What's Next?: The Prediction and Management of Exotic Species in the Great Lakes

Workshop held
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campus Inn
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I. Abstract

A workshop entitled ***What's Next? The Prediction and Management of Exotic Species in the Great*** Lakes was held in October 1991 to examine issues pertaining to exotic species and to recommend prevention and control strategies for future unplanned introductions into the Great Lakes. As long as the Great Lakes are inoculated with exotic species, new species will become established regardless of the state or condition of the ecosystem. As legislative and regulatory policies are designed to prevent new unplanned introductions, they must consider vector management and broaden in scope to include the North American continent. The workshop recommends that: 1) ballast water controls extend from the Great Lakes to the North American continent and include provisions to monitor both compliance to and effectiveness of the regulations; 2) a public education program be developed in the Great Lakes basin to alert the public of the dangers associated with releasing exotic species into non-native waters; 3) studies begin immediately to determine the extent of actual or potential release of exotic species associated with the aquaculture, bait fish, and pet industries and advisories should be issued against the use of organisms not present in the Great Lakes by these industries; 4) a Nonindigenous Aquatic Species Information Network (NASIN) be established to act as a clearing-house for information and coordinator of research and management within North America and a liaison with the regions that serve as the sources for North American introduced species.

II. Introduction

The Great Lakes Fishery Commission was founded in 1955 in response to the catastrophic impact of the introduced sea lamprey on the fisheries of the Great Lakes (Great Lakes Fishery Commission 1956). Since its establishment, the Commission has played an integral role in sensitizing the Great Lakes community to issues that impact the Great Lakes fishery resources (Dochoda 1991). Since 1980, with the discovery of twelve new invasive species in the Great

Lakes, the Commission has become concerned over the introduction of exotic species and their impact on the fisheries resources of the Great Lakes. The Commission, through its technical arm, the Board of Technical Experts, established the Introductions Task Area in July of 1989 with two objectives in mind The primary goal of the Task Area was to focus on the origin, probable transport mechanism(s), demography, and impacts of Great Lakes exotics with the hope that analysis of past invasions will help prevent future invasions. A comprehensive inventory of the introduced flora and fauna of the Great Lakes was developed in which the case histories of over 130 exotic species of the Great Lakes were presented and information on entry vectors and impacts on aquatic resources were analyzed. A second goal of the Task Area was to convene a workshop entitled: "What's Next? The Prediction and Management of Exotic Species in the Great Lakes." The objectives of this workshop were to examine the vulnerability of the Great Lakes system to past and future invasions of alien species and to recommend future information and research needs that 1) enhance knowledge of vectors and impacts of specific problem invaders and 2) help formulate policies and establish institutional arrangements to assist in the prevention and control of introduced species. This document summarizes the ideas and recommendations of the "What's Next?" workshop held at the Campus Inn, Ann Arbor, Michigan on October 8-9, 1991.

III. Vulnerability of the Great Lakes to Invasion

Biological invasions are one of the most pervasive and least understood anthropogenic perturbations of the world's ecosystems. This global mixing of species has contributed to the worldwide loss of biodiversity in aquatic and terrestrial systems (Baker and Stebbins 1965, Heywood 1989). Historically, the rate of intercontinental dispersal of living organisms and their component genetic material has accelerated with increased human activity around the world (DiCastri 1989). In the Great Lakes, over three centuries of European exploration, colonization, and commercial development have set the stage for invasions of introduced species, the loss of many native stocks, and the deterioration of important habitats (Ashworth 1986).

Exotic species, organisms transported by humans into regions where they did not exist in historical time, have invaded the Great Lakes since settlement of the region by Europeans. Since the early 1800's, at least 136 exotic species have successfully become established in the Great Lakes and of this total, about 10% have had significant impacts (Mills et al. 1993). The first major introduction to the Great Lakes basin was the sea lamprey, *Petromyzon marinus,* a parasitic fish that probably entered the Great Lakes through canals or attached to boats (Morman et al. 1980). It had a devastating impact on native species such as the lake trout which were already in decline because of anthropogenic disturbances (Pycha and King 1975). The alewife, *Alosa pseudoharengus,* a fish introduced in the 1870s into Lake Ontario, has caused major impacts on the Great Lakes system (Smith 1970). Massive dieoffs of alewives and their subsequent buildup on lake shores and beaches in the 1960s became a highly visible indicator that something was seriously wrong with the Lakes. The unchecked alewife populations suppressed native species such as yellow perch (Brandt et al. 1987). Fisheries biologists, however, alleviated the problem by stocking non-native salmonids as predators to control the alewife (Stewart et al. 1981). The common *carp, Cyprinus carpio,* was introduced in the 1870s to augment the declining commercial food fishes of the Atlantic Coast and the Great Lakes but had a profound impact on habitat used by waterfowl and more favored fish species (Emery 1985). The recent arrival of the zebra mussel, *Dreissena polymorpha,* represents a new disturbance which could have long-term impacts on the structure of pelagic and benthic communities in the Great Lakes.

The rate of invasions by aquatic species in the Great Lakes has increased over the past two centuries (Figure 1). In the past 15 years, the Great Lakes have been invaded by an average of one organism per year. These findings suggest that the Lakes have become increasingly more vulnerable to invasion. In the mid-1980's, the Scientific Committee on the Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU) set out to assess the attributes of invaders and characteristics of vulnerable systems. Traditionally, ecologists have believed that disturbance makes a system more vulnerable to invasion because most undisturbed

systems have a community structure that resists invaders (Elton 1958). Mooney and Drake (1989), however, note that the level of disturbance is directly related to the rate that human activities inoculate the system with new species. Almost 30% of the exotic species of the Great Lakes, for example, have been discovered since 1959, and many of these were introduced in the

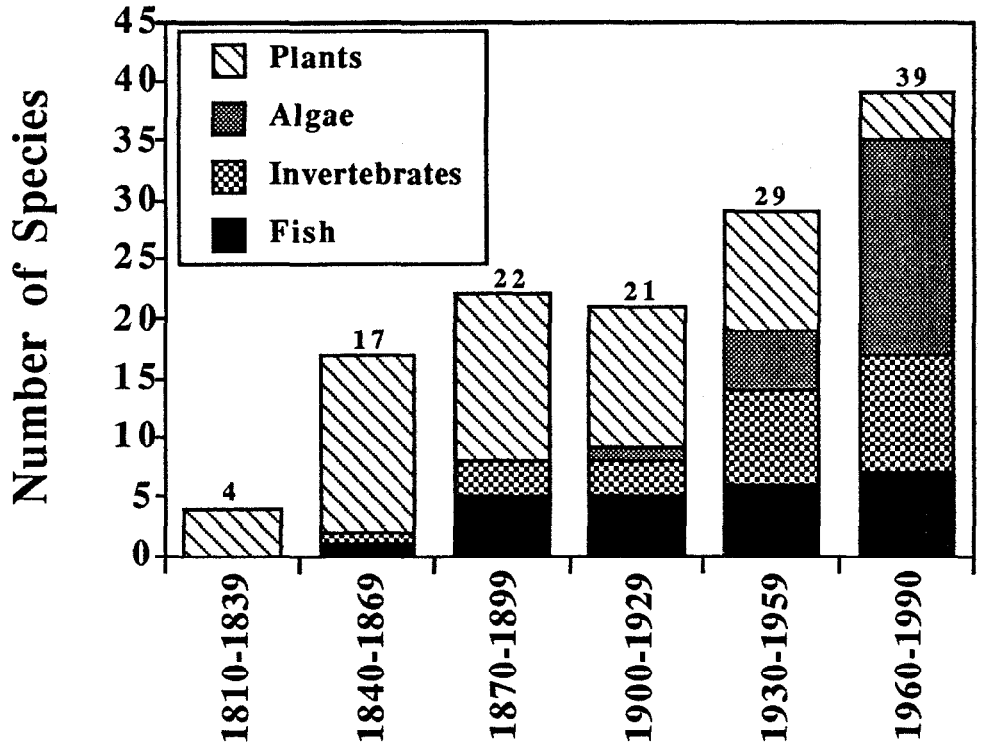

Figure 1. A timeline of introductions (N = 132) in the Great Lakes sorted by taxon. Data excludes four species whose dates of entry into the Great Lakes are unknown. The total number of species is indicated above each bar.

ballast water of ships that entered the Lakes through the St. Lawrence Seaway. The Seaway allowed large volumes of foreign water to enter the Great Lakes as ship's ballast water. In the early to mid 1980s, Seaway ship traffic was higher compared to recent years (Captain Jim Perkins,

St. Lawrence Seaway Authority, personal communication, 1992) suggesting a higher rate of freshwater inoculation perhaps leading to such recent Great Lakes exotics as the zooplankter *Bythotrephes* cederstroemi, the zebra mussel *(Dreissena polymorpha),* and *the* fishes *Proterorhinus marmoratus, Neogobius melanostomus,* and *Gymnocephalus cernuus.*

IV. Policy

In the Great Lakes, nearly one-third of introduced species have been associated with ship ballast water. In September 1990, the International Joint Commission and the Great Lakes Fishery Commission concluded that "immediate action is required by Governments to reduce the risk of unwanted exotic species being introduced to the Great Lakes ecosystem through the discharge of ballast waters from oceangoing ships (International Joint Commission-Great Lakes Fishery Commission 1990)." The Commissions recommended mandatory mid-ocean ballast exchange for all oceangoing ships, research programs which encompass the entire scope of the exotic species and ballast water problems, and global cooperation for research and development of policy and technology. In response to the concerns raised by both Commissions, the United States and Canadian governments acted in the following manner:

1. The Canadian government set up voluntary Great Lakes Ballast Water Guidelines that were implemented in May of 1989. A research program designed to test both the effectiveness and compliance of these guidelines took place between May and December of 1990 and found that most ships entering the St. Lawrence Seaway during this period were complying with the new guidelines (Dochoda 1991, Locke et al. 1991).

2. The United States Congress passed the Nonindigenous Aquatic Nuisance Species Prevention and Control Act of 1990. This act calls for the U.S. Coast Guard to report on options available to prevent ballast introductions, requires that all ocean-going vessels

entering the Great Lakes undergo ballast exchange or treatment and requests the Marine Environmental Protection Committee of the United Nations International Maritime Organization to set up a ballast task group (Dochoda 1991).

Such legislative and regulatory policies are a necessary first step toward the elimination of unwanted aquatic pests in North American waters. Despite ballast exchange regulations and guidelines for the Great Lakes, the continuing threat to the ecosystem by invasions from Eurasia is real (Carlton et al. in prep.). The current guidelines focus OR the *St.* Lawrence River but organisms can also enter the Great Lakes from other routes (e.g., Hudson River, Atlantic Coast, Mississippi River, etc.). Just as unwanted organisms outside of the Great Lakes watershed can impact this large freshwater resource, exotic pests in the Great Lakes can also pose a threat to other North American waters. So, the policy associated with the exotic species issue must broaden in scope to a continental view.

Legislative and regulatory efforts must also consider other transport mechanisms used by exotic species to gain access to the Great Lakes basin (Mills et al. 1993). Consequently, vector management is critical in order to prevent nonindigenous species from entering the Great Lakes basin. In addition to ballast water controls, future policy decisions should consider the following vectors:

1. Fish Stocking Programs-The deliberate stocking of nonindigenous species into the Great Lakes has occurred since the 1870s when Pacific salmon and common carp were released by government agencies (Emery 1985). Government agencies continue to stock species into the lakes resulting in a schism between those that promote the revitalization of sustainable native populations and those who support continued introductions of non-native species. Deliberate releases of organisms into lakes may have short-term benefits, as the stocking of salmonids in the Great Lakes, but the long-term impacts may not be

beneficial. As new fish species and stocks are introduced into the Great Lakes, the parasites and diseases that these fish carry are also released The threat of diseases and parasites must be taken into consideration when regulations concerning the importation and rearing of any fish species into the Great Lakes are designed.

2. Bait Fish Industry-The importation, culture, and distribution of bait fish in North America needs close regulation. In the mid 1980s, the European rudd, *Scardinius erythrophthalmus,* was imported from Europe, cultured in a facility in Arkansas, and distributed to bait dealers in 14 states before fisheries biologists became aware of the problem (Burkhead and Williams 1991). The rudd has since been captured in 8 of the states where the fish had been distributed (Burkhead and Williams 1991). Future importations by the bait industry are difficult to predict and regulations restricting these introductions are necessary.

3. Aquarium Industry-This mechanism is a major pathway that some organisms have used to enter North American waters. For example, many tropical fish species become established in the southern U.S. after escaping from aquarium aquaculture or being dumped from an aquarium (Courtenay et al. 1984). Aquatic plants and invertebrates have also been introduced into and spread within North America through aquarium releases. Like those of the bait fish industry, trends in the importation of invertebrates, fish, and plants by the aquarium industry are difficult to predict. Currently, for example, most of the aquarium introductions are tropical fish that could not survive in the Great Lakes basin. In the future, however, if colder water species become more popular then the threat to the Great Lakes by new aquarium introductions may increase.

The introduction of nonindigenous species is a global problem. Two-thirds of the non-native organisms entering the Great Lakes since the opening of the St. Lawrence Seaway have been

associated with ships (Mills et al. 1993). In addition to bringing organisms in, however, ships also carry the flora and fauna of the Great Lakes to other parts of the world. In addition to global considerations, it is recommended that strategies for vector management include a continental perspective. Organisms that are introduced to one part of North America will most likely spread to other parts of the continent. The invasion of the Asiatic clam, *Corbicula fluminea, into* North America is a classic example of this phenomenon. The clam was introduced to the west coast of North America and rapidly colonized most of the United States (Counts 1986). Regulations must be set up continentally, taking in the concerns of the United States, Canada, France (St. Pierre and Miguelon Islands), and Mexico into consideration.

V. Research and Development

It is evident that significant legislative and regulatory actions need to be taken immediately to reduce the risk of unplanned introductions into Great Lakes waters. However, our knowledge and understanding of factors involved with the establishment of exotic species in new environments hinders our current ability to develop effective strategies for prevention and control. New and continuing research on vectors, prevention strategies, and invasion ecology need to be examined concurrently with actions to reduce the impact of exotics on Great Lakes resources.

Biological invasions may lead to extensive ecological alterations to the structure of pre-invasion communities. These alterations may arise through a wide variety of processes, including (but not limited to) interspecific competition, disturbance, predation, spread of disease, and altered pollutant pathways. Many of these processes have been deduced through the correlation of the arrival of an exotic species and the subsequent alteration of a native species; far fewer have been tested through experimentation. Exotic species may also have broad economic (and other social) impacts on the human communities which have historically relied upon the non-altered resources (such as food stocks and raw water supplies).

In the Great Lakes, the exotic species issue is one of a multiple set of resource management concerns that influence Great Lakes ecosystem health. The exotics species issue must come into consideration along with water quality and fisheries management objectives. At present, significant unplanned introductions are currently under way in the Great Lakes and it would be advantageous to learn more about ecosystem responses to these invasions. Whole lake, field and laboratory, and modelling studies are all approaches that could provide basic theoretical and empirical information for specific invasion cases. Such research opportunities could lead to generalizations critical for general ecosystem management of the Great Lakes. It is important, however, to begin coordinated research programs as soon as a new introduction occurs. Therefore, the workshop recommends that a Nonindigenous Aquatic Species Working Group (NASG) be established to coordinate research dealing with the analysis of newly introduced species. In the case of the European ruffe, a research team able to scope a range of attributes including life history, ecology, habitat requirements, and environmental tolerances would provide information critical for the development of management strategies. Using such an approach, Lake Erie managers, for example, would be in a better position to prepare for the ruffe and its impact on such native species as yellow perch.

VI. Management Strategies

The management of future Great Lakes invasions must consider three broad categories: prevention, containment, and control. Prevention stops invasions before they occur, containment prevents an introduced species from spreading once introduced, and control minimizes the impact of the introduced species on the ecosystem. Knowledge of potential invaders should provide the basis for vector management, which is the best prevention strategy. For the Great Lakes, five categories of entry mechanisms have been identified: unintentional releases, ship-related introductions, deliberate releases, entry through canals, and movement along railroads and highways. Nearly two-thirds of the introduced species of the Great Lakes gained access to the

basin by unintentional releases (escapees from cultivation, bait, aquarium, and accidental releases) and by ships. Future management strategies to prevent the introduction of unwanted pests to the Great Lakes must consider these vectors. Based on historical evidence, contingency planning would be advisable for such organisms as nuisance aquatic vegetation, fouling organisms, and human parasites or disease agents.

As long as exotic species are inoculated into the Lakes, new species will become established regardless of the state or condition of the ecosystem. Potential invaders exist for every lake state or condition. Enhanced water quality and improved habitat conditions in the lakes, for example, could favor invasion by pollution intolerant species, and vice versa. Prevention of new introductions through ecosystem management is a formidable task unless management is focused toward a single invading species or a subset of species. Consequently, the only effective means to prevent introductions on a large scale into ecosystems like the Great Lakes is through vector management.

If organisms gain access to the Great Lakes, then managers of these resources must begin measures to contain and control pest species. Containment policies must address all potential vectors of escapement from sites of initial introduction. The invasion of the European fish species *Gymnocephalus cernuus,* or the ruffe, is a prime example of a recent introduction to the Great Lakes where individuals have escaped from the initial receiver site through the ballast water of an intralake ship (J. Selgeby, U.S. Fish and Wildlife Service, personal communication). Even if containment only slows the dispersal of an unwanted pest, the practice allows managers additional time to prepare a course of action using information provided by initial analyses of the new invader's effect on receiving ecosystems. Finally, control strategies vary among organisms and managers generally must consider a potential range of biological, physical, and chemical control measures.

VII. Future Invaders

Many exotic species in the Great Lakes are native to Eurasia (59%) and there is no question that invasions of the Great Lakes of organisms from this region will continue. Some of these introduced species will impact the Great Lakes environment substantially. To date, nearly 10% of all non-native species in the Great Lakes have had substantial impacts and it is reasonable to suggest that this trend will continue. The timing and extent of these introductions, however, will depend on many factors, including transport mechanisms, preventative mechanisms in the recipient region, human activity, the fecundity and mobility of organisms, habitat conditions, invasion history, and the susceptibility of the Lakes. The ability to recognize potential future invaders could clearly be a useful exercise toward the prevention of new introductions. Agriculture quarantines, for example, attempt to stop the introduction of well known species that could have large economic and ecological effects on North American crops and livestock

An inventory of potential invasive pest species from other continents combined with information on their life *history,* ecological requirements, dispersal patterns, and methods of control is an essential prelude toward development of strategies for prevention and control. Looking in the European donor region for potential invaders, Carlton et al. (in prep.) predict that a snail and an amphipod, *Potamopyrgus antipodarum* and *Corophium curvispinum* will invade North America and the Great Lakes. Both of these organisms have an extensive invasion history in Europe, interface regularly with transcontinental transport mechanisms, are highly fecund, and are tolerant to a wide range of environmental conditions. Advance knowledge of potential invaders to the Great Lakes represents a first step toward the prevention of unplanned introductions. This prediction process would be greatly facilitated through the cooperation and collaboration among scientists, both within North America and globally.

A Nonindigenous Aquatic Species Information Network (NASIN) made up of researchers

within North America and among other donor regions (e.g., Europe, Asia, South America, and Central America) could bring future potential invaders of aquatic habitats and their ecology to the attention of ecologists, managers, and policy makers. NASIN's clearing-house would be set up to organize the exchange and dissemination of information among task forces in North America and donor *regions* around the world. A North American perspective is clearly important because one region of North America often serves as a donor region for another. NASIN's clearing-house, for example, would have first warned ecologists about the potential invasion of *Potamopyrgus antipodarum,* into North America from Europe, Australia, or New Zealand and then informed them about the invasion of the species into the Snake River basin in Idaho (Bowler 1990). The invasion of this species into North America was predicted by Carlton et al. (in prep.) without knowledge of the snail's discovery in the Snake River, Idaho in 1987, which was documented in a specialized *journal, Proceedings of the Desert Fish Council.*

Although many exotics of the Great Lakes are widely distributed throughout Europe some, are much more limited (e.g., spiny water flea *(Bythotrephes cederstroemi),* round goby *(Neogobius melanostomus),* and tubenose goby *(Proterorhinus marmoratus). These* species do not have invasion histories and are not highly fecund or tolerant to wide environmental conditions, but must have interfaced with a transoceanic transport mechanism while relatively abundant in the donor region and been released during favorable environmental conditions in recipient regions. If an information network like NASIN had been in place prior to the invasions of these species, however, an indicator that the introduction was imminent may have surfaced. Forging relationships among scientists in regions that regularly exchange species would allow the unpublished observations and intuition of those working with native or introduced species of a donor region to become more readily available to scientists working in the receiving regions.

VIII. Summary of Recommendations

The Great Lakes Fishery Commission has recently formulated a strategic vision for the Great Lakes for the decade of the 1990s which encourages the rehabilitation and protection of healthy aquatic ecosystems in the Great Lakes. To achieve this goal, the Commission intends to promote activities which will prevent no further loss of native aquatic populations or species and to establish policies, legislation, and programs that prevent the unintentional introduction and establishment of non-native organisms to the Great Lakes. The following are recommendations of the "What's Next?: The Prediction and Management of Exotic Species in the Great Lakes" workshop which will help the Commission achieve, in part, long term goals:

1. The release of ballast water containing fresh or brackish water organisms anywhere in North America could lead to the establishment of nonindigenous species which could secondarily disperse (naturally or by human activities) to the Great Lakes. The workshop recommends that 1) joint United States-Canada regulations be enacted to extend Great Lakes ballast water controls to the North American continent and 2) legislation include funds to monitor the compliance and effectiveness of such regulations.

2. The unintentional release of non-native aquatic organisms by the public into new environments could lead to the introduction of nonindigenous species to the Great Lakes basin. The workshop recommends that a basin wide public education program be initiated to alert the public about environmental, economic, recreational, and health dangers of releasing exotic species into non-native waters.

3. The holding of fish species not indigenous to the Great Lakes, anywhere in the Great Lakes basin could lead to the unintentional establishment of such species in these Lakes. The workshop advises that:

a. non-indigenous cold water and temperate fish species should not be sold as live bait or as pets in the Great Lakes basin.

b. aquaculture or fisheries stocks being imported into the Great Lakes system should be monitored for disease pathogens and parasites.

c. cold water and temperate fish species should not be cultured or released in the Great Lakes basin unless they have previously been introduced.

d. studies to monitor the compliance with and effectiveness of such advisories should be undertaken by appropriate agencies.

4. The extent of the actual or potential release of nonindigenous species associated with the aquaculture, bait fish, and pet industries is not known. Consequently, the effectiveness of remedial measures would thus be difficult or impossible to quantify. The workshop recommends that studies begin immediately to quantify those vectors that are addressed by recommendations 2 and 3 before regulations are implemented.

5. A partial understanding of the breadth and magnitude of the potential for future invasions by non-indigenous species into the North America and the Great Lakes could be achieved by an assessment of invasions currently in progress in major donor regions such as Eurasia and other regions of North America. The workshop recommends that a Nonindigenous Aquatic Species Information Network (NASIN) be designed to undertake such studies and serve as a clearing-house for information gathered.

6. When a new introduction occurs, the coordination and support of research and management

efforts should be expedited. The workshop recommends that a Nonindigenous Aquatic Species Working Group (NASG) be established within NASIN from the United States and Canadian government agencies and other invited parties to coordinate research and management efforts as new introductions occur and oversee North American concerns and regulations.

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References

Ashworth, W. 1986. *The Late, Great Lakes.* New York: Alfred A. Knopf, Inc.

Baker, H., and Stebbins, G. (eds). 1965. *The genetics of colonizing species. New* York:

Academic Press.

Bowler, P.A. 1990. The rapid spread of the freshwater hydrobiid snail *Potamopyrgus antipodarum (Gray)* in the Middle Snake River, southern Idaho. *Proc. Desert Fish Council* 21: 173-182.

Brandt, S.B., D.M. Mason, D.B. MacNell, T. Coates, and J.E. Gannon. 1987. Predation by alewives on larvae of yellow perch in Lake Ontario. *Trans. Am. Fish, Soc.* 116: 641-645.

Burkhead, N.M., and Williams, J.D. 1991. An intergeneric hybrid of a native minnow, the golden shiner and *an exotic* minnow, *the* rudd. *Trans. Am. Fish. Soc.* 120: 781-795.

Carlton, J.T., C.L. Secor, and E.L. Mills. In prep. Future invasions of European invertebrates into North American fresh waters: What's next?

Counts, C.L. III. 1986. The zoography and history of the invasion of the United States by *Corbicula fluminea* (Bivalvia: Corbiculidae). *Am. Malacological Bull. Special Ed. 2: 7-39.*

Courtenay, W.R. Jr., D.A. Hensley, J.N. Taylor, and J.A. McCann. 1984. Distribution of exotic fishes in the continental United States. pp. 41-77, In Courtenay, W.R. Jr. and Stauffer, J.R. Jr. 1984. *Distribution, Biology, and Management of Exotic Fishes.* Johns Hopkins University Press, Baltimore, 430 pp.

DiCastri, F. 1989. History of biological invasions with special emphasis on the Old World. pp. 1 - *29,* In J.A. *Drake* et al. (eds.) *Biological Invasions: A Global Perspective.* John Wiley and Sons, New York. 525 pp.

Dochoda, M.R. 1991. Meeting the challenge of exotics in the Great Lakes: the role of an international commission. Can. J. Fish. Aquat. Sci. 48 (suppl. 1): 171-176.

Elton, C.S. 1958. *The Ecology of Invasions by Animals and Plants.* London: Methuen and Co Ltd.

Emery, L. 1985. *Review of fish species introduced into the Great* Lakes, *1819-1974.* Great Lakes Fishery Commission Technical Report No. 45. Great Lakes Fishery Commission, Ann Arbor, Michigan.

Great Lakes Fishery Commission. 1956. Annual *report* for the year 1956. Great Lakes Fishery Commission.

Heywood, V. H. 1989. Patterns, extents and modes of invasions by terrestrial plants. In *Biological Invasions: a Global Perspective.* ed. J.A. Drake et al. pp. 31-60. New York: John Wiley & Sons.

International Joint Commission-Great Lakes Fishery Commission. 1990. Exotic species and the shipping industry: the Great Lakes-St. Lawrence ecosystem at risk. International Joint Commission, Washington and Ottawa; Great Lakes Fishery Commission, Ann Arbor, MI.

Locke, A., D.M. Reid, W.G. Sprules, J.T. Carlton, and J.C. van Leeuwen. 1991. Effectiveness of mid-ocean exchange in controlling freshwater and coastal zooplankton in ballast water. *Can. Tech. Rep. of Fish. Aquat. Sci. No.* 1822.

Mills, E.L., J.Leach, J.T. Carlton, and C.L. Secor. 1993. Exotic species in the Great Lakes: A history of biotic crises and anthropogenic introductions. J. *Great Lakes Res.* In Press.

Mooney, H.A. and J.A. Drake. 1989. Biological invasions: A SCOPE program overview. pp. 491-508, In J.A. *Drake* et *al.* (eds.) *Biological Invasions: A Global Perspective.* John Wiley and Sons, New York. 525 pp.

Morman, R.H., Cuddy, D.W., and Rugen, P.C. 1980. Factors influencing the distribution of sea lamprey *(Petromyzon marinus)* in the Great Lakes. *Can. J. Fish. Aquat. Sci.* 37(11): 1811-1826.

Pycha, R.L. and G.R. Ring. 1975. Changes in the lake trout populations of southern Lake Superior in relation to *the* fishery, *the* sea lamprey, and stocking, 1950-1970. *Great Lakes Fishery Commission Tech. Rep. 28: 1-34.*

Smith, S.H. 1970. Species interactions of the alewife in the Great Lakes. *Trans. Am. Fish. Soc.* 99(4): 754-765.

Stewart, D.J., J.F. Kitchell, and L.B. Crowder. 1981. Forage fishes and their salmonid predators in Lake Michigan. *Trans. Am. Fish. Soc.* 110: 751-763.

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