

Aquatic Invasive Species

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Introduction

Progress towards the restoration of the Great Lakes continues to be undermined by the ongoing introduction and range expansion of more than 180 aquatic species. About 10% of these introduced species have become invasive; that is, their introduction has adversely affected the environment, economy and/or human health. Economic losses caused by AIS in the Great Lakes basin are estimated at \$5 billion per year (Great Lakes Regional Collaboration 2005). Great Lakes ecosystems are impacted by AIS through: the degradation of habitats, competition or predation with native and naturalized species, and alterations in the flow of nutrients that underpin all food webs.

The full impact on wildlife and biodiversity values of the Great Lakes cannot be measured, but we do know AIS have been responsible for extirpating or severely restricting distributions of formerly dominant native fish species (e.g., mid and deep water coregonid fishes like shortnose cisco, the globally rare lake sturgeon; (Great Lakes Regional Collaboration 2005, Hein et al. 2006); and are likely to be the cause of the major decline in diporeia (an amphipod - crustacean), a major prey item that supports many of the Great Lakes food web and fisheries production.

In the United States, invasive species are thought to be the primary agent of decline for more than 42% of all threatened and endangered species. Worldwide aquatic invasions are considered the leading threat to biodiversity of aquatic ecosystems (Hein et al. 2006, Olden et al. 2006). The effects of AIS may be more severe and longer lasting than chemical pollution, or flow and hydrological alterations. AIS are prominent and impacting the biodiversity of almost all of the conservancies global freshwater priorities (Table 1.).

In many instances, it is the same common species or organism causing harm. For example, common carp account for over 90% of the biomass in the Murray-Darling Basin (Australia), but are also invasive in the Mississippi, and Colorado Rivers and Great Lakes. Introduced crayfish threaten globally unique spring endemics in Colorado River basin and plant or macrophyte communities of Upper Mississippi and Great Lakes. In addition, the recent invasion of the Colorado River by quagga mussels was a result of its initial invasion of the Great Lakes and subsequent spread into the Mississippi basin.

	The Great Lakes	Paraguay-Parana River	Zambezi River	Rivers of the Andes	Yangtze River	Murray-Darling Basin	Sth U.S. Rivers	Colorado River	Mississippi River	Pacific Salmon Ecosystems
Crayfish	I				I	I	I	I	I	P
Mollusk	I	I					I	I	I	P
Carp(s)	I	I			I	I	I	I	I	
Tilapia			I			I	I	I	I	
Trout	I	I		I		I	P	I	I	I
Hydrilla							I	E	I	I
Water hyacinth	P	P	I		P	P	I		I	
Brazilian Elodea	P					I	I		I	P
Eurasian Milfoil	I						I	I	I	P

Table 1. Common invasive animals and plants that threaten biodiversity in global freshwater priorities, I = introduced and established, P = probably present but not invasive, or in neighboring watersheds, E = eradicated.

Invasion is a process (Fig.1) whereby species enter and are carried in a pathway incidentally (e.g. ballast water) or on purpose (commerce in live trade) to another location. A proportion may become established, spread and eventually become abundant enough to impact ecological, human health or economic values.

Non-native aquatic species enter the Great Lakes primarily through four pathways: maritime commerce (in ballast water, sediment or on ship hulls), in the trade in live organisms, through recreational activities (boating), or via canals and waterways that artificially connect the Great Lakes to other watersheds like the Mississippi River (Ricciardi 2006). Effective restoration and conservation of Great Lakes biodiversity requires prevention of further introductions into and spread of AIS around the Great Lakes basin. In addition, with a wide variety of invasive species already established in the Great Lakes, methods are required to manage existing populations to help protect and restore the basin's ecological, human health and economic values.

The Nature Conservancy recognized the need to build capacity in AIS management in order to meet its goals of protecting 10% of the world's major habitats. As a first step, the Conservancy's Great Lakes Program and Global Invasive Species Initiative formally launched an AIS Program in January 2007. This new program is centered in the Great Lakes, but is structured to draw upon the organization's global resource base and experience in managing terrestrial invasive species, federal and international policy.

Our aim is to help develop solutions at multiple scales in the basin that can also be transferred to other sites in North America and internationally. We have focused our limited resources on prevention strategies designed to close major pathways of invasion into and within the Great Lakes basin and the US. In the future as we build capacity, we will increasingly work to develop and promote research agendas and demonstration projects on control and management of established invasive species threats (Table 1).

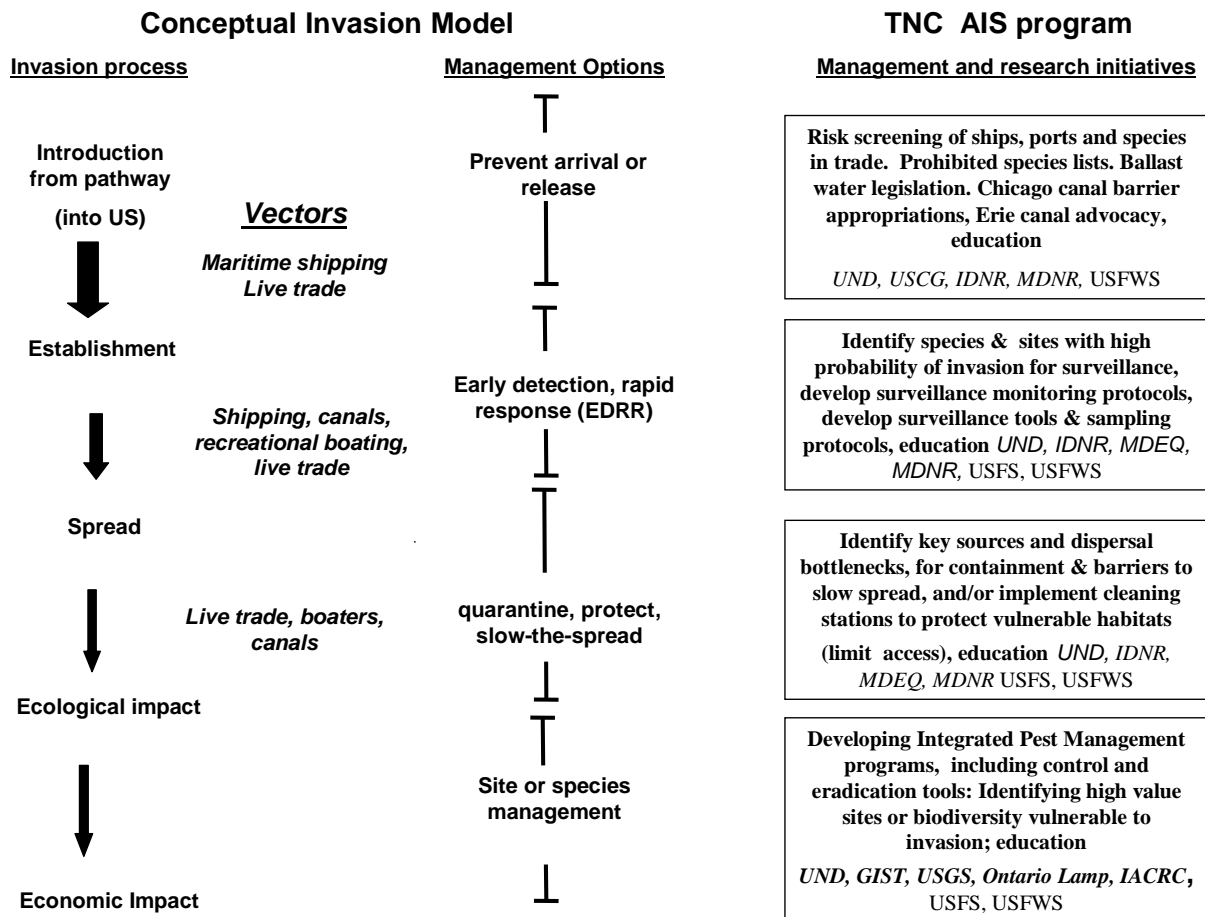


Figure 1. Stages common to all invasions, the major vectors of introductions, and typical management responses at each stage of the invasion pathway. The right column represents the current strategies that underpin the Conservancy AIS program. Arrows in the left column decrease in width to represent the decline in species number through the invasion process. Adapted from Lodge et al 2007, UND = University of Notre Dame

The Nature Conservancy is uniquely positioned to help provide leadership on aquatic invasions. The Conservancy's regional, North American and global programs enable staff to coordinate and broker responses across multiple jurisdictions that often prove problematic for government agencies.

As a land owner, the Conservancy is interested in controlling AIS in waterways within the preserves it manages, and its biodiversity interests lend themselves to ecosystem-based management approaches. Site-based projects have the potential to act as important demonstration projects to test new management techniques and could serve as centers of invasive species research. In the Great Lakes the diversity and abundance of small lakes and rivers are ideal for experimental manipulations and control trials.

Finally, the Conservancy has well-developed working relationships with numerous universities and research agencies that are recognized global leaders in invasive species ecology (e.g., University of Notre Dame; University of California, Davis; Invasive Animals Cooperative Research Centre in Australia). These relationships will help ensure we can bring the best technical advice to bear on these complex problems, and then share these solutions globally. For example, we have established a formal relationship with the University of Notre Dame to progress areas of mutual interest. This collaboration has been instrumental in rapidly building an effective AIS program, and developing a credible presence in the basin.

Guided by collaborations with management agencies and regional, national and international science and policy leaders, we are positioning to develop a range of tools and demonstration projects to inform management choices about cost effective prevention, early detection & rapid response (EDRR), slow-the-spread, and control strategies for invasive species globally.

Objective 1. *Shipping pathways:* Decrease rates of primary introductions to Great Lakes basin through coastal and oceanic shipping pathways (e.g., ballast water, hull fouling, anchors).

Since 1959, when ocean going vessels gained access to the Great lakes, about 70% of the introduced species that have established in the basin arrived by transoceanic shipping (Ricciardi 2006). Over 40% of these ship-borne taxa are clearly invasive, the most notorious of these being the zebra mussel.

Policy initiatives led by Cat Hazelwood in the Worldwide Office/GIST have focused on ensuring strict ballast water treatment legislations are enacted

by the federal government. At the time of writing, passage of the US Coast Guard Reauthorization Act seems likely and this will require all ships trafficking in US waters to treat their ballast water discharges and implement best management practices to stop the continued spread of invasive species from maritime vessels.

We are supporting research designed to identify which international ports contribute shipping traffic to the region and pose the highest risk to Great Lakes because they are environmentally similar (i.e. temperate freshwaters). This research is led by our collaborator, David Lodge at the University of Notre Dame, and is funded by Great Lakes Protection Fund.

Research also includes efforts to develop a genetic detection tool designed to enable rapid identification of high risk invasive species in ballast water, in management time frames. Both aspects of this research program are designed to provide regulatory and compliance agencies and the supply chain (shipping, insurance and industry) with the means to identify and manage high risk vessels and develop appropriate timely management responses.

Objective 2. *Trade in live organism:* Decrease rate of primary introductions and secondary spread arising from trade in live organisms.

Introductions arising from the trade in live organisms are the second most significant source of new invasive species to the Great Lakes (Ricciardi 2006). The trade of live organisms is extensive, with hundreds of thousands of fish, invertebrates, plants, and other organisms traded each year. Species are imported directly for the aquarium (e.g., Eurasian water-milfoil) and water garden (e.g., purple loosestrife) trades, aquaculture, and live food industries (e.g. carps).

The trade in live organisms is largely unregulated, and this allows the importation, interstate commerce, and widespread dispersal of numerous problem species including known invasive species (Keller and Lodge 2007). Some of these individuals are eventually either accidentally or deliberately released and become established in natural waterways.

At federal, state and city levels, the possession and sale of a small number of invasive species is prohibited - although lists of banned taxa are inconsistent and this limits the effectiveness of individual state efforts. Some jurisdictions rely heavily upon federal laws like the Lacey Act, even though the latter has proven to be largely ineffective at prohibiting species with only 19 taxa banned from sale, movement or entry into the United States.

Successful listing under Lacey Act takes an average of four years to be processed by which time most are already established in the US (Fowler et al. 2007).

There is growing interest in the Great Lakes region to develop a more comprehensive and consistent approach to the live trades that is supported by robust science. At federal levels, we are providing feedback on the draft legislation that would strengthen the Lacey Act and require a complete risk assessment of all species in the trades.

Organisms in trade is also a pathway of specific interest to the GLP-ANSTF panel, reflecting a growing recognition of the benefits of a consistent regional approach, the need for common risk assessment protocols, and the desirability of a common black list among states and cities across the Great Lakes. We have had recent success working with University of Notre Dame to encourage the City of Chicago to ban from sale and possession 26 known or potential aquatic invaders. This model ordinance required the City's Department of Environment to establish and maintain a list of species deemed to pose a large risk of either becoming invasive, or, in the case of species already established, that commerce could significantly spread further, using up-to-date science.

Working with many of the world's leading risk assessment specialists, we are helping to facilitate, develop and disseminate pre- and post-import screening or risk assessment protocols at state, regional, federal and international levels. Our approach is modeled on the recognized international risk assessment standards adopted by Australia and New Zealand that work on the principle that high-risk species are pre-emptively removed from the trade, while species that pose a low risk remain in commerce.

A recent economic assessment by Notre Dame researchers of the cost/benefit of these approaches in Australia demonstrated that within 10 years net economic benefits accrue (Keller et al. 2007). The Conservancy has considerable expertise in terrestrial plant risk assessment (Gordon et al 2008) and is helping lead development of a series of landmark voluntary codes of conduct within the terrestrial plant trades and horticulture industries that we hope will eventually be expanded to include aquatic plants.

Objective 3. Canals and artificial connectivity: Halt introduction into and spread from Great Lakes basin of AIS arising from artificial hydrological connections (e.g., Chicago Sanitary and Ship Canal).

A small number of canals built to facilitate the conveyance of bulk goods and commodities (and

in the case of the Chicago Sanitary and Ship Canal, storm and waste water), are important pathways of invasion by AIS into watersheds that were naturally separated. The Chicago Sanitary and Shipping Canal (CSSC) link the Great Lakes basin to the Mississippi Basin, and together these systems cover over 40% of continental US land area.

These watersheds contain almost half of the nation's fish and mussel species; as well as a remarkable diversity of plants, invertebrates, amphibians, and reptiles, many of which are endangered and threatened due to the cumulative impacts of invasive species and environmental degradation. For instance, the Mississippi River contains the most biologically diverse mussel fauna in the world (131 mussel species), and yet over half are thought to be threatened by invasive species like zebra mussels and habitat impacts.

The Great Lakes, via the CSSC, have been a significant source of invasive species to the Mississippi River, and this artificial connection has increased the potential for spread of invasive species across the United States, as recently demonstrated by the introduction of Quagga into the Colorado River. However, it is the imminent threat to the Great Lakes posed by bighead and silver carp migrating from the Mississippi River basin up the Illinois River that has received most of the recent publicity. These fish have the potential to deplete plankton populations and will directly compete with the young of most native fish species. If they become established in the Great Lakes, they could have a devastating impact on the systems water quality, food webs and commercial and recreational fisheries.

Up to three electrical barriers are being built in CSSC to try and prevent carps from entering the Great Lakes, and we have focused initial policy efforts on ensuring that the Army Corp of Engineers (ACE) is fully funded. There is recognition however, that these barriers will not fix the problem and long-term solutions are needed to prevent transit of AIS in either direction.

A 2003 workshop on this issue recommended that the only likely permanent solution would be to re-establish the natural hydrologic separation (Great Lakes Regional Collaboration 2005). We are presently working to identify studies that could advance the process towards achieving biological separation.

The challenge is how to develop solutions that can work within the constraints of the Chicago Waste and Storm Water Management Systems, and also cater to other commercial and recreational users of the system. We are supporting research at Notre Dame to quantify the risks posed by CSSC to the Great Lakes and Mississippi River that will quantify

potential impacts and help justify development of a long sustainable solution. In the future, we hope to help facilitate development of solutions to the transit of harmful organisms in the Erie Canal. The latter was identified as a priority restoration action of the Lake Ontario biodiversity strategy that was facilitated by the Conservancy and Nature Conservancy Canada, through the Lake Ontario Lake-wide Management Plan (LaMP). We hope that development of solutions to close this pathway, while still allowing boating traffic to transit through the Erie Canal, could act as catalyst or demonstration project for the Chicago Sanitary and Ship Canal.

Objective 4. *Recreational boating:* Decrease rates of secondary spread of AIS due to recreational boating activities.

Small-craft recreational boaters are important vectors in the secondary spread of AIS through their transfer on hulls, fishing gear, anchor lines, in live wells, bilge water, and bait buckets. Prominent recent examples include the introduction of the disease Viral Hemorrhagic Septicemia (VHS) into inland lakes around the Great Lakes basin arising from the movement of bait or contaminated water by recreational boaters. Similarly, the arrival of quagga mussels in Lake Mead (Colorado River), was probably due to the movement of hull fouled houseboats from the Midwest.

The scale of the problem is large, with 10,000+ inland lakes, and an estimated 6 million individual registered boaters in Great Lakes states and provinces. Efforts to prevent the spread of species are underway at multiple levels — township, county, regional and national — and include public awareness and education (signage, brochures), boat inspections, cleaning stations, survey and early detection, and control or eradication programs.

We are working with Notre Dame to develop guidance on the most cost-effective technologies and interventions strategies. Our preliminary analyses indicate that efforts aimed at preventing spread from infested high use sites would make the biggest difference to slowing the spread of pest species around the region.

In contrast, the more common approach that is focused on protecting a few highly valued lakes is likely to be less effective at both slowing regional spread, and protecting these systems in the long term (unless they can be completely isolated). As AIS become established at more and more sites, there is increased potential for new introductions to valued sites, as each new infestation acts as another potential

source of invasion. Hence, if our goal is to slow the spread across the region in order to protect multiple sites, it makes more sense to focus on containing the heavily used and infested lakes, rather than protecting individual valued lakes (at least in the early stages of invasion).

Invaded lakes in neighboring watersheds outside the basin can also act as important sources and staging points for new introductions into the Great Lakes. Hydrilla is a federally listed aquatic invasive plant species with an ability to displace native plant communities and reduce recreational opportunities.

The threat posed to Great Lakes states is well recognized and until recently, it was thought to be absent from all mid-western states. However, its discovery in Lake Manitou (a Northern Indiana watershed that borders the basin) illustrates both the potential for neighboring watersheds to seed invasives into the Great Lakes and importance of surveillance monitoring.

In response to the hydrilla incursion, we have secured funding to develop surveillance protocols for Early Detection and Rapid Response (EDRR) for Northern Indiana and Southern Michigan. Our goal is to increase the chances of detecting new incursions while populations are small, localized, and still vulnerable to containment, control or eradication (Lodge et al 2006).

Existing surveillance efforts lack a common framework and rely heavily upon volunteer efforts by individual lake associations or community groups, which are not focused on high risk sites. We will work with Michigan and Indiana Departments of Natural Resources, fisheries researchers and University of Notre Dame to develop an early detection monitoring framework for Northern Indiana and Southern Michigan to assist hydrilla delimitation survey efforts in the region, and to assess the value of dispersal models in coordinating EDRR surveillance efforts. If successful, we will scale up and promulgate the approach across the basin.

Finally, a good knowledge of the distribution patterns of AIS is a necessary pre-requisite for informed management responses especially following detection of new introductions (Lodge et al 2007). Knowledge of the distribution patterns of invasive species is patchy across the basin and the lack of good information in some states is a major impediment to effective management. An ongoing inventory and monitoring program that uses standardized survey methodologies is needed to develop a more comprehensive understanding of the distribution of AIS across the region and to inform pest management priorities.

Objective 5. *Integrated pest management:* Develop an integrated pest management strategy that includes control or eradication tools to reduce the dominance and environmental impacts of established AIS on Great Lakes basin ecosystems.

Prevention of new introductions alone will not lead to successful restoration of Great Lakes biodiversity. The decline in the fisheries and native biodiversity of the Great Lakes can be attributed in no small part to predation, competition and ecosystem impacts of a discrete number of AIS (AIS).

The most damaging species include several recent arrivals to the Great Lakes -- two dreissenid mussels (zebra and quagga), the round goby, and two zooplankton species (the spiny and fish-hook water fleas). The impacts of these species have compounded the longer term effects of introduced alewife and sea lamprey, whose numbers peaked in the 1950s and 1960s despite control efforts, continue to impede the restoration of native fisheries. These established AIS damage native communities in myriad ways.

The two water fleas are replacing native zooplankton and appear to be unpalatable to native predators. Competition or predation by alewife and sea lamprey has contributed to the decline or suppression of game fish, such as lake trout, whitefish, chub, and lake herring. The dreissenids have altered the energy pathways depriving the pelagic (open water) zone of essential nutrients and diminishing the range and abundance of the native amphipod (diporeia) that supports many sports and forage fish species.

Although the round goby may feed on dreissenids, it also competes with and preys heavily on the eggs and larvae of several native fishes. The combination of zebra and quagga mussels, round gobies and a type of algae called cladophora have resulted in outbreaks of avian botulism that have killed more than 70,000 Great Lakes water birds over the past decade.

Despite limited investment in freshwater pest management tools, there are local and international examples of integrated pest management programs that demonstrate the feasibility to control AIS to enable recovery of target native biodiversity. In the basin, sea lamprey control is achieving fair success through an integrated program using barriers, traps, and lampricide treatments.

Insect predators are being successfully combined with vector management and selected herbicide treatment to control purple loosestrife. Internationally, the Invasive Animal Cooperative Research Centre in Australia is investing \$10 million over a seven-year program to test a range of genetic, disease, trapping, pheromone and biocide options to control common carp and tilapia. In addition, the US Fish and Wildlife

Service are testing the efficacy and selectivity of micro-pellets of potassium chloride as a potential site-based mussel control tool, while laboratory trials of a selective natural biocide for zebra and quagga mussels that is derived from native soil bacteria is showing promising results.

There is also interest in testing whether restoration of native predators like sturgeon has the potential to reduce the abundance and impacts of zebra and quagga mussels. However, there is little coordination of these efforts and no long term strategy with the goal of developing an integrated set of pest management tools exists. The Conservancy is well-positioned to provide important leadership on these issues and help drive development of control and eradication tools.

Aquatic control and eradication tools are arguably more urgently needed outside the Great Lakes in regions where localized endemics are threatened with extinction by introduced species of fish, crayfish and amphibians. For example, spring, wetland, and riverine environments of the arid Southwestern United States harbor a disproportionately large number of endemic and rare species that contribute significantly to the biodiversity of these arid landscapes. However, introduced fish, crayfish and amphibians threaten the long term survival of many species.

For example, at Three Forks, Arizona; three mountain streams form the east branch of the Black River (a Conservancy portfolio site in the Arizona-New Mexico Mountains ecoregion) are home to at least three rare and/or endemic species of concern: (1) the federally threatened Chiricahua leopard frog, whose last known reproducing site in the White Mountains is Three Forks; (2) the California floater, Arizona's only native mussel last state populations are the Three Forks and its associated streams; and (3) the Three Forks spring snail, endemic to the Three Forks area and under consideration for emergency federal listing.

Following the discovery of introduced crayfish in 1993, all three native species have declined. By 2003, no frog egg masses were recorded, and spring snail populations had largely migrated from spring sources into open water, where the risk of predation is higher. Non-native crayfish populations, however, have increased dramatically, with more than 3,000 crayfish captured in two nights of trapping at three spring sites in 2003.

Intensive trapping is at best capable of controlling crayfish numbers to densities that might prevent extinction, but this approach is not sustainable and more effective crayfish control tools are urgently needed. However, it is increasingly difficult to attract funding for the development of control and eradication tools. The research questions are not attractive to

government science funding agencies (they are basic “unsexy” science), it requires a long term investment (10+ years) that is typically beyond agency or political cycles, and where these species only impact biodiversity there is little incentive for private investment (unlike agricultural weeds). Nevertheless, the Great Lakes, with its abundance of small lakes and rivers and AIS expertise, has the potential to be an important laboratory for the development of new management tools that can be shared and applied across the nation and globally.

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