Strategic Directions for Research on Aquatic Invasive Species for the Upper Midwest Environmental Sciences Center

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Executive Summary

The U.S. Geological Survey's (USGS) Upper Midwest Environmental Science Center (UMESC) has a long history of research in aquatic invasive species—primarily in chemical control of nuisance fishes. The purpose of this document is to identify strategic research directions for invasive species research at UMESC to expand the scope of research from chemical control to include other research directions important to resource managers. This document identifies strategic research directions on invasive species to help Center Management (1) assess new proposals for "base-funded" research, (2) encourage proposals for cyclical USGS funding, (3) focus Center activities in regional or national invasive species planning and advisory activities, and (4) enhance science leadership within existing partnerships related to prevention and control of aquatic invasive species.

Vision

The UMESC will play a more vital role in the USGS to advance the prevention and control of aquatic invasive species by building on Center strengths, developing and growing current partnerships, and applying our collective talents

Assets and Capabilities of the Upper Midwest Environmental Sciences Center for Research on Aquatic Invasive Species

The UMESC is particularly well-positioned to conduct research on aquatic invasive species within the Upper Mississippi River System, the Great Lakes, and the Illinois Inland Waterway that artificially connects the two basins. The culmination of the following factors ensures that the UMESC increase its science impact on the issue of invasive species in the Upper Midwest and on the national front: (1) proximity to two highly invaded ecosystems; (2) the Center's extensive history on invasive species research; (3) strong partnership with the Long Term Resource Monitoring Program; (4) close association with the Great Lakes Fishery Commission; (5) strong quantitative focus; (6) strengths in geospatial, landscape, decision support tool development, and risk assessments; (7) an extensive Invasive Species Containment and Research Complex for culturing and experimenting with aquatic invasive species; (8) the increasing awareness and concern of invasive species by resource managers; and (9) the development of a more cohesive and strategic research plan.

Resource Management Needs for Aquatic Invasive Species Research

The top research priorities identified for the Center by resource managers in a survey and a follow up UMESC-sponsored workshop included conducting assessments to help prevent new introductions, developing new control methods, assessing impacts of invasive species, preventing new invasions, and developing tools to respond rapidly to new introductions. The need to conduct risk assessments and to develop new methods for species screening to prevent new introductions was the most discussed research priority for invasive species. The top species identified by partners were overwhelmingly zebra mussels and Asian carps (bighead and silver carps). Major concerns over these species included preventing their further introduction,

establishment, and spread; developing control alternatives; developing management techniques; identifying their ecosystem effects; and understanding their population dynamics.

Research Directions

Over the next 5 years, invasive species research at the UMESC should highlight activities within the following research directions:

Research Direction 1: Preventing the Introduction of Aquatic Invasive Species
Develop tools to aid managers and other decision makers in preventing the introduction of aquatic invasive species in the United States.

Research Direction 2: Early Detection, Rapid Response, and Spread of Aquatic Invasive Species
Use current expertise at the UMESC to provide science support for resource managers to eradicate newly reported aquatic invasive species and to predict their potential spread in the Great Lakes and Upper Mississippi River basins.

Research Direction 3: Science Support for Monitoring Aquatic Invasive Species
Improve and refine methods used by resource managers to monitor expanding populations of aquatic invasive species in the Upper Mississippi River System.

Research Direction 4: Ecology and Effects of Aquatic Invasive Species
Study the ecology of and identify and quantify the effects of harmful aquatic invasive species on native ecosystems and their components in the Great Lakes and Upper Mississippi River basins.

Research Direction 5: Control and Management of Aquatic Invasive Species
Work with resource managers to develop, improve, and implement alternatives for controlling aquatic invasive species to allow restoration and management of native species and ecosystem function.

Strategic Direction

Research areas to be most aggressively pursued at the UMESC on aquatic invasive species should be supported by both the President's budget and the USGS Invasive Species Program, relate to the unique strengths of the UMESC, and meet resource manager needs. In a survey and follow up UMESC-sponsored workshop, resource managers resoundingly identified Asian carps and zebra mussels as priority species in the Great Lakes and Upper Mississippi River basins. Research on Asian carps is identified in the FY05 President's budget and will be supported by the USGS Invasive Species Program in FY05. These facts, taken with the regional and national concerns regarding Asian carps, support the conclusion that the UMESC should focus research efforts especially on Asian carps, and secondarily on zebra mussels, in the near future, with the caveat that research efforts should be responsive to new species of concern should they emerge. Given the expertise of UMESC scientists, research should focus on preventing their further spread, developing methods to monitor their distribution, developing rapid response plans, determining their effects on native taxa and habitats, and developing control and management strategies for these problematic invasive species.

Recommendations

The following recommendations help to focus invasive species research at the UMESC and to better ensure its success:

1. Because the resulting ecological and physiological shifts and changes caused by invasive species are intrinsically complex, the most productive and efficient research on invasive species integrates across disciplines and spatial and temporal scales. A significant portion of invasive species research conducted at the UMESC should be interdisciplinary, making full use of the talents of UMESC staff (toxicologists, ecologists, chemists, statisticians, and geospatial specialists), and including collaborations within the USGS, the DOI, academic institutions, and other entities as needed.

2. The UMESC should plan strategically with other USGS Centers as well as with management agencies to more effectively reduce duplicity and to leverage appropriated dollars on aquatic invasive species issues. It will also be important to foster new collaborations both within the BRD and in the other disciplines of the Bureau. Full advantage of applicable USGS programs such as the Invasive Species Program and the focus areas of the Upper Mississippi River and the Great Lakes should also be taken.

3. As stated in the National Invasive Species Management Plan (National Invasive Species Council 2001), "the first line of defense for invasive species is prevention." A portion of the research on aquatic invasive species at the UMESC should target prevention in the context of the USGS mission.

4. Invasive species research at UMESC should make full use of contacts within the Center for further research on invasive species such as the administration of the LTRMP at UMESC, the UMESC USFWS contact, the UMESC NPS contact, and the chairs of the Research and Risk Assessment Committee of the Mississippi River Basin and Great Lakes Panels on Aquatic Nuisance Species.

5. The UMESC should use the opportunity presented by membership on the steering committee for the new National Institute for Invasive Species Science in Fort Collins, Colorado, to enhance the role of the Center in this new virtual institute.

6. A UMESC representative should continue to visit field offices of DOI agencies and other resource management agencies in the Great Lakes and Upper Mississippi River System to keep appraised of research needs and interests.

7. Progress made by refocused research on invasive species at the UMESC should be reviewed periodically as a specific part of the USGS cost center review process.

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Appendixes

Acknowledgments

This plan was initiated at the request of Dr. Leslie Holland-Bartels, the Upper Midwest Environmental Sciences Center (UMESC) Center Director, in a charter for the invasive species strategic plan development team (included in this document as an appendix) and was developed by the following UMESC staff: Cindy Kolar (team leader, ecology and fisheries, Branch of Chemistry and Physiology), Michael Boogaard (chemistry, Branch of Chemistry and Physiology), Verdel Dawson (toxicology, Branch of Chemistry and Physiology, retired), Steven Gutreuter (ecology and statistics, Branch of Aquatic Sciences), Brian Ickes (ecology and fisheries, Branch of Aquatic Sciences), Eileen Kirsch (ecology and birds, Branch of Terrestrial Sciences), and Kirk Lohman (ecology, Geospatial Sciences and Decision Support Laboratory). An earlier draft of this document was reviewed by potential partners and other interested parties at a workshop hosted by the UMESC in La Crosse, Wisconsin, June 23, 2004. This document is a result of comments received from workshop participants and further discussions at the UMESC. We wish to sincerely thank those who gave of their time and energy to improve this strategic plan.

A. Purpose of this Strategic Plan

Definition of terms (modified from Executive Order 13112)

Nonindigenous (or non-native) species
With respect to a given ecosystem, any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem

Invasive species
A nonindigenous species whose introduction does or is likely to cause economic or environmental harm or harm to human health

Research on aquatic invasive species has been an important and productive part of the research conducted at the U.S. Geological Survey's (USGS) Upper Midwest Environmental Sciences Center (UMESC) since the inception of the laboratory in the 1950s and has resulted in more than 170 publications (Appendix A) and innumerable reports and technical assistance documents. Through time the majority of this research has focused on the chemical control of invasive fishes. Early efforts to develop chemical control techniques for common carp and other nuisance fishes expanded in the 1960s to a monumental and highly successful effort to control the invasive sea lamprey in the Great Lakes. These efforts, in cooperation with the Great Lakes Fishery Commission (GLFC; see Appendix B for a more thorough description of this involvement), constituted the Center's major research emphasis on invasive species through the early 1990s. After that time, the UMESC extended its chemical control talents to newly established nonindigenous species in the Great Lakes (e.g., Boogaard et al. 1996), and recently, to assessments of taxon-specific chemicals and integrated control of invasive fishes in the southwestern United States (Dawson and Kolar 2004). Other research efforts at the UMESC have examined the effects of invasive species such as zebra mussels and reed canary grass on the Upper Mississippi River System (UMRS). UMESC scientists have experience developing models to predict potential fish invaders in the Great Lakes (Kolar and Lodge 2002), have growing capabilities in conducting risk assessments on invasive species, and have been involved in the early detection and monitoring of invasive species in the UMRS (USGS 1999). The Long Term Resource Monitoring Program (LTRMP) for the UMRS, under the guidance of the UMESC, for example, documented the introduction and expansion of bighead and silver carps in the Upper Mississippi River System. See Appendix C for a more thorough discussion of the history of invasive species research at the UMESC and Appendix D for background on the LTRMP. Although research on aquatic invasive species at the UMESC has been productive, it has become more responsive and less strategic over time.

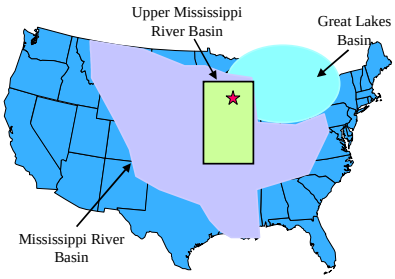
As a result, the UMESC Center Director developed a UMESC invasive species strategic plan development team and provided a charter to guide the team in developing a strategic plan that identifies strategic research directions for UMESC to pursue (Appendix E). The goal of identifying strategic research directions for invasive species research is to expand the scope of research at UMESC from chemical control to include other research directions important to resource managers. This document is the final product of the development team and is the result of group discussions, team writing, and a UMESC-sponsored workshop to obtain comment and review from resource managers. The purpose of this strategic plan is to identify strategic research directions on invasive species at the UMESC to help Center Management to (1) assess new proposals for "base-funded" research, (2) encourage proposals for cyclical USGS funding, (3) focus Center activities in regional or national invasive species planning and advisory

activities, and (4) enhance science leadership within existing partnerships (e.g., GLFC, LTRMP) related to prevention and control of aquatic invasive species.

B. Introduction to Invasive Species Issues

Most nonindigenous species established outside their native range do not cause observable changes in the invaded ecosystem, but a small percentage are perceived as a nuisance. These invasive species can be economically costly (Pimentel et al. 2000), have negative effects on human health (e.g., West Nile virus, malaria, Cholera), and have significant negative environmental effects (e.g., zebra mussels, leafy spurge, and kudzu). Each year thousands of species from microbes to mammals are intentionally or accidentally introduced into the United States (Ludke et al. 2002). Because a single introduction may persist for centuries, the introduction and spread of invasive species are perhaps the least reversible human-induced global change under way (Kolar and Lodge 2002).

The UMESC is located in proximity to two major North American watersheds that have been highly invaded by aquatic and wetland nonindigenous species, the Great Lakes and Mississippi River Basins. More than 160 nonindigenous aquatic species have arrived via an array of introduction vectors and a variety of physical pathways to become established in each of these ecosystems (Rasmussen 1998, NOAA National Center for Research on Aquatic Invasive Species 2004, USGS 2004b). Ninety known aquatic and wetland nonindigenous species have been introduced into the Upper Mississippi River System (UMRS) alone (USGS 2004b). Recent invaders to the Upper and Middle Mississippi River that have either become abundant, have threatened native endangered species (e.g., the Higgins' eye pearly mussel and winged mapleleaf), or have otherwise negatively altered the ecosystem include the zebra mussel, bighead carp, silver carp, and purple loosestrife. Negative effects from historical invasions of the ecosystem, such as declines in native submersed plants and buffalo fishes caused by common carp, are only now beginning to be understood (Bellrichard 1994). Since the sea lamprey invaded the Great Lakes in the 1940s, invasive species have shaped and defined the ecology of that ecosystem. The rate of invasion continues to increase in the Great Lakes, even since requiring incoming ships to exchange fresh water in their ballast tanks with salt water prior to entering the Great Lakes (Holeck et al. 2004). The role of artificial connecting waterways as corridors for species movement has been highlighted recently since several invasive species (e.g., the zebra mussel and white perch) have used the Illinois Inland Waterway to spread from the Great Lakes to the Mississippi River Basin and



Location of the U.S. Geological Survey's Upper Midwest Environmental Sciences Center (indicated with a star).

several others (e.g., bighead and silver carps) are poised to spread to the Great Lakes from the other direction.

C. Context for Developing Strategic Research Directions for Aquatic Invasive Species for the Upper Midwest Environmental Sciences Center

U.S. Geological Survey and the Invasive Species Program

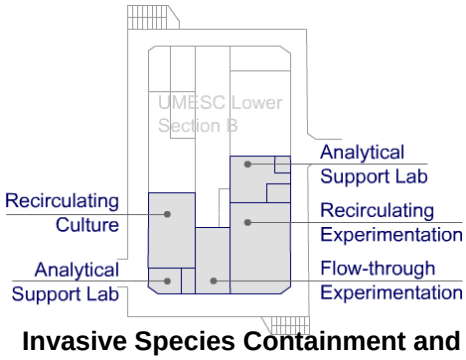
As the primary research agency within the U.S. Department of the Interior (DOI), USGS fills an important niche in Federal efforts to combat invasive species in natural and semi-natural areas. The USGS Invasive Species Program supports cooperative efforts to document and monitor the introduction and spread of invasive species, study the ecology of invaders and factors in the resistance of habitats to invasion, forecast probabilities and locations of future invasions, and develop methods for minimizing their effects (USGS 2004a). The Invasive Species Program is developing a virtual National Institute for Invasive Species Science that will include research conducted at other USGS Science Centers in conjunction with the new National Institute for Invasive Species Science facility in Fort Collins, Colorado. In the future, the USGS Invasive Species Program Element will focus on developing predictive understanding of the relationships between invasive species and environmental drivers operating at many spatial and temporal scales (USGS 2004a).

Upper Midwest Environmental Sciences Center

The UMESC is 1 of 18 USGS biological research and technology centers throughout the United States. The UMESC is located on 65 acres of federally owned land in La Crosse, Wisconsin. We cooperate with the states of Illinois, Iowa, Minnesota, Missouri, and Wisconsin to manage six field stations, which are a critical part of the Nation's largest river inventory, monitoring, and science program. Nearly 200 people work at the Center and field stations. The majority of ecological research at UMESC is conducted in support of the DOI issues and lands in the Upper Midwest. The UMESC links its research closely with other USGS science centers to broadly address ecological and population concerns throughout the Nation's heartland. Ecological research at the UMESC is grouped into five research themes: river ecology (UMESC has conducted extensive research on the effects of commercial navigation and water management on large rivers), restoration of degraded habitats (e.g., mercury in aquatic food webs, chronic effects of contaminants on birds, nutrient enrichment in the Upper Mississippi River), declining species (wide range of research on birds, fish, amphibians, and freshwater mussels of national concern), invasive species (primarily the control and management of aquatic invasive species), and decision support (habitat planning projects, Habitat Needs Assessment Tool, conflict resolution over navigation development and endangered species).

The UMESC has made substantial contributions toward the better understanding of the prevention and control of aquatic invasive species. The UMESC is particularly well-positioned

to conduct research on aquatic invasive species within the UMRS, the Great Lakes, and the Illinois Inland Waterway that artificially connects the two basins. The culmination of the following factors ensures that the UMESC can increase its science impact on the issue of invasive species in the Upper Midwest and on the national front: (1) proximity to two highly invaded ecosystems; (2) the Center's extensive history on invasive species research; (3) strong partnership with the LTRMP; (4) close association with the GLFC; (5) strong quantitative focus; (6) strengths in geospatial, landscape, decision support tool development, and risk assessments; (7) an extensive Invasive Species Containment and Research Complex for culturing and experimenting with aquatic invasive species; (8) the increasing awareness and concern of invasive species by resource managers; and (9) the development of a more cohesive and strategic research plan.



Invasive Species Containment and Research Complex at the Upper Midwest Environmental Sciences Center

D. Challenges for the Future

Refocused and expanded research efforts at the UMESC on aquatic invasive species should take full advantage of Center facilities and human resources, such as extensive laboratory and field capabilities and tool development expertise, to meet resource management needs at the regional and national level. The UMESC should, however, look beyond current strengths at the Center to emerging invasive species issues.

Changing Societal Needs

While UMESC has gained a considerable reputation for successful chemical control of aquatic invasive species (particularly fish), continuing to focus invasive species research solely in this area does not seem prudent. Over the past few decades, the cost to register an existing compound as a new piscicide has increased dramatically because of regulatory changes and was recently estimated at over $5 million (Hubert 2004). Estimated costs of developing a new compound as a piscicide are estimated to be $35-50 million (Hubert 2004). In addition, social pressures against applying chemicals to the environment are significant. For example, although chemical tools were available to attempt to eradicate Eurasian ruffe early in their invasion into Lake Superior, management agencies were reluctant to apply piscicides. Thus even though there is ongoing need in chemical control of aquatic invasive species, a continued single focus on chemical control may not reflect the cutting edge products and services that UMESC scientists can provide. UMESC scientists continue to have unique capabilities in chemical control methodologies and regulatory affairs, and although invasive species research efforts at the Center will lead to diversification of research, it should not preclude work in this area. Research conducted at the UMESC on aquatic invasive species needs to be responsive to the changing political and social climates.

Identifying Resource Management Needs and Developing Strategic Research Directions for Aquatic Invasive Species at the UMESC

Research directions presented in this plan were developed by consulting various documents on invasive species research priorities and results of a resource management survey and a workshop breakout session on resource management research priorities for aquatic invasive species. Documents consulted included the National Invasive Species Management Plan (National Invasive Species Council 2001) and the Invasive Species Program Element Five Year Strategic Plan (USGS 2004a), both important at the national level, and several documents regarding research priorities for invasive species at the regional level (see Appendix F for a listing of documents that were consulted).

The major source of input from resource mangers on the content of this strategic plan was obtained from a facilitated workshop that UMESC hosted at the Radisson Hotel, in La Crosse, Wisconsin, on June 23, 2004. The workshop was attended by 25 people from Federal and state agencies (including USGS, U.S. Fish and Wildlife Service [USFWS], U.S. Forest Service [USFS], National Park Service [NPS], U.S. Environmental Protection Agency [USEPA], U.S. Army Corps of Engineers [USACE], Minnesota Department of Natural Resources, and the Missouri Department of Natural Resources), nongovernmental groups (The Nature Conservancy, Mississippi Interstate Cooperative Resource Association, and the Wisconsin Sea Grant Program), and academic institutions (University of Minnesota). The purpose of the workshop was to obtain comment on an earlier draft of this manuscript and to discuss UMESC capabilities in aquatic invasive species research, obtain input on the immediate regional research needs on invasive species, and identify areas of overlap between UMESC research priorities and resource management agencies. Prior to the workshop, we asked participants to provide the top three invasive species research priorities of their agency to fuel a breakout session during the workshop. Priorities from those lists, in conjunction with discussion at the workshop, were used to develop an understanding of the top research needs for aquatic invasive species in the Great Lakes and Mississippi River basins.

Top research priorities identified by resource managers included conducting risk assessments to help prevent new introductions, developing new control methods, assessing impacts of invasive species, preventing new invasions, and developing tools to respond rapidly to new introductions. Most of the action-based priorities identified prior to and during the workshop were similar, but submissions prior to the workshop included more focus on prevention, whereas during the workshop, the need for developing tools to respond rapidly was stressed. The need to document the effects of invasive species on habitats and native species to justify money spent on control and restoration was mentioned by several groups. The need to conduct risk assessments and to develop new methods for species screening to prevent new introductions was the most discussed research priority for invasive species. The top species-focused priorities identified by resource managers were overwhelmingly zebra mussels and Asian carps (bighead and silver carps). Top concerns over these species included preventing their further introduction, establishment, and spread; developing control alternatives; developing

management techniques; identifying their ecosystem effects; and understanding their population dynamics.

E. Strategic Research Directions for Aquatic Invasive Species at the Upper Midwest Environmental Sciences Center

Research directions for invasive species at the UMESC are organized into the same categories that are used in the USGS Invasive Species Program Element 5-Year Strategic Plan. Our strategic plan identifies a subset of five programmatic areas that are most appropriate for the UMESC to focus research efforts aquatic invasive species: (1) preventing the introduction of aquatic invasive species; (2) early detection, rapid response, and spread of aquatic invasive species; (3) science support for monitoring of aquatic invasive species; (4) ecology and effects of aquatic invasive species; and (5) control and management of aquatic invasive species. The common thread of risk assessment and ecological forecasting can be found throughout each of these programmatic areas. Ecological forecasting and risk assessment are appropriate at all stages of the invasion process—introduction, establishment, spread, and impact—and are capabilities needed within the Federal government to further progress in understanding invasive species issues. These tools include an array of categorical, qualitative, and quantitative methods, some of which include geospatial applications. A substantial niche in ecological forecasting and risk assessment exists, particularly in freshwater and wetland ecosystems and species, within the USGS for the UMESC. Developing a specialization in ecological forecasting and risk assessments, rather than being species or ecosystem focused, would allow the UMESC to apply them to a variety of ecosystems and species as well as to both basic and applied ecological problems.

In the following section, each recommended area of emphasis will be discussed and described. For each, the issue, relevant UMESC assets, rationale for UMESC involvement, and the experience of UMESC scientists in the type of research are briefly described.

Research Direction 1: Preventing the Introduction of Aquatic Invasive Species

Issue. Most research on invasive species has been reactive and occurred after a species is established, is spreading quickly, or is negatively affecting the invaded ecosystem. In the past decade, however, growing emphasis has been placed on preventing the establishment and spread of invasive species. This change in research emphasis is evident in the published literature, in the stated needs of resource managers, in the National Invasive Species Management Plan, and in proposed legislation regarding aquatic invasive species. The most appropriate time to prevent a species invasion is prior to the species being introduced into the United States. After it has become established, often the best that can be done is to prevent spread to uninvaded areas.

Relevant UMESC Assets. The UMESC has the following human, physical, and informational resources that would be of benefit for research on preventing the introduction of aquatic invasive species: (1) geospatial modeling capabilities, (2) statistical and geospatial

quantitative expertise, (3) wide range of biological expertise, (4) some past experience in risk assessments and ecological forecasting, and (5) access to LTRMP and other relevant databases.

Rationale and Experience. Increasing the capability to accurately predict potential invaders and potential effects on invaded ecosystems is central to successfully combating the damaging effects of some invasive species. UMESC scientists have been involved in two projects relevant to preventing introductions of aquatic invasive species: predicting potential fish invaders in the Great Lakes and conducting a biological synopsis and risk assessment on Asian carps to support the decision by the USFWS to list these species as injurious wildlife under the Lacey Act. In addition, UMESC expertise on conducting risk assessments to prevent the introduction of aquatic invasive species has been sought by the Canadian government, the Great Lakes Panel on Aquatic Nuisance Species, the Mississippi River Basin Panel on Aquatic Nuisance Species, and several state governments.

Research Direction 2: Early Detection, Rapid Response, and Spread of Aquatic Invasive Species

Issue. Growing evidence indicates early control of potentially harmful invasive species can prevent them from attaining nuisance levels. Therefore, detecting such nonindigenous species soon after their introduction may be the key to preventing subsequent negative consequences. After an invading species is detected and a risk assessment determines that a rapid response control effort is called for, a control plan must quickly be developed. Development of these plans requires technical expertise (e.g., of chemical efficacy and application) not widely available. Also, after a species becomes established it becomes important to understand the likelihood that the species will spread.

Relevant UMESC Assets. The UMESC has the following human resources to benefit research on the early detection, rapid response, and spread of aquatic invasive species: (1) extensive and unique expertise in chemical control of fishes, (2) geospatial expertise, (3) expertise in developing chemical treatment plans for flowing waters, and (4) risk assessment and other quantitative expertise.

Rationale and Experience. UMESC scientists have extensive experience in research on chemical control of fishes and the facilities and expertise at the Center have made us a national leader in this field. Because of this expertise, resource managers previously have sought the help of UMESC scientists in developing chemical control plans. UMESC scientists have provided technical assistance to management agencies regarding rapid response to new invasions and serve on the Chemical Control Group of the Chicago Rapid Response Committee. Center scientists also have expertise in geospatial and statistical modeling as well as in risk assessments to predict the potential spread of aquatic invasive species.

Research Direction 3: Science Support for Monitoring Aquatic Invasive Species

Issue. Accurate monitoring of invasive species is important in understanding their rate of spread, ecology, and population biology, and is important in developing control plans and

management strategies. Monitoring of invasive species has been identified as a key area in need of improvement in the National Invasive Species Management Plan. Standard survey methods used by monitoring programs, however, were not developed to accurately detect rare species (relevant to early detection of invasive species) or particular invasive species because of their unique behaviors or areas they inhabit. Therefore, innovative, accurate, and reliable methods of monitoring invasive species are needed.

Relevant UMESC Assets. The UMESC has the following human, physical, and informational resources that would benefit scientific support for monitoring of aquatic invasive species: (1) access to expertise within the LTRMP, (2) access to LTRMP data sets, (3) statistical expertise, and (4) geospatial capability.

Rationale and Experience. The UMESC has taken on a national leadership role in the monitoring of riverine aquatic organisms through strong partnering capabilities with the LTRMP (see Appendix D for a description of the LTRMP). As specialists in monitoring of aquatic organisms, UMESC personnel may be approached to develop methods to accurately monitor invasive species in particular situations.

Research Direction 4: Ecology and Effects of Aquatic Invasive Species

Issue. Once an invasive species is established, it is often necessary to determine the ecological effect, especially when such effects are perceived to be economically detrimental. Thus, determining the effects of an invasive species is critical to developing control strategies, management alternatives, or other approaches to mitigate the negative effects from their introduction. Additionally, investigating the effects of invasive species on ecosystems provides an opportunity to learn valuable lessons that can be applied to future invasions. Ecologically, invasive species can affect the abundance, productivity, and survival of native species either directly—by predation and competition or indirectly—by altering nutrient and energy flow pathways or the physical environment. Such effects often result in astounding economic and sociological consequences. Decisions concerning how to control invasive species—and where and at what spatial and temporal scales control can be effective in terms of supporting (restoring) native species and natural ecosystem processes—require an understanding of the full range of effects that some particularly harmful invasive species may cause.

Relevant UMESC Assets. The UMESC has the following human and physical resources that would benefit research on the ecology of invasive species: (1) extensive ecological experience—many historical and ongoing studies in aquatic ecosystems; (2) scientists with diverse specializations; (3) geospatial capabilities; (4) statistical expertise, and (5) extensive facilities, equipment, and infrastructure in place to conduct field and laboratory studies.

Rationale and Experience. Ecosystems are increasingly under threat from certain invasive species, and some invasions can have profound ecological and economic consequences. Comprehensive understanding of the effects of invasive species requires research on the basic biology of the invasive species (autecology) and how it interacts with its environment and the native biotic community (synecology). UMESC scientists have been conducting ecological

research for decades and have extensive experience in field and laboratory ecological studies. Excluding those on contaminants and birds, there have been more than 70 scientific publications related to the ecology of aquatic species published by UMESC scientists in the past 20 years (see Appendix G for selected UMESC ecological publications).

Research Direction 5: Control and Management of Aquatic Invasive Species

Issue. By the time a nonindigenous species is reported to have invaded a new habitat, it is usually already well established and has begun to negatively affect native species and their ecosystem. Managers are then faced with the problem of ecological restoration and management of a highly disrupted system. Options for restoration and management of native species and ecosystem function are limited. Technical expertise, decision support, and risk assessments that evaluate different control and management alternatives are critical to the development of viable management plans.

Relevant UMESC Assets. The UMESC has the following human, physical, and informational resources that would benefit research on managing aquatic invasive species and restoring native habitats and taxa: (1) 40-year history in controlling invasive species (i.e., partnering with the GLFC in sea lamprey control; see Appendix B); (2) geospatial expertise; (3) scientists with diverse backgrounds; and (4) extensive facilities, equipment, and infrastructure to enable laboratory and field research.

Rationale. Scientists at the UMESC have a long history of developing tools and operational plans for the management of invasive species, particularly in the chemical control of nuisance fishes. Scientists from UMESC have demonstrated leadership in the chemical control of sea lamprey in the Great Lakes for 40 years in partnership with the GLFC (see Appendix B). Continued involvement with the GLFC to control sea lampreys in the Great Lakes ensures that the UMESC will not lose capability in this area. With the continuing spread of invasive species, the UMESC should expect to be called upon to continue collaborating on research aimed at developing new approaches to controlling invasive species and restoring native habitats.

F. Strategic Research Directions, Goals, Objectives, and Examples of Research Projects

Below are the objectives of each identified research direction for aquatic invasive species at the UMESC. With each objective are examples of potential research projects at the UMESC given the strengths of the Center, current trends in research on invasive species, and resource management needs. These examples are not intended to be a work plan; rather, they exemplify the types of questions envisioned under each objective.

Research Direction 1: Preventing the Introduction of Aquatic Invasive Species *Goal. Develop tools to aid resource managers and other decision makers in preventing the introduction of aquatic invasive species in the United States.*
Objective 1. Use ecological forecasting and risk assessment information to develop priorities to prevent the initial introduction of potential aquatic invasive species.
Example: Establish a robust system for ranking risk assessment factors that could be used to determine the most critical pathways of entry, vectors of transport, species most likely to become established, and habitats most at risk
Example: Conduct risk assessments for individual species (e.g., bighead and silver carp risk assessments to support USFWS listing decisions for injurious species under the Lacey Act)
Example: Develop species screening tools to assess risk of potential new invaders
Example: Identify high-risk entry points for aquatic invasive species (e.g., ports, aquaculture facilities near highly connected inland waterways) to prevent introduction through better pathway control
Resource management agencies interested in preventing the introduction of aquatic invasive species A partial listing of agencies or entities that have funded or are currently funding this type of research includes National Aeronautics and Space Administration (NASA), USFWS, USEPA, USACE, the Great Lakes Protection Fund, and state management agencies. International Association of Fish and Wildlife Agencies (IAFWA) has also expressed interest.

Research Direction 2: Early Detection, Rapid Response, and Spread of Aquatic Invasive Species *Goal. Use current expertise at the UMESC to provide science support for resource managers to eradicate newly reported aquatic invasive species and to predict their potential spread in the Great Lakes and Upper Mississippi River basins.*
Objective 1. Use ecological forecasting and risk assessment to aid resource managers with decision-making processes after new aquatic invaders are detected early.
Example: Quantify risk of recently discovered invading species to determine the level appropriate response (i.e., in a given situation, are the risks posed by a particular invader serious enough to lead to rapid response)
Objective 2. Collaborate in the development of rapid response plans for the control of invasive aquatic species.
Example: Identify high-risk entry points for aquatic invasive species (e.g., ports, aquaculture facilities near highly connected inland waterways) in preparation for rapid response initiatives
Example: Develop and demonstrate UMESC capabilities in providing science support for rapid response to aquatic invasive species (e.g., pilot project integrating geospatial and chemical control expertise)
Example: Maintain existing advisory roles on rapid response committees (e.g., Chicago Rapid Response Committee) and provide scientific expertise for interagency rapid response teams
Objective 3. Use ecological forecasting and risk assessment information to prevent and predict the spread of established invaders to uninvaded areas.
Example: Conduct risk assessment of the potential for established invaders to invade new areas (e.g., zebra mussels into inland lakes, bighead and silver carps into backwater habitats)
Example: Develop geospatial management tool to determine regions or habitat types of the UMRS most vulnerable to invasion
Example: Model the spread of individual species in the UMRS over time to identify risky pathways, hindrances to spread (e.g., Lock and Dam 19), taxa that spread quickly, or habitats most prone to invasion
Example: Test theorized causes and correlates of invasibility with case studies
Resource management agencies interested in early detection, rapid response, and spread of aquatic invasive species A partial listing of agencies or entities that have funded or are currently funding this type of research includes USFWS, NPS, Bureau of Reclamation (BOR), and USACE.

Research Direction 3: Science Support for Monitoring Aquatic Invasive Species *Goal.* Improve and refine methods used by resource managers to monitor expanding populations of aquatic invasive species in the Upper Mississippi River System.
Objective 1. Develop and improve monitoring methods so that resource managers can more reliably detect and monitor aquatic invasive species.
Example: Develop scientifically sound monitoring techniques that provide multi-scale data and optimize human resources
Example: Determine whether methods developed above can be applied to different taxa
Example: Develop methods to assess populations of bighead and silver carps in the UMRS and round goby in the Illinois Inland Waterway
Objective 2. Use existing monitoring expertise at UMESC, especially within the LTRMP, to develop effective strategies for tracking the status and trends of invading aquatic species.
Example: Synthesize existing LTRMP data sources for information on nonindigenous species within the UMRS and identify hotspots of invasion
Example: Evaluate methods developed for native species to monitor invasive species
Example: Integrate historical records, remote sensing data, and field sampling data in geographic information systems to document spatial and temporal patterns of expanding invasions at landscape and regional scales
Resource management agencies interested in science support for monitoring aquatic invasive species A partial listing of agencies or entities that have funded or are currently funding this type of research includes USACE and the GLFC in the Illinois Inland Waterway, USFWS in the Great Lakes, NPS on a regional or national scale, and state management agencies.

Research Direction 4: Ecology and Effects of Aquatic Invasive Species *Goal.* Study the ecology of and identify and quantify the effects of harmful aquatic invasive species on native ecosystems and their components in the Great Lakes and Upper Mississippi River basins.
Objective 1. Study the physiology, ecology, and population dynamics of aquatic invasive species to develop possible avenues for control and mitigation (autecology of invasive species).
Example: Identify areas or stages susceptible to control (chemical, physical, and biological)
Example: Determine specific life-stage habitat requirements of aquatic invasive species to predict effects on native species, constraints to spread, and areas to implement control
Example: Determine native taxa most likely to be affected by invasive species
Example: Examine life history characteristics of invading species (i.e., Asian carps) in field and laboratory experiments to better determine the potential spread of the species
Objective 2. Determine the individual and cumulative effects of aquatic invasive species on ecosystem processes (synecology of invasive species).
Example: Determine the effects of aquatic invasive species on energy pathways, food webs, and the physical environment (e.g., increased suspended sediment resuspension, and destruction of vegetation)
Example: Assess the direct and indirect effects of aquatic invasive species on habitats and species of management concern
Objective 3. Study ecosystem level processes and conditions that may control aquatic invasive species or keep them from spreading (effects of management).
Example: Study the efficacy of management techniques in controlling invasive species and reducing their spread such as fire, erosion, and deposition processes, atmospheric and climatological stresses, chemical pollution, land use changes and management practices, chemical applications, habitat manipulation, and habitat restoration
Example: Assess whether dams alter the extent of effects of invasive species on native species (i.e., does floodplain restoration differentially benefit invasive or native species)
Example: Determine whether properties of ecosystems affect vulnerability to invasion (e.g., food-web complexity, predator abundance, potential pathogens and parasites, connectivity, resilience, nutrient enhancement, altered hydrology, other disturbances, climate change, and production)
Resource management agencies interested in ecology and effects of aquatic invasive species Understanding the effects of invasive species on native species, particularly imperiled species, is a need of many management agencies. A partial listing of agencies or entities that have funded or are currently funding this type of research includes NPS, U.S. Forest Service (USFS), USFWS, IAFWA, the Great Lakes Protection Fund, and state management agencies.

Research Direction 5: Control and Management of Aquatic Invasive Species *Goal. Work with resource managers to develop, improve, and implement alternatives for controlling aquatic invasive species to allow restoration and management of native species and ecosystem function.*
Objective 1: Maintain and demonstrate UMESC capability in chemical control of aquatic invasive species.
Example: Provide technical assistance to agencies responsible for controlling aquatic invasive species, and for restoring native species, critical habitat, or threatened and endangered species
Example: Publish a synthetic paper on the current state of chemical control effectiveness for aquatic species or produce marketing document of UMESC capabilities in chemical control
Objective 2. Collaborate with interdisciplinary teams to develop and implement new approaches and methods to control aquatic invasive species.
Example: Develop new formulations of general or selective chemical toxicants
Example: Develop new biological control methods
Example: Develop integrated pest management strategies
Example: Provide assistance with regulatory affairs to resource managers as needed to implement new control alternatives
Objective 3. Develop scientifically valid procedures to help guide managers in effectively managing aquatic invasive species.
Example: Develop protocols for rapid response, preventing range expansion, selecting tools for reducing populations of invasive species, restoring habitats altered by invasive species, or protecting and restoring threatened and endangered species
Example: Develop tools to choose appropriate management actions based on ecological forecasting and risk assessments
Objective 4. Collaborate on research to understand the ecological processes most in need of restoration in the Mississippi River System to mitigate the effects of aquatic invasive species.
Example: Identify sites and processes most in need of restoration
Example: Develop adaptive management frameworks for restoring native species in the face of invaders
Example: Evaluate whether floodplain restoration differentially benefit invasive species or native species
Resource management agencies interested in control and management of aquatic invasive species A partial listing of agencies/entities that have or are currently funding this type of research includes USFWS, GLFC, USEPA, NPS, Sea Grant Program, BOR, USACE, and state agencies.

G. Research Areas of Emphasis within the Identified Strategic Research Directions

The field of invasive species research is broad and natural resource management agencies are interested in a wide variety of research questions on aquatic invasive species. This strategic plan identifies research directions that are most appropriately addressed at the UMESC and is not meant to be a work plan. Because invasive species research at UMESC currently involves a small number of staff and because of current and anticipated budgetary constraints, it is prudent for the UMESC to identify avenues of research on aquatic invasive species that should be most aggressively pursued at the Center. Focusing research efforts in one or two research directions in the near future will better enable development of higher impact of scientific products.

Research areas to be most aggressively pursued at the UMESC on aquatic invasive species should be supported by the President's budget, the USGS Invasive Species Program, relate to the unique strengths of the UMESC, and meet resource management needs. Resource managers resoundingly identified Asian carps and zebra mussels as priority species in a survey and a UMESC-sponsored workshop. Research on Asian carps is identified in the FY05 President's budget and will be supported by the USGS Invasive Species Program in FY05. These facts, taken with the regional and national concern regarding Asian carps, indicate that the UMESC should focus research efforts especially on Asian carps, and secondarily on zebra mussels, in the near future, with the caveat that research efforts should be responsive to new species of concern, should they emerge. Given the expertise of UMESC scientists, research should focus on preventing their further spread, developing methods to monitor their distribution, developing rapid response plans, determining their effects on native taxa and habitats, and developing control and management strategies for these problematic invasive species.

H. Recommendations

The following recommendations help to focus invasive species research at the UMESC and to better ensure its success:

1. Because the resulting ecological and physiological shifts and changes caused by invasive species are intrinsically complex, the most productive and efficient research on invasive species integrates across disciplines and spatial and temporal scales. A significant portion of invasive species research conducted at the UMESC should be interdisciplinary, making full use of the talents of UMESC staff (toxicologists, ecologists, chemists, statisticians, and geospatial specialists), and including collaborations within the USGS, the DOI, academic institutions, and other entities as needed.

2. The UMESC should plan strategically with other USGS Centers as well as with management agencies to more effectively reduce duplicity and to leverage appropriated

dollars on aquatic invasive species issues. It will also be important to foster new collaborations both within the BRD and in the other disciplines of the Bureau. Full advantage of applicable USGS programs such as the Invasive Species Program and the focus areas of the Upper Mississippi River and the Great Lakes should also be taken.

3. As stated in the National Invasive Species Management Plan (National Invasive Species Council 2001), "the first line of defense for invasive species is prevention." A portion of the research on aquatic invasive species at the UMESC should target prevention in the context of the USGS mission.

4. Invasive species research at UMESC should make full use of contacts within the Center for further research on invasive species such as the administration of the LTRMP at UMESC, the UMESC USFWS contact, the UMESC NPS contact, and the chairs of the Research and Risk Assessment Committee of the Mississippi River Basin and Great Lakes Panels on Aquatic Nuisance Species.

5. The UMESC should use the opportunity presented by membership on the steering committee for the new National Institute for Invasive Species Science in Fort Collins, Colorado, to enhance the role of the Center in this new virtual institute.

6. A UMESC representative should continue to visit field offices of DOI agencies and other resource management agencies in the Great Lakes and UMRS to keep appraised of research needs and interests.

7. Progress made by refocused research on invasive species at the UMESC should be reviewed periodically as a specific part of the USGS cost center review process.

I. Implementation Constraints

The wealth and diversity of scientific expertise, facilities, equipment, and infrastructure at the UMESC puts the Center in a good position to further develop invasive species research efforts. Assigning personnel dedicated to implementing the plan is essential. Additional training may be necessary for several UMESC scientists to further develop expertise in risk assessment and ecological forecasting. Hiring an ecosystem modeler could strengthen the risk assessment and environmental effects aspects of the strategic plan. Collaboration or contract with other agencies or universities, however, can meet this need should it become necessary.

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K. Glossary

BOR	Bureau of Reclamation
BRD	Biological Resources Discipline
DOI	U.S. Department of the Interior
GLFC	Great Lakes Fishery Commission
IAFWA	International Association of Fish and Wildlife Agencies
LTRMP	Long Term Resource Monitoring Program
NASA	National Aeronautics and Space Administration
NPS	National Park Service
UMESC	Upper Midwest Environmental Sciences Center
UMRS	Upper Mississippi River System
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

L. Scientific Names of Species Used

Plants	
Leafy spurge	*Euphorbia esula*
Kudzu	*Pueraria montana* var. *lobata*
Reed canary grass	*Phalaris arundinacea*
Purple loosestrife	*Lythrum salicaria*
Invertebrates	
Higgins' eye pearly mussel	*Lampsilis higginsii*
Winged mapleleaf	*Quadrula fragosa*
Zebra mussel	*Dreissena polymorpha*
Fishes	
Bighead carp	*Hypophthalmichthys nobilis*
Buffalo fishes	*Ictiobus* sp.
Common carp	*Cyprinus carpio*
Eurasian ruffe	*Gymnocephalus cernuus*
Round goby	*Neogobius melanostomus*
Sea lamprey	*Petromyzon marinus*
Silver carp	*Hypophthalmichthys molitrix*
White perch	*Morone americana*

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Appendix B. Background on the Upper Midwest Environmental Science Center's Involvement in the Great Lakes Fishery Commission's Sea Lamprey Control Program

Sea lampreys (*Petromyzon marinus*) are primitive, jawless fish that are parasitic to other fishes during their adult life stage. They use an oral disk to attach to larger fish and sharp teeth to rasp through the scales and skin of host fishes to feed on their body fluids. Massive fluid loss and infections at the wound site often result in death to the host fish. During its life as a parasite, each sea lamprey can kill the equivalent of 40 or more pounds of fish.

Sea lampreys are native to the Atlantic Ocean and ascend streams and rivers to spawn. They were first found in Lake Erie in 1921, after traveling through the Welland Canal. From Lake Erie, sea lampreys invaded the three remaining Great Lakes. By the 1940s, sea lampreys were abundant in all of the upper Great Lakes, contributing to severe reductions in the lake trout (*Salvelinus namaycush*), whitefish (*Coregonus* sp.), and cisco (*Coregonus artedii*) populations. Commercial catches of lake trout from Lakes Superior and Huron declined from 4.5 million pounds annually before sea lampreys invaded to about only 300 thousand pounds annually in the early 1960s. Motivated by the resulting collapse of commercial fisheries in the Great Lakes, the governments of the United States and Canada created the Great Lakes Fishery Commission (GLFC) by bilateral agreement in 1955 to protect the fisheries resources of the Great Lakes Basin.

An intensive multinational sea lamprey control program, implemented by the Canadian Department of Fisheries and Oceans (DFO) and the U.S. Fish and Wildlife Service (USFWS), has relied heavily on the use of the larval lampricides 3-trifluoromethyl-4-nitrophenol (TFM) and 2',5-dichloro-4'-nitrosalycylanilide (niclosamide). Aggressive implementation of the control program has reduced adult sea lamprey populations and allowed the recovery of important fish stocks worth $3.5 billion annually to the economies of the Great Lakes states and Canadian provinces.

Because larval sea lampreys remain burrowed in the sediments of streams and rivers for 4 to 7 years, the control program focused on this life stage. A program was begun to identify a chemical that could be used to control larval sea lamprey. In the process of screening more than 6,000 chemicals during the 1950s, USFWS scientists discovered the compound TFM, which demonstrated significant selectivity in killing sea lampreys without affecting other aquatic organisms. A chemical control program based on TFM had begun. Since that time, another lampricide, niclosamide, was also identified, followed by the development of a number of specialized formulations of both chemicals. Of the 5,747 streams and tributaries of the Great Lakes, about 250 are chemically treated on a 3-5 year cycle.

In a typical treatment, the concentration of TFM to be used is determined by on-site toxicity testing and/or analysis of the physico-chemical characteristics of the water that affect TFM toxicity (pH, alkalinity, discharge). Treatment concentrations of TFM used in tributaries of the Great Lakes range from 1 to 14 mg/L depending on the water quality of the treated stream. In most applications, only TFM is applied to control sea lampreys. Occasionally a combination of TFM and Bayluscide is applied to reduce the amount of TFM required for treatment. This is a

cost effective measure in instances where large quantities of TFM would normally be required, such as streams or rivers with high discharge rates. A granular formulation of Bayluscide is also used as a control tool. It is applied in lentic areas and streams where TFM applications are impractical, such as the St. Marys River. In addition to chemical control of larval sea lamprey, growing emphasis continues to be placed on the integrated control of this detrimental invasive species, including trapping, sterile-male release, the construction of barriers, and new research on using pheromones produced by sea lamprey to control their populations.

The role of Upper Midwest Environmental Sciences Center (UMESC) scientists in the control of sea lamprey in the Great Lakes has three major goals. The first is to assist the GLFC, the USFWS, and the DFO with technical aspects of the chemical sea lamprey control program. The second objective is to provide regulatory affairs liaison with Health Canada and the U.S. Environmental Protection Agency (USEPA) for maintaining the registrations of the lampricides and pursing registrations for sea lamprey pheromones. The third is to conduct research to support the sea lamprey control program.

A major emphasis of the technical assistance provided by UMESC staff involves direct assistance to the control agents. Examples of the assistance include the following: (1) providing science-based information to aid in the development of treatment guidelines for bodies of water which are habitats for threatened and endangered species; (2) providing analytical services by conducting assays of the active ingredients in production batches of the lampricide formulations; and (3) verifying the concentrations of the field standards that are used to assure the accuracy of the sea lamprey control applications. Center staff also monitors reports of adverse effects resulting from the use of the lampricides, and file reports of the effects with USEPA. Additionally, UMESC staff serves as contacts for inquiries from the public regarding the use of the lampricides and their potential impacts on the environment and human health.

Because the use of TFM and niclosamide in streams tributary to the Great Lakes is regulated by the USEPA and in Canada by Health Canada, both agencies require that registrations of the chemicals be maintained and updated continually to ensure their safety to humans and the environment. The UMESC staff has extensive technical knowledge of fishery management chemicals and the Sea Lamprey Control Program and consequently work closely with the technical staff of USEPA, Health Canada, the GLFC, the U.S. Department of State, USFWS, and DFO to ensure that the two control chemicals are available for sea lamprey control functions. In fulfilling these commitments to the GLFC, UMESC staff has a continuing responsibility for reviewing and upgrading the registration status of both lampricides to current guidelines of the regulating agency and for providing data to ensure that the registrations are kept current in both countries. UMESC staff has also been instrumental in obtaining Experimental Use Permits from the USEPA to field test two sea lamprey pheromones that show promise for piscicide free control of sea lampreys in the future.

Objectives of research conducted at the UMESC to support the sea Lamprey Control Program include developing new lampricide formulations and improving existing formulations, improving treatment models to enhance the efficiency of applications of the lampricides and assessing the risk of lampricide applications to non-target organisms.

Appendix C. History of Invasive Species Research at the Upper Midwest Environmental Sciences Center

The study of invasive species at the Upper Midwest Environmental Sciences Center (UMESC) dates back to the formation of a federal research presence in La Crosse, Wisconsin in the 1950s. The American Fisheries Society resolved at its 88th annual meeting in 1958 to recommend an expansion of research in fish control to the Secretary of the Interior. In that same year, Congress made the first appropriation for establishment of the Fish Control Laboratory at La Crosse, Wisconsin. The Bureau of Sport Fisheries and Wildlife established the laboratory in 1959. The initial mission of the laboratory was to develop means for efficient manipulation of freshwater fish. In particular, safe and economical controls (chemical, biological, electrical, or mechanical) were sought for undesirable fish populations in standing and flowing waters. The objectives were sufficiently broad to encompass investigation and development of any new tools that may be useful in fishery management, fish culture, or fishery research. Early recognition was given to the potentials of chemical control agents such as general and selective toxicants, attractants, repellants, anesthetics, sterilants, spawning inducers, osmoregulators, marking dyes, medications for diseases, and sedatives and decontaminants for fish distribution. Emphasis was on finding selective toxicants for invasive and nuisance fishes.

Early studies involved evaluations of various chemicals such as toxaphene and antimycin as piscicides. Much of the research focused on development of general toxicants, but the laboratory soon became involved in the effort for selective control of sea lamprey (*Petromyzon marinus*) in the Great Lakes. The Fish Control Laboratory at La Crosse and the Hammond Bay Biological Station at Hammond Bay, Michigan, operated in the development and registration of the lampricides TFM and Bayluscide that are still being used as the primary means of managing sea lamprey populations in the Great Lakes. In the 1960s and 1970s, the laboratory concentrated its invasive species research on the efficacy and environmental safety of the lampricides. These studies included toxicity to target and non-target organisms, analytical methodologies, residue studies, uptake, metabolism, and elimination studies, photolysis studies, and microbial degradation studies. During this time, rotenone was also being developed and registered as a piscicide. New piscicidal candidates were being evaluated such as juglone, isobornyl thiocyanoacetate (Thanite), Salicylanilide I, and the selective toxicants, Squoxin and 2-(digeranylamino)-ethanol (GD-174).

In 1947, Congress passed the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) that regulated the licensing and application of pesticides, primarily for agriculture. Initially the U.S. Department of Agriculture was given the responsibility of registering pesticides. The responsibility passed to the U.S. Environmental Protection Agency (USEPA) when it was created in 1970. Amendments to FIFRA were made in 1980 and 1988, with the latter amendment requiring that all pesticides registered prior to 1984 undergo a reregistration process. This was largely done because testing methodology had improved significantly, and Congress felt this necessitated repeating the registration process for older chemicals. Consequently, in the late 1980s and 1990s research effort was once again centered on the previously registered piscicides, antimycin, rotenone, TFM, and Bayluscide. New data, primarily involving safety studies, were collected and submitted to the USEPA in support of the reregistration process.

Thus, development of chemical controls for nuisance fishes such as common carp (*Cyprinus carpio*) at the UMESC was expanded in the 1960s to the control of invasive sea lamprey in the Great Lakes. These two efforts constituted the Center's major research emphasis on invasive species through the 1980s. The late 1980s brought a rapid expansion of the number of nonindigenous species in the aquatic systems of the Upper Midwest. New invasive organisms found their way into the Great Lakes, presumably by way of ballast water discharges from ocean-going vessels. These included the zebra mussel (*Dreissena polymorpha*) , Eurasian ruffe (*Gymnocephalus cernuus*) , and round goby (*Neogobius melanostomus*). The range of the zebra mussel expanded considerably in the 1990s, and the species became a serious ecological threat throughout the Great Lakes and the Mississippi River Basin. As a result of these new invasions and range expansions, the UMESC expanded its success with sea lamprey and focused its chemical control talents on new Great Lakes invasive species. In response to the zebra mussel invasion of the Upper Mississippi River System, UMESC scientists also examined food-web effects of zebra mussels on native fishes and birds, their ability to bioaccumulate toxins, and on ways to minimize the likelihood of introducing zebra mussels concurrent with native mussel conservation activities. Also from the 1990s until currently, the Long Term Resource Monitoring Program for the Upper Mississippi River, under the guidance of the UMESC, has documented the introduction and expansion of bighead (*Hypothalmichthys nobilis*) and silver carps (*Hypothalmichthys molitrix*) and other fishes such as white perch (*Morone americana*) in the system.

In 2002, the UMESC stepped out of its regional focus to partner with the Bureau of Reclamation to assess integrated strategies to control invasive fishes in the southwestern United States. The native fish fauna of the southwestern United States, including that in the Gila River Basin in Arizona and New Mexico, is critically imperiled as a result of the introduction and establishment of nonindigenous fishes. As a result, UMESC scientists assembled a comprehensive review of integrated management techniques to control nonnative fishes.

Appendix D. Background on the Long Term Resource Monitoring Program

The Long Term Resource Monitoring Program (LTRMP) was authorized under the Water Resources Development Act of 1986 (Public Law 99-662) as an element of the U.S. Army Corps of Engineers' Environmental Management Program. The LTRMP is being implemented by the Upper Midwest Environmental Sciences Center, a U.S. Geological Survey science center, in cooperation with the five Upper Mississippi River System (UMRS) States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin. The U.S. Army Corps of Engineers provides guidance and has overall Program responsibility. The mode of operation and respective roles of the agencies are outlined in a 1988 Memorandum of Agreement.

The UMRS encompasses the commercially navigable reaches of the Upper Mississippi River, as well as the Illinois River and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers. Congress has declared the UMRS to be both a nationally significant ecosystem and a nationally significant commercial navigation system. The mission of the LTRMP is to provide decision makers with information for maintaining the UMRS as a sustainable large river ecosystem given its multiple-use character. The long-term goals of the Program are to understand the system, determine resource trends and effects, develop management alternatives, manage information, and develop useful products.

The LTRMP, a component of the Environmental Management Program for the UMRS, is administered by the U.S. Geological Survey's Upper Midwest Environmental Sciences Center (UMESC) in La Crosse, Wisconsin. The LTRMP supports six field stations operated by state agencies in Illinois, Iowa, Minnesota, Missouri, and Wisconsin to collect most of the monitoring data. Information on important ecosystem components, including water quality, fish, vegetation, and macroinvertebrates are obtained annually using standardized procedures. Other data such as land cover/land use and bathymetry are gathered and analyzed periodically. Monitoring activities focus primarily on six study areas: Navigation Pools 4, 8, 13, and 26 and the Open River Reach on the Mississippi River and La Grange Pool on the Illinois River. Information from monitoring activities and a variety of other sources are available online at the Center's Data Library Web site http://www.umesc.usgs.gov/data_library/data_library.html.

Appendix E. Charter for the Invasive Species Strategic Plan Development Team

Background

The Upper Midwest Environmental Sciences Center (UMESC) has a long history of study of invasive species dating back to the original formation of a federal research presence in La Crosse WI in the 1950's. Efforts to develop chemical controls for common carp to mitigate impacts to waterfowl production soon expanded in the 1960's to a monumental and highly successful effort to control invasive sea lamprey in the Great Lakes. These two efforts constituted the Center=s major research emphasis on invasives through the 1980's and the early 1990's. However, the 1990's brought a rapid expansion of the number of nonindigenous species in the aquatic systems of the Upper Midwest. The invertebrate zebra mussel (discovered in Lake St. Claire near Detroit Michigan in 1988) expanded dramatically in the 1990's to become a serious ecological threat throughout the Great Lakes and the Mississippi River Basin. Populations of the fishes round goby (St. Clair River north of Detroit, 1990) and Eurasian ruffe (western Lake Superior, 1986) have become predominant in areas of the Great Lakes with the round goby threatening expansion into the Mississippi River Basin through the Illinois Waterway System. As a result of these new invasions, UMESC expanded its success with sea lamprey and focused its chemical control talents on new Great Lakes nonindigenous species. The Center expanded its existing ecological program on the Upper Mississippi River to examine zebra mussels in the river. Also on the river, the Long-term Resource Monitoring Program for the Upper Mississippi River, under the guidance of UMESC, has documented the introduction and expansion of several new species of Asiatic carps, a result of accidental releases from private aquaculture farms. In 2002, UMESC stepped out of its regional focus to partner with the Bureau of Reclamation to assess integrated strategies to control invasive fishes in the Southwest United States. Here, species originally stocked into SW waters for sport fishery purposes are now in conflict with endangered species restoration efforts.

Numerous Abase@ budget reductions in the early 1990's resulted in most of the Center=s invasive species research being directed under reimbursable contracts for partners such as the Great Lakes Fishery Commission or funded by other DOI agencies (e.g. FWS, BOR). Center research has become less strategic and increasingly opportunistic and short-term in nature. However, the physiological breadth and ecological complexity of the expanding array of invasive aquatic species requires a more holistic and strategic research approach if control measures are to be effective or ecological consequences are to be understood. Also, societal concern for this issue has increased as economic and long-term ecological impacts have become more evident.

Several retirements of UMESC senior research staff have allowed the Center Director to begin a restructuring of the Center research approach to invasive species that combines a re-infusion of Abase@ funds with existing reimbursable efforts to produce a more cohesive and effective long-term research approach. A new senior scientist was hired (FY03) to lead this effort, the first step of which is development of a Center Strategic Plan for Invasive Species.

Guidance

The Committee=s output will be used as a road map by Center Management to 1) assess new proposals for Abase-funded@ research, 2) encourage proposals for cyclical USGS funding, 3) focus Center activities in regional or national invasive species planning and advisory activities, 4) enhance science leadership within existing partnerships (e.g. GLFC, LTRMP) related to impacts or control of invasive species, and 5) identify new partnerships that are appropriate for UMESC. Below is some guidance under which the Committee should function:

The Committee=s work is strategic and is not to develop specific study plans
UMESC plan must Aroll up@ under the 5-year Invasive Species Program Element Strategic Plan.
UMESC=s plan will reflect that USGS is the science arm for DOI agencies and should target efforts toward critical management concerns of those agencies.
UMESC research must take advantage of the unique combination of talents housed in the Center, across organizational unit, particularly in the geospatial, landscape, and decision support arenas.
Any UMESC research must be framed in a philosophy of Athink globally, act locally.@
The Plan should, if possible, expand off of existing long-term partner-funded tactical or technical activities of the Center (e.g. LTRMP, GLFC).
The Plan will direct UMESC in critical science directions that have demonstrated, or the committee believes will demonstrate, expanding funding opportunities in a 5-year time frame.
The Plan must stand alone. Therefore, the document should include as appendices background materials describing past research of the Center and any planning or partner documents the UMESC plan might point to.
The Strategic Plan should not simply address desired research directions, but consider what are appropriate communication strategies, UMESC leadership/committee participation, and even thoughts on future staffing needs, all at a strategic level.

Timing and Mode of Operation

The Committee is expected to provide an executive briefing to the Center Senior Science Forum and the Management Team by September 15. Thus a complete draft of the Strategy Document will be provided to Management NLT Sept 1, 2003. The Committee will take an opportunity for a mid-course assessment by meeting with the Center Director in June. It is essential that the Committee reach out and interact with all Center staff and appropriate partners to gather insight on options for the strategic direction of UMESC=s Invasive Species Program. If the Committee believes it needs travel funds to accomplish elements of this assignment, a specific request should be made to the Center Director. All meeting and interactions will be documented and included as appendices to the final report. Upon acceptance of the draft document, the Team will work with the Center Communications Team to produce a final document to be shared with USGS regional and headquarter=s staff and appropriate partners

Committee Composition

The Committee is composed of seven members (and a recorder), all of whom are willing to become familiar with National, USGS, and Partner invasive species activities that influence future UMESC research options. The Center Director in consultation with the Management Team and Committee Chairperson selected six Center science and technical staff to participate in this planning effort. These staff were selected because they represent the breadth of existing UMESC talent in invasive species as well as capabilities in emerging science areas.

Cindy Kolar, Committee Chair
Verdel Dawson
Mike Boogaard
Eileen Kirsch
Steve Gutreuter
Brian Ickes
Kirk Lohman
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Appendix F. Strategic Documents of Other Entities for Invasive Species Research at the National or Regional Scale Consulted in Developing This Strategic Plan

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2. Species of concern: Midwest Natural Resource Group. Partner Responses for Early Detection and Rapid Response
3. National Invasive Species Council. 2001. Meeting the invasive species challenge: National Invasive Species Management Plan. 80 pp. Available online at http://www.invasivespecies.gov.
4. U.S. Geological Survey Invasive Species Program Element Five Year Strategic Plan. 2003 (draft). 50 pp.
5. Mississippi River Basin Panel on Aquatic Nuisance Species Risk Assessment and Research Committee ANS Research Priorities for the Mississippi River Basin (draft) January 2004
6. U.S. Fish and Wildlife Service. 2002. Fish and Wildlife Resource Conservation Priorities. Region 3. January 2002. Version 2.0. 34pp.
7. U.S. Geological Survey Eastern Region Integrated Science Priorities
8. Research priorities for aquatic invasive species. Hearing before the Subcommittee on Environment, Technology, and Standards Committee on Science. House of Representatives, One hundred seventh Congress, Second Session. June 20, 2002. Serial Number 107-72. Available online at http://www.house.gov/science.
9. Non-native Invasive Species Framework for Plants and Animals in the U.S. Forest Service, Eastern Region. 2003. R9 Regional Leadership Team, April 11, 2003.
10. Strategic plan for the U.S. Geological Survey Program on the Status and Trends of Biological Resources, 2004-2009.
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