual impacts. Finally, the conclusion brings together key findings from these chapters and uses them to design a blueprint for a spatially explicit DST that is responsive to the major needs, concerns, priorities, and opportunities identified within these prior chapters.

Chapter 1: Public Perspectives on Genetic Biocontrol Technologies for Controlling Invasive Fish

Understanding people’s knowledge, attitudes, and concerns about genetic biocontrol can help researchers understand the challenges and opportunities that may be encountered during development of these technologies. This study conducted eight focus groups in the United States Great Lakes and Lake Champlain region to assess different stakeholders’ views about genetic biocontrol technology, factors affecting whether or not they support its use, and recommendations on how to proceed with its development. Stakeholders were excited about having a new invasive species control tool, but they were deeply concerned about potential unintended consequences. The primary concerns relate to ecological impacts, along with the cost of development and the possibility that such efforts will distract from other, ongoing control work. Participants made a number of recommendations to genetic biocontrol developers, including setting up regulatory systems, conducting independent cost benefit analyses and risk assessments, and engaging stakeholders throughout the development process.

INTRODUCTION

Invasive fish have been shown to harm native aquatic species through predation, competition, hybridization, and introduction of new diseases (Allendorf 1991). Unfortunately, currently available control tools are not species specific, have non-target impacts, and often require continuous inputs of time and resources (Schwartz 1986, Bulow et al. 1988, Marking 1992, Verrill and Berry 1995). Researchers and natural resource managers have begun exploring novel control options, including the use of genetic modification to biologically control invasive fish (Kapuscinski and Patronski 2005). Two genetic modification techniques show the most promise: chromosome set manipulations and recombinant DNA methods. Although these technologies have the potential to be an effective and species-specific control tool, they also have potential risks and uncertainties. I report results from focus groups exploring stakeholder reactions to the technologies and associated issues of risk.

Chromosome set manipulations (deliberate change in haploid sets of chromosomes) include triploidy and the Trojan chromosome approach. Triploidy refers to an organism that contains three sets of chromosomes instead of the normal two. Triploidy in fish can lead to sterility. The presence of triploids in a wild population can decrease the number of successful matings, ultimately leading to a reduction in population size (Kapuscinski and Patronski 2005, Benfey 2010). In the Trojan chromosome method, researchers develop YY “supermales” (normal males have an X and a Y chromosome) that are hormonally treated to induce them to mate as females and then released into the wild to mate with XY males. Matings between YY and XY fish are unable to produce female offspring with the required two X chromosomes. Over time, repeated stocking of the female-behaving “supermales” can produce increasingly skewed sex ratios, driving wild populations to be predominantly male (Cotton and Wedekind 2007).

Recombinant DNA techniques rely on the insertion of a transgene—a novel genetic construct synthesized by recombinant DNA methods—into a fish genome, creating a genetically modified fish that expresses the trait associated with that transgene (Thresher

2008). The inserted transgene imparts a deleterious effect on individual fishes or on the populations as a whole. Such transgenic fish would be stocked in the wild and mate with the invasive population. The deleterious transgene would spread through the invasive population and ultimately lead to a reduction in the population size. Researchers in Australia are currently exploring a “daughterless” gene that would cause fish to have only male offspring (Brown and Walker 2004, Thresher 2008).

Genetic biocontrol is a potentially controversial way to control invasive aquatic species, as it involves releasing genetically manipulated fish into natural environments. Ascertaining the opinions and concerns of stakeholders—interested and affected parties—can help researchers understand potential challenges and opportunities that may be encountered during the technologies’ development. The concept of risk is highly subjective and stakeholder involvement is critical in framing it appropriately (Slovic 1999). Further, stakeholder representatives can contribute valuable knowledge that complements that of scientific experts, an enrichment of the knowledge-base especially useful in complex, uncertain situations (Bäckstrand 2003). The importance of stakeholder opinion and involvement in the development of such technologies is highlighted by Thresher and Kuris (2004) who elicited opinions from a diversity of Australian stakeholders (e.g., representatives from conservation groups, fisheries and aquaculture industries, managers, and scientists) about several potential invasive species control options. They found that genetic biocontrol was one of the less acceptable options; determining the reasons behind such rankings can help decide whether and how to move forward with the technologies. In this study, we used focus groups to gain in-depth information on how stakeholder groups in the United States react to genetic biocontrol technologies and the reasoning behind those reactions. This work is a unique and groundbreaking attempt to bring stakeholders into the discussion about using genetic modification technologies as a potential control tool for invasive fish. Our findings were shared with researchers, managers, regulators and other interested parties at the International Symposium on Genetic Biocontrol of Fish, held in Minneapolis, Minnesota, USA in 2010.

METHODS

Focus groups are a valuable technique to expose "underlying attitudes, opinions, and behavior patterns" (Pramualratana et al. 1985). Group discussions, rather than one-on-one responses to an interviewer, allow participants to talk more freely and concentrate the discussion on points they find most important. Such discussions are especially valuable for gaining understanding of how affected populations view issues for which little is known (Byers and Wilcox 1991). The economic and environmental costs of invasive species (Pimentel 2005) mean that effective control tools are in demand, and the diversity of interested and affected parties makes this a useful area for exploring stakeholder reactions. Developing new technologies for genetic biocontrol of invasive species and deciding whether to bring them into practical application will require a good understanding of people's knowledge base, values, attitudes, and concerns (Schot 2001).

I conducted eight focus groups in 2009-2010 with stakeholders interested in or affected by the potential use of genetic biocontrol in the United States Great Lakes region and the Lake Champlain region. The Great Lakes and Lake Champlain are valuable fresh water ecosystems facing significant invasive species problems. Group size ranged from four to 16 participants, with 61 total participants. Focus group locations were chosen for their convenience to stakeholders and the local Sea Grant offices (university-based programs that work with coastal communities) coordinating the recruitment of participants. Local Sea Grant offices identified key stakeholders in the area and we worked together to extend invitations via email and over the phone. Participants came from a number of stakeholder groups in each of the eight locations, including state, federal, and regional management agencies, non-governmental organizations, commercial and recreational user groups, citizen groups, and tribal groups (Figure 1). All of these groups were involved with the conservation, management or use of natural resources available in the Lakes, and they were not necessarily representative of the general public. Power differentials among participants can result in participants being reluctant to express their true opinions (Krueger and Casey 2000). This, however, was a relatively minor concern in these focus groups for several reasons: 1) no participant in a given focus group had a position of authority over any other; 2) the focus groups were convened and conducted by parties with no vested interest in the approval or disapproval of the technology; and 3) all focus group discussions, including the identity of the participants, were confidential so participants could speak without fear of repercussion.

Focus groups should provide a comfortable environment in which participants feel able to share their opinions, ideas, and concerns without fear of retribution or disapproval (Krueger and Casey 2000). To this end, the facilitator emphasized that she was not involved with developing genetic biocontrol, nor was she a proponent or an opponent of the technologies. The facilitator also emphasized that research on this technology was in its infancy and that the focus groups were an exploratory effort to gather as wide a range of perspectives as possible. Given this goal, all opinions and viewpoints, both pro and con, would be valuable additions to the focus group discussion as well as to the upcoming Symposium.

Because genetic biocontrol is a relatively new idea, most participants had little, if any, knowledge about the topic. To provide all participants with the necessary information to take part in the discussion, background information packets were distributed to participants prior to the focus groups (Supplemental Materials1-3), and included questions the focus group would be discussing, information about two methods of genetically altering fish for biocontrol applications (chromosome set manipulations and recombinant DNA methods), and references for more information. These background information packets provided participants with the basic knowledge needed to participate productively in the focus group discussions. The focus group discussions were structured around a set of 12 questions (Supplemental Material 1) that proceeded in stages. Opening questions asked for general background on their interest in the lakes area and invasive species control, and their initial reactions to genetically modified organisms (GMOs). Transition questions focused on how stakeholders felt about using GMOs to control aquatic invasives. Key questions focused on the pros and cons of genetic biocontrol, negative consequences that worried them the most, and what would either encourage or discourage their support for the technologies' development and use. Participants were given time to individually list these benefits and concerns on paper before discussing as a group. The facilitator then collected those lists at the end of the focus groups. Finally, closing questions focused on recommendations for whether or how scientists and agencies should proceed with developing the technologies and any other issues not covered in the discussion. Immediately after each focus group, the facilitator and any assistants summarized their general impressions and identified any key points or observed themes. The facilitator did not move on to subsequent questions until all participants had the opportunity to weigh in on the question at hand and the topic had been thoroughly explored. Therefore, the length of the discussion varied with the number of participants in the group. Both the focus group discussions and the debriefing were recorded and later transcribed for analysis.

Analysis of focus group discussions proceeded in three phases. First, text from individual focus group transcripts was sorted into categories related to different reactions to the technologies (e.g., concerns, benefits, recommendations). Second, the text in each category was coded for emerging themes and key points. Each focus group's transcript was coded separately and then together, compiling overlapping themes across multiple focus groups. Finally, each participant's initial hand-written list of potential concerns and benefits associated with the technologies was coded as well, grouping the individually listed benefits and concerns into broader categories (Tables 1 and 2). These lists were anonymous, individual lists could not be linked with specific participants. The facilitator did all coding using NVIVO qualitative analysis software (Gibbs 2002). This methodology allowed me to quantify the responses by focus group, but not by individual.

RESULTS

Initial reactions

Each focus group discussion began with participants verbally sharing initial reactions when presented with the term genetically modified organisms or GMO. Participants' initial reactions tended to fall into four major categories of association: 1) science fiction,

2) food and agriculture, 3) concerns about the uncertainty and danger associated with the technologies, and 4) public perception of the technologies.

Science fiction

All groups mentioned something related to this theme, with the term "Frankenfish" coming up in six of the focus groups and Michael Crichton's *Jurassic Park* in five. As one participant explained, "Just gut reaction, [a] mad scientist sitting in a lab cooking up something evil with weird parts." These terms tended to evoke laughter and nodding from the other participants, indicating that such ideas resonated even if they did not dominate the discussions.

Food and agriculture

Participants brought up the benefits of specific genetically modified (GM) crops (e.g., increased food production, pest resistance), as well as the downsides of their use (e.g., controversy, food safety concerns) in seven focus groups. Some participants considered these associations to be positive in that the field of agriculture had used genetic engineering technologies successfully, while others expressed worry over the controversies and concerns associated with negative and unintended consequences, as well as the negative reactions to GM food consumption.

Uncertainty and danger

Concerns related to this theme dominated both the initial discussion and the entire focus group. In this initial stage, ideas of uncertainty included unknown costs and consequences, and irreversibility. As one manager put it:

> Well, I think it's a high – a potentially high gain if it works, but the down sides are it's a high risk. We don't know what we're tinkering with. You're tinkering with long-term genetic and evolutionary processes that we do not understand if we get in there, and start messing with the genetic code of this species, and/or other species. If indeed we do it wrong, we're stuck with it on a permanent basis.

Participants also noted that the uncertainties inherent in genetic biocontrol were exacerbated by its infancy. Participants indicated that they did not know nearly enough to adequately understand its risks or benefits, nor could anyone else given its newness.

Although the majority of participants were still willing to explore the potential of genetic biocontrol, they also felt that the combination of unknowns and negative connotations surrounding the technologies made their use farfetched. More detailed discussions of risk and benefit followed these initial reactions later in the focus groups.

Public perception of the technologies

In general, participants felt that the public would have a strong negative reaction to the idea of genetic biocontrol technologies. They thought public acceptance would be a “huge uphill battle” because of negative perceptions of GMOs, fear of the unknown and potential risks, as well as general mistrust of scientists and “their wild and crazy ideas.” However, they felt that such a negative response would likely vary among groups. For example, some representatives at the focus groups said they would never support the technologies (e.g., nonprofit agency, sport fishing group), while others (e.g., sport fishing group, angling association) could see supporting the technologies or imagine scenarios that would encourage support.

Other participants felt that the way the issue was framed would have a major impact on the public’s response. A shift from “GMO fish” to “daughterless carp” to “getting rid of round goby” would elicit very different responses from the public. Given the importance of how the issue is presented, participants were concerned about who would inform the public and whether people in charge of the message could be trusted or would be perceived as trustworthy. Given the complexity of the issues, some participants felt that the public’s response might have more to do with their relationship to the organization disseminating information rather than with the information itself. Regardless, or, perhaps, because of these issues, participants considered it crucial to engage the public early and often and that public acceptance would be vital before these technologies could be deployed.

Benefits of the technologies

After discussing their initial reactions to the idea of genetic biocontrol, participants were asked to write down its potential benefits (Table 1) and then discuss them as a group.

Participants' responses generally fell into the following three categories: 1) development of a new, potentially effective control for aquatic invasive species, 2) other benefits related to development and use of new technologies, and 3) concerns about benefits (Table 1). Only categories of benefits with more than five responses are discussed below, as these represent the major themes that emerged from the lists. Quotations from the discussion of the lists are provided to illustrate the major categories that emerged.

Existence of a new, potentially effective invasive species control tool

Most immediately and frequently mentioned was the benefit of having a new potential invasive species control tool. One comment from an aquaculturalist encapsulated the sentiments articulated by many participants:

> Well, one, I think the possibility to create a new cost-effective way to eliminate or reduce an invasive species. Two, it could create a way to 100 percent eliminate an invasive species. And three, it could create a new way to reduce or eliminate an invasive species that has no other present strategy to deal with it.

Other identified benefits included having a way to reduce invasive populations and the positive ecosystem changes that would follow their removal. Participants also liked the idea of having a tool that could make invasive species eradication possible, controlling species in locations currently untreatable, or simply having one more control tool in the toolbox. There were also suggestions that genetic biocontrol could be self-sustaining and that, after the initial investment, would require less time and money than current options.

Participants also highlighted genetic biocontrol's potential benefits as compared to current control methods. They liked the fact that genetic biocontrol might lead to the use of fewer chemical controls, potentially far fewer non-target impacts and less habitat disturbance than rotenone chemical treatments or physical removal of organisms. When making these comparisons, however, some participants tempered the potential benefits by saying that although genetic biocontrol methods might not have the weaknesses associated with our current control methods, they might have their own, more serious weaknesses.

Increased technological capacities and job creation

A perhaps unexpected benefit of researching genetic biocontrol techniques was that it would increase the knowledge base related to the technologies and provide valuable insights to other fields. One participant expressed doubt that the technologies would ever be useful in controlling an invasive population but felt that the research "might spawn a lot of good knowledge and good benefits to society outside of invasive species control." This feeling was echoed by participants in seven of the focus groups, who said while they did not think they would ever support the use of genetic biocontrol, they could still support the research taking place in a lab and producing knowledge useful in other arenas. Participants also saw new jobs arising from the research, development, and use of the technologies.

Concerns about benefits

Although participants were open to the benefits of these technologies, many discussed them with some hesitation and hedged listed benefits with qualifiers. As one participant talked about the potential to reduce pollution by reducing use of chemical controls, he added that genetic biocontrol posed an increased risk of biological pollution. When asked to list his potential benefits, another participant responded: "Well, I said 'possible use against invasive species'. I said, 'because of the unknown potential to create disaster, benefits are questionable.'" Although a few participants embraced the idea of genetic biocontrol, "I'm sure it's got to go through environmental impact procedures, but if it's got a potential for a large impact on something that's invasive that we can't control any other way, bring it on.", most participants were more cautious. The following exchange between two participants illustrates the difficulty that some had identifying concrete benefits:

> **Participant A:** "These are all just benefits assuming this technology works, right?"
> **Participant B:** "I guess that's why I had problems coming up with benefits!"

Indeed, several participants were unable to identify potential benefits of the technologies or specifically indicated they thought there were no benefits whatsoever.

Concerns about the technologies

Participants' discussion of concerns was far more pervasive than that of benefits. Mentions of potential concerns occurred throughout the entire focus group sessions, most notably in the discussion of participants' initial reactions to the technologies and during more nuanced discussions of their potential benefits. Participants listed five major categories of concerns: 1) ecological 2) related to uncertainty, 3) financial, 4) technological, and 5) regulatory. In this part of the discussion, participants also identified several previously unidentified concerns. Only these major categories of concerns are discussed below, as these represent the major themes that emerged from the lists. Once again, quotations from the discussion of the lists are provided to illustrate the major categories that emerged.

Ecological concerns

The largest category was, unsurprisingly, ecological concerns. This included specific concerns about the impacts that biocontrol fish could have on species other than the targeted invasive species (i.e., non-target impacts) and the dangers of transgenes being transferred to non-target organisms. Participants were also concerned about the impacts that genetically manipulated organisms could have on the food chain, especially the potential for harm to human health if humans consumed a biocontrol fish or an organism that had consumed one. Another important concern in this category was whether the biocontrol fish could escape from the targeted environments into which they are released and make their way back to areas where the target species are native and valued organisms. Participants recognized that a species invasive in one region can be desired or even a native or endangered species in other regions. One manager used the example of largemouth bass, a valued species in the US, which is considered an invasive elsewhere, "[People] may decide that they want to take genetic modification steps and release this genetically modified largemouth over in Japan, but what if people were to bring that fish then over from Japan and drop it into [our] waters?" This idea resonated with many participants and the importance of making sure no such scenario is possible before using the technologies was repeated in six focus groups.

Uncertainty

Uncertainty about every aspect of the technologies' development, deployment, and impact permeated the discussion of concerns in every focus group. Participants were concerned about lack of information about the unintended impacts resulting from the use of genetic biocontrol technologies and the lack of control managers would have after organisms are released. They also felt uncertain about the unpredictability of these new technologies and the possibility of as of now unimagined impacts. Participants were concerned not only that something might go wrong with the technologies, but that we are unable to predict how or why things might go wrong. Participants came up with multiple potential negative outcomes or impacts, such as the biocontrol fish being better disease carriers, or the proteins expressed by the modified genes being allergens, or that the effects of genetic modification could make the organism problematic in new ways. Participants emphasized that they were suggesting such outcomes not because they thought they were *likely*, but because they thought they were *possible*. They stressed that all negative outcomes or impacts should be investigated no matter how unlikely. One participant attempted to describe her concern that the levels of uncertainty could never be adequately resolved and that use of genetic biocontrol organisms could result in negative consequences that would far outweigh the negative consequences of the target invasive species alone:

> I think everybody who has dealt with invasive species on the Great Lakes knows about not only unintended consequences, but unanticipated consequences. When you study invasional biology in a lab, you say an invasive species will impact the habitat. It will eat and – it could eat other species. This could outcompete for spawning grounds. And you have this list of things you go through as far as impacts an invasive species will have on an ecosystem. When you actually get out there in the lakes, they're interacting with each other. And we've turned this corner in the Great Lakes where we're having these unanticipated consequences of botulism outbreaks. Who in the hell would have thought we'd have botulism outbreaks? You know, dead zones, toxic algae blooms. And they're all attributed to the interactions of invasive species. So it's just – it's really frightening to think we're adding more invasive species, and we're thinking about adding GMOs to try and control invasive species.

Financial concerns

Concerns related to this category surfaced in every focus group. Such concerns primarily centered on the amount of money required to develop and adequately test biocontrol fish and whether this would divert money from other, potentially more important needs. One participant worried that thoroughly testing the technologies could cost “kabillions of dollars” and still not be worth the money. They stated, “Fifteen years later, we’re going to say, ‘All right, now we’re ready to test something in a fishbowl.’ And meanwhile, if we just spent $50,000 on a pile of rocks and dammed [access to the waterbody] up to begin with, we wouldn’t be sitting here having a problem.”

Technological concerns

Participants also explored concerns surrounding the technologies’ implementation, including issues such as the technologies’ effectiveness, the stability of the manipulated gene over time, and whether developers had the ability to adequately test biocontrol technologies for the concerns raised in this discussion. Participants also wondered about the number of biocontrol fish needed for an control effort to succeed and whether developers had the ability to produce sufficient numbers, particularly if a control effort were to be attempted over a large geographic scale (such as the Great Lakes). Finally, participants talked about the uncertainties associated with the technologies: whether removal of the target invasive species will have the intended ecological effect and how the technologies might fare in the face of re-invasion events.

Regulatory concerns

Concerns about regulations began with which agencies would be in charge and how to deal with the cross-jurisdictional issues. These technologies are being designed for release into the wild, and participants were concerned about what might happen when the biocontrol fish cross political boundaries or how agencies would deal with a situation in which one jurisdiction approved use of biocontrol fish but a neighboring jurisdiction did not. Other concerns related to how regulations addressing the complexity of the technologies would be crafted. One participant wondered whether politicians would have sufficient understanding of the scientific issues to regulate biocontrol fish properly:

> Are we going to allow politicians to decide on the regulations for the application of these genetically modified organisms when they couldn’t even listen to the scientific advisors years ago trying to point out all these problems we have with different ways to stop invasive species?

New concerns: escape into native range, ownership, false hope, ethical concerns

Several sets of concerns identified by the focus groups are worthy of special note given their absence from, or limited mention in, literature on genetic biocontrol. First, as discussed above, concerns about biocontrol fish moving into their native range. Second, participants expressed concern about who would own, and therefore control, the technologies. Participants worried that profit rather than ecological management goals could be driving the technologies' development. They also worried that, once the technologies are developed, managers may find that the development company has a disproportionate amount of control over their management decisions. Third, they worried that genetic biocontrol would give people a false sense of hope about our ability to control invasive species. They worried that it would reduce the political will to prevent new invasions and the sense of urgency once new invasions are detected. Finally, participants raised concerns surrounding the morality and ethics of genetic modification. Participants from six focus groups talked about their moral and ethical concerns associated with these technologies. These concerns included whether it was morally acceptable to release imperfectly understood, potentially harmful technologies and whether there might be wide-spread public objection to scientists "playing God."

Concerns outweigh benefits

Overall, participants identified in their hand-written lists far more potential concerns associated with genetic biocontrol technologies than potential benefits. They listed 300 concerns compared to 156 benefits. This pattern carried over into discussions of benefits and concerns as well. Considerably more time was spent discussing concerns and discussions of concerns arose spontaneously throughout the entirety of all focus groups.

Concerns also varied more widely, falling into 11 broad categories and 22 subcategories, while benefits fell into eight broad categories and three subcategories. The lack of variation among the benefits is highlighted by the observation that 79% of listed benefits fall into the most frequently listed category (a potentially effective control tool), the most frequently listed category of concerns however (ecological concerns) only make up 29% of concerns. Finally, although all participants listed concerns, five participants felt the benefits associated with the technologies were either nonexistent (4) or unknown (1). In general, participants said the discussions had the effect of increasing the number of concerns they had about the technologies. Not only were their initial concerns valid, but they were also aware of new, equally valid concerns.

These results should be interpreted with care. Participants pointed out in the ensuing discussion that several issues raised were two-sided; they could be considered either a benefit or a concern depending on the context of the scenario. These included: the potential eradication of pests would be good, but perhaps that would lead to major problems if the biocontrol fish then travelled into areas where the target species is not considered invasive. Additionally, the self-perpetuating nature of the technologies would be good in that it would allow for reduced management efforts and potential control of large water bodies, but such self perpetuation could also reduce managers' ability to recall the technologies should something go wrong. In many ways, benefits and concerns arise from the same characteristics.

What influences support for the technologies?

After listing their concerns and benefits, the facilitator led the participants in a discussion to identify issues that would most encourage or erode their support of genetic biocontrol's development and use. The overarching themes that emerged from this discussion are discussed below.

Discouragement of support

The majority of issues found to discourage support were related to confirmation of the concerns identified earlier in the discussion (e.g., if the biocontrol fish did indeed spread to non-target areas). Several new important issues did arise, including secrecy in development and testing and the lack of effective regulations guiding such processes. One participant specifically mentioned his concern with the role of the U.S. Food and Drug Administration in the regulatory process given the mandated confidentiality in its process[A]. Several participants (from four groups) felt unable to support the technologies if evidence emerged that resources could be better used elsewhere in an invasive species management strategy. One participant wondered whether pursuing these technologies was responsible given that use of existing technologies can still be improved: "We're using a hammer as a screw driver right now. We should have used the hammer as a hammer and a screwdriver for a screwdriver. Once we learn that, then we can develop the chainsaws." Prevention efforts were frequently mentioned as a more effective use of limited funds.

Finally, some participants felt that support would decline if there was evidence that the technologies were being pursued for profit instead of for ecological benefit[B]. A representative from a non-profit organization felt particularly strongly about this:

> If at any point I felt that this whole thing was being pushed forward because of a corporate, and them trying to find a product that they can market, and get out there, and make a lot of money off of, as opposed to what's driving the research, and what's driving the program, being the eradication of invasive species… I would definitely walk right away from it, and not support it at all.

Encouragement of support

Similarly, support for genetic biocontrol would increase with evidence supporting the benefits and reducing the concerns identified earlier in the discussion. New issues, however, included the need for favorable cost-benefit analyses of the technologies' development, development of an 'off switch' so the biocontrol fish could be "deactivated" and independent verification of all risk assessments. Several participants felt that they could support the technologies' use only in a crisis situation. The reasoning behind this opinion was that they would support genetic biocontrol options if there was a situation that could not be made any worse, even if the technologies had unintended negative consequences. If the target ecosystem was already considered a loss, and even if

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[A] Currently the Food and Drug Administration has claimed regulatory authority over animals modified using recombinant DNA techniques under the Federal Food, Drug, and Cosmetic Act (Showalter-Otts, this issue).

[B] Genetic biocontrol technology is not currently being developed as a commercial product. However, the only genetically modified fish currently available in the US is a commercial product (the GloFish™, a GM zebra danio *Danio rerio*).

the technologies have all the negative impacts feared, the attempt would not damage anything they were trying to protect.

Issues of uncertainty also played a role in this part of the discussion. Participants from four focus groups mentioned they felt there was currently insufficient information even to say whether or not they would support future development of the technologies and that more information would be needed in order for them to form an opinion. Further, participants from three focus groups felt that there was so much uncertainty inherent in the technologies that they would never feel comfortable supporting it. As one put it, in order to support the technologies he would need to see proof of "zero risk, which is going to be really hard to do."

Recommendations for development

Finally, participants discussed recommendations that they would like to make to genetic biocontrol technologies developers. Although some were concerned about their lack of specific expertise, many were emphatic that their recommendations should be used as general guidelines. These recommendations fall into seven categories:

1) First, do no harm

Developers should move forward only if they are sure they are not going to make an already frustrating aquatic invasive species situation worse. Some participants even suggested a method of recalling or deactivating the biocontrol fish be developed.

2) Engage as many viewpoints as possible during development

Stakeholders should be included early and often to ensure that the technologies are addressing their needs and that a broad set of potential concerns are identified and addressed. The greater the number of potential concerns that are proactively assessed, the more likely it will be to reduce the possibility of unintended consequences once the technologies are deployed. Important lessons could also be learned from elsewhere (e.g., other countries, past attempts at biocontrol).

3) Require thorough, unbiased testing by an objective, independent group

Those who test the technologies should not have ties to technologies' developers. Ideally, testing should involve multiple groups, all of whom are independent. Thorough testing includes extensive tests using smaller, controlled experiments as well as more complex, large scale tests of the biocontrol organisms' interactions with the rest of the ecosystem.

4) Utilize a case-by-case approach targeting specific species or areas

Developers should choose an invasive species to manipulate that is causing enough damage to be worth the cost of development. Managers should also choose to deploy the technologies in areas in which unintended consequences are not likely to cause irreparable damage (i.e. not an area of special ecological or economic value) and from which movement into other areas is unlikely. Testing of the technologies should also be specific to each potential management application.

5) Employ clear go/no-go reasoning

The development process should move forward incrementally, making sure at each step that it makes sense to proceed (i.e. there is continuing evidence that it would have the desired effects). There should be a decision-making framework for both development and use of the technologies, and this framework should include both a comprehensive risk assessment as well as a thorough cost-benefit analysis.

6) Develop an effective regulatory framework

A regulatory framework specifically designed to address genetic biocontrol issues should be developed, as it is unclear whether current regulatory mechanisms are sufficient. Regulatory frameworks should coordinate both within- and cross-jurisdiction actions. They should also regulate initial releases of the technologies, require long term monitoring, and designate who is responsible for negative consequences should they occur.

7) Ensure transparency at all steps

The entire process - development, testing, regulation, release, and monitoring - should be done in a transparent fashion and efforts should be made to communicate information to the public and other interested parties throughout the process.

Reaction to the Focus Groups

Most participants were pleased that they were being consulted and given the chance to share their viewpoints with those developing the technologies and they hoped that groups such as this would continue to be held throughout the development process. As one participant said:

> It is a good thing that those who are organizing the study have reached out. You know, practice as past, you may not necessarily have seen something like this where they just say, 'Okay, we're going to… do it.' And then maybe you don't even know that it was going on… we don't see the bill, so we don't even know what happened [or] the time and energy that's spent. I'm glad that in the face of that that we're getting an opportunity to provide that input. Hopefully, it will be given the weight that it truly does deserve from a very wide variety of perspectives and expertise in here.

Some participants, however, were wary about whether these results would be used to sidestep stakeholder issues instead of addressing them:

> **Participant A:** "Could you imagine if they had the discussion that we're having right now before they brought the Asian carp in… That's the part I'm getting out of this. At least we're having a chance to discuss it before it happens."
>
> **Participant B:** "Unfortunately, there's another way of looking at it, and unfortunately, giving them this information about where the fears are also gives them the opportunity to say 'Okay, now what do we have to do to massage those fears to get them to think the way we want them to think so that we can go forward with what we want to do.' You know, it's a double edged sword is what it is. It feels good to be able to have your say and let them know. However, by letting them know, that also gives them the edge to come back at you from the other side and say, 'Okay, this is how we fix everything you just said,' and make you feel… better about what they're about to do [without actually fixing it.]"

DISCUSSION

The focus group discussions contained three broad themes. The first centered on issues of uncertainty, whether about the technologies and their impacts, the motivations surrounding their development and use, or the information available. The second was the desire to act cautiously, with thorough testing and an emphasis on prevention efforts instead of research into new control methods. Third, participants continually returned to questions of balance. Questions continually arose about how best to: 1) spend limited funds, 2) determine where efforts should be focused, 3) weigh and compare the technologies' benefits and costs, and 4) determine who bears its risks and benefits. Overall, discussions indicated that most participants were supportive of genetic biocontrol research for its own sake, regardless of whether it would ultimately achieve the desired goals. However, they set very high standards for deciding whether to use the technologies in the field. A few participants were against proceeding with its development at all. They felt that the resources used to develop it could be put to better use (i.e. restoration and prevention) and pursuing it would open a Pandora's Box of new problems.

The focus group results indicate several important points regarding development of genetic biocontrol technologies. Stakeholders should be included throughout the development process as a source of advice on which technologies and levels of risk they find acceptable as well as a source of valuable local knowledge. Such input may prove valuable to developers, risk assessors, and policy makers when guiding technology development, instituting risk assessments, and crafting regulatory frameworks. Even within the limited scope of these focus groups, participants helped identify potential sources of uncertainty that had received limited, if any, mention in the literature. Involving them as partners throughout the development process would likely lead to identification of key uncertainties and research questions. Participants felt it important to involve the public throughout the process regardless of the complexity of the technologies. Indeed, the more complex the technologies, the greater the onus on the developers to communicate key issues clearly to diverse audiences. At the beginning of any new genetic biocontrol technologies development project, public support could be increased through a cost benefit analysis showing that developing these technologies is the most effective use of limited funds. Such analyses should elucidate two key concerns: 1) whether these technologies are a more effective way to deal with the problem than other available options, and 2) whether the problem is a more pressing issue than other issues faced in the management area. The uncertainty surrounding both the benefits and the costs associated with novel technologies could make these analyses impossible to produce or largely theoretical until late in the development process. It is possible that this more open and transparent approach to technology development and management will help engender public acceptance of decisions, even if they do not necessarily agree.

To be clear, the rationale for increased public involvement in the decision making process is not simply to take advantage of their knowledge and to increase public acceptance of a novel technology but also because they have the right to participate in decisions that will impact their lives. Implementing public participation, however, comes with its own set of challenges. These include concerns that public involvement leads to decisions that default to the status quo when faced with uncertainty, the difficulty of recruiting representative groups of participants, and maintaining active participation over a long decision making process, as well as concerns about the additional costs in resources and time (Irvin and Stansbury 2004, Tait 2009).

When it comes to moving forward with this, or any other novel biocontrol technologies, participants had an array of issues that, if addressed, would make the use of the new technologies more acceptable to them. Some of these issues are possible to address (i.e., achievable with current technology and methods available), some are possible but challenging to address, and some are impossible to address. Those who wish to develop and use new technologies, however, will have to find ways to explicitly acknowledge them all – those they address as well as those they do not.

Those issues that are currently possible to address include clearly defining and explaining the specifics of the technologies to the general public, providing accurate estimates of the cost of development, providing proof that the technologies will have their intended effect, allowing for transparency in the development and funding, allowing for independent verification of all findings, and only using the technologies once regulatory and monitoring mechanisms are in place. Addressing these issues, while adding to the development costs, would increase stakeholder support of and confidence in any new natural resources management approaches.

Other issues that would increase stakeholder confidence and support, but that would be challenging to address, include providing proof that the new technology is the best use of resources, showing that it would be used only in a crisis situation (i.e. a situation in which the ecosystem was so damaged that any additional damage done by the genetic biocontrol would have a negligible impact), and ensuring that the technologies are reversible. Both showing that the technologies are the best use of resources and that they would be used in a doomsday scenario are challenging because they require proof that, in the former case, no other management need is as worthy of funding and, in the latter case, that no other management options are possible. Proving this will be difficult because both of these scenarios require ruling out all other options, of which there can be many.

Some issues identified cannot be completely addressed. Participants requested proof of "zero risk" and that all possible negative impacts are tested. This, however, is not possible, especially with technologies developed primarily in laboratory settings. Technology developers must work with regulators and stakeholder groups to determine how close to "zero" risk is feasible and acceptable, and which impacts are highest priority and which can be left untested. As a result of these compromises, some stakeholders will never be fully satisfied with the level of safety demonstrated and never approve of the new technologies. There will also be stakeholders who are against developing genetic biocontrol technologies for reasons that cannot be addressed in any development, risk assessment or regulatory framework. Attempting to satisfy these stakeholders may not be possible, but responding to their position and weighing it against those who support development will be necessary.

The range of issues that stakeholders want to see addressed makes clear that they have very different standards than do genetic biocontrol developers and researchers. Participants indicated that they want a broader set of issues addressed, including some that are currently not possible to address. For example, many of the participants wanted "proof" of the technologies' efficacy, something that cannot be shown until the technologies are used in the field. This puts developers and stakeholders in a catch-22 situation because the evidence needed to inform the decision to proceed is impossible to collect until after the technologies have been released and used for some time in natural environments.

The range of issues and the degree to which stakeholders want them addressed will likely vary with the degree of trust that stakeholders have in the groups making the decisions related to the technology's development. A lack of public trust in the government agencies making the decisions is a major problem (Slovic 1993, NRC 1996). Those making these decisions can work to build trust by using a transparent and honest decision making process that allows for iterative communication with the public and gives the public influence over the final decision (Slovic 1993, NRC 1996, Peters et al. 1997).

Participants' involvement in the focus groups shifted and in some cases increased their perception of the range of valid concerns about the technologies. Further stakeholder engagement may lead to additional shifts in perception, some in a more sophisticated and nuanced direction that will allow stakeholders to frame questions and prioritize concerns with greater clarity and precision. Such engagement might enable a greater understanding of which issues can be addressed, providing opportunities for stakeholders, developers, and scientists to develop a set of issues and methods for addressing them that is more generally acceptable. Some participants stated that their position would change with increased information about the technologies. Indeed, some became more open to the technologies and some became more skeptical in the short timeframe of the focus groups discussions. Such shifts suggest that concrete information about the specifics of genetic biocontrol and its proposed management could shift stakeholder perspectives significantly. Whether or not these shifts would be in support of the technologies is unclear.

This study had two significant limitations. First, because participants were grouped by region and not affiliation during analysis, I could not compare reactions from different stakeholder groups. Second, due to the limited number of focus groups I could not compare the reaction of stakeholders from different geographic regions. However, the goal was to capture the initial reaction to the idea of genetic biocontrol and identify stakeholder recommendations for the technologies' development and use, not necessarily to analyze such results by stakeholder group or geographic location. Variation of responses between stakeholder groups is a possible area for future investigation.

Results of this study agree only in part with results from two prior studies investigating the public's reaction to genetic biocontrol of invasive fish. Importantly, invasive species are a broadly recognized problem for the focal aquatic ecosystems of all three studies, specifically the Great Lakes in this study and the Murray Darling River Basin in the prior two studies. In the first of these prior studies, the Australian CSIRO Centre for Research on Introduced Marine Pests held a series of workshops that, among other things, looked at the strengths, weaknesses, and acceptability for a number of control options for aquatic invasive species (Thresher and Kuris 2004). Researchers found that although genetic biocontrol was not unacceptable to workshop participants, it did rank among the less acceptable control options. This is in line with my findings that focus group participants were willing to consider the idea of genetic biocontrol in the Great Lakes and Lake Champlain region, but had serious hesitations regarding its use. Focus group participants wanted strong assurances on a much wider range of issues (e.g., economic, ecological, ethical), whereas the Australian participants seemed only to need "strong evidence that the genetic modification would remain confined to the pest species." Many of my study's participants shied away from the idea of releasing biocontrol fish across an entire aquatic ecosystem as proposed by Thresher and Kuris (2004); instead, they felt more comfortable with the technologies' use in smaller, more contained areas. The second study investigated the Australian public's reaction to the idea of using daughterless carp to control common carp in Australia (Fisher and Cribb 2005), using phone surveys to elicit rankings by 600 citizens of seven benefits and eight concerns about such a control method. Their results were the opposite of mine, as Australian respondents indicated that they felt the benefits associated with the daughterless carp control method outweighed the concerns. Differences in methodologies (e.g., using a pre-determined list benefits and concerns from which to choose versus open-ended discussion in focus groups) and survey population differences (e.g., members of the Australian public versus select Great Lakes stakeholders) may account for the differing results. Even so, there were several points on which stakeholders in both studies agreed: 1) safety, species specificity, efficacy, and cost-benefit issues need to be addressed and 2) the process of addressing such issues should be transparent.

Taken together, these three studies suggest that the specific approach used to engage stakeholders will affect their responses to questions about possible environmental release of a novel technology, such as genetic biocontrol. The different conclusions about the acceptability of genetic biocontrol between focus group participants and Australian members of the public (Fisher and Cribb 2005) suggest that responses can be influenced by respondents' background and relationship to the issue. The way that information and opinions are elicited is also important. Australian respondents in the phone survey (Fisher and Cribb 2005) were presented with a preexisting list of benefits and concerns about a specific technology (daughterless carp) to rank, while focus group participants were allowed to articulate, unprompted, their own lists of benefits and concerns about genetic biocontrol technologies' more generally. These two methodological differences should be carefully considered, as the concerns and benefits identified in the lists in the Australian study and our focus groups differed significantly. Care and sophisticated thinking is needed when choosing transparent processes for engaging with stakeholders and the broader public, as each approach comes with its own limitations and biases. Other future research priorities include exploring which stakeholder groups should be included in engagement activities especially considering the transboundary nature of the technologies. Finally, it is important to remember that many of these issues will vary on a case-by-case basis and should be reexamined for each proposed use of genetic biocontrol technologies.

CONCLUSION

Involving broader groups of stakeholders in formal consideration of novel technologies is important for substantive, normative and instrumental reasons (Fiorino 1990, NRC 1996). Substantively, stakeholder representatives can contribute valuable knowledge that complements that of scientific experts, enriching the knowledge-base used to guide technology development and risk assessment. Normatively, stakeholder groups may be affected by the technologies' use and therefore have the right to participate in deliberations about its merits. Instrumentally, including interested and affected stakeholders in evaluation and decision making processes can lead to better informed and more legitimate decisions.

The results of the focus groups in this study support all three of these reasons for involving stakeholders early and often in discussions that inform decisions surrounding genetic biocontrol and other new technologies. Focus group participants identified a wider range of concerns than those typically focused on in the literature on genetic biocontrol (substantive). These include new social, economic and ethical issues. Additionally, some participants questioned whether removing invasive species is the correct effort to focus on for natural resource management. Thus far, genetic biocontrol literature has focused on genetic and ecological risks such as instability of the genetic construct, gene flow and the regional impact of stocking genetically modified organisms (Muir and Howard 1999, Kapuscinski and Patronski 2005, Thresher 2008). Participants also spoke about the importance of stakeholder and broader public involvement (normative). They felt that their involvement was critical and that its inclusion early and throughout the process would shape how the technologies were received and if their use would be accepted. Finally, participants outlined recommendations for development of these technologies that include principles of robust decision-making (e.g., transparency, structure (Gibbons 1999, Ludwig 2001, Salwasser 2002)) indicating that incorporation of these recommendations would strengthen the development process both objectively as well as in the eyes of the public (instrumental).

That focus group participants identified critical and previously unmentioned concerns as well as pertinent recommendations for development at the nascent stage of the technologies highlights the importance of including stakeholder perspectives in the development of genetic biocontrol technologies specifically, and new technologies in general. Thoroughly assessing the complete range of concerns and proceeding in a manner viewed as legitimate is crucial for deploying new technologies perceived to have many potential risks, and these results indicate that involving stakeholders is a critical step in identifying those risks.

Table 1-1. Main categories of potential benefits of genetic biocontrol technology. Categories were developed from the hand-written lists generated by each participant during the focus group, and from the resulting discussion of those lists. Footnotes provide brief descriptions of concerns not discussed in the text of the article.

Benefits	**Frequency on Lists** **(# of Focus Groups)**
A new, potentially effective control tool	123 (8)
Existence of a new control tool	*49 (8)*
Positive impacts associated with an effective control tool	*49 (8)*
Reduced use of old control tools	*25 (8)*
Increase in technological capabilities/ knowledge base	14 (7)
Job or industry creation	5 (3)
Preemptive ability[A]	4 (1)
Useful at large spatial scales[B]	4 (3)
Area-specific control[C]	3 (3)
Public reaction[D]	2 (2)
Educational opportunity[E]	1 (1)
Total benefits listed	*156*
No benefits can be identified	4 (2)
The benefits are unknown	1 (1)

[A] Potential for a tool that can be deployed preemptively (i.e. before the species are established)
[B] Potential for use at large spatial scales where current tools are ineffective
[C] Ability to target a specific area in the control effort
[D] Positive response of the public to aggressive actions with observable results
[E] Opening for dialog with the public about invasive species

Table 1-2. Main categories of concerns regarding genetic biocontrol technologies. Categories were developed from the hand-written lists generated by each participant during the focus group, and from the resulting discussion of those lists. Footnotes provide brief descriptions of concerns not discussed in the text of the article.

Concerns	**Frequency on Lists** **(# of Focus Groups)**
Ecological concerns	86 (8)
Impacts on native species genetics	*23 (6)*
Environmental impacts	*16 (8)*
Food chain concerns	*16 (6)*
Impacts of the transgenics on other species	*16 (6)*
Escape into other areas/native ranges	*15 (4)*
Concerns related to uncertainty	68 (8)
Unintended consequences	*19 (6)*
Uncontrollability	*19 (6)*
Unknowns	*16 (6)*
Unpredictability	*14 (7)*
Financial concerns	46 (7)
Cost of development and testing	*26 (6)*
Diverting money or effort from other needs	*18 (6)*
Impact on Industry	*2 (1)*
Technological Concerns	32 (8)
Effectiveness	*11 (6)*
Stability of altered genes	*8 (3)*
Spatial scale feasibility	*7 (3)*
Ability to completely test	*4 (2)*
Ability to produce enough transgenics	*2 (2)*
Regulatory Concerns	16 (6)
No regulations currently exist	*8 (4)*
How will regulation deal with multiple jurisdictions	*3 (2)*
Who will be responsible for regulation	*3 (1)*
Lack of clarity regarding regulatory goals	*1 (1)*
Long term responsibilities	*1 (1)*
Control/ownership issues	15 (5)
Public acceptance[A]	14 (5)
Timeline issues[B]	9 (8)
Ethical issues	8 (3)
Monitoring issues[C]	4 (3)
False hope	2 (2)
Total concerns listed	300

[A] Will the technologies' use be acceptable to the general public?
[B] How long will it take before the technology is ready for deployment, and how long will we have to wait to see its impacts?
[C] How do you design, implement and fund a program to monitor effectiveness of the technology and any potential impacts?

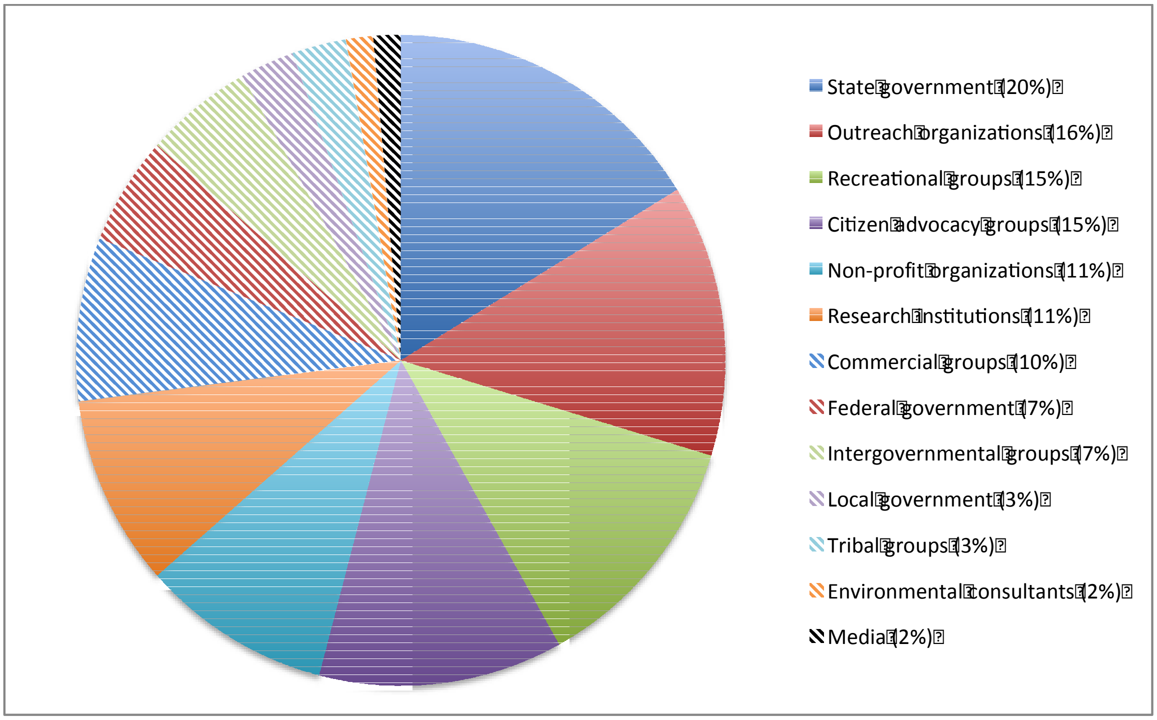

Figure 1-1. Participant affiliations, compiled across all eight focus groups. The total percentage (summed across all categories) is greater than 100% as several participants were representing multiple interest groups.

Chapter 2: Aquatic Invasive Species Management: Manager Perspectives on the Current Decision-Making Process

with Dr. Anne R. Kapuscinski

Managing aquatic invasive species (AIS) is a wicked problem – messy, overlapping with other environmental and economic issues, and without any obviously correct answers. Improved understanding of the current decision-making environment is needed to identify the strengths and weakness of the current process and to suggest improvements. Towards this goal, we conducted thirty-one interviews with managers involved in AIS management around the Mississippi River Basin and concentrated in Minnesota to better understand their on-the-ground perspectives of AIS decision-making as well as the priorities and concerns influencing those decisions. These interviews also explored the strengths and weaknesses of the existing decision-making process and the ways in which a decision support tool could be of use. We found that managers at all levels viewed AIS management as encompassing a wide range of priorities that need to be balanced with one another (e.g. prevention and containment efforts, research into new control tools, control and eradication efforts), a balancing act complicated by inadequate direction as to the relative importance of these priorities. Managers were also highly conscious of the economic issues associated with all aspects of AIS management. Identified strengths and weaknesses of the existing process all involve either the presence or absence of principles of a robust decision-making process. Strengths include the coordination between agencies and the communication with the broader public. The prevailing approach, however, lacks several robust decision-making principles including sufficient scientific basis, structure, documentation, and an adaptive element. Our results indicate that AIS decisions could be strengthened by explicitly incorporating these principles into the decision-making process and that a decision support tool would be an effective way to incorporate them.

INTRODUCTION

Rittel and Webber introduced the concept of the wicked problem. Problems are ‘wicked’ when they cannot be clearly defined or separated from other, larger, issues and circumstances surrounding the problem (knowledge base, available resources, legal limitations, etc.) change over time; when problems lack a ‘stopping rule’ (i.e. set criteria that tells you the solution has been found); when potential solutions are not ‘wrong’ or ‘right’ but ‘better’ or ‘worse’; when every problem is unique; and when the possible solutions are not a limited and discrete set of options (Rittel and Webber 1973, Conklin 2006). Management of aquatic invasive species (AIS) is a quintessential wicked problem for natural resource managers. Issues of invasive species management are necessarily tied up with other issues such as fisheries management (itself a wicked problem (Jentoft and Chuenpagdee 2009), recreational use issues, and global shipping practices, to name a few. Further, AIS management is a socially complex problem, with different players having different goals, different definitions of the problem, and different ideas about acceptable solutions. This social complexity makes an already wicked problem even more wicked (Conklin 2006). Invasive species managers are attempting to balance competing demands and multiple priorities with limited resources. In this paper we empirically examined the process and factors influencing the current decision making environment for AIS managers in order to uncover opportunities for improving their decisions.

Scholars have suggested several principles of decision making in order to deal with these wicked problems. Together these principles lead to a more robust decision making process, which we define as a process that supports decision making under conditions of high complexity and uncertainty and that allows decision makers to learn from and explain the reasoning behind their decisions even if decisions do not lead to the intended results. First, the value-laden nature of these complex decisions has led to calls for making decisions in a manner that is *participatory* (participation of all interested and affected groups, most of whom are not experts) and *transparent* (Gibbons 1999, Ludwig

2001, Bäckstrand 2003). Broader participation will allow for inclusion of multiple perspectives and "knowledge, agendas, needs and concerns" of social groups who are not part of traditional, technocratic decision making methods (Bäckstrand 2003). Incorporating the principles of participation and transparency will allow the values influencing the decision making process to be made explicit (Ludwig 2001). This will lead to a more thorough understanding of how the decision was reached and will, in turn, make the final decision more socially acceptable (Bäckstrand 2003) and the entire process more "socially robust" (Gibbons 1999).

Although multiple ways of knowing should inform the decision making process, a second principle urges making *science-based* decisions (Lubchenco 1998, Mills et al. 2001, Salwasser 2002, Bäckstrand 2003), that is, decisions grounded in and consistent with current scientific knowledge germane to the wicked problem. Lubchenco argues that the complex problems faced by society require "more comprehensive information, understanding, and technologies for society to move toward a more sustainable biosphere" (1998). Scientific involvement in the decision-making process can offer an objective tool for sifting through the competing value-laden positions (Mills et al. 2001). Finally, as more reliable information becomes available, the uncertainty surrounding an issue can decrease, reducing the complexity of the problem (Salwasser 2002).

Thirdly, the lack of complete knowledge and high uncertainty surrounding wicked problems has led to calls for an *adaptive* or *iterative* learning element to the decision making process (Lee 1993, Salwasser 2002, Conklin 2006). An adaptive process allows decision makers to gather information from attempts at a solution and use it to inform subsequent attempts. These partial solutions are not failures but learning opportunities. Each attempt at a solution allows for better understanding and definition of the problem and a clearer sense of what makes a decision 'better' or 'worse.' Taking an adaptive/iterative approach also allows decision makers the *flexibility* to adapt their decision making process in light of new information. This flexibility is also important in an arena where inconsistent information is available for each decision and decisions must be made with what is available as opposed to what is ideal (Hammond et al. 1999).

Although flexibility is important, so is making decisions in a *structured* and *consistent* manner (Hammond et al. 1999, Salwasser 2002). Structuring the process in a consistent manner allows people to revisit the steps taken to make the decision and understand how it was reached. It also helps increase the transparency of the decisions by being clear how “science, risk, uncertainty, values and tradeoffs” are included and relate to one another in the decision making process. *Documenting* the decisions as they are being made reinforces the benefits arising from a structured process as well as providing a method for returning to the decision and assessing it in light of new information (Funtowicz and Ravetz 1992).

Decision support tools (DSTs) can powerfully help managers to prioritize among competing management needs, allocate scarce resources across multiple problems and explicitly incorporate the above robust decision making principles. In the 1970s researchers began to develop the idea of decision support systems. This idea came out of two areas of research: studies of organizational decision-making and on interactive computer systems (Keen and Morton 1978). Decision support tools are especially useful for natural resource management decisions because they allow integration and viewing of from a variety of sources, they set transparent standards for evaluation, and they provide users with a simple and powerful way to communicate their findings (Fedra 1995).

It is difficult to improve upon the existing approach to AIS management until there is a clear understanding of its strengths and weaknesses and it is difficult to design appropriate DSTs until there is a clear understanding of what issues they should address. The purpose of this study was to characterize the current decision making process for AIS management and identify its strengths and weaknesses. We interviewed 31 natural resource managers and researchers involved with AIS management. These interviews identified influences on their management decisions, their top management and economic concerns, and their AIS priorities in order to more clearly define the context in which AIS management decisions are made. We analyzed manager descriptions of current decision-making processes to assess existing strengths and weaknesses. Finally, we asked interviewees whether and how a decision support tool could be useful in their work in order to determine what they saw as their most pressing needs.

We focused this study on AIS management in the U.S. state of Minnesota for two reasons. First, compared to other states, Minnesota has been extremely proactive about aquatic invasive species management (Minnesota Department of Natural Resources n.d.). Second, aquatic invasive species management in Minnesota is an especially complex problem both institutionally and logistically, crossing several agency jurisdictions and balancing the demands created by over 15,000 inland lakes (Dean and Gorham 1976), a challenge due to the varied ecology of these lakes as well as the sheer magnitude of the water bodies in need of management, as well as those created by international waters (Lake Superior) and the headwaters of the Mississippi River, whose entire basin drains approximately 40% of the lower 48 states (U.S. Environmental Protection Agency 2008).

METHODS

Thirty-one individual interviews with natural resource managers and researchers were conducted from July of 2008 through April 2009. Interviewees were chosen for their involvement in and knowledge of invasive species management. The majority of interviewees were associated with federal (13) or state (13) government agencies, with the remainder (5) associated with non-profit or consulting organizations. Because the focus of this research was on AIS management in the state of Minnesota, USA, most interviewees (22) either were specifically concerned with management in the state of Minnesota or had a management area that contained all or part of Minnesota. These interviewees were chosen to provide ample representation of the state and federal agencies involved in AIS work in the state of Minnesota. Prior interviews suggested the remaining interviewees (9) as being valuable informants about the current state of AIS decision-making. These interviewees were chosen to provide additional useful perspectives from agency managers from outside of Minnesota. Indeed, five of these nine interviewees were also tangentially involved in AIS work in Minnesota (i.e., involved in the same regional panels). Initially several key informants were identified through purposive sampling and were then used to expand in the interview pool via snowball technique (Rubin and Rubin 1995).

The interviewees were chosen in part because of their ability to speak of the involvement of the wide range of jurisdictions and agencies at the various levels of AIS management. Interviewees were also chosen from all levels of the invasive species management process and ranged from those who made decisions about how to treat specific lakes to those who helped set state or regional AIS policies.

Interviews were conducted both in person and over the phone and lasted from one to two hours. The interviews were conducted as qualitative, open ended, semi-structured interviews (Rubin and Rubin 1995, Creswell 2003). The interviews were structured around a set of 18 questions (Appendix C). These questions covered three main themes. First, the interviews explored issues that influenced management decisions. This section included questions about managers' concerns and priorities (both generally and specifically relating to AIS) as well as questions about ecosystem services and attributes they were concerned with protecting. Secondly, the interviews focused on the current decision-making processes used by the managers and their agencies. This section explored issues about who was involved in the decisions, how decisions were reached, and factors considered in the decision making process. Finally, the interviews explored whether and how a formal decision support tool would be useful to managers in their AIS decision-making process.

Content analysis of the interviews was done using both transcripts of the interviews as well as detailed notes taken during the interviews. All transcripts and notes are solely in the possession of the author. The data were analyzed using NVIVO qualitative analysis software. NVIVO is designed to aid in the storage and categorization of data and the creation and manipulation of codes (Gibbs 2002). In qualitative research, codes are used to describe and organize the data and emerging themes (Miles and Huberman 1994). Codes are not predetermined, but arise from the data itself (Strauss and Corbin 1990).

The data were coded by the interview questions asked. The resulting categories of data were then examined for emerging themes and coded for categories within those themes. For example, under the main category of whether and how a DST could be useful in AIS management decisions, responses were first coded for whether they described an *issue* that should be addressed by a DST or a *characteristic* a DST should possess. Further coding was then done within each of those categories to describe themes emerging within the discussions of issues and characteristics.

The majority of coding was done using an inductive process, that is, the codes arose from the content of the interviews and were not pre-determined. Emerging themes arose from repetition and patterns found in the interview content. The one exception to this was the coding of the descriptions of current decision support processes. Although these responses were coded for spontaneously arising themes, they were also coded in a deductive fashion in which the characteristics of a robust decision-making process were used as predetermined codes.

RESULTS

Issues Influencing Manager Decisions

During the interviews, thirty interviewees were presented with a list of ecosystem services (Appendix D). These services have been identified for fresh water bodies and can be divided into four broad categories – provisioning, regulating, cultural, and supporting (Millennium Ecosystem Assessment 2005). Interviewees were asked to pick the top five services that they were most concerned with protecting (Table 2-1). The most frequently chosen services were biodiversity, water quality, recreation, and game species abundance. These belonged to three separate categories of services. Overall, however, services from the provisioning category were chosen far more frequently than those from other categories, while services from the regulating category were chosen the least frequently.

When prompted to explain their choices, the most repeated explanation (n=28) was that the services chosen were integral in protecting ecosystem stability and function. As one manager, an ecologist, put it: “once you’ve [destroyed the natural ecological processes] you’re pretty much affecting all these other things, such as cultural values and recreation and property values and so forth, so that’s why I kind of focused on the ecology. Because it all stems from… screwing up the ecosystem.” The second most frequent explanation (n=15) was that they were choosing services that were valued or needed by humans. One state level manager explained that he felt that he was responsible for representing the various user groups in his work and that his priorities should reflect those of the groups. Other interviewees talked about this motivation in different, sometimes contradicting ways. One manager said that he didn’t really consider aesthetics to be an ecosystem service but that “a pretty looking lake” was something people valued a great deal. A non-profit employee, on the other hand, talked about how access to fresh water was “one of the fundamental rights to life… and it’s something we should protect.” Other explanations for why managers chose the services they did included protecting those services that had economic value (n=9) and protecting those services that were part of their agency’s mandate (n=4).

Two interviewees explained that their choices were motivated by picking those services they felt were the most “encompassing” of the other services on the list. They felt it was important to protect all the services and chose those “encompassing” options as a way of getting around being limited to selecting five. Finally, one interviewee explained that she chose those services around which there were political opportunities; openings at the federal policy level where there was the momentum for change and the opportunity to make those “shift[s] for the better.”

When asked whether AIS threaten their top five ecosystem services, all interviewees thought their top five services were at least partially threatened by invasive species. Although most interviewees gave an immediate yes to this question, a few qualified their response be saying that other issues would have a bigger impact on their chosen services (n=1) or that AIS would only threaten some of the services on the list (n=2). Two interviewees were also concerned about potential ripple effects from multiple invasions: the change in the landscape and ecosystem structure and the fact there are now environmental changes occurring that they were not able to predict such as “botulism outbreaks, the dead zone, … the toxic algae bloom”.

All but one interviewee also felt that protecting their chosen services played a role in driving their management decisions. Some interviewees also felt that their management decisions were influenced by their agency mandates and by public and political pressure. As one federal level employee put it: the chosen services are “a big part of [the management decisions] because of our legal requirements… it’s not something we just do for the sake of it. It’s all based on law, regulation, and policy, and congressional budgets, unfortunately.” Some interviewees explained that they were actually managing with other aims in mind (e.g., AIS prevention, fisheries management) but felt that success in management for those goals would also protect ecosystem services. When asked this question one interviewee responded by saying that “really, it all comes down to prevention… if we prevent the spread [of AIS], we’re protecting those values.” Two interviewees expressed reservations as to how much impact their desire to protect ecosystem services actually had. One felt he was too far removed from influencing the issues (“like climate change and energy use and how we transport goods”) that had broad impacts on those services. Another indicated that, in his experience, multiple groups were involved in making management decisions so his particular priorities had only a limited impact on the final outcome.

Interviewees were also asked for their top concerns for the water bodies in their management area. There were no bounds placed on this question and 30 interviewees listed 86 separate management concerns (Appendix E). Of those 86 concerns 54 were concerns related directly to AIS. These include specific AIS of concern (19), prevention of new introductions and spread of AIS (12), direct impacts of AIS (6), and concerns about public education, buy-in, and involvement (5). Fourteen of the concerns are indirectly related to AIS. These include concerns about the health of native species (4), protecting ecosystem services (4), and managing for the health of the ecosystem, particularly if the system is facing changes (4). Finally, 18 concerns are unrelated to AIS. These include concerns about larger scale drivers of change, like climate change, altering the ecosystem (5), concerns about the manipulation of habitats resulting from such activities as over control of aquatic plants and fisheries harvests (4), and concerns about landscape level impacts like nutrient loading (3).

When the conversation focused on manager's invasive species management priorities managers identified 70 priorities that fell under nine priority headings (Table 2-2). In addition, two interviewees listed development of a management plan as a top priority and two other interviewees listed aspects they thought should be emphasized in their management actions (long-term focus, adaptive approach, and integrated control). More details on the identified priorities can be found in Appendix F.

Finally, interviewees were asked about their top economic concerns related to AIS management. Some economic concerns had arisen elsewhere in the discussion – managers listed the costs of AIS control and economic impacts of invasive species as management concerns as well as listing adequate funding for AIS control as an AIS management priority. This question, though, asked interviewees to think specifically about the economic issues they saw as most pressing for AIS management. Thirty interviewees listed 73 economic concerns (Appendix G). Of these, 17 concerns, identified by 15 interviewees, were focused on the costs of control and 54 concerns, identified by 24 interviewees, were focused on the cost of the damages caused by AIS. Of the 30 interviewees who answered this question, only nine interviewees identified both the costs of control *and* the costs of damages, whereas the remaining 21 only listed concerns from one category or the other. Concerns about costs of control went beyond simple expense. One manager expressed his frustration with the lack of long-term funding, saying that the problem is not "that there isn't money there; it's just that it's spread out year by year" – an approach that undermines the success of many management projects. Two managers talked about the difficulty of fitting AIS issues into a budget with so many other management needs competing for limited funding. Concerns were also raised about the lack of funds to deal with less pressing control costs such as research into new control options and monitoring efforts. Of the 54 concerns related to the costs of damages, 41 involved costs that are typically measured in monetary terms. These include costs to fisheries, utilities, and industries like shipping and tourism. The remaining 13 concerns were related to less easily measured damages such as environmental damages, the loss of ecosystem services, and loss of "personal enjoyment." As one manager put it: "It's a loss of personal enjoyment. It's a loss of – I don't go to the beach anymore because it's just full of zebra mussels and stinky, rotted fish." Five managers also specified that one of the greatest economic concerns for them was a lack of information concerning the true cost of invasive species spanning the damages, control costs, and uncertainties associated with invasive species management.

Current Decision Making Process

Interviewees were asked about the current decision making process with which they were involved. Their responses were coded for mentions of characteristics recommended for a robust decision making process (i.e. the characteristics identified above in the introduction). Interviewees were not directly asked whether they felt these characteristics described their processes, rather their descriptions of the processes were coded for *spontaneous* mentions of the characteristics. The most striking result is how infrequently these valued characteristics seem to be a part of the AIS decision-making processes (Table 2-3). Additionally, in these descriptions several, relatively few interviewees referred to how the inclusion of a consistent structure (4), an adaptive/iterative approach (2), transparency (1), and a scientific basis (1) would improve their current decision making process.

Interviewees also identified characteristics other than the robust decision characteristics described above. Other characteristics of the decision making process that were repeatedly mentioned were coordination between agencies and other interested groups (16), the influence of legislative mandates and other policy demands (5), and the restrictions posed by budgets (5). Interestingly, although uncertainty is a major part of wicked problems, only one interviewee mentioned the need to deal with uncertainty as part of the existing decision making processes.

The most frequently mentioned characteristic of the decision making process was the coordination that took place between the interviewees' agencies and interested groups. Sixteen interviewees talked about the integral role coordination and communication between multiple agencies and experts played in their decision making process. This is not surprising given that, when asked, the most frequently mentioned strengths of the current process were the ability to involve a diverse and knowledgeable staff (8), to coordinate between agencies and interest groups (5), and communicate effectively with the broader public (3). This coordination is not necessarily an official component of the system, however. Several interviewees mentioned that the coordination between their organization and others had more to do with key individuals and relationships and little to do with institutionalization.

Managers spend a significant amount of time and place a great deal of importance on their engagement with other parties; 22 of the 31 interviewees mentioned either participation or coordination as being a key part of their decision making process. These elements appear especially important given the number and diversity of groups involved. When interviewees were asked who was involved in the decision making process the groups identified ranged from the general public to various industries to government organizations ranging from the local to the national (Table 2-4). As one interviewee put it: "there isn't a single agency that we don't work with." This magnitude and diversity emphasizes the importance of coordination skills, not only bringing all of these groups into the process but also balancing the differing values and perspectives that each group brings to the table.

After describing their decision-making process, interviewees were asked to describe what they saw as the process's strengths and weaknesses. Although interviewees showed consistency when it came to identifying the strengths of the current decision making process, there was much more diversity when it came to identifying the weaknesses. Given that coordination was considered a strength of the process, it is interesting to note that one of the most frequently mentioned weaknesses was the lack of leadership and confusion over overlapping jurisdictions (7). One interviewee from a non-profit said that she worked with many agencies and non-governmental groups in her work and that

> one of the biggest challenges [was] figuring out not necessarily who singularly should be in charge, but how do all these authorities complement each other and work together. It's a huge problem.

The contradictions of having successful ad-hoc coordination but weak leadership may also be explained, in part, by the informal nature of some of the communication between agencies.

Other weaknesses identified by the interviewees include a lack of information/science (7), a lack of structure (4), a process that is too slow and time consuming (4), a process that is not adaptive (3), and a lack of documentation (2). These weaknesses are of particular interest given that these are characteristics of a robust decision making process.

Interviewees were also asked for examples of successful or flawed decisions. Four of the interviewees brought up the sea lamprey control program as an example of a successful decision-making process. They identified the level of inter-agency coordination, the integral role of research in the program, and the scientific basis for the decisions as the reasons for the program's success. Two other managers described decisions where decision-makers and members of the public had worked together to set goals and reasonable expectations for management actions and to ensure public support for those actions. Interestingly, when talking about flawed decisions three interviewees said they felt unable to give examples because they had little information of the results of their actions. As one manager put it, "This is a question I struggle with, because I don't know if I have any good examples one way or the other, because I don't know necessarily what the outcomes are or have been." This manager went on to emphasize the need for well-documented decisions so that past reasoning could at least be understood and, with increased information, hopefully improved.

Finally, the majority of interviewees felt that the inclusion of a wide range of people and groups improved the decision making process. One manager even felt that more people, from a wider variety of specialties, should be included in the process. One interviewee, however, felt that the main weakness of the decisions that he had been involved with was that too many people with an insufficient background in AIS management were involved.

Decision Making Needs

Of the 31 interviewees only one said that he did not think a DST would be useful in his work. Of the remaining 30 interviewees, five were open to the idea of DSTs but skeptical about their actual use. Two of these managers were skeptical because they did not see how a DST would fit into their current decision-making process. Two other managers' skepticism was based on their concerns about how reliable and accurate a DST could be especially given concerns about the quality and availability of information feeding into it. As one interviewee put it: "the information out is only gonna be as good as the information in. If we don't know these things ahead of time – that's where the holes in [existing model] were… there just wasn't enough information that you could plug in this thing." The remaining interviewees, however, were completely supportive of a DST being incorporated in their work. In fact, one manager went so far as to say that "there isn't a single decision that wouldn't benefit from [one]."

Although some managers expressed skepticism about using a DST, all interviewees (including the one who did not think a DST would be useful in his work) had suggestions for a DST that would be useful in invasive species management. Interviewees had between one and six suggestions each, with a total of 100 suggestions. Of those 100 suggestions 80 were issues that would be easier to address through use of a DST and 20 were of characteristics that managers felt any DST should have (Table 2-5). (Appendix H)

Virtually every aspect of invasive species management was mentioned as benefiting from decision support – from early detection and rapid response, to selecting a control option, to measuring effectiveness of management actions. Similarly, multiple aspects of the decision making process were also mentioned. These aspects include having background information, assessing risks of actions and inaction, predicting the outcomes of different actions, and prioritizing where to take actions and which actions to take. Overall, these responses indicate that DSTs would be both useful and welcome in multiple facets of AIS management.

When talking about DSTs, 11 of the interviewees identified 20 characteristics that they would want to see in any and all new DSTs. These include:

- Easily understood and communicated
- Transparent
- Inclusion of a knowledge repository
- Flexibility
- Consistency and repeatability
- Documentable
- Efficient
- Spatially explicit
- Explicitly deals with uncertainty

Strikingly, these characteristics correspond neatly with those characteristics that have been suggested as part of a robust decision-making process as well as with weaknesses that managers had identified in their decision-making processes. These responses make clear how DSTs can both respond to the needs of managers and improve their decision-making process. In spite of this, however, interviewees did not feel that DSTs were a silver bullet for AIS management problems. As one manager put it:

> I gotta tell you, in my mind, decision support tools are great, but there's never gonna be a nomograph that gives you the answer. It's always gonna be something you go through, and then you set it aside, and the art and science will come together with your judgment. And there's a great art at managing invasive species... It's incredibly complicated and the more you do, the longer you're at it, the more complicated you realize it is.

Discussion

Our results show managers of AIS are preoccupied with balancing multiple competing priorities with inadequate clarity regarding their relative priority and overall management goals, both of which challenge the effectiveness of AIS management. In addition to shedding light on the various priorities and concerns influencing management decisions, we found that managers identified strengths of the existing decision-making processes that correspond to robust decision-making characteristics and identified weaknesses corresponding to the absence of robust decision-making characteristics. This underscores the need to find tractable ways to facilitate the application of these characteristics in actual natural resource management scenarios.

Valuable insights into managers' motivations are provided by the ecosystem services they identified as those they were most concerned with protecting as well as their explanations for their choices. The most frequently given explanation for why they chose particular ecosystem services was a desire to protect ecosystem function. However, the most frequently chosen services were from the provisioning category, which is more aligned with human needs than ecosystem function. In fact, services in the provisioning and cultural categories, both of which are more associated with human needs and values were far more frequently chosen than services in the supporting and regulating categories, which are more related to ecosystem function. The mismatch between the most commonly used language explaining the rationale behind their management priorities and the most commonly selected priorities suggests that there is a complicated relationship between what managers aim to protect and why they are protecting it. These results underscore the need for the parties who drive the decision-making process to become more explicit and transparent about the goals of and motivations behind managing a given AIS so that decisions can be made with those goals prioritized.

Interview results also showed that the wicked problem of how to manage aquatic invasive species cannot be viewed in isolation. Its connection to broader management issues recurs in the interviews. First, managers see the ecosystem services they want to protect as being threatened by AIS. Second, and more explicitly, the majority of the interviewees' concerns for the waterbodies in their management area were related either directly or indirectly to the presence of AIS. This result, however, could be biased by our having chosen interviewees who had a relationship to AIS management. It is worth noting, however, that even those management concerns seemingly unrelated to AIS do have some connection. Climate change, for example, will affect how vulnerable an ecosystem is to invasion as well as the success of potential invaders (Rahel and Olden 2008). The process for making AIS management decisions should explicitly recognize this interconnectedness as should any DST.

When it comes to the specifics of AIS management, our results point to a few key findings. First, the AIS management priorities identified by managers correspond with priorities identified in management plans of the National Invasive Species Council (2008) and the Aquatic Nuisance Species Task Force (2007). This signals that managers dealing with AIS issues at all levels recognize the importance of the same suite of issues. It is also worth noting that neither the interviewees nor the management plans had any clear indication of the relative importance of these priorities.

Second, these interviews highlighted the importance of economic concerns in the AIS arena. Discussion of economic issues arose throughout the interviews – in the explanation of priorities for protection of ecosystem services, in discussions of AIS management priorities, in explanations of the current decision-making processes, and as an issue for a DST to address. When directly asked about economic issues of greatest concern, however, managers focused more on costs that could clearly be measured in dollars as opposed to those costs and damages that defy monetization. It would be worth further exploration of this issue to determine whether monetized costs were more frequently mentioned because there is more information about them, because they are easier to quantify in terms of dollars, or because they are more influential or more valued.

Finally, it was striking how infrequently the characteristics of robust decision-making described in the introduction arose during interviewees' descriptions of their current decision-making processes. These results came from spontaneous mentions of those characteristics and, thus, might differ if interviews had directly asked managers about the role of these characteristics in their decision-making. Importantly, the infrequent mention of the characteristics in the process descriptions corresponds with interviewees' identification of the strengths and weaknesses of their processes. The strengths and weaknesses discussed all have to do with either the presence or absence of robust decision-making characteristics. Most interviewees recognized that the inclusion of participation made their decisions stronger and that the lack of structure, documentation, and an adaptive approach made their process weaker. This confirms that the characteristics of robust decisions from scientific literature resonate with those who are making on-the-ground decisions.

The correlation between the characteristics of a robust decision-making process and the strengths and weaknesses articulated by the interviewees continued in the interviewees' descriptions of what they would like to see in a DST. Using a DST would allow managers to explicitly incorporate many of the characteristics they would like in the decision-making process (e.g., documented, retraceable decisions). Use of a DST would allow decision makers to follow a consistent structure to reach decisions that, for some of them, is currently lacking. For example, a reliable DST could provide a consistent structure for making decisions about where to focus monitoring efforts. Further, use of a DST would allow decision makers to clearly explain to stakeholders how and why they reached specific decisions and to document the process. All of these aspects of a DST would address weaknesses in current decision-making processes identified by interviewees and would apply regardless of the form of the DST used.

CONCLUSION

Our results confirm that management of AIS is indeed a wicked problem. Managers are attempting to balance a wide range of management concerns and priorities as well as those of a wide range of groups who are involved in the decision-making process. Managers are attempting to incorporate societal, economic, and ecological concerns when making AIS decisions. They are attempting to incorporate groups from all levels of government as well as non-governmental groups varying from the commercial to the non-profit. Finally, they are attempting to address multiple priorities with limited indications of which issues should take precedence. Roberts (2001) identified three different methods of coping with wicked problems: 1) authoritative, which requires a clear leader who has the power to implement a single solution; 2) competitive, which requires an open market situation in which potential solutions are played against one another until a single one remains; and 3) collaborative, in which multiple stakeholders work together to find an acceptable solution. Collaborative approaches require more time and compromise than the other approaches but, given the realities of AIS management, in this situation collaboration is the most practicable option. It may also be the most culturally acceptable and politically feasible option in the USA. The importance of participation and coordination in the interviewees' work indicates their recognition that a collaborative approach is necessary.

Our findings indicate that managers would welcome multiple DSTs into the decision-making arena both to help them address various AIS issues as well as to assist them to make the process adhere more closely to principles of robust decision-making. Further, an appropriately designed DST could be a valuable tool in a collaborative decision-making process (Chun and Park 1998). Managers possess specialized and unique knowledge regarding on-the-ground realities of AIS management. Including their perspectives of the current decision-making process allows us to be more focused and effective in any attempts to improve it.

Table 2-1. Interviewees' top five ecosystem attributes and services. Interviewees were presented with a list of ecosystem attributes and services and asked to select their top five. The table below depicts the number of times each attribute or service was chosen.

Ecosystem services	**Number of Times Chosen**
Provisioning	*66*
Water quality	23
Game species abundance	14
Non-game species richness and abundance	9
Commercial and industrial services	8
Water quantity	6
Fresh water	3
Property values	2
Food	1
Supporting	*38*
Biodiversity	25
Nutrient cycling	9
Habitat	2
Landscape condition*	1
Native species assemblages*	1
Cultural	*31*
Recreation	16
Aesthetics	7
Cultural values	7
Public awareness*	1
Regulating	*18*
Hydrological regime regulation	5
Biotic resistance	4
Climate regulation	3
Pollution control and detoxification	3
Erosion protection	2
Natural hazard regulation	1

*Services that were not included on the preexisting list, but were spontaneously added by interviewees

Table 2-2. Interviewees' top invasive species management priorities, compiled from answers when asked to list their top three priorities in ecosystem management. The first number denotes the number of times priorities in that category were listed and n denotes the number of interviewees who had priorities within that category.

Priority	Number of mentions
Prevention	15 (n=11)
Management*	12 (n=10)
Containment	9 (n=8)
Coordination	8 (n=5)
Legislation	8 (n=7)
Research	6 (n=5)
Outreach	6 (n=6)
Reduce Impacts	4 (n=4)
Funding	2 (n=2)

*Although management can be considered a broad category encompassing all other categories in this table, interviewees were referring to management and control of invasive species currently present in the ecosystem.

Table 2-3. Characteristics of a robust decision-making process identified by interviewees' descriptions of the current decision-making processes (number of mentions that coded to one of these robust characteristics).

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Characteristic of Robust Decision Process	Number of mentions
Participatory	14
Science-based	7
Structured/Consistent	5
Flexible	4
Adaptive/Iterative	3
Documentable	3
Transparent	1

Table 2-4. Organizations that interviewees identified as being involved in AIS decision-making processes, with number of times each type was identified across all interviews.

Type of Organization	Number of times identified
Federal Agencies (e.g. US Fish and Wildlife Service, Army Corps of Engineers)	72
State Agencies (e.g. Departments of Natural Resources, Fisheries and Wildlife, Environmental Quality)	67
Regional Coordinating Panels (e.g. Aquatic Nuisance Species Task Force (national and regional panels), Great Lakes Fishery Commission)	32
Local Government (e.g. Municipalities, watershed districts, lake improvement districts)	29
Public (e.g. Lake associations, resource users, angler groups)	27
Environmental Groups	10
Industry (e.g. Shipping, aquaculture, pet)	8
Universities	7
Tribal Groups	4

Table 2-5. Issues for a decision support tool to address, as identified by interviewees. Within the parentheses, the first number denotes the number of times suggestions in that category were listed and n denotes the number of interviewees who had suggestions within that category.

Issue (# of suggestions)	Examples
Decision making guidance (25, n=14)	Stepwise guidance for less experienced managers, which strategies should be used at which locations
Prediction (16, n=12)	Ranking new species for invasiveness, likelihood of damage resulting from an invasion
Prioritization (13, n=11)	Where to put money across a landscape, how to use limited funds
Information storehouse (13, n=7)	What are the available control options? What is surrounding the affected area?
Go/No-go determinations (10, n=7)	Costs of actions vs. no action, feasibility questions
Risk assessments (3, n=2)	Risk assessments for agencies working in an infested area

Chapter 3: Analysis of the National Invasive Species Act: Purposes, Impacts, and Suggestions for Improvement

with Dr. Anne R. Kapuscinski

The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 and its reauthorization as the National Invasive Species Act of 1996 (NISA) is the keystone policy instrument for addressing the management of aquatic invasive species (AIS) in the United States. It represents a major step forward in the evolution of federal policy instruments addressing AIS from 1900 to the present. NISA is the only statute that attempts to address the problem of AIS broadly (i.e. not on a species by species basis and across the entire country). We reviewed peer-reviewed and grey literature, as well as interviewed natural resource managers for their perspectives on the impact of AIS policy instruments, in order to assess whether or not NISA has met its stated goals. Our analysis suggests that NISA has not had its intended effects, even though its goals correspond to those of on-the-ground AIS managers. NISA has had limited success in preventing AIS introductions via ballast water and has no authority to prevent introductions via other pathways. There is also little indication that NISA has slowed the spread of AIS already present in the country. The Act has, however, been more successful in leading national and regional coordination efforts. We propose that prevention of new introductions via pathways other than ballast water be granted to a federal agency, potentially the U.S. Environmental Protection Agency under the Clean Water Act. We also propose that the Aquatic Nuisance Species Task Force be granted additional authority and resources to allow it to further increase regional coordination of control and containment efforts. These two recommendations would clarify and streamline leadership on federal efforts to prevent introductions of and manage AIS as well as allow a more effective use of limited resources.

INTRODUCTION

Federal policy on aquatic invasive species (AIS) management is complex, with multiple policy instruments playing a role. In this paper we review fourteen of these policy instruments for their main purpose and then take a more in-depth look at the National Invasive Species Act (NISA). We focus on NISA because it is the only piece of federal legislation that is specifically designed to address the invasive species issue. Our examination of the NISA identifies the main goals of NISA, explores whether NISA has had its intended purpose in regard to those goals, and considers natural resource managers' perspectives on NISA. Finally, we propose ways in which NISA could be strengthened in future reauthorizations.

Aquatic invasive species are an ever-growing problem, and human behaviors are responsible for increasing the rate of invasions far beyond the historical environmental norms (Mack et al. 2000). Invasive species are responsible for negatively affecting evolutionary pathways (Mooney and Cleland 2001), ecosystem function (Mack et al. 2000), and the quality and quantity of outdoor recreation opportunities (Eiswerth et al. 2005). Pimentel et al. (2005) estimated that the economic cost of invasive species to Americans is approximately $120 billion per year. Both national and international groups have identified invasive species as a key environmental threat. This paper critically examines the key U.S. policy instrument for managing AIS, looking specifically at the strengths and weaknesses of the legislation. Our approach is unique in that it combines evidence from published literature regarding the successes and failures of NISA with evidence from the experiences of natural resource managers whose work takes place under the aegis of NISA. Finally, as NISA is already overdue for reauthorization, this paper is a timely look at ways in which NISA could be strengthened in the future.

Methods

The analysis began by identifying and reviewing the goals of fourteen federal-level policy instruments relevant to the management AIS and then proceeded to focus on a critical analysis of whether NISA had succeeded to achieve its stated purposes. The review of policy instruments and our analysis of the success of NISA were pursued through analysis of information available in peer-reviewed and gray literature, the latter of which included government reports, databases and websites. In the section on NISA below, we specify how we used these information sources to pursue specific questions relevant for each stated purpose of the act. We also obtained manager perspectives about the functional role of existing AIS policy through a series of interviews with natural resource managers whose jobs include addressing AIS issues. The methods for conducting and analyzing these interviews are described in Chapter 2. Among a longer list interview questions posed to natural resource managers, information for this analysis primarily drew on their responses to the following three questions (Appendix C):

1. To what degree are other agencies included in your management actions?
2. What legislation/management plans most directly influence your management action? Do you have improvements/suggestions/changes you would like to see in these plans or legislation?
3. What are your top priorities in invasive species management? What are your strategies for reaching these? Can you be specific/elaborate?

Review of Federal Aquatic Invasive Species Policy

Currently, there are 11 federal acts, two agreements, and one executive order that address, in some specific capacity, the management or control of aquatic invasive species (Table 3-1). Appendix I presents a detailed history of the evolution of federal policy instruments pertaining to management of AIS. It places the fourteen identified policy instruments into one of five key periods from 1900 to 2007.

Of these fourteen policy instruments, four have been considered a major tool in the fight against invasive species: the Lacey Act (Fowler et al. 2007), the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 and its reauthorization the National Invasive Species Act of 1996 (UCS 2002), and Clinton's Executive Order 13112 (Simberloff 2003, Pimentel et al. 2005). NISA is unique among these in that it was specifically designed to manage aquatic invasive species (unlike the Lacey Act) and it was passed by Congress and has regulatory authority (unlike Clinton's Executive Order).

There were several key moments in the evolution of AIS legislation. The Lacey Act was the first piece of legislation to have an impact on management of AIS. Although the main purpose of the act was to reduce wildlife poaching, the act made deliberate introductions of "injurious wildlife" illegal. Unfortunately, the act's scope is limited to those species officially listed under it (often called the "black list"). The Convention on the Great Lakes is notable in that it established the Great Lakes Fisheries Commission with the specific goal of controlling the invasive sea lamprey (*Petromyzon marinus*) in the Great Lakes, making it the first piece of legislation to mandate control of an established invasive species. The 1995 Agreement on the Application of Sanitary and Phytosanitary Measures was designed to "harmonize" sanitary and phytosanitary measures among World Trade Organization members and was designed to address the tension between reducing obstacles to international trade and concerns that such trade facilitates invasive species introductions. Most recently, Clinton's 1999 Executive Order dealt with federal level coordination of the invasive species problem. The order established the National Invasive Species Council (NISC) but its impact is limited by a lack of legislative mandate and congressionally authorized funding.

The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 and its reauthorization as the National Invasive Species Act of 1996 (hereafter referred to as NISA) is unique among existing policy instruments in that was specifically designed to address the problem of AIS. Unlike the Lacey Act, it addressed both prevention and control and its approach to prevention is to focus on pathways of introduction (e.g., ballast water) rather than establishing a limited list of forbidden species. Unlike the

Convention on the Great Lakes, it aimed at dealing with multiple species across all US waterbodies. This law codified federal recognition of the serious and widespread nature of the invasive species problem.

NONINDIGENOUS AQUATIC NUISANCE PREVENTION AND CONTROL ACT (1990) AND ITS REAUTHORIZATION, THE NATIONAL INVASIVE SPECIES ACT (1996)

It wasn't until 1990 that the federal government enacted legislation that directly addressed the invasive species problem. In contrast to the fairly narrow concerns of previous laws with regard to aquatic invasive species, the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 was concerned with all aquatic invasive species, although zebra mussels were of special concern, in all US water bodies. In 1990 the 101st Congress enacted Public Law 101-646, Title I of which is the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990. This was an incredibly ambitious law given the wide range and difficulty of the issues it tried to address. The law was enacted because both the House and Senate recognized that nonindigenous aquatic species were having an "enormous impact… on the economy and the aquatic environment" (Congressman Hertel, Congressional Record 10/1/90). The driving force behind this piece of legislation seems to be the realization that zebra mussels, an invasive species in the Great Lakes, were causing "millions of dollars in damage" (Congressman Davis, Congressional Record 10/1/90) and that more species like them were on the way. It is interesting to note that, during discussions of H.R. 5390, no one went on record as opposing the bill. It is also interesting to note that the concern of legislators was not about the ecological or environmental issues attendant upon invasions of nonindigenous aquatic species, but rather about the "negative economic impact on commercial and recreational fisheries, municipal and industrial water supplies, and shipping interests" (Congressman Hertel, Congressional Record 10/1/90).

As passed, the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 had five stated purposes:

1. Prevent future unintentional introductions of nonnative aquatic species by creating guidelines for ballast water management that reduce the spread of invasive species through ballast water exchange.
2. Coordinate research, prevention, monitoring, control, and information dissemination regarding zebra mussels and other aquatic invasives at the federal level.
3. Develop, and put into use, methods for preventing, monitoring, and controlling unintentional introductions of nonindigenous species via pathways other than ballast water exchange.
4. Understand and reduce economic and environmental impacts of established nonindigenous species.
5. Establish a program to research and develop tools to assist the States in managing and removing zebra mussels.

Reducing introductions via ballast water exchange (Purpose 1)

The Act authorized regulations mandating ballast water exchange outside the exclusive economic zone (EEZ) or some other, equally effective, method of ballast water management. Congress gave authority to the Secretary of the department in which the Coast Guard operates (currently the Department of Homeland Security) to issue regulations preventing nonindigenous species introductions via ballast water exchange. The regulation promulgated by the Coast Guard in 1993 mandated ballast water management for all vessels operating within the Great Lakes after operating beyond the EEZ and was expanded to include vessel operating within the Hudson River in 1994. These vessels were required to carry out their ballast water exchange beyond the EEZ, retain their ballast water, or adhere to a pre-approved alternative management plan.

Federal coordination (Purpose 2)

The Act called for creation of the Aquatic Nuisance Species Task Force (hereafter, the Task Force). This Task Force was to oversee several studies required by the act as well as creating and implementing a national plan. This national plan aimed to prevent introduction and dispersal of nonindigenous aquatic species, control and research species already present, and spread the information obtained through these research efforts to the appropriate parties. Finally, the act gave the Task Force authority to approve management plans submitted by the states and give out federal grants for the implementation of those plans.

Alternative pathway management (Purpose 3)

The Task Force was to lead management of pathways other than ballast water exchange and reduction of the impact of nuisance species already present. The Task Force was to identify these alternative pathways, assess the risk that species introduced by these pathways would become nuisances, and evaluate whether the measures used to prevent introductions via these pathways are effective. When significant risks are identified, the Task Force then was given the responsibility to respond to "minimize the risk." This program also had the responsibility of detecting introductions and dispersal of nuisance species. The program also made the Task Force responsible for deciding when management of invasions was necessary and then "develop[ing] a proposed control program to achieve the target level of control."

Understanding and reducing impacts of AIS (Purpose 4), especially zebra mussels (Purpose 5)

The Act called for research to be done to increase understanding and reduce economic and environmental impacts of established nonindigenous species. Also, the Task Force was charged with assisting the states in development of their own AIS management plans.

Congress intended this statute to result in the end, or the substantial minimization, of nonindigenous species introductions via ballast water exchange, the identification of other invasion pathways and a similar response to close them off, and a federally coordinated management effort that would control or eradicate populations of nuisance species that are already established in the US, especially the zebra mussel.

Later, this statute was amended by the National Invasive Species Act of 1996 and its purpose expanded to create voluntary guidelines to prevent or reduce the introduction of nonindigenous aquatic species via ballast water transfer in all US waters in addition to the mandatory requirements in the Great Lakes. The 1996 amendments also increased the number of invasive species of concern mentioned by name – from a sole mention of zebra mussels to mentions of eight other specific species as well as categories of shellfish pathogens and aquatic nuisance vegetation species. Although NISA applies to all AIS, the increasing number of species referred to by name in the Act indicates the increasing awareness of the AIS problem.

ASSESSMENT OF NISA'S SUCCESS IN ACHIEVING ITS PURPOSES

In order to determine how successful NISA was in achieving its goals and in what areas it could be improved, we used peer-reviewed and grey literature to assess whether or not NISA met its stated goals for each of its five purposes.

Preventing ballast water introductions (Purpose 1)

The assessment with respect to this first purpose focuses on addressing whether rates of ballast water mediated introductions had decreased post-NISA and whether continuing introductions could be related to compliance issues or loopholes in NISA. This assessment is based on information about ballast water mediated introductions and compliance with ballast water regulations both pre- and post-NISA, as well as information gathered on current gaps in the legislation and methods for addressing those gaps.

The implementation of ballast water regulations has not been as effective as hoped in reducing the spread of AIS. Nonindigenous aquatic species in the Great Lakes were found at a higher rate in the 1990s (post-regulations) than in any of the three prior decades (Grigorovich et al. 2003). This trend seems likely to continue given a 2007 study by Drake and Lodge which found samples of between 200 and 1000 unique taxonomic groups in ballast tanks in the Great Lakes between 2000 and 2002. Of those, between 14 and 39 had not yet been found to be freeliving in the Great Lakes.

A September 2005 report from the United States Government Accountability Office found that continued spread of nonindigenous species through ballast water exchange was not due to noncompliance with these regulations. The failure resulted from the large number of vessels exempt from the regulations, the lack of alternate discharge zones for vessels unable to carry out the recommended method of ballast water exchange, and the fact that ballast water exchanges are not sufficient for removing or killing the nonindigenous species present in the ships. In fact, reports from the Ballast Information Clearinghouse indicate that compliance with ballast water regulations is slowly but steadily improving (Ruiz et al. 2000, Ruiz et al. 2001, Miller et al. 2004, Miller et al. 2007, Ballast Information Clearinghouse n.d.). Nationwide compliance with reporting requirements increased from 20.8% in 1999-2000 to 79.3% in 2005. Of those, the percentage of vessels reporting partial or complete ballast water discharge in US waters, without an open ocean ballast water exchange, decreased from 15.2% in 1999-2000 to 7.2% in 2005. A significant percentage of those vessels performing open ocean ballast water exchanges, however, were not performing exchanges in compliance with the regulations. In 2005, 58.8% of vessels performing open ocean exchanges did so within the 200 mile EEZ.

The Coast Guard has encouraged the development of new technologies that could be used to solve these issues. In 2004 the agency formed the Shipboard Technology Evaluation Program (STEP) to promote research into new shipboard methods of ballast water management (United States Coast Guard n.d.). At present, there are no new tools readily and widely available and none that are sanctioned as a legal alternative to ballast water exchange.

Another major gap is the lack of regulation for vessels categorized as NOBOB (no ballast on board), which make up the majority of the ships entering the Great Lakes (almost 70% according to a 2003 report from the United States Government Accountability Office, around 90% according to a 2005 paper by Duggan et al.). Even though these vessels do not have to comply with ballast water exchange regulations, they can still carry thousands of gallons of water and sediments that carry live nonindigenous species into US waterways. In examining residual sediment and water, Duggan et al. (2005) found samples of seven AIS that had been established in the Great Lakes, some of which were discovered after the ballast water regulations had been implemented.

The GAO report also found that state governments were becoming frustrated with the ineffective federal regulations and moving to implement more restrictive regulations at the state level. Indeed, several states and environmental groups successfully sued the EPA in order to require the agency to regulate ballast water under the Clean Water Act instead of under NISA (Northwest Environmental Advocates 2011). In response to this, the EPA has released a proposed rule that would bring US ballast water treatment standards in line with the International Maritime Organization and set the numeric effluent limit for ballast water as numbers of living organisms per cubic meter discharged (Environmental Protection Agency 2011). This, however, is still insufficient for some states, leaving them to propose standards 100 times to 1000 times more stringent (Environmental Protection Agency 2011).

Overall, the purpose of NISA to prevent ballast water introductions has not been achieved. Ballast-water-mediated introductions continue to occur and the regulations have significant loopholes that allow ships to continue to function as pathways for AIS introductions. States, recognizing that NISA's regulations are not having the intended effect, have begun to explore alternate methods for preventing ballast-water-mediated introductions.

Federal level coordination (Purpose 2)

Regarding this coordination purpose, we examined the structure and function of the Aquatic Nuisance Species Task Force, the group created by NISA to spearhead federal level coordination of AIS management. We focused on whether the Task Force has brought federal and state agencies together as intended and what AIS management priorities they are pursuing.

The Task Force is co-chaired by the Fish and Wildlife Service and the National Oceanic and Atmospheric Administration. Other federal members include the Army Corps of Engineers, the Bureau of Land Management, the Bureau of Reclamation, the Department of State, the Environmental Protection Agency (EPA), the Forest Service, the Maritime Administration (in the Department of Transportation), the Coast Guard, the National Park Service, the Animal and Plant Health Inspection Service, and the US Geological Survey. Ex-officio members include representatives from fisheries and aquaculture associations, utility groups, research centers, and tribal authorities. (Aquatic Nuisance Species Task Force (a) n.d.)

The Task Force also established six regional panels (Western, Great Lakes, Northeast, Mid-Atlantic, Gulf and South Atlantic, and the Mississippi River Basin) that coordinate AIS priorities and activities within each region (Figure 3-1). In interviews with natural resource managers, 20 of 31 interviewees identified national or regional cooperative panels as playing a role in their AIS decision-making process. Twelve of those managers specifically identified the Task Force or a Task Force regional panel.

The Task Force created a structure of five committees, each of which has made significant contributions according to its own reporting (Aquatic Nuisance Species Task Force (b) n.d.):

Control - developed control and management plans for seven AIS (Asian carp, brown tree snake, *Caulerpa*, European green crab, mitten crab, New Zealand mudsnail, and ruffe). It has also approved 33 state and 3 interstate ANS management plans.

Research - responsible for identifying research needs and priorities, both short and long-term, and facilitating research planning and information sharing. This work includes developing a protocol for evaluating AIS research proposals.

Detection and monitoring - conducted a number of ecological surveys in several systems (e.g., Great Lakes, Cook Inlet, San Francisco Bay) in order to gather base-line data about the system and any AIS present.

Prevention - developed, in collaboration with the National Invasive Species Committee, a guide for identifying, assessing the risk of, and prioritizing invasions pathways. It also created a risk analysis process for generic AIS.
Communication, education, and outreach - developed two national campaigns that bring together multiple partners from within the government and the private sector to inform the public about preventing the spread of AIS via recreational activities (Stop Aquatic Hitchhikers!) and the aquarium and ornamental trade (Habitattitude).

To sum up, the Task Force has involved key federal agencies at the federal level and formed regional panels made up of key state agencies to facilitate coordination at the regional level. This two-level structure also helps coordination among the regions and between the regional and federal levels. Further, the Task Force created five committees, each of which focus on a critical aspect of AIS management and each of which has accomplished major projects in support of those aspects. Clearly, the Task Force is playing a significant role in coordinating national and regional AIS management.

Alternative pathway management (Purpose 3)
We assessed the success of NISA regarding alternative pathway management by examining how well the organizational framework of the Task Force and National Invasive Species Council facilitates identification of potential AIS pathways. We also took a closer look at the nine species mentioned by name in NISA to determine their likely pathways of introduction and whether NISA has any effect over those pathways.

The Task Force, in collaboration with the National Invasive Species Council, has developed a framework for government agencies to use in identifying potential pathways for invasion, assessing the risk they pose, and prioritizing their relative importance (Aquatic Nuisance Species Task Force and National Invasive Species Council 2007). This framework focuses on unintentional, human-mediated pathways and not on deliberate introductions. The framework provides general pathway charts that the individual agency can use as a starting point for its analysis and guides users in narrowing the list to those pathways related to the agency's mission. The analysis takes a first cut at prioritizing pathways by determining whether those pathways pose a threat to human health (Threat Level A), economic health (Threat Level B), and ecosystem health (Threat Level C). The second cut of the analysis prioritizes pathways based on the frequency and geographic scope of potential invasion events. The third step of the analysis lays out a questionnaire to be used as an expert elicitation tool to gather information from experts on the probabilities of introduction and establishment, the potential impacts, and the available mitigation tools. Ideally, this step would be done using a focus group rather than a single expert. This third step relies on semi-quantitative rankings and the experts' identifications of possible sources of uncertainty associated with each ranking (i.e., lack of expertise, biological unknowns, insufficient information).

Although this framework is designed to assess *unintentional* pathways of introduction, an analysis of the USGS Nonindigenous Aquatic Nuisance Species Database found that the most common methods of introduction for fish, reptiles, and amphibians listed involve *intentional* pathways: stocking, aquarium or pet releases, and bait releases (Fuller 2004). Additionally, of the nine species mentioned by name in NISA four were introduced via ballast water, two were brought in as aquarium plants, two were brought in as ornamental plants, and one was likely introduced via multiple pathways (Table 3-2).

Clearly, stocking and other intentional releases are critical pathways of introduction. The National Invasive Species Act and the Task Force, however, have no jurisdiction, authority, or enforcement power over these pathways. Fish stocking currently falls under the jurisdiction of the states rather than the federal government. The only jurisdiction the federal government currently has over these pathways is the ability to prohibit importation or release of those species listed as injurious under the Lacey Act. Such a narrow authority over these pathways limits NISA's ability to stop introductions.

The Task Force does attempt to influence intentional introductions via the ornamental and aquarium trades through two voluntary programs. Habitattitude (Habitattitude n.d) is a public awareness program sponsored by Task Force and the Pet Industry Joint Advisory Council and aimed at aquarium hobbyists, pond owners, and water gardeners. Another public awareness campaign, Stop Aquatic Hitchhikers! (Stop Aquatic Hitchhikers n.d.), is aimed at reducing AIS spread through recreation use, including bait release. State and federal agencies, tribal government, user groups, educational groups, and private industry are working together on this campaign. Both campaigns are aimed at education of target groups about the AIS problem and encouraging best management practices, especially advocating a cessation of species releases. There is evidence that public awareness is correlated with reduced spread of AIS (Jensen 2010), suggesting that these campaigns are having the intended impact even though they do not have legal authority.

The lack of authority of NISA over pathways of introduction other than ballast water appears to be one of the biggest weaknesses of the Act. Species of significant concern are entering the country via pathways over which federal agencies have little or no authority. Although the framework developed by the Task Force and the National Invasive Species Committee helps agencies determine which pathways are of greatest concern, agencies will not be able to make significant strides shutting down those pathways until they are granted the enforcement power to do so.

Understanding and reducing impacts of AIS (Purpose 4), especially zebra mussels (Purpose 5)

To address the impact of NISA on understanding and reducing impacts of AIS, especially zebra mussels, we searched published literature and government databases for information on the nine species mentioned by name in NISA. To determine whether the impacts of AIS have been reduced for the nine species named in NISA, we assessed 1) the effectiveness of currently used control tools and 2) the spread of the species:

1) *Control tool effectiveness*

Currently all the AIS named in the act, with the exception of zebra mussels, are controlled using physical removal methods and non-species specific pesticides (Table 3-3). These methods are labor intensive, expensive, and often require repeated treatments. Zebra mussel control, while having many more potential tools to choose from, also suffers from these limitations.

2) *Spread*

Eight of the nine species have continued to spread in the US with new sightings of Eurasian water milfoil, hydrilla, ruffe, water hyacinth, and zebra mussel occurring as recently as 2011 (United States Geological Survey n.d.). Brown mussel (*Perna perna*) has remained restricted to Texas, with its most recent documented sighting in 1995.

Our analysis used the presence of AIS in the USA and existing tools for reducing that presence as a proxy for "reducing impacts" and found that NISA has not had its intended effect (Table 3-3). It is worth noting that all these species were present in the US, often in multiple states, before being named in either the Nonindigenous Aquatic Nuisance Prevention and Control Act in 1990 or its reauthorization, NISA, in 1996 (Table 3-3). The continuation of AIS spread is not surprising given the lack of effective control tools and the lack of federal enforcement capabilities under NISA to control spread within the US.

An in-depth review of the current understanding of ecological and economic impacts of invasive species is beyond the scope of this paper. Exploring these issues would, and has, required papers focused solely on that topic (Fletcher et al. 1985, Mooney and Cleland 2001, Leung 2002, Pimentel et al. 2005, Eiswerth et al. 2005).

COMPARISON OF NISA'S PURPOSES WITH PRIORITIES OF NATURAL RESOURCE MANAGERS

Thirty-one natural resource managers participated in qualitative, semi-structured interviews. Interviewees were selected for their involvement in AIS management. We compared the purposes articulated in NISA with the priorities articulated by AIS managers for their own work (Chapter 2) and found a high degree of agreement between the high-level federal legislation and the on-the-ground priorities of managers at a variety of levels (Table 3-4). The information in Table 3-4 is in response to a question about interviewees' top three invasive species management priorities.

For the most part, priorities identified by managers receive at least some mention as a priority of NISA. The two categories of manager priorities that are not mentioned in NISA – improving existing legislation and acquiring sufficient funding – are issues that one would not expect to find addressed within a piece of legislation. This agreement signifies that the issues laid out by policy makers resonate with the on-the-ground realities of managers.

There is, however, a difference in emphasis between the priorities of NISA and those of AIS managers. NISA places a great deal of emphasis on prevention via ballast water management while managers thought more broadly about potential invasion pathways. In fact, when managers spoke about ballast water management the focus tended to be the need for more effective ballast water legislation. Also, managers placed a heavy emphasis on the importance of educational and outreach programs. Many felt that public understanding and support was key for any AIS management program to be effective. The National Invasive Species Act, on the other hand, has one brief mention of the need to establish and implement education programs. Finally, there is a significant amount of disagreement on the AIS of greatest concern between those identified by NISA and by managers. During interviews, when asked about AIS of greatest concern, managers listed 14 species (Table 3-5). Of these, only Eurasian water milfoill, hydrilla, and the zebra mussel were also mentioned in NISA. Also, with repeated mentions counted separately, the managers' list of species had 53 entries. Of those, Eurasian water milfoil was listed twice, hydrilla was listed twice, and zebra mussels were listed 13 times. Overall, this suggests that the species given priority by policy makers are not the same species that managers view as needing the most attention. It is beyond the scope of this analysis to determine whether the priorities of the managers or of the NISA are more appropriate. The mismatch between the two sets of priorities, however, points to disagreements or a lack of communication between those creating the policy and those tasked with carrying it out. Better understanding and increased agreement could allow for the creation of policy that is better aligned with on-the-ground realities of AIS management.

MANAGER PERSPECTIVES ON EXISTING LEGISLATION

Managers were asked which, if any, pieces of legislation or management plans were influential in their work (Table 3-6). Overall, legislation was listed somewhat more frequently than management plans (35 vs. 22 times), but both legislation and management plans seem to play an influential role in managers' work. When looking only at the influential legislation, state laws were mentioned slightly more frequently than NISA and both were mentioned far more frequently than the Lacey Act. Although NISA does not seem to have a great deal of influence in the management process, the appearance of influences increases when one considers that many of the state management plans were created with funding from NISA and that most of the national management plans referred to were created by the Task Force, itself created by NISA. It is also important to note that, in answering this question, two interviewees explained that access to funding had the most influence over their work and that, for the most part, funding came from the state government, not the federal.

Managers were also asked whether they had any suggestions for improving existing legislation. Five participants had no suggestions and eight participants felt that the most pressing need was improved funding rather than new legislation. However, managers did make 47 suggestions for improving AIS legislation falling into four broad categories: improving policies addressing key invasion pathways, streamlining legislation and making it more comprehensive, focus on national level control of AIS species once they are present, and improving enforcement (Table 3-7).

First, managers talked about the need for more comprehensive policies to address the principal invasion vectors. They wanted to see improved ballast water legislation – legislation that covered alternatives to ballast water exchanges, that covered NOBOB vessels, that was consistent across states, and that increased the stringency of ballast water management requirements. Managers also wanted the oversight of other invasion pathways to be more carefully legislated. Several managers talked about the need to pre-screen species before they are brought into the country to help reduce invasions via aquaculture and ornamental trades or intentional releases. These managers wanted to see a systematic, documented process for assessing imported species and listing them as allowed or prohibited. Finally, managers wanted legislation in place to assist in early detection and eradication attempts.

The need for more streamlined and comprehensive AIS legislation was also brought up frequently. Managers felt that current legislation led to overlapping and unclear authorities and felt that one comprehensive piece of legislation that addressed the AIS problem “holistically instead of piecemeal” and that designated one clear authority to take on the leadership position could help. Managers wanted to see legislation that not only coordinated the various agencies, but encouraged agencies to make AIS a priority. Finally, managers wanted to see legislation that would help encourage consistency across states. Aquatic invasive species are a problem with no respect for political borders and management of a region is only as strong as the state with the weakest legislation. Support from the federal level could help states deal with the problems resulting from this unevenness within a given region.

Managers also wanted to see legislation that focused on national level control efforts for AIS once they become established in the country. This included taking a national level approach to slowing the spread of invasive species and, more specifically, allowing for more stringent interdiction and quarantine laws.

Finally, managers felt it was important to improve enforcement of existing legislation and give existing and future legislation “more teeth” when it came to enforcing their requirements.

NISA REAUTHORIZATIONS

The National Invasive Species Act was due for reauthorization in 2002, but this has not yet been accomplished. Bills reauthorizing NISA were introduced in the House and Senate in 2003, 2005, and 2007, but Congress never voted on them.

The 2007 versions of the Senate bill (S. 725 and S. 791) include elements that address many of the concerns articulated by managers. These bills would have raised the standards for ballast water management, set up a screening process for planned importations of aquatic organisms, set up an early detection monitoring program of high priority pathways, and set up an emergency fund for rapid response efforts. These bills proposed actions to streamline federal level coordination. S. 791 names the National Invasive Species Council as the body tasked with coordinating all relevant groups, including the Task Force. Finally, these bills replaced much of the general language found in NISA with more specific goals and methods for achieving them. For example, while NISA has a brief reference to outreach and education, these bills called for posting of public warnings, clean watercraft requirements, and proper bait disposal requirements. In addition to improving the clarity of the policy-makers intent, this specificity could help achieve greater consistency between states.

Although these bills do show significant improvements, it is ultimately a moot point. They were never voted on and, as of 2012, no reauthorizations of NISA have been introduced since 2007.

DISCUSSION

Overall, it is clear that NISA was attempting to address the appropriate range of AIS issues: prevention, control of species once they arrive, and federal level coordination. The attempt, while making clear the importance of the AIS issue, fell short in almost every aspect.

Ballast water regulations in NISA were a good first step, but they are insufficient. Existing regulations have raised awareness of ballast water as an invasion pathway and nationwide compliance with reporting has increased while un-exchanged ballast water discharge in US waters has decreased. However, there has been a continued inflow of invasive species via vessels that are exempt from exchange requirements and from

NOBOB vessels, critical gaps that need to be addressed. The Act's impact on other invasion pathways is limited. Although it called for identification and management of those pathways, no specific pathways were mentioned in the legislation and no authority or enforcement ability was granted.

The Act does not seem to have had much of an impact on control of invasive species once they are present in the country. Spread continues after arrival, with no federal authority to control it, and control tools remain limited, leaving managers with few options. This aspect received limited attention in the Act and deserves to become more of a priority.

NISA has engendered extensive coordination. It has led to national (the Task Force), regional (Task Force regional panels), and state (Task Force approved state management plans) coordination. However, clearer leadership at the national level is needed. The dual existence of the National Invasive Species Council and the Task Force and the lack of a clear lead agency complicate coordination efforts. Further, there are currently no formal methods for helping achieve consistent regulations among states within the same region or watershed. Inconsistencies result in industry and public confusion, which can lead to decreased compliance, and a region's overall policies are only as strong as the weakest policies within it. An instrument encouraging and aiding consistency could help overcome these obstacles.

Finally, NISA only briefly mentions the idea of public outreach and education. This weakness seems especially critical given the importance that on-the-ground managers place on this element of AIS management. One of the managers interviewed felt that getting the public "on board" with AIS management goals was more important than anything Congress said or did.

The National Invasive Species Act is not having the results intended by Congress. This leads us to recommend a reframing of AIS policy that more closely aligns existing institutional mechanisms with the two prongs of AIS management: 1) preventing new invaders from arriving and 2) managing invasive species once they arrive. We propose that reauthorization of NISA should 1) grant lead authority over alternative pathways for AIS introduction especially those pathways associated with intentional introductions (e.g. stocking, aquarium trade) to a federal agency and 2) provide the Task Force with additional authority and resources to allow it to assist in regional coordination of control of established AIS.

The National Invasive Species Act has proved to be insufficient in preventing the arrival of new invaders. Our first proposal is to grant a federal agency the authority to regulate alternative pathways (i.e. pathways other than ballast water). Aquatic invasive species of significant concern are entering the country and spreading through pathways other than ballast water. These pathways include stocking programs, the aquarium and pet trade, and bait releases. Currently, the only federal authority over these pathways comes from the Lacey Act and is limited to those species specifically listed as prohibited under that Act. The current approach is clearly inadequate for preventing invasions via these pathways. One approach to this would be to expand EPA's management, under the Clean Water Act, to include other AIS pathways. This approach would take advantage of existing legal authority and enforcement power, obviating the need for entirely new legislation. The Clean Water Act includes "biological materials" as a form of pollution. A 2002 ruling, which was upheld in 2008 (Northwest Environmental Advocates), required the Clean Water Act to view escaped aquaculture fish as pollutants (Firestone and Barber 2003) and the recent ruling is explicit in including all AIS. This could allow the EPA to take a clear lead role in the prevention aspect of the problem. This approach, however, would require the EPA to become a member of the Task Force to ensure that the work being done by the EPA is coordinated with other aspects of AIS management as well as additional resources being allocated to the EPA to allow it to take on these additional responsibilities effectively.

Once invasive species are present in the USA, effective national and regional coordination becomes the most important tool in preventing further spread. Giving the Task Force the authority and the resources to facilitate creation of consistent regulatory policy within regions would allow it to improve the effectiveness of the coordination work it has already undertaken. For example, once a state has a management plan approved by the Task Force, the state receives financial support from the Task Force. This allows the Task Force to make sure these plans meet certain basic standards. Consistency in regional AIS regulations could be achieved if the Task Force had the resources to provide a similar financial incentive for states adhering to Task Force standards in their regulatory approach. As much of the movement of AIS occurs at the watershed level, the regional groups formed by the Task Force have the opportunity to play a critical role. Coordinating priorities within a region would allow for more effective communication with the public and for taking management actions on a scale consistent with watershed geographies rather than political boundaries.

The issue of control should also be addressed through serious investment in control methodologies. Currently, available tools require repeated investments of time and money and are only capable of small-scale eradications (Schwartz 1986, Marking 1992, Verrill and Berry 1995). Given that multiple jurisdictions are struggling with the same species, combining their ability to invest in new technology would allow for more effective leveraging of limited resources. Government funding agencies, philanthropic organizations, the private sector, and research institutions could collaborate to support a national endeavor to identify and fund priority research and development of control measures. This could be modeled on public health efforts, such as was done to successfully eradicate polio (Quadros et al. 1992).

The two prongs of AIS management could also benefit from decision support tools (i.e., an information based system that helps provide a systematic decision-making framework). On the prevention side, screening tools could help determine which species are of most concern and risk analysis tools, building on the framework developed by the Task Force and the National Invasive Species Committee, could help determine which pathways pose the greatest risk and, therefore, need to be monitored more meticulously. Such a decision support tool could help identify key areas for monitoring for new arrivals or where control efforts would have the greatest impact. Interviews with managers suggest they would find decision support tools to be useful in multiple aspects of AIS management (Chapter 2).

All of these approaches would be aided by increased funding. As it is unlikely that natural resource management budgets will see significant increases, we suggest integrating AIS management into broader environmental goals in order to see multiple benefits from every action and expenditure. This would include a more holistic approach within the field of AIS management (i.e. focusing on actions that could mitigate the impact of multiple species) as well as connecting AIS issues to a broader set of environmental management goals (i.e. improving ecosystem health to reduce invasibility). Consolidating and streamlining leadership would allow the many players in AIS management to work together and take advantage of limited resources more effectively.

CONCLUSION

The National Invasive Species act was an important evolutionary step in AIS policy instruments but there is room for significant improvement. This analysis and the perspectives of AIS managers at various levels identify key gaps in the current legislation: insufficient regulation of invasion pathways, the need for clearer leadership and more streamlined use of limited resources, and a greater focus on control of AIS once they are present. We suggest an approach that could address these issues: designating federal authority for managing alternate invasion pathways and giving the Task Force and its regional panels the resources and the authority to further improve coordination of control policies. This approach would build on existing agencies and authorities and better use limited resources.

Table 3-1. Federal policy instruments for oversight of AIS and the responsible departments, agencies, and programs.

Federal Policy Instruments	Department/Agency/Program
Lacey Act (1900)	US Department of Interior
Federal Insecticide, Fungicide, and Rodenticide Act (1947)	US Environmental Protection Agency
Convention on Great Lakes Fisheries between the US and Canada (1955)	Great Lakes Fisheries Commission
National Environmental Policy Act (1970)	All Departments and Agencies
Endangered Species Act (1973)	US Department of Interior – Fish and Wildlife Service US Department of Commerce – National Oceanic and Atmospheric Administration
Nonindigenous Aquatic Nuisance Prevention and Control Act (1990)	US Department of Interior – Fish and Wildlife Service US Department of Transportation – Coast Guard US Environmental Protection Agency US Department of Defense – Army Corps of Engineers US Department of Commerce – National Oceanic and Atmospheric Administration Aquatic Nuisance Species Task Force Great Lakes Panel on Aquatic Nuisance Species
Alien Species Prevention and Enforcement Act (1992)	US Department of Agriculture US Department of Interior - Postal Service
North American Agreement on Environmental Cooperation (1994)	Council of the Commission on Environmental Cooperation[11]
Agreement on the Application of Sanitary and Phytosanitary Measures (1995)	US Department of Agriculture
National Invasive Species Act (1996)	US Department of Interior – Fish and Wildlife Service US Department of Transportation – Coast Guard US Environmental Protection Agency US Department of Defense – Army Corps of Engineers US Department of Commerce - NOAA
Water Resources Development Act (1999)	US Department of Defense – Army Corps of Engineers
Executive Order 13112 (1999)	National Invasive Species Council

[11] This is a tri-national entity established by the US, Canada, and Mexico.

Great Lakes Fish and Wildlife Restoration Act (2006)	US Department of Interior – Fish and Wildlife Service
Water Resources Development Act (2007)	US Department of Defense – Army Corps of Engineers

Table 3-2. Method of introduction for species that are named in NISA.
All information from this table comes from the USGS NAS Database (United States Geological Survey n.d.)

Species	**Method of introduction**
Brown mussel	Ballast water
Green crab	Multiple pathways
Eurasian water milfoil	Ornamental plant
Hydrilla	Aquarium plant
Chinese mitten crab	Ballast water; possibly intentional release
Ruffe	Ballast water
Water chestnut	Aquarium plant
Water hyacinth	Ornamental plant
Zebra mussel	Ballast water

Table 3-3. AIS species named in NISA: impacts and control tools.
All information from this table comes from the USGS NAS Database (United States Geological Survey n.d.) except where noted

Species	**Control tools**	**Spread across US (State first documented in: year of first documentation: number of states currently found in)**
Brown mussel	Physical removal, chemical control (Rajagopal et al. 2003, Barataria-Terrebonne National Estuary Program n.d.)	TX: 1990: 1
Green crab	Physical removal – trapping and barriers, biological control being researched	MA: 1833: 13
Eurasian water milfoil	Physical removal, herbicides, biocontrol being researched	VA: 1881: 46 (and DC)
Hydrilla	Physical removal, herbicides, biocontrol using grass carp (another problematic invasive)	FL: 1953: 29
Chinese mitten crab	Physical removal – trapping and barriers	OH: 1975: 8
Ruffe	Physical removal, rotenone	MN: 1986: 3
Water chestnut	Physical removal, herbicides, biocontrol being researched	MA: 1859: 11 (and DC)
Water hyacinth	Physical removal, herbicides, biocontrol only minimally successful	LA: 1884: 27
Zebra mussel	Chemical molluscicides, manual removal, desiccation, thermal, acoustical vibration, electrical current, barriers, coatings, toxic piping, CO2 injections, UV light, anoxia, hypoxia, flushing, biological control	OH, MI: 1988: 30

Table 3-4. Comparison of NISA and manager priorities; n denotes number of mentions during interviews.

Manager Priority	Associated NISA Purpose
Developing and carrying out management plans and programs (n=19)	Developing a national plan Procedure for creating state plans
Prevention of new introductions (n=15)	Ballast water regulations Identifying and managing alternative pathways
Containing existing introductions and preventing spread (n=9)	Detecting introductions and dispersal Managing invasions when necessary
Developing improved legislation and regulations (n=8)	n/a
Facilitating coordination between responsible groups and agencies (n=8)	Aquatic Nuisance Species Task Force Regional Task Force panels
Outreach and education efforts (n=6)	Establish and implement educational programs
Research and development, especially that of new control tools (n=6)	Exploratory studies and additional research
Reduction of AIS impacts (n=4)	Understanding and reducing AIS impacts
Acquiring sufficient funding (n=2)	n/a

Table 3-5. Aquatic invasive species of concern mentioned by managers during interviews. Asterisk denotes species mentioned in NISA.

Species of Concern	Number of Mentions
Alewife	1
Asian carp	9
Brittle naiad	1
Common carp	1
Curly leaf pondweed	1
*Eurasian water milfoil	2
*Hydrilla	2
Kudzu	1
New Zealand mudsnail	3
Quagga mussel	11
Sea lamprey	2
Snakehead	2
Viral hemorrhagic septicemia (VHS)	4
*Zebra mussel	13

Table 3-6. Legislation and management plans that managers mentioned as being influential.

Legislation/Management plan	**Number of Mentions**
State laws	12
NISA	9
Agency management plans	8
State management plans	8
Lacey Act	5
National management plans	5
Clean Water Act	2
Endangered Species Act	2
Convention on Great Lakes Fisheries	2
Executive Order 13112	1
Clean Air Act	1
Regional management plans	1
Federal Aid in Sport Fish Restoration Act	1

Table 3-7. Suggested improvements for existing AIS legislation mentioned by managers during interviews.

Improvement	**Number of Mentions**
Creating comprehensive policies to address principal invasion vectors	*23*
Improved ballast water legislation (unintentional)	9
Pre-importation screening of species and carriers (intentional)	8
Rapid response and eradication	2
Streamlined, comprehensive AIS legislation	*14*
Encompassing all AIS issues	5
Designating clear leadership and authority	4
Emphasizing agency coordination	3
Aiding consistency across states	2
National level control of AIS once they are present	8
Improving enforcement	2

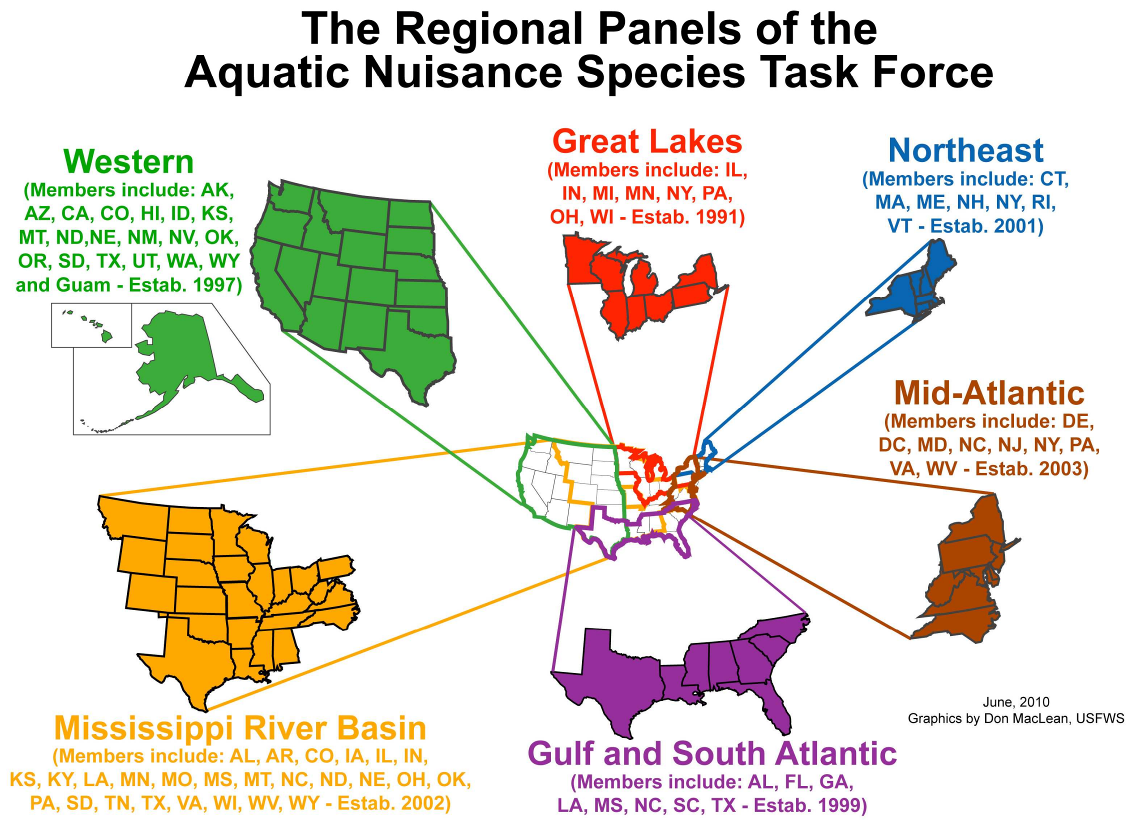

Figure 3-1. Regional panels of the Aquatic Nuisance Species Task Force. Taken from the Aquatic Nuisance Species Task Force website.

CONCLUSION: A Decision Support Tool Blueprint for Aquatic Invasive Species Management

INTRODUCTION

Currently, invasive species management tends to be conducted on a case-by-case basis and in crisis mode. Tempel et al. (2004) found that invasive animals were present in all USA wilderness areas but only 15% of the areas surveyed in the continental USA had management plans for dealing with them. Inadequate funds and personnel were the reasons most often given for the absence of management plans. There are clearly gaps between discovering the presence of invasives, determining that they are a problem, and taking steps to do something about them. This method of management is a labor, time, and money consuming process. This is especially unfortunate because the field of invasive species management often calls for quick decisions on limited budgets.

Another obstacle for invasive species managers is the sheer magnitude of the problem. Effective invasive species management requires a great deal of work on a number of fronts. For example, The National Strategy and Implementation Plan for Invasive Species Management (2004), recommends 19 separate and distinct short-term actions tied to prevention, early detection and rapid response, control and management, and rehabilitation and restoration as well as 11 additional overarching goals. Attempting to achieve the priorities outlined in that single plan would be daunting enough, but to this we must add all of the other priorities outlined in other legislation, policy recommendations, and management plans.

There is no shortage of policy instruments aimed at addressing management and control of AIS. At the federal level alone, there are 14 separate policy instruments (11 acts, 2 agreements, and 1 executive order) (Chapter 3). These policies are the responsibility of nine previously existing federal departments and agencies and also motivated the creation of five additional interagency groups (Great Lakes Fisheries Commission, Aquatic Nuisance Species Task Force, Great Lakes Panel on Aquatic Nuisance Species, Council of the Commission on Environmental Cooperation, National Invasive Species Council). These interagency groups have since released additional policy instruments in the form of management plans and programs. Further, additional agencies, not specifically called on in the legislation, have joined in the fight against invasive species: the US Geological Survey has created a Nonindigenous Aquatic Species information resource and NOAA has formed the National Center for Research on Aquatic Invasive Species.

Invasive species managers are dealing with multiple priorities, agencies, and jurisdictions. Decisions they make must also take into account the ecological, economic, and social issues. In this paper I lay out the justification for developing a decision support tool (DST) to aid in aquatic invasive species (AIS) management, explore how the results of my previous chapters inform creation of a DST that is trusted by stakeholders, useful to managers, and consistent with current policy instruments. My results support the development of a DST that helps users prioritize where in a given geographic area management actions (i.e., monitoring, inspections, or control efforts) should take place.

DECISION SUPPORT TOOLS

Decision-making by natural resource managers is especially difficult because these decisions involve complex ecological issues as well as social, economic, and political considerations. In the 1970s researchers began to develop the idea of decision support systems. This idea came out of two areas of research: organizational decision-making and interactive computer systems (Keen 1978). Decision support tools are especially useful for natural resource management decisions because they allow integration and simultaneous viewing of information from different sources, they set transparent standards for evaluation, and they provide users with a simple and powerful way to communicate their findings (Fedra 1995).

Managers and researchers have already developed multiple decision support tools for use in invasive species management. These tools can be divided into three categories: highly specific, broadly applicable, and management focused.

Highly specific tools have been designed for managing one species in a fairly narrow context. For example, the Yield Loss Prediction Tool for Field-Specific Risk Management of Asian Soybean Rust (University of Kentucky 2009) addresses only one issue for farmers: whether it is financially worth their while to control for soybean rust on their fields. Although these tools are useful in their specific context, they cannot be expanded to make decisions in different situations. Broadly applicable tools bring together a large amount of information, synthesize it, and make recommendations as to which tools are available and most effective. One example of this type is the report issued by the Global Invasive Species Programme, *How to Address One of the Greatest Threats to Biodiversity: A Toolkit of Best Prevention and Management Practices* (Wittenber and Cock 2001). These documents summarize information in order to make broad recommendations, but they are more helpful for setting policy and other higher-level decisions. Such broad tools fail to provide meaningful on-the-ground advice to managers.

The third type of tool is one that assists managers in making a complex decision in a number of different contexts. For example, Cacho et al. (2004) designed a model to help managers decide whether a weed invasion should be eradicated, contained, or not managed at all. This model applies to multiple species and takes into account economic as well as ecological considerations. Unfortunately, these tools are often released as a static product, making it difficult for users to manipulate them in ways that would make them more useful for their particular needs. These tools can also be ‘black boxes’ leaving users with little understanding of how the inputs relate to the decision recommendations.

DECISION SUPPORT TOOL BUILDING BLOCKS

My research focused on collecting the information needed to design management-focused DST for AIS management. Information on stakeholder perspectives was collected in a series of focus groups around the Great Lakes and Lake Champlain (Chapter 1). Information on manager motivations and priorities was collected from qualitative, semi-structured interviews with natural resource managers in the Mississippi River Basin

(Chapter 2). Finally, an analysis of the National Invasive Species Act provided information on legislative mandates, weaknesses, and opportunities (Chapter 3).

Stakeholder perspectives (Chapter 1)

The focus groups on genetic biocontrol of AIS also provide valuable information for design of a DST. Public pressure can play a significant role in AIS decisions. If the design of a DST takes into account stakeholders priorities and concerns it is more likely that stakeholders will trust the resulting tool and respect the decisions resulting from its use.

Focus groups made several recommendations that provide useful guidelines for other AIS management decisions in general. These include:

- First, do no harm – AIS management is an already frustrating situation, stakeholders want to make sure management actions will not cause additional problems and that limited funds are spent reducing problems rather than increasing them.
- Engage multiple viewpoints – Involving stakeholders early and often will allow the resulting decisions to better reflect their needs and values.
- Employ clear go/no-go reasoning – Using a framework that lays out the logic of the decisions improves their defensibility and acceptability especially if the decision or its results are not what the public wanted.
- Use a transparent process – A transparent process would encourage stakeholder participation as well as facilitate communication of decisions and their rationale.

Focus group participants raised three concerns important in DST development: ecological impacts, financial concerns, and uncertainty. First, participants were concerned about adverse non-target impacts of genetic biocontrol technology. These impacts, especially those related to impacts on other species and human health, should be considered in all AIS decisions and should be addressed in a DST. Second, participants were aware of the limited resources available for AIS management and research. They felt that, whenever possible, cost-benefit analyses should be done to help ensure those limited funds are spent as effectively as possible. Linking action costs with outcomes could be an important part of a DST. Finally, uncertainty was one of the prominent themes during the focus groups. Decision support tools should have explicit mechanisms for identifying and addressing sources of uncertainty in the decision-making process.

Policy analysis (Chapter 3)

The analysis of the National Invasive Species Act was intended to examine its goals, its methods for achieving those goals, and whether it has been successful. This analysis led to the recommendation that lead authority to prevent new introductions via pathways other than ballast water should be granted to a federal agency, potentially the U.S. Environmental Protection Agency under the Clean Water Act. We also proposed that the Aquatic Nuisance Species Task Force be granted additional authority and resources to allow it to further increase regional coordination of control and containment efforts of populations for AIS that are already established in the USA. These task forces have demonstrated the ability to coordinate the various agencies and jurisdictions involved in AIS management. Developing for them a DST that would explicitly focus on prioritizing actions across a watershed could help improve this coordination. A tool that helps determine where in a watershed certain actions should be focused could provide these groups with support for further coordination or consolidation of resources. Given that AIS spread shows no respect for political jurisdictions, a tool that is organized by geographical boundaries rather than political ones could further improve coordination efforts.

Manager perspectives (Chapter 2)

The manager interviews were designed to determine the priorities and concerns driving manager actions and decisions, elicit manager perspectives on the strengths and weaknesses of the current decision-making process, and identify potential roles for a DST in their work. Results should inform the design of a tool that directly responds to the needs of AIS managers. They also can aid in determining what data should be included in a DST and what characteristics the DST should have.

Managers identified their top priorities in the field of AIS management (Table 2-1). Prevention of spread, containment of existing AIS populations, and coordination between concerned agencies and stakeholders ranked relatively highly on the range of issues managers were attempting to address (Table 2-2). Interestingly, these priorities are the same ones as our policy analysis (Chapter 3) identified as opportunities for improving the desired outcomes of the National Invasive Species Act.

Managers also identified the ecosystem services they were most concerned with protecting (Table C-1). These services, or a proxy for them, should be part of the decision-making process. A DST should consider how best to protect these ecosystem services as well as how management actions could affect them.

Managers indicated that the strengths of the current decision-making process are

- the diverse and knowledgeable agency staff involved in AIS management,
- their ability to communicate with the general public, and
- the coordination between agencies and other interested parties.

They indicated that the weaknesses of the current process are

- unclear leadership and overlapping jurisdictions,
- insufficient information,
- a process that is too time-consuming,
- a lack of documentation, and
- insufficient capacity to adapt to changing conditions.

Removing these weaknesses would overlap with several key principles of robust decision-making: transparency, documentation, adaptive to changing conditions and information, flexible but structured and consistent. Managers' recognition of these gaps with respect to robust decision-making was indicated by their identification of DST characteristics they would find valuable. These include:

- easily understood and communicated,
- transparent,
- inclusion of a knowledge repository,

- flexibility,
- consistency and repeatability,
- documentable,
- efficient,
- spatially explicit, and
- explicitly deals with uncertainty

In summary managers are clearly aware that their current decision-making processes lack important characteristics and see the use of a DST as way to incorporate them. It is worth noting that many of the concerns identified by stakeholders in Chapter 1 (e.g., documented and transparent decisions, the need to address uncertainty) are also important to managers. This indicates that these issues are critical and should be included in any AIS decision support tool.

Finally, managers identified that a DST would strengthen their ability to address multiple aspects of AIS management (Table C-2).

DECISION SUPPORT TOOL BLUEPRINT

We suggest a spatially explicit tool that allows managers to determine where, in a given geographical area, to take specific management actions (i.e., monitoring, inspections, control efforts). This will be accomplished by linking Geographic Information Systems (GIS) data with an expert system. GIS is a computer system for "capturing, managing, analyzing, and displaying all forms of geographically referenced information" (ESRI n.d.). Using this approach will allow the DST to be spatially explicit and view management actions within the context of an entire watershed or management area. Expert systems are computer programs designed to provide the decision-making ability of an expert (Jackson 1998). They use a dialog interface to prompt users to answer questions. The answers to these questions are then incorporated into the system's knowledge base and then the system uses an inference engine to reason with the rules and produce an 'expert' recommendation. The expert system would allow incorporation of user priorities and information that cannot be expressed spatially. Combining information from the GIS and the expert system will lead to outputs consisting of the identification of areas important for monitoring, inspections, and control efforts (Figure C-1). Finally, our DST will include a multi-criteria ranking technique to help prioritize between the areas identified, should the number of areas identified exceed the number of actions that can be taken with available resources. The technique proposed in this framework is known as the SMART technique (simple multi-attribute rating techniques) (Ralls and Starfield 1995).

The focus of this tool was chosen to aid managers in their attempt to prevent the spread of invasive species within their management areas and contain or reduce populations of invasive species already established. The envisioned DST will provide the clear, logical, and transparent process that is important to both stakeholders and managers. The GIS layers will also function as an information storehouse. That is, much of the required information will not need to be reassembled for each decision, thus improving the efficiency and speed of decision-making. Inclusion of the expert system allows the tool to take advantage of the knowledge of experienced managers. Finally, SMART is a technique that allows the DST to incorporate a participatory element. This tool will result in documented decisions that provide guidance and assist in prioritization.

GIS layers incorporated in the tool will be chosen to represent:

- the ecosystem services managers wish to protect – for example, information about recreational opportunities (e.g., boat access points), commercial and industrial services (e.g., location of power plants, areas important for commercial fisheries), and information about game species distributions;
- information about AIS species of concern – for example, current distributions and potential habitat;
- information about management and legal jurisdictions – for example, information about political borders and areas of responsibility for involved agencies; and
- information about potential AIS pathways and connections – for example, include information about natural (e.g., streams and waterways) and human mediated (e.g., shipping and high traffic routes) pathways.

The expert system will contain three sets of questions:

- questions that allow managers to assign relative weights to the GIS elements;
- questions to elicit area-specific information that cannot be expressed geographically (e.g., whether AIS is interfering with recreation, the economic value of AIS threatened activities);
- and questions that elicit action-specific information (e.g., the cost of various management actions, whether the actions would be politically or logistically feasible).

The information from the expert system will be combined with the information from the GIS layers and, together, will produce a GIS layer that identifies areas important for monitoring, inspections, and control efforts. The next step, when appropriate, would be to use the SMART technique to prioritize among areas. A user would take all identified areas and rank them from most to least desirable for a number of criteria (e.g. public response, cost, effectiveness), which have previously been weighted by their relative importance. The output from this weighted ranking will allow managers to see which outcome best fits their priorities. Appendix J walks through an example using the SMART technique. This technique has a number of benefits. It allows explicit consideration of issues that cannot be modeled numerically or compared directly. It also allows managers working in different areas to alter the relative weights of the different criteria to suit their particular management situation, making a single model widely applicable. Users can manipulate the relative weights of the criteria during a single decision making process in order to evaluate the robustness of the top ranked outcome. Finally, working through the SMART process can be done in a participatory fashion, involving representatives from various stakeholders groups. This allows stakeholders a voice in the process and a clear way to view how their priorities influenced the final decision.

BASIC DESIGN OF DECISION SUPPORT TOOL

Below, I present the basic design and highly simplified illustrative sample of the DST described above. The tool is designed to guide the user through a four-step process. Step 1 is a purely GIS based step in which multiple GIS layers are used to begin to identify high priority sites. Step 2 adds a series of 'expert questions' which link to the GIS layers in order help managers to further prioritize those sites. Step 3 is another series of 'expert questions' to help managers determine which type of management action is most appropriate for a given site. Finally, if managers need additional help further prioritizing those sites, I have outlined an optional step 4 for how to do so with SMART, an existing multi-attribute ranking technique.

In this simplified, example version of the DST, I have used randomly generated numbers to stand in for real GIS layers and a smaller set of GIS layers and questions than would be used in a working version of the DST.

GIS Based Step (Step 1)

The first step of the DST is the GIS based step (Figures C-2 – C-5).

In this example tool, most data layer pixels are filled in with random numbers. This provided an unbiased way of generating hypothetical layers. Readers should beware, however, that these numbers may not make sense for a real environmental context; for instance, the random number generator approach led to the placement of power plants (with heated effluent plumes that provide habitat for some AIS) on approximately half of the management area pixels. Two layers, human pathways and natural pathways, were not generated through random numbers in order that the 'pathways' in these layers could be connected and discrete in the simplified tool. The layer depicting the use level of the pathways uses random number generators within the pathway pixels and zeros for all non-pathway pixels.

For the GIS based step of the example tool, GIS information is used to fill three sets of data needs and create three intermediate GIS data matrices:

1) Current spread of AIS (Figure C-2) – In a real tool, this would be created using GIS layers of the species distribution of the AIS in the management area. The example version presented here does not contain multiple species-specific GIS layers. Instead, there is a single layer in which each pixel has a value of 0 (multiple AIS present), 1 (a single AIS present), or 2 (no AIS present). In a real version of this tool, a set of GIS layers, with each one depicting the distribution of a different AIS within the management area, could be combined to accurately reflect the number of AIS present in each pixel. When using real GIS layers, users should remember to calibrate the data matrix for this step in such a way that the highest value is given to un-invaded pixels, with the value of the pixel decreasing as the number of AIS present increases.

2) Current state of the management area (Figure C-3) – This data set is used to produce a GIS data matrix of key environmental attributes of the management area, as identified by natural resource managers, and key landmarks within the area. In the example version, the key manager attributes include biodiversity, water quality, and game species abundance; and landmarks include boat access points and power plants, which have heated effluent plumes that provide suitable habitat for some AIS. For biodiversity, water quality, and game species abundance each pixel is given a value of 0 (for the least desirable state) to 5 (for the most desirable state). For boat access points and power plants, both locations prone to being negatively impacted by AIS, each pixel is given a value of 0 (indicating absence) or 1 (indicating presence). Together these layers are summed to give an overall value to each pixel with higher values indicating pixels that are more valuable candidates for possible AIS management (i.e. have higher biodiversity, higher water quality, with a boat access point or power plant).

3) Connectivity within the management area (Figure C-4) – This data set is used to produce a data matrix giving information about natural and human pathways for

invasion within the management area. In the example tool, there are two GIS layers in which the presence of human mediated pathways (e.g shipping and other watercraft traffic routes) and natural pathways (e.g. streams and other waterways) is indicated by a 1 and the absence is indicated by a 0. A third GIS layer indicates the level of human use of these pathways with 0 indicating no use due to no presence of pathway and 5 indicating high use.

In the GIS step of the DST, the data matrices produced by each of these sets of data are summed into a single Step 1 data matrix (C-5).

In the example tool, in lieu of real data, random numbers were used to simulate GIS layers, which allowed me to directly sum the GIS layers to create the AIS, state of the area, and connectivity of the area data matrices as well as directly sum those three matrices into a single Step 1 data matrix. When creating these matrices for a real version of the tool, quantitative values for these layers will be available. These values could be used instead of the presence/absence metrics and rankings shown in this example tool. In developing a tool that uses quantitative data, the developer will need to build-in two weighting steps (neither of which were included in this example tool):

- When combining GIS layers into each of the three intermediate data matrices (AIS, state, connectivity) it will be necessary to make sure the quantitative data are weighted properly, so that each layer carries equal weight in the final matrix. For example, the matrix on state of the management area involves GIS layers of very different kinds of data---biodiversity, water quality, and game species abundance. The value scales for each GIS layer should be calibrated so that each layer contributes equally to the final data matrix.
- After generation of the three intermediate data matrices, it will be necessary to properly weight the three matrices relative to one another, so that each carries the same amount of influence over the pixels in the final Step 1 data matrix. If left un-weighted, intermediate matrices that result from many combined layers (e.g. state of the management area) could have a greater influence over the final Step 1 matrix than an intermediate matrix with fewer layers (e.g. spread of AIS).

Expert System Questions Influencing the GIS Step (Step 2)

The next step of the DST is a series of questions designed to 1) include additional information in the final Step 1 data matrix that would not be represented in GIS layers and 2) assign weights to the GIS layers in the previous step so that they reflect the priorities of decision makers actually using the tool (Figures C-6 – C-9).

1) To include additional information that is not captured in the GIS layers, users can create additional GIS layers to capture additional information. This information will be added to the Step 1 matrix and retained within the DST as information for future decisions.

   The layers that users can create include:

   - Where are AIS interfering with recreational opportunities? Rank these areas 1 (slightly) through 3 (significantly).
   - Where are AIS interfering with commercial fishing opportunities? Rank these areas 1 (slightly) through 3 (significantly).
   - Where are AIS interfering with power plant or other industry functioning? Rank these areas 1 (slightly) through 3 (significantly).
   - Identify any areas where your agency would be unable to access or have difficulty accessing in order to take management actions. Rank these areas 1 (some access difficulty) to 3 (unable to access).

When using real, quantitative data from GIS layers to create the Step 1 matrix, the values used in the above rankings should be on a scale appropriate for the range of values in the pixels in that matrix.

In this example version, a fictitious fisheries manager only added one additional layer (Where are AIS interfering with recreational opportunities?). Her priority areas for protecting recreational opportunities are represented through increasing the value of the pixels in those areas from 1 to 3, depending on the severity of the AIS problem in that pixel (Figure C-6).

2) Users will also answer questions to help assign weights to the GIS layers (produced in the first step of the decision support tool) relative to one another.

   Questions of this sort include:

   - Which is a higher priority: preventing any invasions into currently un-invaded waterbodies or control the level of invasions in high quality areas?

     The answer to this question results in a new layer that will be added to the final Step 1 data matrix. If the user wants to prioritize un-invaded areas, those pixels will be given increased value in the GIS layer. If the user wants to prioritize high quality areas, those pixels with high values for biodiversity, water quality, and game species abundance will be given increased value in the GIS layer.

     In this example version, our fictitious fisheries manager indicated her priority was preventing invasions into currently un-invaded areas. The priority was reflected by increasing the value of all un-invaded pixels in the intermediate matrix representing the current spread of AIS (Figure C-2) by 5, an arbitrary value (Figure C-7). In a real DST, decision-makers would come to a consensus regarding how much weight to assign to this and other preferences.

   - What is the relative importance of reducing AIS impacts on recreation, industry, and ecosystem health? Assign percentages to each (summing to 100%).

These percentages will be used to assign relative weights to the GIS layers making up the data matrix of the current state of the management area. The percentage assigned to recreation determines the weight assigned to the layers of game species abundance and boat access points. The percentage assigned to industry determines the weight assigned to the layer of power plant locations. The percentage assigned to ecosystem health determines the weight assigned to the layers of biodiversity and water quality.

In this example version, our fictitious fisheries manager gave recreation a weight of 50%, gave industry a weight of 20%, and gave ecosystem health a weight of 30%. These preferences were incorporated in the data matrix, by adjusting the relative weights of the GIS layers making up the intermediate matrix that represents the current state of the ecosystem (Figure C-3). In order to reflect the recreation weight of 50%, the GIS layers for game species abundance and boat access points were each increased by 25% when being summed for the area information data matrix. To reflect the industry weight of 20%, the GIS layers for power plants was increased by 20%. To reflect the ecosystem health weight of 30%, the GIS layers for biodiversity and water quality were each increased 15% (Figure C-8). A real DST should be designed to allow users to manipulate the weights of all GIS layers in order to accurately reflect their relative importance.

It is worth reemphasizing the importance of making sure all GIS layers within an intermediate matrix and the intermediate matrices themselves are equally weighted at the end of Step 1. Equal weighting at the end of Step 1 means that the manager priorities expressed in Step 2 are appropriately influential. At the end of Step 2, users will have a weighted version of the final Step 1 data matrix with pixel values now increased to reflect the priorities of managers. The example matrix (Figure C-9) now reflects the priorities of our fictitious fisheries manager.

Expert System Questions For Selecting Final Areas for Management Actions (Step 3)

Once the first and second steps of the DST have identified the pixels that are high priority for management actions, the third step of the DST is a series of questions to help users determine what type of management action (i.e. monitoring, quarantine, or control effort) is best suited to each high priority pixel. Quarantine refers to any action oriented towards preventing spread of AIS from that location (e.g. shutting down a boat launch location or restricting access to a site). Control effort refers to any action oriented towards reducing the population of AIS at that location (e.g. physical removal or the use of chemical control options).

Responses to these questions and the relationships between them, and therefore the action recommended by the DST, will be determined by the specifics of the management area and the capabilities of the agency using the DST. Below are some general examples:

- For a high priority pixel without any AIS present, if the user answered 'yes' to the question "Have pathways into the pixel been identified?" and 'yes' to the question "Are identified pathways controllable?," the expert system would likely recommend monitoring.
- For a high priority pixel with AIS present, if the user answered 'yes' to the question "Have pathways out of the pixel been identified?" and 'yes' to the question "Are identified pathways controllable?" and 'no' to the question "Are control tools available for the AIS present?," the expert system would likely recommend quarantine.
- For a high priority pixel with AIS present, if the user answered 'yes' to the questions "Are control tools available for the AIS present?" and 'yes' to a question about whether a control action is affordable (the level at which a control action becomes too expensive to be feasible would be determined through consultation with the users), the expert system would likely recommend control.

When creating the list of questions that will be a part of the expert system, knowledge and understanding of the management area will be crucial. Many of the questions used will likely be questions that managers already ask themselves when making these decisions. This tool will help formalize the process and make explicit the relationships among the questions. Over time, this will allow managers to have a clearer understanding of how their answers to these questions relate to the each other, the management actions taken, and the results of those actions.

SMART System for Final Prioritization (Step 4)

At the end of this process, if the number of high priority pixels identified for management actions is greater than the number of areas within which managers can afford to take actions, users can use a Single Multi-Attribute Ranking Technique (SMART) process to determine which management actions should be taken in a prioritized smaller number of areas.

To do this, users should identify the criteria that are their highest priorities and will have the most influence on their decision making process. Many of these criteria will have been made explicit during earlier portions of the DST. Once those criteria have been identified users will have to predict the extent to which management actions taken at each of these sites will meet these criteria. A general description of SMART can be found in Appendix J.

CONCLUSION

This approach addresses many of the needs identified by managers and stakeholders. First, this design allows the DST to act as an information repository. GIS data can be added and updated as more is collected, other improvements in understanding are reflected in improving the logic of the expert system (something that can be done without computer experts as the programming of the expert system relies on logical "if… then" statements rather than specialized programming languages) and in improving the answers users provide to the expert system (something that requires no reprogramming at all).

This means that the tool would be adaptive without requiring laborious upkeep. Further, the tool could be freely available to users, for example, via the Internet. It could also be an open-source tool, allowing interested parties to produce additional versions of the DST tailored to their circumstances.

This design also helps improve the documentation and traceability of decisions made with it. Each use of the tool could generate a digital-file or paper trail documenting the decision and the priorities influencing can be created by saving and printing the GIS layers, answers to the expert system questions, and the intermediate, final, and weighted GIS maps. This will allow managers to recreate past decisions and even rerun decision-making processes in the light of new evidence. Both of these actions will allow managers to take a more adaptive approach to their AIS decision-making. Interviews with managers found that the current decision-making process does not facilitate incorporation of the results of previous decisions into subsequent decisions (Chapter 2), a major obstacle for the actual practice of adaptive management. Because the logic behind every decision reached with the DST is stored, the time and effort required to accurately and transparently incorporate results of previous decisions into the information evaluated to make subsequent decisions will be dramatically reduced. In addition, managers will be able to theoretically rerun decisions made in the past, which did not have the intended outcome, in order to determine which elements of the decision-making process could have led to a different decision. Such uses of a DST offer the potential to transform AIS management by dismantling existing barriers to practicing adaptive management.

Another advantage to this DST is that it can be created and maintained with limited specialized knowledge. Basic GIS skills will be needed to both use and update the tool, but little other specialized knowledge would be necessary. Although it would be valuable to engage someone skilled in decision support and expert systems in creating the initial version of the DST, typical natural resource managers could maintain and update this tool in-house due to the low level of technical knowledge required for these tasks. This has two significant advantages: 1) few resources would need to be devoted to the technical aspects of tool maintenance, and 2) managers involved in its use and upkeep could be those managers most familiar with the management area, which will help keep the information in the tool up to date and reflecting the best current understanding of the management ecosystem.

This design takes advantage of existing strengths (i.e., knowledgeable managers, relationships with other agencies and stakeholders) and existing information (i.e., GIS layers already in existence) and helps to address weaknesses (i.e., clarify jurisdictions, document decisions, implement a consistent but adaptive decision process). Finally, this approach helps improve robustness of decisions by incorporating principles of robust decision making that are currently inadequately represented in the AIS decision-making process.

This tool design is unique in its combination of sophisticated technology and participatory elements. Tools exist that combine GIS with multi-criteria methods but they rely heavily on mathematical modeling and can become black boxes that erode trust by decision-makers and influential stakeholders (Malczewski 2006). A tool recently developed by USGS, which helps prioritize conservation objectives across a watershed is a step in the direction of what we are proposing (Rohweder et al. 2011). This tool, however, focuses only on spatial data and incorporates no non-spatial elements and few non-ecological ones. The DST proposed in this paper is novel in its approach and in its responsiveness to the priorities and concerns articulated by managers and stakeholders, and could offer significant aid to those facing difficult AIS management decisions.

Table C-1. Ecosystem services managers are most concerned with protecting (based on Table 2-1 in Chapter 2).
Interviewees were presented with a list of ecosystem attributes and services and asked to select their top five. The right column gives the number of times each attribute or service was chosen.

Ecosystem Services	**Number of Times Chosen**
Biodiversity	25
Water quality	23
Recreation	16
Game species abundance	14
Non-game species richness and abundance	9
Nutrient cycling	9
Commercial and industrial services	8
Aesthetics	7
Cultural values	7
Water quantity	6

Table C-2. Issues for a decision support tool to address, as identified by interviewees (copied from Table 2-5 in Chapter 2). Within the parentheses, the first number denotes the number of times suggestions in that category were listed and n denotes the number of interviewees who had suggestions within that category.

Issue (# of suggestions)	**Examples**
Decision making guidance (25, n=14)	Stepwise guidance for less experienced managers, which strategies should be used at which locations
Prediction (16, n=12)	Ranking new species for invasiveness, likelihood of damage resulting from an invasion
Prioritization (13, n=11)	Where to put money across a landscape, how to use limited funds
Information storehouse (13, n=7)	What are the available control options? What is surrounding the affected area?
Go/No-go determinations (10, n=7)	Costs of actions vs. no action, feasibility questions
Risk assessments (3, n=2)	Risk assessments for agencies working in an infested area

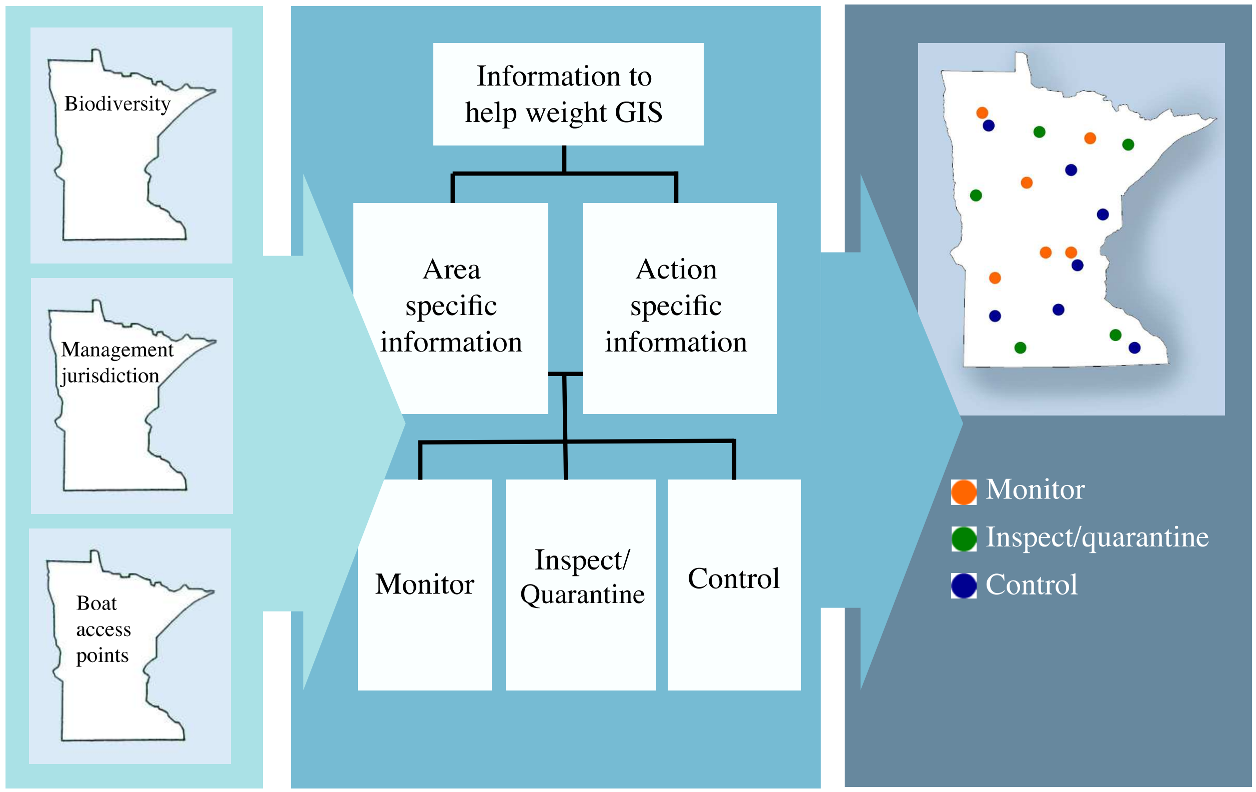

Figure C-1. Schematic of proposed decision support tool. The first panel gives examples of the types of GIS layers that will be used. The information from the GIS layers will be combined with data from the expert system (second panel). The expert system produces recommendations for key areas for monitoring, inspections or quarantines, and control efforts. The final output of the DST is a GIS layer with those key areas marked (third panel).

AIS distribution: 0=multiple AIS present, 1=one AIS present, 2=no AIS

0	2	1	1	1	0	1	1	0	2	0	1	2	1	0	0	1	2	2	2
2	1	2	0	1	1	1	1	0	1	2	0	1	2	2	2	1	1	0	0
0	0	2	1	0	1	2	2	0	2	2	2	2	0	0	2	2	0	1	1
0	1	1	1	1	0	2	1	2	0	0	1	1	2	0	2	2	1	2	2
0	0	1	1	1	0	0	1	1	0	1	0	1	2	1	1	2	2	0	1
0	1	0	1	0	0	1	0	0	0	2	2	1	0	0	1	0	2	0	1
1	1	2	2	1	1	1	2	0	2	2	1	2	1	1	2	2	1	0	0
0	0	0	1	2	2	1	1	1	2	0	2	1	0	0	2	1	0	2	1
0	2	0	2	1	0	1	0	0	1	2	1	1	1	0	1	1	2	0	1
1	2	1	0	2	0	1	1	0	1	0	0	1	1	1	0	2	2	1	1
2	0	2	1	1	2	0	0	0	1	1	1	0	0	0	1	1	1	0	2
1	2	1	2	0	1	0	2	1	0	2	2	2	1	1	2	2	2	0	0
2	1	2	0	2	1	2	0	2	0	2	2	1	0	1	0	2	0	0	0
2	0	2	0	1	0	2	0	1	0	1	2	2	2	1	1	0	0	2	1
0	2	2	0	2	2	0	1	1	0	2	2	0	1	2	0	2	1	0	0
1	0	1	2	1	0	2	0	1	2	1	0	0	2	0	1	2	0	1	1
0	2	1	0	0	2	2	0	1	1	2	0	0	2	0	2	2	2	2	2
2	1	2	0	0	2	2	2	1	2	1	2	2	2	2	0	0	0	0	0
2	2	0	0	0	1	2	1	2	1	0	0	0	0	0	2	1	1	2	2
0	1	1	1	2	1	2	0	1	2	2	1	0	0	1	0	0	0	2	2

Figure C-2. Intermediate data matrix from GIS step (Step 1) of the DST depicting current spread of AIS in the management area. Each pixel has a value of 0 (multiple AIS present), 1 (a single AIS present), or 2 (no AIS present).

Area information: Higher numbers = higher value areas

A)

9	8	15	12	5	1	4	14	8	6	7	8	13	11	7	9	3	11	11	13
6	7	9	6	6	7	9	14	9	10	9	8	8	11	8	16	16	7	12	9
14	8	11	8	7	11	13	5	15	5	13	5	7	6	6	11	6	10	10	12
6	7	6	8	1	10	9	8	14	6	5	6	4	14	7	9	8	7	10	6
10	9	7	8	6	9	13	8	10	10	11	8	14	4	8	8	12	9	11	8
6	11	9	6	6	6	12	8	8	11	8	5	10	11	6	7	5	13	8	14
13	9	14	13	8	10	9	8	7	11	9	8	14	8	16	8	5	6	6	10
9	9	11	10	2	4	9	13	3	5	7	15	11	5	11	15	8	13	7	8
8	6	11	8	6	10	6	8	5	15	9	10	4	12	7	4	8	5	11	11
12	7	5	12	10	11	8	5	9	10	9	6	6	7	8	8	12	13	11	13
6	11	11	6	12	7	4	9	10	6	13	9	7	13	11	8	8	7	6	9
10	8	12	11	10	4	5	8	10	13	13	12	7	2	7	5	9	8	7	9
7	10	7	5	5	7	6	9	15	9	10	6	6	9	5	7	6	8	6	4
9	10	10	9	9	7	9	11	7	3	13	10	11	9	12	8	11	4	6	10
9	6	8	12	6	3	9	13	10	5	9	7	10	10	12	11	11	8	7	10
10	8	12	4	7	9	12	11	8	6	7	5	7	9	3	5	9	8	8	3
10	8	9	10	9	5	11	8	3	5	5	10	11	4	3	10	14	10	7	11
8	9	10	7	7	8	10	6	9	7	11	10	11	10	11	8	8	10	10	6
7	4	12	3	4	9	10	11	8	8	10	8	6	1	8	9	8	6	7	8
12	11	8	13	9	14	6	11	10	9	9	8	10	8	9	7	15	12	15	13

Biodiversity: level of biodiversity from 0 (least) to 5 (most)

B)

5	2	5	5	5	1	1	5	0	3	2	3	3	3	0	3	3	4	5	5
3	4	1	0	1	3	3	3	1	5	2	5	5	3	4	4	5	3	2	3
2	0	4	1	2	4	5	0	5	2	2	0	0	5	1	4	3	4	3	4
0	1	1	0	0	3	3	4	5	0	2	1	1	4	2	4	4	2	3	0
3	1	4	0	2	3	2	3	2	1	5	2	4	0	0	2	3	3	3	3
0	5	2	3	2	1	2	0	2	4	3	4	1	4	2	2	1	3	5	5
3	2	5	4	1	1	3	1	5	3	3	0	5	3	5	3	1	0	0	3
5	0	5	5	1	1	0	4	0	1	5	3	4	2	5	5	1	4	3	2
1	1	5	3	1	3	1	1	1	5	2	4	2	3	2	1	1	4	5	3
2	0	2	1	4	3	0	3	3	1	0	0	0	1	2	0	5	5	5	5
1	0	3	3	3	5	3	2	4	0	5	4	5	4	2	0	4	3	1	5
3	5	3	3	3	2	1	2	2	5	2	5	4	1	1	1	4	1	4	4
1	3	2	1	2	0	1	3	4	0	4	1	1	5	1	2	1	2	0	1
2	4	5	0	2	0	1	3	3	0	4	5	4	3	4	5	5	0	4	3
2	1	2	4	1	0	0	4	1	1	0	0	2	1	4	0	4	3	1	4
3	2	1	0	5	5	3	1	1	5	2	0	1	3	0	1	1	4	4	3
4	1	5	2	4	0	5	3	2	3	2	2	3	0	2	2	5	5	3	3
0	4	5	2	1	3	5	1	4	0	4	3	4	4	3	3	1	3	5	2
5	0	3	3	3	5	1	4	1	1	3	1	1	0	4	1	0	3	0	3
4	2	4	5	2	4	5	3	3	2	1	5	5	2	2	0	5	1	4	3

Water quality: level of water quality from 0 (worst) to 5 (best)

C)

0	5	5	0	0	0	2	4	2	0	1	4	4	5	0	2	0	5	4	4
1	0	5	0	5	3	4	5	2	0	0	2	0	4	1	5	5	1	4	3
5	3	5	3	3	5	3	1	5	2	5	2	2	0	1	5	3	1	2	5
2	4	2	3	1	1	1	0	5	3	1	1	0	5	1	3	0	3	3	3
4	4	0	2	1	1	5	4	3	3	4	1	5	0	4	4	4	2	5	1
0	4	2	0	3	0	5	5	3	3	4	0	2	3	4	2	0	5	2	5
5	3	4	4	5	4	1	1	0	4	4	2	3	1	4	4	3	3	1	5
3	4	3	4	0	3	5	5	1	2	1	5	3	0	5	5	2	4	1	5
1	2	3	0	3	4	0	4	0	3	4	2	0	3	0	0	4	0	2	2
3	2	0	5	2	2	5	0	0	2	5	3	3	2	1	4	2	5	1	5
1	5	2	0	4	0	0	2	3	2	4	1	0	5	4	1	3	0	3	4
5	0	3	3	4	0	3	4	2	5	5	5	0	0	2	0	1	4	0	2
2	2	3	0	3	4	3	1	4	3	1	3	1	0	2	2	0	5	4	0
4	2	1	5	3	3	3	4	3	1	5	1	4	4	3	1	2	0	0	1
5	3	2	2	4	0	5	3	4	1	5	0	5	5	3	5	4	0	4	3
2	5	5	2	1	3	3	5	3	0	2	4	3	4	0	3	3	2	3	0
3	5	1	4	3	2	4	1	0	2	1	5	3	4	1	5	4	4	0	3
2	5	2	3	5	0	0	4	1	5	5	4	2	1	2	2	4	2	3	0
0	3	5	0	0	2	4	1	2	2	5	5	3	0	0	5	5	1	4	3
2	5	2	1	0	5	0	3	4	4	3	1	1	0	2	2	4	5	5	5

Game species abundance: level of abundance from 0 (least) to 5 (most)

D)

3	1	4	5	0	0	1	5	5	2	4	0	5	2	5	3	0	2	1	2
2	2	1	4	0	0	0	5	5	5	5	0	3	4	3	5	5	3	5	2
5	3	0	3	2	2	4	3	4	0	4	2	4	1	3	0	0	4	3	2
3	0	2	4	0	5	4	3	2	2	1	4	2	5	3	1	3	1	3	2
2	3	1	5	3	3	4	1	4	5	1	4	5	3	4	2	5	3	2	3
5	0	4	2	0	4	4	2	3	2	0	1	5	4	0	1	2	4	1	3
4	3	3	3	2	4	4	5	0	3	2	5	5	2	5	0	0	2	5	0
0	3	1	0	0	0	4	3	2	2	1	5	2	1	0	4	5	5	1	0
4	1	2	5	2	2	3	3	3	5	3	3	0	5	4	2	1	0	3	5
5	4	2	4	3	4	2	0	5	5	3	1	3	3	4	4	5	2	3	2
3	5	5	1	3	1	0	3	2	4	2	2	0	4	4	5	1	4	1	0
1	3	4	3	2	2	0	1	5	2	5	2	2	0	3	2	3	1	1	2
4	4	1	3	0	2	1	3	5	5	3	1	4	2	2	1	3	0	2	1
2	3	2	2	3	2	4	2	0	0	2	2	2	1	5	2	4	3	2	5
1	2	3	5	1	3	3	4	5	3	4	5	1	4	4	5	1	4	1	2
4	0	4	2	1	0	5	4	4	1	2	0	2	1	3	0	4	1	0	0
2	1	2	3	0	2	0	3	0	0	1	1	3	0	0	2	4	0	3	4
5	0	2	0	0	4	5	0	3	1	0	2	5	4	5	1	2	4	1	3
2	0	4	0	0	0	4	5	5	4	0	2	1	0	3	1	2	0	2	2
4	4	0	5	5	3	1	5	1	2	3	0	2	5	5	4	4	5	5	4

Boat access points: 0=absence, 1=presence

E)

0	0	0	1	0	0	0	0	0	1	0	0	1	1	1	1	0	0	1	1
0	0	1	1	0	1	1	1	0	0	1	1	0	0	0	1	1	0	1	0
1	1	1	1	0	0	0	0	0	0	1	0	1	0	1	1	0	0	1	1
0	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
0	0	1	1	0	1	1	0	0	0	0	1	0	1	0	0	0	0	1	1
0	1	1	0	1	0	0	0	0	1	1	0	1	0	0	1	1	1	0	0
0	0	1	1	0	1	1	0	1	1	0	0	1	1	1	1	1	0	0	1
1	1	1	0	1	0	0	1	0	0	0	1	1	1	1	0	0	0	1	1
1	1	0	0	0	1	1	0	0	1	0	1	1	0	1	0	1	1	0	1
1	1	0	1	1	1	0	1	1	1	0	1	0	1	0	0	0	0	1	0
0	0	0	1	1	0	1	1	1	0	1	1	1	0	1	1	0	0	0	0
0	0	1	1	1	0	0	1	1	1	1	0	1	1	1	1	0	1	1	1
0	0	0	1	0	1	0	1	1	0	1	0	0	1	0	1	1	0	0	1
0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1
1	0	1	1	0	0	1	1	0	0	0	1	1	0	0	1	1	1	1	1
0	0	1	0	0	1	0	1	0	0	0	0	1	1	0	0	1	1	0	0
0	0	0	0	1	1	1	1	1	0	0	1	1	0	0	0	1	0	1	0
0	0	0	1	1	0	0	1	0	1	1	1	0	1	0	1	0	0	0	1
0	1	0	0	1	1	1	0	0	1	1	0	0	1	1	1	1	1	0	0
1	0	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	0	0	0

Power plants: 0=absence, 1=presence

F)

1	0	1	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	1
0	1	1	1	0	0	1	0	1	0	1	0	0	0	0	1	0	0	0	1
1	1	1	0	0	0	1	1	1	1	1	1	0	0	0	1	0	1	1	0
1	1	1	0	0	0	1	1	1	1	1	0	1	0	1	1	1	1	1	1
1	1	1	0	0	1	1	0	1	1	1	0	0	0	0	0	0	1	0	0
1	1	0	1	0	1	1	1	0	1	0	0	1	0	0	1	1	0	0	1
1	1	1	1	0	0	0	1	1	0	0	1	0	1	1	0	0	1	0	1
0	1	1	1	0	0	0	0	0	0	0	1	1	1	0	1	0	0	1	0
1	1	1	0	0	0	1	0	1	1	0	0	1	1	0	1	1	0	1	0
1	0	1	1	0	1	1	1	0	1	1	1	0	0	1	0	0	1	1	1
1	1	1	1	1	1	0	1	0	0	1	1	1	0	0	1	0	0	1	0
1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	1	1	1	1	0
0	1	1	0	0	0	1	1	1	1	1	1	0	1	0	1	1	1	0	1
1	0	1	1	0	1	0	1	0	1	1	1	1	1	0	0	0	1	0	0
0	0	0	0	0	0	0	1	0	0	0	1	1	0	1	0	1	0	0	0
1	1	1	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0	1	0
1	1	1	1	1	0	1	0	0	0	1	1	1	0	0	1	0	1	0	1
1	0	1	1	0	1	0	0	1	0	1	0	0	0	1	1	1	1	1	0
0	0	0	0	0	1	0	1	0	0	1	0	1	0	0	1	0	1	1	0
1	0	1	1	1	1	0	0	1	0	1	1	1	0	0	1	1	1	1	1

Figure C-3. Intermediate data matrix from GIS step (Step 1) of the DST depicting the current state of the management area (A). For biodiversity (B), water quality (C), and game species abundance (D), each pixel is given a value from 0 (least desirable state) to 5 (most desirable state). For boat access points (E) and power plants (F), each pixel is given a value of 0 (absence) or 1 (presence). These layers are summed to give an overall value to each pixel (A), with higher values indicating pixels that are more valuable candidates for AIS management.

A)

Pathways:(Higher(numbers(=(higher(use(pathways

1	0	0	0	2	3	0	0	0	0	5	0	0	0	0	0	0	0	0	0
4	0	0	0	0	3	3	0	0	0	2	0	0	0	0	0	0	0	0	0
4	4	3	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	5	0	0	3	0	0	0	0	0	0	0	0	0
0	0	5	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0
0	0	5	0	0	0	0	0	0	5	5	0	0	0	0	0	0	0	0	0
0	0	1	3	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
0	0	0	3	0	0	0	0	0	0	4	3	0	0	0	0	0	0	0	0
0	0	0	5	0	0	0	0	0	0	4	0	4	0	0	0	0	0	0	0
0	0	0	5	0	0	0	0	0	0	4	0	0	2	0	0	0	0	0	0
0	0	0	2	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0
0	0	0	5	4	0	0	0	0	0	3	0	0	0	0	4	0	0	0	0
0	3	5	1	3	3	4	1	5	3	3	2	2	5	2	3	2	0	0	0
0	3	0	0	0	0	0	0	0	0	5	0	0	0	0	2	0	4	0	0
0	3	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	0	5	0
0	5	0	0	0	0	0	0	0	0	3	0	0	0	0	1	1	4	0	2
2	2	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	1	1	0
0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	2	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	2

B)

Natural)pathways:)0=absence,)1=presence

1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

C)

Human(mediated-pathways:-0=absence,-1=presence

0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

D)

Pathway-use:-level-of-use-from-0-(no-pathway)-to-5-(high-use)

1	0	0	0	2	3	0	0	0	0	5	0	0	0	0	0	0	0	0	0
4	0	0	0	0	3	3	0	0	0	2	0	0	0	0	0	0	0	0	0
4	4	3	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	5	0	0	3	0	0	0	0	0	0	0	0	0
0	0	5	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0
0	0	5	0	0	0	0	0	0	5	5	0	0	0	0	0	0	0	0	0
0	0	1	3	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
0	0	0	3	0	0	0	0	0	0	4	3	0	0	0	0	0	0	0	0
0	0	0	5	0	0	0	0	0	0	4	0	4	0	0	0	0	0	0	0
0	0	0	5	0	0	0	0	0	0	4	0	0	2	0	0	0	0	0	0
0	0	0	2	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0
0	0	0	5	4	0	0	0	0	0	3	0	0	0	0	4	0	0	0	0
0	3	5	1	3	3	4	1	5	3	3	2	2	5	2	3	2	0	0	0
0	3	0	0	0	0	0	0	0	0	5	0	0	0	0	2	0	4	0	0
0	3	0	0	0	0	0	0	0	0	4	0	0	0	0	1	0	0	5	0
0	5	0	0	0	0	0	0	0	0	3	0	0	0	0	1	1	4	0	2
2	2	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	1	1	0
0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	2	0
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	2

Figure C-4. Intermediate data matrix from GIS step (Step 1) of the DST depicting connectivity within the management area (A). For human-mediated pathways (B) and natural pathways (C), each pixel is given a value of 0 (absence) or 1 (presence). For the level of human use of these pathways, each pixel is given a value from 0 (no pathway) to 5 (high use). These layers are summed to give an overall value to each pixel (A), with higher values indicating more used pathways.

Matrix indicating high priority areas based on Step 1

10	10	16	13	8	4	5	15	8	8	12	9	15	12	7	9	4	13	13	15
12	8	11	6	7	11	13	15	9	11	13	8	9	13	10	18	17	8	12	9
18	12	16	9	7	12	16	7	15	7	19	7	9	6	6	13	8	10	11	13
6	8	8	9	2	10	11	14	16	6	8	7	5	16	7	11	10	8	12	8
10	9	13	9	7	9	13	9	12	10	16	8	15	6	9	9	14	11	11	9
6	12	14	7	6	6	13	8	8	16	15	7	11	11	6	8	5	15	8	15
14	10	17	18	9	11	10	10	7	13	15	9	16	9	17	10	7	7	6	10
9	9	11	14	4	6	10	14	4	7	11	20	12	5	11	17	9	13	9	9
8	8	11	15	7	10	7	8	5	16	15	11	9	13	7	5	9	7	11	12
13	9	6	17	12	11	9	6	9	11	13	6	7	10	9	8	14	15	12	14
8	11	13	9	13	9	4	9	10	7	16	10	7	13	12	9	9	8	6	11
11	10	13	18	14	5	5	10	11	13	18	14	9	3	8	11	11	10	7	9
9	14	14	6	10	11	12	10	22	12	15	10	9	14	8	10	10	8	6	4
11	13	12	9	10	7	11	11	8	3	19	12	13	11	13	11	11	8	8	11
9	11	10	12	8	5	9	14	11	5	15	9	10	11	14	12	13	9	12	10
11	13	13	6	8	9	14	11	9	8	11	5	7	11	3	7	12	12	9	6
12	12	10	10	9	7	13	8	4	6	11	10	11	6	3	12	16	13	10	13
10	10	12	7	7	10	12	8	10	9	15	12	13	12	13	8	8	10	12	6
9	6	12	3	4	10	12	12	10	9	11	8	6	1	8	11	9	7	9	11
12	12	9	14	11	15	8	11	11	11	16	9	10	8	10	7	15	12	17	17

Figure C-5. Final data matrix from GIS step (Step 1) depicting the summed value of each management area pixel at the end of Step 1. This matrix is produced by summing each of the intermediate matrices (Figure C-2, Figure C-3A, Figure C-4A). Higher values indicate pixels that are higher priority for management actions.

Areas where recreational opportunities have been impeded: from 0 (not at all) to 3 (significantly)

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	2	3	2	0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	0

Figure C-6. Data matrix representing areas where are AIS interfering with recreational opportunities. Each pixel has a value from 0 (no AIS problem) to 3 (severe AIS problem).

AIS distribution: 0=multiple AIS present, 1=one AIS present, 7=no AIS present

0	7	1	1	1	0	1	1	0	7	0	1	7	1	0	0	1	7	7	7
7	1	7	0	1	1	1	1	0	1	7	0	1	7	7	7	1	1	0	0
0	0	7	1	0	1	7	7	0	7	7	7	7	0	0	7	7	0	1	1
0	1	1	1	1	0	7	1	7	0	0	1	1	7	0	7	7	1	7	7
0	0	1	1	1	0	0	1	1	0	1	0	1	7	1	1	7	7	0	1
0	1	0	1	0	0	1	0	0	0	7	7	1	0	0	1	0	7	0	1
1	1	7	7	1	1	1	7	0	7	7	1	7	1	1	7	7	1	0	0
0	0	0	1	7	7	1	1	1	7	0	7	1	0	0	7	1	0	7	1
0	7	0	7	1	0	1	0	0	1	7	1	1	1	0	1	1	7	0	1
1	7	1	0	7	0	1	1	0	1	0	0	1	1	1	0	7	7	1	1
7	0	7	1	1	7	0	0	0	1	1	1	0	0	0	1	1	1	0	7
1	7	1	7	0	1	0	7	1	0	7	7	7	1	1	7	7	7	0	0
7	1	7	0	7	1	7	0	7	0	7	7	1	0	1	0	7	0	0	0
7	0	7	0	1	0	7	0	1	0	1	7	7	7	1	1	0	0	7	1
0	7	7	0	7	7	0	1	1	0	7	7	0	1	7	0	7	1	0	0
1	0	1	7	1	0	7	0	1	7	1	0	0	7	0	1	7	0	1	1
0	7	1	0	0	7	7	0	1	1	7	0	0	7	0	7	7	7	7	7
7	1	7	0	0	7	7	7	1	7	1	7	7	7	7	0	0	0	0	0
7	7	0	0	0	1	7	1	7	1	0	0	0	0	0	7	1	1	7	7
0	1	1	1	7	1	7	0	1	7	7	1	0	0	1	0	0	0	7	7

Figure C-7. Data matrix representing the manager's priority of protecting uninvaded areas. This data matrix is a modified version of the matrix in Figure C-2. Here, each pixel with no AIS present has had its value increased from 2 to 7.

Area information: Higher numbers = higher value areas

11	9	18	14	6	1	5	17	10	7	8	9	16	13	9	11	3	13	13	15
7	8	11	7	7	8	11	17	11	12	11	9	10	13	10	19	19	8	14	11
17	10	13	10	8	13	15	6	18	6	16	6	9	7	7	13	7	12	12	14
7	8	7	10	1	12	11	10	16	7	6	7	5	17	8	11	10	8	12	7
12	11	8	10	7	11	16	9	12	12	13	10	17	5	10	9	14	11	13	10
7	13	11	7	7	7	14	9	10	13	9	6	12	13	7	8	6	15	9	16
15	11	17	15	9	12	11	10	8	13	11	10	17	10	19	9	6	7	7	12
10	11	13	12	2	5	11	15	4	6	8	18	13	6	13	18	10	15	8	9
10	7	13	10	7	12	7	10	6	18	11	12	5	14	9	5	9	6	13	13
14	9	6	14	12	13	9	6	11	12	11	7	7	8	10	10	14	15	13	15
7	13	13	7	14	8	5	11	12	7	15	11	8	15	13	10	9	8	7	10
12	10	14	13	12	5	6	9	12	15	16	14	8	2	8	6	11	9	8	11
8	12	8	6	6	8	7	11	18	11	12	7	7	11	6	8	7	9	7	5
11	12	12	11	11	8	11	13	8	4	15	12	13	11	14	9	13	5	7	12
11	7	10	14	7	4	11	16	12	6	11	9	12	12	14	13	13	10	8	12
12	9	14	5	8	10	14	13	10	7	8	6	8	11	4	6	11	9	9	3
12	9	11	12	11	6	13	10	4	6	6	12	13	5	3	12	17	12	8	13
10	10	12	8	8	10	12	7	11	8	13	12	13	12	13	9	9	12	12	7
8	5	14	3	5	11	12	13	10	10	12	9	7	1	10	11	10	7	8	9
14	13	9	16	11	17	7	13	12	11	11	9	12	10	11	9	18	14	18	15

Figure C-8. Data matrix representing the manager's relative priorities for protecting recreation, industry, and ecosystem health. This data matrix is a modified version of the matrix in Figure C-3. Here, the values of the GIS layers for game species abundance and boat access points were each increased by 25%, the GIS layer for power plants was increased by 20%, and the GIS layers for biodiversity and water quality were each increased 15%.

Matrix indicating high priority areas for monitoring based on Steps 1 and 2

12	16	19	15	9	4	6	18	10	14	13	10	23	14	9	11	4	20	20	22
18	9	18	7	8	12	15	18	11	13	20	9	11	20	17	26	20	9	14	11
21	14	25	13	10	14	23	13	18	13	27	13	16	7	7	20	14	12	13	15
7	9	11	14	4	12	18	16	23	7	9	8	6	24	8	18	17	9	19	14
12	11	16	13	10	11	16	10	14	12	18	10	18	12	11	10	21	18	13	11
7	14	16	8	7	7	15	9	10	18	21	13	13	13	7	9	7	22	9	17
16	12	25	25	10	13	12	17	8	20	22	11	24	11	20	16	13	8	7	12
10	11	13	16	9	12	12	16	5	13	12	28	14	6	13	25	11	15	15	10
10	14	13	22	8	12	8	12	8	21	22	13	10	15	9	6	10	13	13	14
15	16	7	19	19	13	10	9	14	15	15	7	8	11	12	10	21	22	14	16
14	13	20	10	15	15	5	13	14	10	18	12	8	15	14	11	10	9	7	17
13	17	15	26	16	6	6	16	13	15	26	21	15	3	9	17	18	16	8	11
15	16	20	7	16	12	18	12	30	14	22	16	10	16	9	11	16	9	7	5
18	15	19	11	12	8	18	13	9	4	21	19	20	18	15	12	13	9	14	13
11	17	17	14	14	11	11	17	13	6	22	16	12	13	21	14	20	11	13	12
13	14	15	12	9	10	21	13	11	14	12	6	8	18	4	8	19	13	10	6
14	18	12	13	11	13	20	10	5	7	17	12	13	12	3	19	24	20	16	20
17	11	19	8	8	17	19	14	12	15	17	19	20	19	20	9	9	12	14	7
15	12	14	3	5	12	19	14	17	11	13	9	7	1	10	18	14	11	18	17
14	14	10	17	18	18	14	13	13	18	23	10	12	10	12	9	21	17	28	24

Figure C-9. Final data matrix from Step 2 depicting the weighted value of each management area pixel. This matrix is produced by altering the matrix produced at the end of Step 1 (Figure C-5) through incorporation of manager preferences for protecting recreational opportunities (Figure C-6), protecting uninvaded areas (Figure C-7), and relative preferences for recreation, industry and ecosystem health (Figure C-8). Higher values indicate pixels that are higher priority for management actions. The highest priority pixels are highlighted.

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Appendix A: Focus Group Information Packet

Thank you for taking the time to participate in a focus group to discuss the use of genetically modified organisms as a biocontrol for aquatic invasive species. You have been invited to participate because you represent a group that may be affected by the intended and unexpected consequences of this technology's use.

In our dicussion, we are hoping to capture the full range of opinions held by participants on the topic of genetic biocontrol as this information will be invaluable in guiding future steps in the environmental risk assessment process, the technology's development, and its regulation. Bringing a new technology like genetic biocontrol of invasive species into practical application will require a good understanding of the stakeholders' opinions, attitudes, and concerns. By conducting a focus group relatively early in the process of developing genetic biocontrol methods, we hope to understand how the you currently view genetic biocontrol approaches and make sure that your views are taken into consideration as the technology moves forward.

These focus groups are being conducted at several locations around the Great Lakes and the results will be compiled and presented at an international symposium addressing the potential for genetic biocontrol as a control for invasive finfish and the risks associated with its use (http://www.seagrant.umn.edu/ais/biocontrol).

Attached, please find a list of the questions we will be discussing in the focus group and some brief background information about genetic biocontrol technology. If you have any questions, please feel free to contact me.

I look forward to talking with you,

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Focus Group Questions

- What comes to mind when you hear people talk about genetically modified organisms?
- What comes to mind when you hear people suggest using genetically modified organisms as a control for aquatic invasive species?
- How do you see genetically modified organisms fitting into an aquatic invasive species control program?
- List the potential benefits of pursuing these technologies.
- List your concerns about pursuing these technologies. Which ones are your top concerns?
- If this technology is pursued, what are the consequences you are most concerned about occurring?
- How do you think your constituents/clients/public would respond to the use of this technology? What do you think their biggest concerns would be?
- What would stop you from supporting this technology?
- What would inspire you to support the use of this technology?
- If you could make a recommendation on whether or how to proceed with developing these technologies what would you say?

Genetic Biocontrol Technology Information

Non-native fish, habitat degradation and water development have combined to become major stressors on the health of native fish and their habitats in the U.S. Southwest. In recent years, the impact of these stressors has led to the precipitous decline of many native fish species endemic to this area. Biologists have been searching for more effective ways to reduce the negative impact of undesirable non-native fish. Improved biological control of non-native fish could help address this complex challenge.

A recent report by Kapuscinski and Patronski (2005) explored the potential for using genetic manipulation methods as a new approach for biological control of non-native fish within the Gila River Basin. The report reviews the status of existing genetic methods including chromosome set manipulations and recombinant DNA techniques; takes a preliminary look at potential ecological and human health risks; outlines policy and regulatory considerations; stresses the need for and presents an approach for multi-stakeholder deliberation; provides general cost and time estimates; and suggests integration of these considerations into a multi-component research and development program. As of the writing of this report, no transgenic animal has been purposefully released into the environment in the United States.

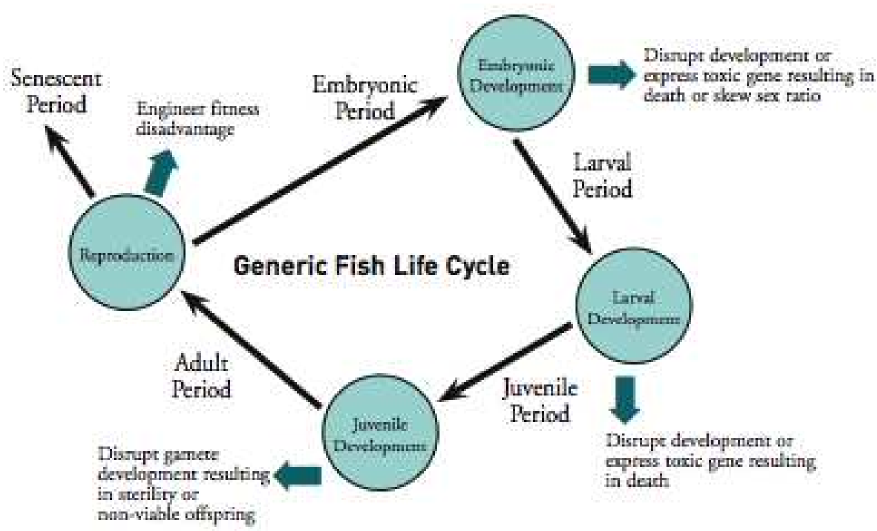
Since the early 1980s, two genetic manipulation techniques—chromosome set manipulations and recombinant DNA methods—have been the focus of considerable research and development to improve aquaculture production traits in fish. Both techniques could be harnessed for biological control of invasive fish species.

Chromosome set manipulations (also called ploidy manipulations) enable production of fish whose chromosomes come entirely from the male or the female parent, or in which the number of chromosome sets is increased from the normal pair to either three sets or four sets. Induction of triploidy refers to inducing fish to bear three sets of chromosomes and, in some fish species, leads to varying degrees of sterility. The presence of the odd set of chromosomes presumably causes mechanical problems involving pairing of homologous chromosomes during each cell division and this disrupts the normal development of gametes to some extent. Fish that are sterile but still enter into courtship behavior could offer one tool for biological control, by reducing the number of successful matings, their presence could lead to a reduction in population size. The idea of using triploid sterilized fish for biological control has been informally discussed within the fisheries community for at least 10 years but has not yet been applied in a field setting.

Another chromosome manipulation approach is known as the Trojan chromosome approach. In this method researchers would induce XY male fish to act as females and mate with other XY males. A portion of the offspring from those matings would be YY "supermales." Those "supermales" would also be treated so as to induce them to mate as females and would then be released into the wild. Because these fish are unable to have female offspring, over time, repeated stocking of the female-behaving "supermales" would lead the serious skewing of the wild populations' sex ratios, leading to predominantly male populations. (Cotton and Wedekind 2007)

Recombinant DNA methods involve the transfer of novel genetic constructs (also called transgenes) into the fish genome, resulting in the development of a "transgenic" fish expressing a novel trait. Biologists have identified and refined techniques for chromosome set manipulations for many fish species and generally understand the associated strengths and weaknesses. The techniques of gene transfer via recombinant DNA techniques are not as fully developed and the strengths and weaknesses not as well understood. Purposefully releasing a transgenic fish expressing a deleterious transgene for biological control of harmful non-native fish species is a relatively new idea for applying recombinant DNA technology.

The recombinant DNA approach to controlling non-native fish populations is the release of transgenic individuals (of the same species as that targeted for control), bearing a deleterious genetic construct (transgene) designed to disrupt a specific aspect of the organism's life cycle or biology. The idea is that the genetically modified fish would be stocked into a wild population. Then, through matings with the wild fish, the deleterious transgene would spread throughout the wild population and, ultimately, lead to a reduction in the population size. A variety of genes could be targeted to control aspects of development, survival, or gametogenesis in offspring. The figure below illustrates various points of possible disruption via transgenic methods during the life cycle of a fish. For example, targeted genes could control for important aspects of body plan or gill development or function during the embryonic or larval periods, or gamete development during the juvenile period. In the future, improved understanding of gene function and regulation could conceivably identify many different genes that could be disrupted or regulated for biological control purposes.



The potential efficacy, strengths and weaknesses of genetic methods for biological control of invasive fish are poorly understood at present. Ongoing research to anticipate the effectiveness and pitfalls of different genetic methods for biological control of fish suggests that in many cases no one method will be adequately effective alone and that achieving desired levels of biological control may require adapting the approaches of integrated pest management to the biological control of invasive fish. An integrated pest management approach might combine genetic methods with mechanical or chemical control methods, as well as the release of pheromone attractants to improve the efficacy of these other methods.

As research in all the required areas (from genetics to population ecology) moves forward, it will be important to periodically re-evaluate understanding of the potential effectiveness and pitfalls of different genetic methods. Meanwhile, we can draw on insights learned from recent research on several related topics: reproductive containment of fish for aquaculture and conservation purposes; integration of transgenes into established populations; risk assessment of transgenic organism release; and traditional biological control of other organisms, such as insects. Each genetic-based method may offer potential benefits that need to be considered in light of the associated risks, which must be carefully identified, assessed, and managed.

Most of the information and language in the following information packet was taken directly from Kapuscinski, A. R. and T. J. Patronski. 2005. Genetic methods for biological control of non-native fish in the Gila River Basin. Contract report to the U.S. Fish and Wildlife Service. University of Minnesota, Institute for Social, Economic and Ecological Sustainability, St. Paul, Minnesota. Minnesota Sea Grant Publication F 20. Information coming from other sources is citied.

The complete Kapuscinski and Patronski (2005) report can be found online at: http://www.seagrant.umn.edu/ais/biocontrol

Cotton and Wedekind. 2007. Control of introduced species using Trojan sex chromosomes. Trends in Ecology and Evolution 22(9): 441-3.

Appendix B: Focus Group Questions

Opening Questions

1) Tell us your name, the agency or organization you are associated with and how you are involved in aquatic invasive species work.

2) What comes to mind when you hear people talk about genetically modified organisms?

3) What comes to mind when you hear people suggest using genetically modified organisms as a control for aquatic invasive species?

Transition Question

4) How do you see genetically modified organisms fitting into an aquatic invasive species control program?

Key Questions

5) List the potential benefits of pursuing these technologies.

6) List your concerns about pursuing these technologies. Which ones are your top concerns?

7) If this technology is pursued, what are the consequences/potential negative impacts you are most concerned about occurring?

8) How do you think your constituents/clients/public would respond to the use of this technology? What do you think their biggest concerns would be?

9) What would stop you from supporting this technology?

10) What would inspire you to support the use of this technology?

Closing Questions

11) If you could make a recommendation on whether or how to proceed with developing these technologies what would you say?

12) The purpose of this discussion was to explore your feelings and opinions on the use of genetically modified organisms as a control tool for aquatic invasive species. Is there anything we missed? Anything you would like to say that you didn't get a chance to?

Appendix C:

Interview Questions

- Currently, what are some of the biggest challenges in invasive species management?
- Are there some AIS species that are of greater concern than others? Which? Why?
- What are your greatest concerns for the water bodies in your management areas? Could you list the top 3 and why?
- What are your top priorities in invasive species management? What are your strategies for reaching these? Can you be specific/elaborate?

- What are your top economic concerns in invasive species management?
- What ecosystem services/values associated with water bodies are you most concerned with protecting? Could you list the top 5 and why?
- Does protecting these services drive your management decisions? Why or why not?
- Do you feel AIS threatens these services? Which values do they threaten?

- Who makes the decision to control or not to control invasive species?
- How is this decision reached? What is the process?
- What are the weaknesses of the current decision-making process? The strengths?

- How do you decide when an invasive population should be controlled? What elements are considered when deciding whether to control an invasive population? Which factors do you consider when deciding which control option is best?
- Are there any other factors that are considered in management decisions that have not been mentioned previously?

- Are there any decisions that you have made/know of that illustrate particularly successful (or flawed) decision making?

- What issues should a decision support tool address to be useful to you?

- To what degree are other agencies included in your management actions?
- What legislation/management plans most directly influence your management action? Do you have improvements/suggestions/changes you would like to see in these plans or legislation?

- Earlier we spoke about challenges in AIS management? Do you see these challenges changing in the future?
- The purpose of our discussion today was to determine how invasive species control decisions are made and how they could be improved. Have I missed anything?

Appendix D:

List of ecosystem services associated with fresh water bodies (as presented to interviewees)

Aesthetics
Biodiversity
Biotic resistance
Climate regulation
Commercial/Industrial services
Cultural values
Erosion protection
Food
Fresh water
Other products
Game species abundance
Non-game species richness and abundance
Hydrological regime regulation
Pollination
Pollution control and detoxification
Property values
Natural hazard regulation
Nutrient cycling
Recreation
Soil formation
Water quality
Water quantity
__Other

Appendix E: Management concerns identified by managers

The columns represent the four broad categories into which the responses were coded. Each entry in a column corresponds to one response or element of one response given by an interviewee.

AIS	AIS related - direct	AIS related - indirect	Non-AIS
Aggressive animals	AIS	Keep lakes as healthy as possible	Climate change
Prevent Asian carp	Invasive species	Biodiversity	Climate change
Asian carp	Invasive species	Species richness and abundance	Climate change
Bighead and silver carp	Invasive species	Endangered species	Nutrients from external sources
Cormorants	Incoming AIS	Loss of native species important to the fish community	Internal nutrients
Prevent earthworm spread	Unknown new species	Native fish habitat restoration	Impacts of tributaries
Eurasian water milfoil	AIS prevention	Protect water supply	Direct effects of fishing
Flowering rush	AIS prevention	Water quality	Impacts of commercial fishing
Hydrilla	AIS prevention	Changes to the trophic structure of rivers	Impacts of harvests
Invasive mussels	Prevention of AIS spread	Dealing with ecosystem changes	Fishing and recreation industries
Submersed invasive plants	Prevention of AIS spread	Dealing with ecosystem changes	Alteration of critical biological processes
VHS	Training agencies to prevent spread	Aesthetics	Landscape level impacts
Zebra mussels	Containment of AIS within infected areas	Manage for competing interests	Habitat loss
Zebra mussels	Manage AIS vectors	Meeting public expectations for ecosystem services	Habitat loss
	Prevent invasions via manmade waterways		Habitat manipulations
	Regulation of trade vectors		Over-manipulation of aquatic plants
	AIS invasions via shipping pathways		Magnitude of forces impacting ecosystem resilience
	Improvement of federal policy to prevent AIS introductions		Inability of policy to adapt to system changes
	AIS control costs		
	Manage species that cause ecosystem shifts		
	AIS impacts on recreational fisheries		
	AIS impacts on native species		
	AIS impacts on recreational opportunities		
	AIS impacts on commercial fisheries		
	AIS related economic impacts		
	AIS impacts on aesthetics		

	Collecting data on AIS economic impacts		
	Assess available information and fill in gaps to improve AIS understanding		
	Weigh costs and benefits, do more good than harm		
	Determine which AIS species are greatest threats		
	Develop a consistent, simple, and comprehensive AIS message for public		
	Get public buy in for AIS work		
	Make public education for AIS a priority		
	Increase AIS public knowledge and awareness		
	Work with public perception and response to AIS		
	Address AIS problems regionally rather than state by state		
	Deal with AIS policy differences in inter-jurisdictional waters		

Appendix F: Invasive species management priorities as identified by managers

The columns represent the nine broad categories into which the responses were coded. Each entry in a column corresponds to one response or element of one response given by an interviewee.

Prevention	**Containment**	**Reduce Impacts**	**Management**	**Legislation**	**Coordination**	**Funding**	**Research**	**Outreach and education**
Prevent AIS introductions	Contain AIS	Reduce nuisance impacts	Manage sea lamprey	Work to get useful legislation	Assist communication	Work to get funding	Conduct research	Outreach and education
Prevent AIS introductions	Contain AIS	Reduce impacts of established invasives	Manage curly leaf pondweed	Achieve policy consensus	Build partnerships	Obtain sufficient funding	Develop more effective tools	Outreach and education
Prevent AIS introductions	Contain AIS	Reduce impacts to allow for native species restoration	Manage zebra mussels	Suitable federal legislation to prevent AIS introductions and spread	Work with stakeholders		Develop more effective tools	Outreach and education
Prevent AIS introductions	Prevent spread of AIS	Pursue no control that is worse that the AIS	Manage Asian carp	Federal level screening for imported species	Facilitate cooperation among stakeholder groups		Develop more effective tools	Outreach
Prevent AIS introductions	Prevent spread of AIS		Management of aquatic plants	Set a national ballast water regulation standard	Understand state and agency priorities		Improve effectiveness of control tools	Dissemination of information
Prevent AIS introductions	Prevent spread of AIS		Comprehensive management plan	Set a regional ballast water regulation standard	Work with states to achieve management goals		Remediation research	Increase awareness
Prevent AIS introductions	Prevent spread of AIS		Comprehensive management plan	Improve ballast water regulations	Support state and tribal AIS programs			

			Comprehensive management plan					
			Comprehensive management plan					
Prevent AIS introductions	Limit spread of AIS		Management and control plan	Improve ballast water regulations	Get involved in regional panels			
Prevent AIS introductions	Prevent spread of Asian carp		Management and control plan					
Prevent AIS introductions			Management and control plan					
Prevent AIS introductions			Access management and inspections					
Prevent introductions via ballast water			Eradication plan					
Implement introduction and decontamination protocols			Long-term management plan					
Implement screening and rapid response protocols			Adaptive management plan					
Monitor new introductions			Integrated management control program					

Appendix G: Economic concerns identified by managers

The columns represent the three broad categories into which the responses were coded. Each entry in a column corresponds to one response or element of one response given by an interviewee.

Cost of Control	**Cost of Damage (Monetary)**	**Cost of Damage (Non-monetary)**
control costs	impacts on water utilities	damages caused by invasives
control costs	impacts on water supply	damages caused by invasives
control costs	interference with water use	environmental damages
control costs	impacts on water services	environmental damages
control costs	impacts on municipal infrastructure/water intake	environmental damages
control costs	costs to municipal water systems	impact on natural resources
control costs are high and ongoing	costs to industry	loss of environmental services
	costs to industry	
management costs	impacts on industries that rely on moving water	non-monetized costs
remediation costs	impacts on shipping	loss of waterbody usage
costs of researching new control methods	impacts on infrastructure	loss of personal enjoyment of waterbody
costs to agency	impacts on tourism	eutrophication
impact on agency's budget	impacts on tourism	potential invasion meltdown
insufficient funding	impacts on tourism	impacts on fish growth and survival
insufficient funding for control	impacts on tourism	
insufficient long-term funding	impacts on tourism	
difficulty balancing competing needs	costs to those engaging in recreational activities	
incorporating AIS funding into the bigger budget	impacts on sport fishing	
	impacts on recreation	
	impacts on recreation	
	impacts on recreation	
	impacts on recreation	
	impacts on recreation	
	impacts on recreation	
	loss of recreational opportunities	
	impacts to recreational boating	
	impacts on commercial and recreational fisheries	
	impacts on commercial and recreational fisheries	
	impacts on commercial and recreational fisheries	
	impacts on commercial and recreational fisheries	
	impacts on fishing industry	
	impacts on fisheries	
	loss of fisheries resource	
	loss of fisheries resource	
	loss of resource use	

	impacts on forest and timber production	
	loss of profits from resource use	
	cost of dealing with damages	
	impacts on property values	
	impacts on the state economy	
	difficulty measuring costs	

Appendix H: Issues for a DST to address

The columns represent the six broad categories into which the responses were coded. Each entry in a column corresponds to one response or element of one response given by an interviewee.

Prediction	Go/No-go?	Prioritizing	Guidance, Structured Decision-Making	Information repository	Risk Assessment
Predict outcome of new approaches	Cost-benefit analysis	Where to spend money?	Step-wise guidance for less experienced managers	Criteria to quantify economic and ecological impacts	Risk analysis
What is the best avenue of control and how likely is it to succeed?	Cost-benefit analysis	Where to spend money across a landscape?	Decision tree for less experienced managers	Information about AIS	Risk assessment
Probability of control success	Cost-benefit analysis	Where to focus management efforts?	Checklists for reviewing an issue	Information about available control options	Risk assessment for working in an infested waterbody
Probability of control success	Cost-benefit analysis, and when other issues should take priority	Where to focus monitoring efforts?	Guidance for following the NIS strategy	Information about available control options	
Probability of preventing introductions	Cost of actions and no actions	Where to monitor?	Provide structure	Information about management options	
Invasiveness of incoming organism	Feasibility of control actions	Geographic areas to prioritize	Help with early detection strategies	Information about available control options	
Hierarchy of newly arriving species	Feasibility of control actions	Balance resources between monitoring and other actions	Framework for responding to an infestation	Technical control information	
Ranking of new AIS	Impacts on industry	Where to prioritize management actions?	Appropriate response for a rapid response	Monitoring information	
Ranking of new AIS	Impacts on system sustainability	Help with resource allocation	Appropriate response for a rapid response	Information about system irreplaceability/vulnerability	
Screening tool for incoming species	Impacts on key species	Help with allocating limited funds	Appropriate response for a rapid response	Ecology of invaded area	

Likelihood of continued introductions		Best use of limited capacity and funds	Rapid response strategies	Information about invaded area	
Potential for a site to impact other sites		Help prioritizing	Where to start?	Information about area around invasion	
Speed of spread		Priority setting system	What to do?	Methods for capturing information	
Potential impacts of AIS invasions			When to end?		
Potential impacts of AIS invasions			Choose an appropriate control response		
Potential impacts of AIS invasions			Containment of existing infestations		
			Prevent spread of AIS		
			Prevent spread of AIS		
			When is it worthwhile to pursue alternative control techniques?		
			Where best to use alternative control techniques?		
			At what level to use alternative control techniques?		
			Assistance with choosing tactics		
			How much energy to put into a control effort?		
			Which strategies to use at which locations?		
			Measure effectiveness of decisions		

Appendix I: Existing legislation affecting AIS management

The Lacey Act (1900)

Of the 14 federal laws and regulations that affect management of aquatic invasive species, the first on the record is the Lacey Act of 1900. Although the main purpose of the act was to reducing wildlife poaching, introduction of non-native birds and mammals "was also a concern." The Lacey Act has been amended several times, most significantly in 1969, 1981, 1988 and 2008 but these amendments had no significant impact the Act's role in management of aquatic invasive species. The Lacey Act prevents deliberate introductions into the wild except under federal authority as well as making it illegal to import, transport, or acquire injurious wildlife. However, only those species specifically listed in the act are considered to be 'injurious wildlife.' This means that a species must go through a formal evaluation before it is added to the list. Oftentimes this means that a species is only considered 'injurious wildlife' after it is already present in the country and causing problems (Fowler et al. 2007).

Although Fowler et al. (2007) refer to the Lacey Act as the "primary legal tool protecting US non-agricultural ecosystems against the introduction and spread of invasive animal species" it is difficult interpret what the actual intent of the legislation was with regard to invasive species, as they are never specifically mentioned in the statute's language. It is also difficult to understand Fowler et al.'s claim in the face of their findings that the Act prohibits the importation of only 17 taxa, nine of which were already present in the continental US at the time of listing. Further compromising the Act's effectiveness is the time it takes to list a new species and the government's lack of authority to regulate that species during the listing process.

The Lacey Act provides for both criminal and civil penalties for those who violate it, and in 2007 the US Fish and Wildlife Service posted 114 inspectors at 38 ports across the country enabling them to inspect approximate 25% of declared wildlife shipments at the US border (Wyler and Sheikh 2009). For those species that are listed as injurious before arriving in the country, it does seem that the Lacey Act has had its intended impact. Fowler et al. (2007) found that, of the seven taxa not present in the continental US at the time of listing, none had established populations at the time of their article. However, a 2009 report to congress (Wyler and Sheikh) found that even some species that are listed as injurious under the Lacey Act are still being smuggled into the country (e.g. Chinese mitten crabs).

The Act's effectiveness is further compromised by the small number of listed species. Currently the rule has two families, two genera, and three species of invasive fish listed as injurious. The United States Geological Survey has a website of nonindigenous aquatic species on which there are 725 separate records of fish alone. Given the tiny fraction of invasive species falling under the jurisdiction of the Lacey Act, as well as the time and the difficulty associated with getting additional species listed under the act, it is clear that the Lacey Act is of limited effectiveness in the overall effort to manage invasive species.

The Lacey Act attempts to thwart invasions at the transport step of the invasion process and, to a lesser extent, the introduction step of the invasion process. However, by focusing solely on listed species and primarily on declared shipments of wildlife, the Lacey Act has a limited impact on those steps. All unlisted species as well as undeclared and accidental shipments go untouched by the legislation. On the other hand, a strength of the Lacey Act is its focus on the management strategy of prevention. Preventing invasive species from arriving in the first place is a far better strategy than attempting to control populations once they arrive (Leung 2002) and the Lacey Act is the main piece of US federal legislation for accomplishing prevention.

Legislation 1947 - 1973

After the Lacey Act, the next enacted law affecting introductions of non-native species was the 1947 Federal Insecticide, Fungicide, and Rodenticide Act. This act gave the Environmental Protection Agency the authority to regulate organisms being brought into the country to function as pesticides. Although not specifically addressing invasive species concerns, it was the first act to give the EPA a voice in determining which deliberate introductions of non-native species should be permitted. Like the Lacey Act, this law focused on the transport and introduction portions of the invasion process and the management strategy of prevention but its scope is limited to those species being imported as pesticides.

The 1955 Convention on Great Lakes Fisheries between the US and Canada was the first federal attempt to specifically and directly address an invasive species problem. This Convention established the Great Lakes Fisheries Commission with the goal of controlling the invasive sea lamprey (*Petromyzon marinus*) in the Great Lakes. This goal also made it the first piece of legislation to look beyond the strategy of prevention and attempt to legislate control of an established invasive species. The Commission also has the responsibility to work to maintain the fisheries of the Great Lakes, which could be construed as managing other invasive species that could negatively impact those fisheries or preventing their introductions in the first place. Furthermore, a 2000 partnership with the US Corps of Engineers to "to protect and improve fish habitat in the Great Lakes" could also be interpreted as resulting in management of invasive species other than the sea lamprey. Ultimately, however, this Convention, despite being the first to directly address invasive species management, was limited in scope to the Great Lakes and to species that could negatively affect fisheries.

Between 1955 and 1970 there was little change to the federal perspective on invasive species management and control. There was an oblique impact on invasive species management in the 1970s with the passage of two laws: the National Environmental Policy Act (1970) and Endangered Species Act (1973). Although neither piece of legislation had the specific intent of addressing invasive species issues, both can be seen as having indirect impacts on AIS management decisions. The Endangered Species Act, for example, would require management of an invasive species if it threatened an endangered native species. The National Environmental Policy Act requires that the federal government consider the environmental impact of non-native species that a federal agency proposes to introduce or that a federal action might inadvertently introduce or move.

Legislation 1990 - 1999

It wasn't until 1990 that the federal government enacted legislation directly addressing the invasive species problem. In contrast to the fairly narrow concerns of previous laws with regard to aquatic invasive species, the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 was concerned with all aquatic invasive species, although zebra mussels were of special concern, in all US water bodies. Furthermore, the law called on the responsible government agencies to prevent future introductions, reduce impacts of established invasive species, develop new prevention and control methods, and coordinate research, prevention and control efforts, and information dissemination at the federal level. This law was the first federal recognition of the serious and widespread nature of the invasive species problem. It also created the Aquatic Nuisance Species Task Force in order to have oversight and coordination at the federal level. Although this attempt was flawed, it was an important first step, as was discussed in the main text of Chapter 3.

In the years following the sweeping and ambitious Nonindigenous Aquatic Nuisance Prevention and Control Act, there was little significant change in the federal picture in terms of aquatic invasive species management. In 1992 the Alien Species Prevention and Enforcement Act made it illegal to ship those organisms designated as 'injurious' under the Lacey Act through the US Mail, thus expanding the reach of the Lacey Act. In 1994, the North American Agreement on Environmental Cooperation between Canada, Mexico, and the United States formed the Council of the Commission on Environmental Cooperation. The objectives of the Agreement were very broad and general goals of environmental protection. Although it is not the focus of the agreement and is only mentioned briefly, there is specific mention of invasive species: "The Council may consider, and develop recommendations regarding… exotic species that may be harmful" (Article 10(2)(h)). Once again, there was no significant change in federal responsibilities but awareness of invasive species was clearly on the rise.

The 1995 Agreement on the Application of Sanitary and Phytosanitary Measures was an agreement to "harmonize" sanitary and phytosanitary measures among World Trade Organization members. Sanitary and phytosanitary measures are defined, in part, as measures "to protect animal or plant life or health within the territory of the Member from risks arising from the entry, establishment or spread of pests, diseases, disease-carrying organisms or disease-causing organisms". The goal of this policy instrument was not to decrease the risk of introducing invasive species through international trade. Instead, it was to limit the impacts that individual member nations' sanitary and phytosanitary measures could have on international trade. This legislation limits the measures that individual member nations can take to prevent introductions of AIS through international trade and actually requires them to consider minimizing the impact on trade when instituting their sanitary and phytosanitary measures. Although reducing the risk of AIS introductions has always had to be balanced with other considerations, this Agreement mandates that international trade be a primary consideration and created a Committee on Sanitary and Phytosanitary Measures that has the power to monitor and challenge the standards, guidelines, and recommendations set out by member nations. Although this legislation contains language to allow the US to limit introductions of invasive species via trade, it also places significant limits on the US's ability to do just that.

The National Invasive Species Act (1996) was a reauthorization of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 that expanded the list of AIS named in the Act and the areas in which voluntary ballast water management was recommended.

The Water Resources Development Act of 1999 does not create any significant changes in the policy arena and invasive species management is not its central focus. It does, however, reinforce the importance of controlling sea lamprey within the Great Lake system.

Clinton's Executive Order 13112 (1999)

In 1999 Clinton issued an Executive Order aimed at coordinating the federal efforts of controlling invasive species. The Executive Order directed all federal agencies to use their programs and authorities to 1) avoid invasive species introductions and spread, 2) monitor, detect, and respond to invasive species populations, and 3) conduct research and educational activities related to invasive species management. The Executive Order also created the National Invasive Species Council and tasked it with creating a national invasive species management plan and encouraging coordination of invasive species management efforts at levels ranging from local to international.

Although this language is certainly broad, it is also vague and confers no additional authorities or requirements when it comes to agency actions. As one federal employee put it "the executive order says that all agencies should be thinking about [invasive species], but some agencies aren't at all." Although the Executive Order's effectiveness is hampered by its lack of legislative mandate, it has had the effect of putting the invasive species issue on every agency's plate and providing some measure of federal coordination for invasive species management efforts.

Legislation 2006 - 2007

The Great Lakes Fish and Wildlife Restoration Act (2006) is another act in which invasive species management is a tangential, rather than primary concern. It does, however, show a growing awareness of invasive species issues. The main goal of the act is to facilitate the creation and implementation of fish and wildlife restoration projects in the Great Lakes, but all of these projects must be consistent with the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990. The Act also reconfirms the responsibility of the Great Lakes Fishery Commission to control populations of sea lamprey within the Great Lakes.

The increased presence of AIS issues in the 2007 version of the Water Resources Development Act, especially in comparison with the 1999 version, is a sign of the growing awareness of the magnitude of the AIS problem. The act authorizes several major studies: one looking into developing and creating a way to prevent AIS spread into the Upper Mississippi River basin, one to determine the feasibility of an AIS barrier at the Lake Champlain Canal, Vermont and New York, and one to finish construction and maintain operations of the Chicago Sanitary and Ship Canal Dispersal Barrier, Illinois. The act also authorizes creation of a management plan for the Upper Connecticut River ecosystem in which AIS are one of eight major issues to be addressed and permits the use of chemical control techniques of invasive aquatic plants in the Lake Champlain basin, Vermont. The increase in AIS projects, as well as more clearly defined goals of the Act, are encouraging signs. However, it is worth noting that, in Section 1006 of the Act, which identified 43 small aquatic ecosystem restoration projects to be studied and carried out, if appropriate, only one of the 43 projects mentioned restoration in response to AIS damage. Further, of the 100 studies to be carried out under the act's authority, only two mention addressing AIS issues. One study develops protocols for using *Euhrychiopsis lecontei* for biological control of Eurasian milfoil in the northeastern USA and one to determine the feasibility an aquatic ecosystem restoration addressing water quality and AIS issues in New York's Finger Lakes. This suggests that there is still room for improvement.

Appendix J: Extended Description of SMART[A]

Simple Multi-Attribute Rating Technique (SMART) is described by Ralls and Starfield (1995) as “ranking of the sum of weighted criteria.” Possible decision options are evaluated in terms of how well they meet criteria that have been identified as important by those using the technique. SMART has become widely used for several reasons: its transparent nature allows users to have greater confidence in the decision-making process, the technique can be used relatively quickly, and it is useful in a group mediation capacity. Goodwin and Wright (1991) identify eight steps of SMART:

1) Identify the decision makers (e.g., natural resource managers from state and federal agencies, representative from environmental and conservation groups, representative from citizen groups and lake associations),
2) Identify the possible decision options (e.g., determine which of the high priority pixels should be selected for management actions),
3) Identify the criteria important to the decision-makers and the decision problem (e.g., recreational opportunities, biodiversity, budget constraints),
4) Evaluate each decision option in terms of how well they address each criterion (e.g., on a scale of 0 to 100, rank each pixel for how well the recommended management action at that site would protect recreational opportunities or how much it would cost),
5) Weight all of the criteria in terms of their relative importance (e.g., determine the relative weight of each criterion listed in step 3, giving each criterion a percentage weight, such that the percentages given to each criterion sum up to 100%),
6) Use the two rankings (steps 4 and 5 above) to get an overall ranking for each decision option (e.g., multiply the weight given to each criterion with the rank of each option for that criterion, then sum those for all criteria for a given option),
7) Identify the top ranking option, and

[A] Goodwin, P., Wright, G. 1991. Decision Analysis for Management Judgement. John Wiley and Sons, West Sussex, England.
Ralls, K., Starfield, A.M. 1995. Choosing a Management Strategy: Two Structured Decision-Making Methods for Evaluating the Predictions of Stochastic Simulation Models. Conservation Biology 9 (1), 175–181.

8) Perform sensitivity analyses to determine how robust the top option is to changes in the relative criteria rankings and to assumptions made in the option evaluation process.