



## Aquatic Nonnative Species

Formerly Indicator # 9002

### Overall Assessment

**Status:** Poor

**Trend:** Deteriorating

**Rationale:** Although no new aquatic nonindigenous species (ANS) have been discovered in the Great Lakes over the past five years, the impacts of established invaders persist and the ranges of ANS within the lakes are expanding. New negative impacts, including synergistic disruptions, are becoming evident.

### Lake-by-Lake Assessment

#### Lake Superior

Status: Poor

Trend: Deteriorating

Rationale: Lake Superior is the site of greatest ballast water discharge in the Great Lakes, but this pathway has led to comparatively fewer ANS establishments. Intrabasin movement of ANS is likely to be of greater consequence, as in the case of recent establishment of Viral Hemorrhagic Septicemia (VHS).

#### Lake Michigan

Status: Poor

Trend: Deteriorating

Rationale: Established invaders continue to exert negative impacts on native species. *Diporeia* populations continue to decline and are rarely found at shallow sites. Viral Hemorrhagic Septicemia (VHS) has recently become established in this lake.

#### Lake Huron

Status: Poor

Trend: Deteriorating

Rationale: Established invaders continue to exert negative impacts on native species. *Diporeia* populations continue to decline and are rarely found at shallow sites.

#### Lake Erie

Status: Poor

Trend: Deteriorating

Rationale: Established invaders continue to exert negative impacts on native species. A possible link exists between waterfowl deaths due to botulism and established ANS (i.e. round goby and dreissenids). Viral Hemorrhagic Septicemia has caused mass die-offs of fish. *Diporeia* has been extirpated.

#### Lake Ontario

Status: Poor

Trend: Deteriorating

Rationale: Native *Diporeia* populations, and the condition and growth of lake whitefish, continue to decline. At shallow sites, *Diporeia* is now absent. A possible link exists between waterfowl deaths due to botulism and established ANS. Viral Hemorrhagic Septicemia has caused mass die-offs of fish.

## **Purpose**

- To assess the presence, number, and distribution of aquatic nonindigenous species (ANS) in the Laurentian Great Lakes, and to understand the means by which these species are introduced
- To aid in the assessment of the status of biotic communities, as ANS alter both the structure and function of ecosystems thereby compromising the biological integrity of these systems

## **Ecosystem Objective**

The goal of the United States and Canadian Great Lakes Water Quality Agreement of 1987 is, in part, to restore and maintain the biological integrity of the Great Lakes ecosystem. Fundamental to this goal is to control existing, and prevent further introduction of, aquatic nonindigenous species.

## **Ecological Condition**

### Background

At least 10% of all ANS introduced to the Great Lakes have had significant impacts on ecosystem health, a percentage consistent with findings in the United Kingdom (Williamson and Brown 1986) and in the Hudson River of North America (Mills et al. 1997). However, among the faunal ANS this percentage is considerably higher (17%). In the Great Lakes, transoceanic ships have been the primary invasion vector. Other vectors, such as canals, intrabasin transport, and private sector activities (e.g., aquarium and bait industries), however, may play increasingly important roles.

### Status of ANS

Of the 77 free-living fauna introduced to the Great Lakes, 17% have had high environmental impacts, 6% have had high socioeconomic impacts (these all also had high environmental impact), and 10% have had high beneficial effects (6 of which also had high environmental impact) (Table 1).

Human activities associated with transoceanic shipping are responsible for over one-third of ANS introductions to the Great Lakes (Fig. 1). Total numbers of ANS introduced and established in the Great Lakes have increased steadily since the 1830s, with some indication of stabilization over the last five years (Fig. 2a). The number of ship-introduced ANS has increased exponentially during the same time period, although this trend may also be slowing (Fig. 2b). Nevertheless, release of contaminated ballast water by transoceanic ships has been implicated in over 60% of faunal ANS introductions to the Great Lakes since the opening of the St. Lawrence Seaway in 1959 (Grigorovich et al. 2003; Ricciardi 2006).

During the 1980s, the importance of ship ballast water as a vector for ANS introductions was recognized, prompting ballast management measures in the Great Lakes. In the wake of Eurasian ruffe and zebra mussel introductions, Canada introduced voluntary ballast exchange guidelines in 1989 for ships declaring “ballast on board” (BOB) following transoceanic voyages; this action followed recommendations by the Great Lakes Fishery Commission and the International Joint Commission. In 1990, the United States Congress passed the Nonindigenous Aquatic Nuisance Prevention and Control Act, producing the Great Lakes’ first ballast exchange and management regulations in May of 1993. The National Invasive Species Act (NISA) followed in 1996, but this act expired in 2002. A stronger version of NISA entitled the Nonindigenous Aquatic Invasive Species Act has been drafted and awaits Congressional reauthorization. In September 2009, the U.S. Coast Guard proposed a two-phase standard for the allowable concentration of living organisms in ballast water discharge within U.S. waters. If proven practical, this rule would be implemented by 2016 and include discharge standards that are 1000x more restrictive than the International Maritime Organization standards (less than 10 viable organisms per cubic meter) ratified by Canada and 24 other countries.

The reported invasion rate following initiation of voluntary guidelines in 1989 and mandated regulations in 1993 has not declined until recently (Grigorovich et al. 2003; Holeck et al. 2004; Ricciardi 2006). However, more than 90% of transoceanic ships that entered the Great Lakes during the 1990s declared “no ballast on board” (NOBOB; Colautti et al. 2003; Grigorovich et al. 2003; Holeck et al. 2004; Fig. 3) and were not required to exchange ballast, despite their tanks containing residual sediments and water that would be discharged in the Great Lakes. Residual water and sediment in these ships have been found to contain several species previously unrecorded in the basin; such species could be discharged after the ship undergoes sequential ballasting operations as it travels between ports within the Great Lakes to offload and take on cargo (Duggan et al. 2005, Ricciardi and MacIsaac 2008). In June 2006, Canada implemented new regulations for the management of residuals contained within NOBOB tanks and requires the salinity of all incoming ballast water to be at least 30 ppt (Government of Canada 2006). In the decade since, we have seen no new ballast water ANS introductions (the last being *Hemimysis anomala*, collected in May 2006) despite a fairly steady number of NOBOB transits.

Recent studies suggest that each of the Great Lakes may differ in vulnerability to invasion. Lake Superior receives a disproportionately high number of discharges by both BOB and NOBOB ships, yet it has sustained surprisingly few initial invasions (Fig. 4). Conversely, the corridor connecting Lake Huron and Lake Erie is an invasion ‘hotspot’ despite receiving disproportionately few ballast discharges (Grigorovich et al. 2003). The greatest number of ANS range expansion species (native or cryptogenic to a portion of the basin but introduced to other areas of the basin) have become established in Lake Superior and Lake Huron, suggesting that intrabasin movement of species should not be ignored. Other vectors, including canals and the private sector, continue to deliver ANS to the Great Lakes and may increase in relative importance in the future.

Second only to shipping, unauthorized release, transfer, and escape have introduced ANS into the Great Lakes. Of particular concern are private sector activities related to aquaria, garden ponds, baitfish, and live food fish markets. Silver and bighead carp escapees from southern United States fish farms have been sighted beyond the electric dispersal barriers in the Chicago Sanitary and Ship Canal, which connects the Mississippi River and Lake Michigan. A prototype barrier was activated in April 2002 to block the transmigration of species between the Mississippi River system and the Great Lakes basin. The U.S. Army Corps of Engineers (partnered by the State of Illinois) completed construction of second and third permanent barriers in 2005 and 2011, respectively. Since 2009, environmental DNA (eDNA) surveillance has been used to complement the use of traditional monitoring and suppression tools. Between 2009 and 2010, DNA of both bighead and silver carp was detected past the electric barriers. However, as of August of the 2011 monitoring year, only silver carp DNA had been detected on the lake side of these barriers; despite an intensive sampling effort in response to three consecutive rounds of positive eDNA tests in the Lake Calumet area, no Asian carp were seen or captured.

Nearly a million Asian carp, including bighead and black carp, are sold annually at fish markets within the Great Lakes basin. Until recently, most of these fish were sold live. All eight Great Lakes states and the province of Ontario now have some restriction on the sale of live Asian carp. Enforcement of many private transactions, however, remains a challenge. The U.S. Fish and Wildlife Service published a final rule in March 2011, officially adding the bighead carp to the federal injurious wildlife list and codifying the Asian Carp Prevention and Control Act. Bighead, silver, and black carp are now listed as nuisance species under the Lacey Act, prohibiting interstate transport. There are currently numerous shortcomings in legal safeguards relating to commerce in exotic live fish as identified by Alexander (2003) in Great Lakes and Mississippi River states, Quebec, and Ontario. These include: express and de facto exemptions for the aquarium pet trade; de facto exemptions for the live food fish trade; inability to proactively enforce import bans; lack of inspections at aquaculture facilities; allowing aquaculture in public

waters; inadequate triploidy (sterilization) requirements; failure to regulate species of concern (e.g., Asian carp); regulation through “dirty lists” only (e.g., banning known nuisance species); and failure to regulate transportation.

## Linkages

**Invasion Meltdown:** Evidence indicates that newly invading species may benefit from the presence of previously established invaders. That is, the presence of one ANS may facilitate the establishment or population growth of another (Ricciardi 2001). For example, the sea lamprey (*Petromyzon marinus*) may have created enemy-free space that facilitated the alewife’s (*Alosa pseudoharengus*) invasion, and the round goby (*Neogobius melanostomus*) and *Echinogammarus ischnus* (amphipod) have thrived in the presence of previously established zebra (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*). In effect, dreissenids have set the stage to increase the number of successful invasions, particularly those of co-evolved species in the Ponto-Caspian assemblage.

[Indicators: Sea Lamprey, Dreissenid Mussels]

**Multi-stressors:** Changes in water quality, global climate change, and land use also may make the Great Lakes more hospitable for the arrival of new invaders. (Indicators: Nutrients in Lakes, Dissolved Oxygen, Water Clarity)

**Secondary Shifts in Native Populations:** ANS may exert significant direct and indirect pressures upon native species, including facilitation of parasitism, transmission of viral/bacterial infections, magnification of toxins, competition, food-web alteration, genetic introgression, degradation of water quality, and degradation of physical habitat. ANS have promoted the proliferation of native nuisance species, including blue-green algae (Skubinna et al. 1995; Vanderploeg et al. 2001). [Indicators: Wetland Species, Lake Trout, Walleye, Preyfish, Benthos, *Diporeia*, Zooplankton Biomass and Health, Threatened Species, Sturgeon, Botulism Outbreaks, Fish Disease Occurrences, Harmful Algal Blooms, *Cladophora*]

**Aquatic Habitat Connectivity:** The potential for ANS to colonize new locations is increased with removal of dams. In contrast, ecological separation of the Great Lakes from the Mississippi River basin is currently being discussed as a way to limit transfer of ANS between these basins.

**Fish Habitat:** Many nonindigenous plants are capable of forming dense mats that may exclude fish from nearshore habitats. Colonization of lakebed areas by dreissenid mussels and the consequent filling of remaining interstitial spaces with pseudofeces and fine-grained sediments led to the exclusion of lake trout from their native spawning grounds (S. Mackey, Habitat Solutions NA, pers. comm.).

## Management Challenges/Opportunities

ANS have invaded the Great Lakes basin from regions around the globe (Fig. 5). Increasing world trade and travel elevates the risk that additional species (Table 2) will continue to gain access to the Great Lakes. Indeed, the arrival of *Hemimysis anomala* was predicted (Ricciardi and Rasmussen 1998). Existing connections between the Great Lakes watershed and systems outside the watershed, such as the Chicago Sanitary and Ship Canal, and growth of industries such as aquaculture, live food markets, and aquarium retail stores will also increase the risk that new ANS will be introduced.

Researchers are seeking to better understand links between vectors and donor regions, the receptivity of the Great Lakes ecosystem, and the biology of new invaders in order to make recommendations to reduce the risk of future invasion. To protect the biological integrity of the Great Lakes, it is essential to closely monitor routes of entry for ANS, to introduce effective safeguards, and to quickly adjust safeguards as needed. The rate of invasion may increase if positive interactions involving established ANS or native species facilitate the establishment of new

ANS. Ricciardi (2001) suggested that such a scenario of “invasional meltdown” is occurring in the Great Lakes, although Simberloff (2006) cautioned that most of these cases have not been well substantiated. Moreover, each new invader can interact in unpredictable ways with previously established invaders, potentially creating synergistic impacts (Ricciardi 2001, 2005). For example, recurring outbreaks of avian botulism in the lower Great Lakes are thought to result from the effects of dreissenid mussels and round gobies, in which the mussels create environmental conditions that promote the pathogenic bacterium and the gobies transfer bacterial toxin from the mussels to higher levels of the food web.

To be effective in preventing new invasions, management strategies must focus on linkages between ANS, vectors, and donor and receiving regions, and have available to them resources in support of early detection and rapid response. However, without measures that effectively eliminate or minimize the role of ship-borne and other emerging vectors (such as live trade and recreational boating, see Mandrak and Cudmore 2010), we can expect the number of ANS in the Great Lakes to continue to rise, with an associated loss of native biodiversity and an increase in unforeseen ecological disruptions. Furthermore, increasing lake temperatures associated with climate change will lead to increased potential for ANS introduced from warmer climates to establish overwintering populations (see Adebayo et al. 2011; Mandrak 1989).

### Comments from the author(s)

Lake-by-lake assessments should include Lake St. Clair and connecting channels (Detroit River, St. Clair River). Species first discovered in these waters were assigned to Lake Erie for the purposes of this report. Moreover, range expansion ANS (those native or cryptogenic to a portion of the basin but introduced to other areas of the basin) should be included in lake-by-lake assessments and perhaps incorporated into future figures. Environmental, socioeconomic, and beneficial impacts of ANS should also receive additional treatment (e.g., Table 1).

### Assessing Data Quality

Data Characteristics	Strongly Agree	Agree	Neutral or Unknown	Disagree	Strongly Disagree	Not Applicable
1. Data are documented, validated, or quality-assured by a recognized agency or organization		X				
2. Data are traceable to original sources		X				
3. The source of the data is a known, reliable and respected generator of data		X				
4. Geographic coverage and scale of data are appropriate to the Great Lakes basin		X				
5. Data obtained from sources within the U.S. are comparable to those from Canada		X				
6. Uncertainty and variability in the data are documented and within acceptable limits for this indicator report		X				
Clarifying Notes: Assessment data in Table 2 is currently in the process of being collected and reviewed; completion is expected prior to release of the final SOGL report in 2012.						

## Acknowledgments

### Authors:

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 Kristen T. Holeck, Department of Natural Resources, Cornell University, Bridgeport, NY

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## List of Tables

Table 1. Nonindigenous species assessed to have a high impact in one or more impact categories.

Source: Great Lakes Aquatic Nonindigenous Species Information System, <http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html> (in prep.)

Table 2. Nonindigenous species predicted in the scientific literature to have a high probability of introduction to the Great Lakes. Probability of introduction, establishment, and predicted level of impact (Environmental, Socioeconomic, Beneficial) are given as High, Moderate, Low, or Unknown.

Source: Adebayo et al. 2011; Bailey et al. 2005; Cole 2001; Cudmore and Mandrak 2005; Cudmore-Vokey and Crossman 2000; Great Lakes Aquatic Nonindigenous Species Information System, <http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html> (in prep.); Grigorovich et al. 2003; Herborg et al. 2007; Johengen et al. 2005; Kipp et al. 2010; Kolar and Lodge 2002; Kolar et al. 2005; Mandrak 1989; Mendoza-Alfaro et al. 2009; A. Ricciardi, McGill University; Ricciardi and Rasmussen 1998; Rixon et al. 2005; Stepien and Tumeo 2006; U.S. EPA 2008.

## List of Figures

Figure 1. Release mechanisms for aquatic nonindigenous species (ANS) established in the Great Lakes basin since the 1830s. Unintentional release encompasses ornamental plant escape, research escape, and parasites/pathogens through fish stocking.

Source: Great Lakes Aquatic Nonindigenous Species Information System, <http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html>; Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.

Figure 2. Cumulative number of aquatic nonindigenous species (ANS) established in the Great Lakes basin since the 1830s attributed to (a) all vectors and (b) only the ship vector.

Source: Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.

Figure 3. Numbers of upbound transoceanic ballasted (BOB) and cargo laden (NOBOB) vessels entering the Great Lakes from 1959 to 2010.

Source: Colautti et al. 2003; Grigorovich et al. 2003; Holeck et al. 2004; Saint Lawrence Seaway Development Corporation Annual Traffic Reports, <http://www.greatlakes-seaway.com/en/seaway/facts/traffic/index.html>.

Figure 4. Lake of first discovery for ANS established in the Great Lakes basin since the 1830s.

Discoveries in connecting waters between Lakes Huron, Erie, and Ontario were assigned to the downstream lake. Species that were widespread at the time of discovery were assigned to the unknown category.

Source: Great Lakes Aquatic Nonindigenous Species Information System, <http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html>.

Figure 5. Regions of origin for aquatic ANS established in the Great Lakes basin since the 1830s.

Source: Great Lakes Aquatic Nonindigenous Species Information System,

<http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html>; Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.

### Last Updated

State of the Lakes Ecosystem Conference (SOLEC) 2011.

Species	Environmental Impact	Socio-Economic Impact	Beneficial Effect
<i>Alosa pseudoharengus</i>	High	High	High
<i>Bithynia tentaculata</i>	High	Moderate	Low
<i>Bythotrephes longimanus</i>	High	Low	Low
<i>Cercopagis pengoi</i>	High	Low	Low
<i>Cyprinus carpio</i>	High	Unknown	High
<i>Dreissena polymorpha</i>	High	High	Low
<i>Dreissena rostriformis bugensis</i>	High	High	Low
<i>Morone americana</i>	High	Moderate	High
<i>Neogobius melanostomus</i>	High	High	Low
<i>Oncorhynchus kisutch</i>	Moderate	Low	High
<i>Oncorhynchus mykiss</i>	High	Low	High
<i>Oncorhynchus tshawytscha</i>	Moderate	Low	High
<i>Osmerus mordax</i>	High	Unknown	High
<i>Petromyzon marinus</i>	High	High	Low
<i>Salmo trutta</i>	High	Low	High

**Table 1.** Nonindigenous species assessed to have a high impact in one or more impact categories.

Source: Great Lakes Aquatic Nonindigenous Species Information System,

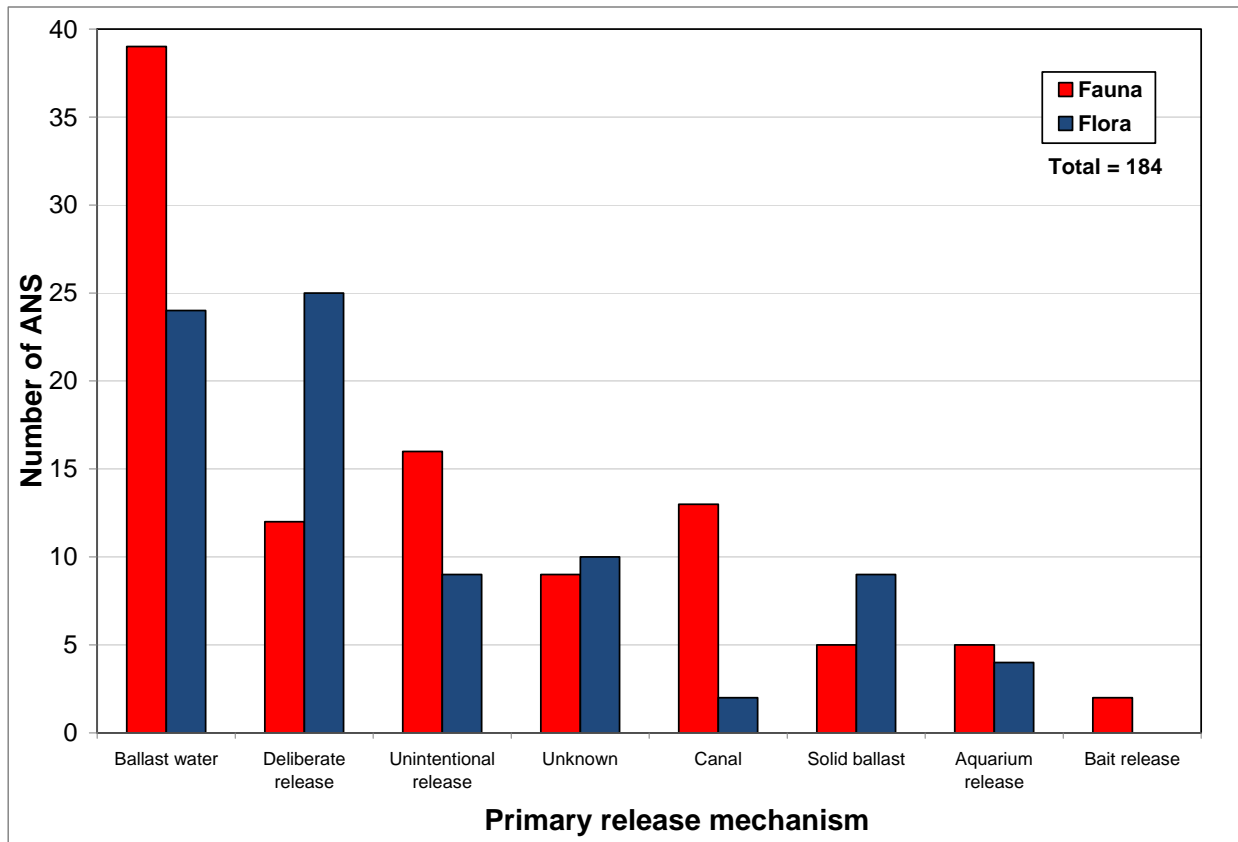
<http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html> (in prep.)

# STATE OF THE GREAT LAKES 2012 - DRAFT

Species	Predicted pathway (source)	Probability of			Reference
		Introduction	Establishment	Impact (E/S/B)	
<b>Fishes</b>					
<i>Alburnus alburnus</i>	ballast water (Eurasia)			High/Low/High	Kolar and Lodge 2002
<i>Atherina boyeri</i>	ballast water (Eurasia)				Kolar and Lodge 2002
<i>Babka gymnotrachelus</i>	ballast water (Eurasia)				Kolar and Lodge 2002; Stepien and Tumeo 2006
<i>Benthophilus stellatus</i>	ballast water (Eurasia)				Kolar and Lodge 2002; Ricciardi and Rasmussen 1998
<i>Channa argus</i>	unintentional release (Asia)	Low	High	Unk./Mod./High	Cudmore and Mandrak 2005; Herborg et al. 2007; Mendoza-Alfaro et al. 2009; Rixon et al. 2005
<i>Clupeonella cultriventris</i>	ballast water (Eurasia)				Kolar and Lodge 2002; Ricciardi and Rasmussen 1998
<i>Cottus gobio</i>	ballast water (Eurasia)				Kolar and Lodge 2002
<i>Ctenopharyngodon idella</i>	canal (Mississippi basin)			High/Low/High	Herborg et al. 2007; Mandrak and Cudmore 2005; Rixon et al. 2005
<i>Cyprinella whipplei</i>	canal (Mississippi basin)				Cudmore-Vokey and Crossman 2000; Mandrak 1989
<i>Hypophthalmichthys molitrix</i>	canal (Mississippi basin)			High/High/High	Herborg et al. 2007; Kolar and Lodge 2002; Kolar et al. 2005; Mandrak and Cudmore 2005
<i>Hypophthalmichthys nobilis</i>	canal (Mississippi basin)			High/High/High	Herborg et al. 2007; Kolar et al. 2005; Mandrak and Cudmore 2005; Rixon et al. 2005
<i>Knipowitschia caucasica</i>	ballast water (Eurasia)				Kolar and Lodge 2002
<i>Leuciscus leuciscus</i>	ballast water (Eurasia)				Kolar and Lodge 2002
<i>Neogobius fluviatilis</i>	ballast water (Eurasia)			High/Low/Mod.	Kolar and Lodge 2002; Ricciardi and Rasmussen 1998
<i>Oncorhynchus keta</i>	deliberate release (Pacific)				Kolar and Lodge 2002
<i>Perca fluviatilis</i>	ballast water (Eurasia)				Kolar and Lodge 2002
<i>Perccottus glenii</i>	ballast water (Eurasia)				A. Ricciardi pers. comm.
<i>Phoxinus phoxinus</i>	ballast water (Eurasia)				Kolar and Lodge 2002
<i>Rutilus rutilus</i>	ballast water (Eurasia)				Kolar and Lodge 2002
<b>Cladocerans</b>					
<i>Cornigerus maeoticus maeoticus</i>	ballast water (Eurasia)				Grigorovich et al. 2003
<i>Daphnia cristata</i>	ballast water (Eurasia)				Grigorovich et al. 2003
<i>Podonevadne trigona ovum</i>	ballast water (Eurasia)				Grigorovich et al. 2003
<b>Copepods</b>					
<i>Calanipeda aquaedulcis</i>	ballast water (Eurasia)				Grigorovich et al. 2003
<i>Cyclops kolensis</i>	ballast water (Eurasia)				Grigorovich et al. 2003
<i>Ectinosoma abrau</i>	ballast water (Eurasia)				Grigorovich et al. 2003
<i>Heterocope appendiculata</i>	ballast water (Eurasia)				Grigorovich et al. 2003
<i>Heterocope caspia</i>	ballast water (Eurasia)				Grigorovich et al. 2003
<i>Paraleptastacus spinicaudus triseti</i>	ballast water (Eurasia)				Grigorovich et al. 2003
<b>Amphipods</b>					
<i>Chelicorophium curvispinum</i>	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
<i>Dikerogammarus haemobaphes</i>	ballast water (Eurasia)				Grigorovich et al. 2003; Ricciardi and Rasmussen 1998
<i>Dikerogammarus villosus</i>	ballast water (Eurasia)	High	High	High/Low/Low	Grigorovich et al. 2003; Ricciardi and Rasmussen 1998
<i>Echinogammarus warpachowskyi</i>	ballast water (Eurasia)				Grigorovich et al. 2003
<i>Obesogammarus aralensis</i>	ballast water (Eurasia)				Grigorovich et al. 2003
<i>Obesogammarus crassus</i>	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
<i>Obesogammarus obesus</i>	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
<i>Pantogammarus robustoides</i>	ballast water (Eurasia)				Grigorovich et al. 2003; Ricciardi and Rasmussen 1998
<b>Mysids</b>					
<i>Limnomysis benedeni</i>	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
<i>Paramysis (Mesomysis) intermedia</i>	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
<i>Paramysis (Serrapalpis) lacustris</i>	ballast water (Eurasia)			Mod./Low/Unk.	Ricciardi and Rasmussen 1998
<i>Paramysis (Metamysis) ullskyi</i>	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
<b>Bivalves</b>					
<i>Monodacna colorata</i>	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
<b>Polychaetes</b>					
<i>Hypania invalida</i>	ballast water (Eurasia)				Ricciardi and Rasmussen 1998
<i>Leyogonimus polyoon</i>	canal (Mississippi basin)	Moderate	High		Cole 2001
<b>Bryozoans</b>					
<i>Fredericella sultana</i>	ballast water (Europe)			High/High/Unk.	Kipp et al. 2010
<b>Rotifers</b>					
<i>Brachionus leydigii</i>	ballast water (widespread)				Bailey et al. 2005; Johengen et al. 2005
<i>Filinia cornuta</i>	ballast water (widespread)				Bailey et al. 2005; Johengen et al. 2005
<i>Filinia passa</i>	ballast water (widespread)				Bailey et al. 2005; Johengen et al. 2005
<b>Plants</b>					
<i>Egeria densa</i>	unintentional release (S. America)				Rixon et al. 2005
<i>Eichhornia crassipes</i>	unintentional release (S. America)				Adebayo et al. 2011
<i>Hydrilla verticillata</i>	unintentional release (widespread)				U.S. EPA 2008
<i>Hygrophila polysperma</i>	unintentional release (Asia)			Mod./Mod./Low	Rixon et al. 2005
<i>Myriophyllum aquaticum</i>	unintentional release (S. America)	High	High	High/Mod./Low	Rixon et al. 2005
<i>Pistia stratiotes</i>	unintentional release (S. America)				Adebayo et al. 2011

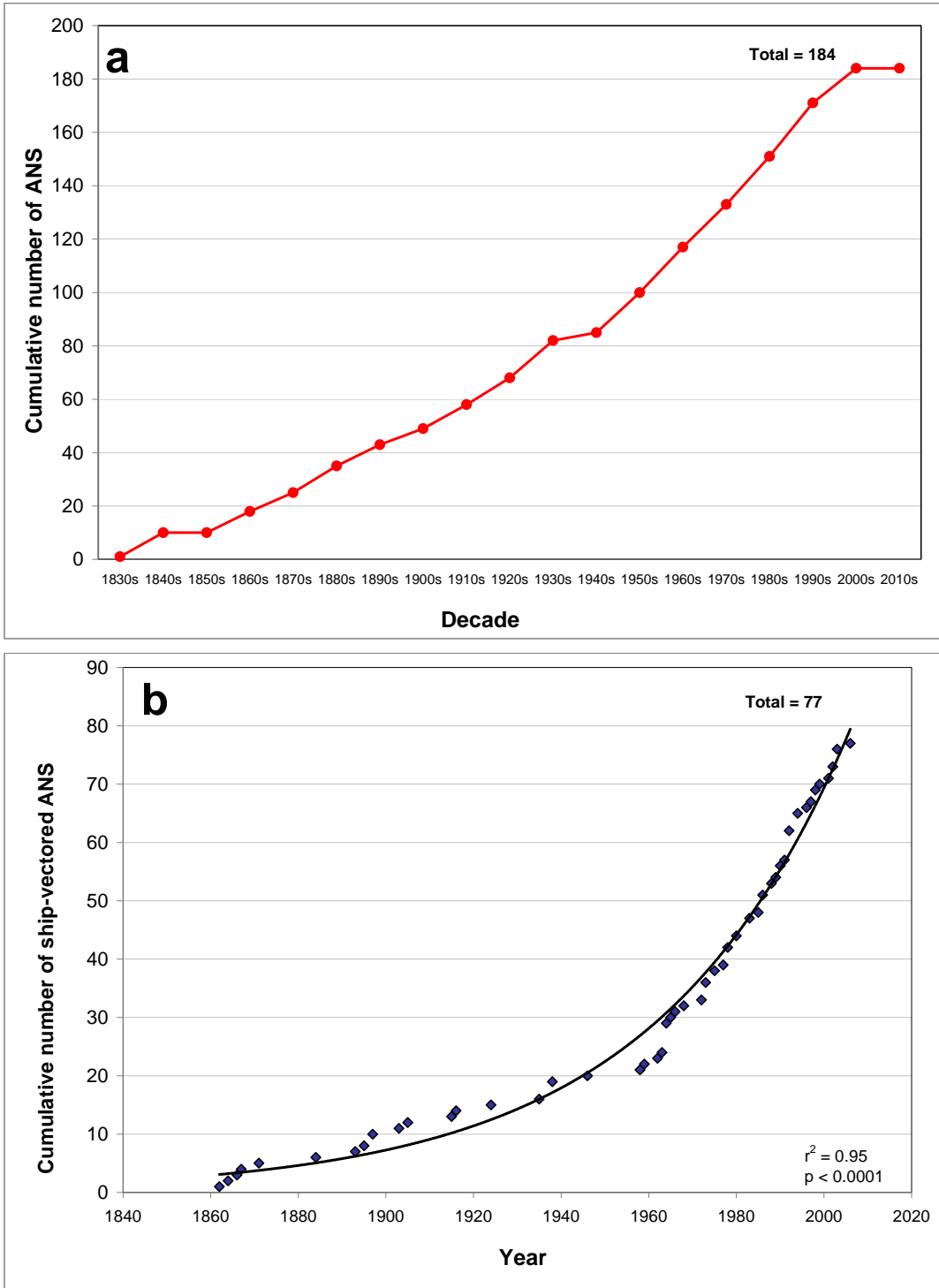
Table 2. Nonindigenous species predicted in the scientific literature to have a high probability of introduction to the Great Lakes. Probability of introduction, establishment, and predicted level of impact (Environmental, Socioeconomic, Beneficial) are given as High, Moderate, Low, or Unknown.

Source: Adebayo et al. 2011; Bailey et al. 2005; Cole 2001; Cudmore and Mandrak 2005; Cudmore-Vokey and Crossman 2000; Great Lakes Aquatic Nonindigenous Species Information System, <http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html> (in prep.); Grigorovich et al. 2003; Herborg et al. 2007; Johengen et al. 2005; Kipp et al. 2010; Kolar and Lodge 2002; Kolar et al. 2005; Mandrak 1989; Mendoza-Alfaro et al. 2009; A. Ricciardi, McGill University; Ricciardi and Rasmussen 1998; Rixon et al. 2005; Stepien and Tumeo 2006; U.S. EPA 2008.



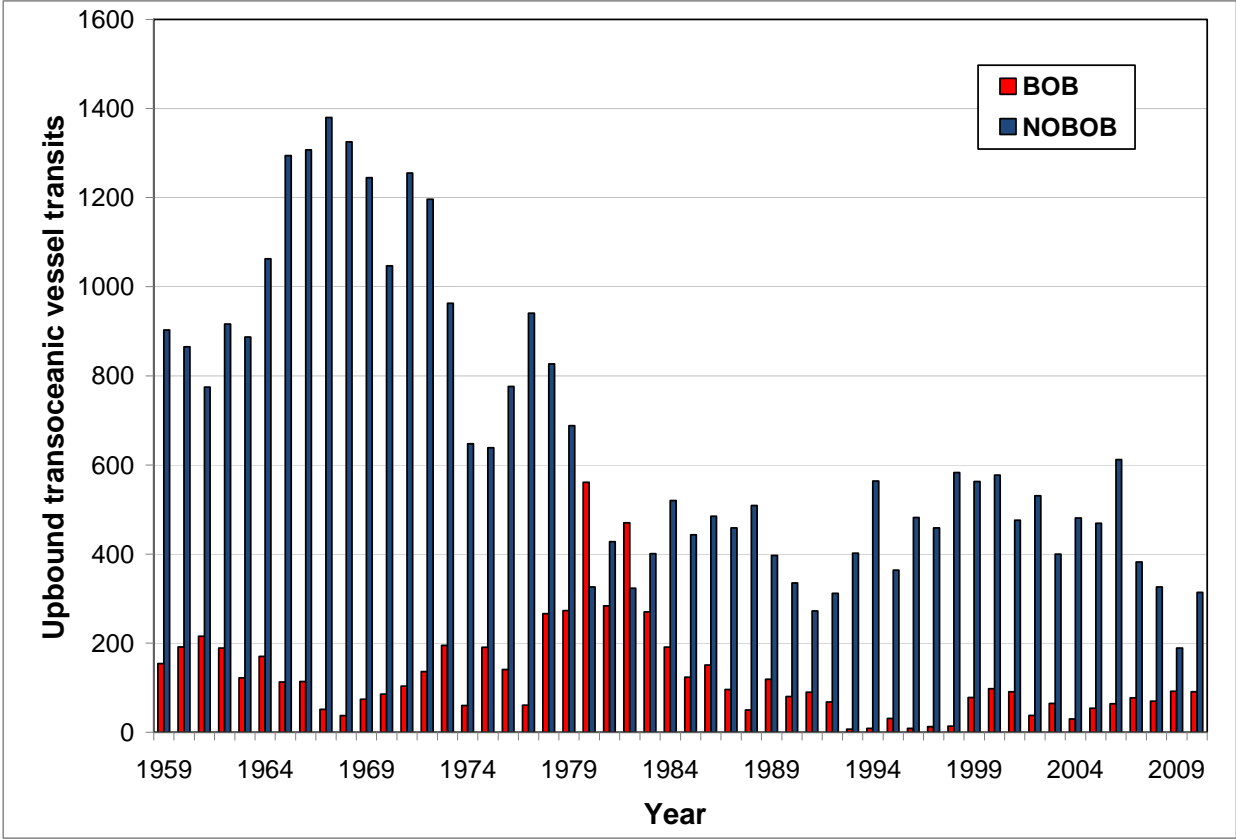
**Figure 1.** Release mechanisms for aquatic nonindigenous species (ANS) established in the Great Lakes basin since the 1830s. Unintentional release encompasses ornamental plant escape, research escape, and parasites/pathogens through fish stocking.

Source: Great Lakes Aquatic Nonindigenous Species Information System, <http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html>; Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.



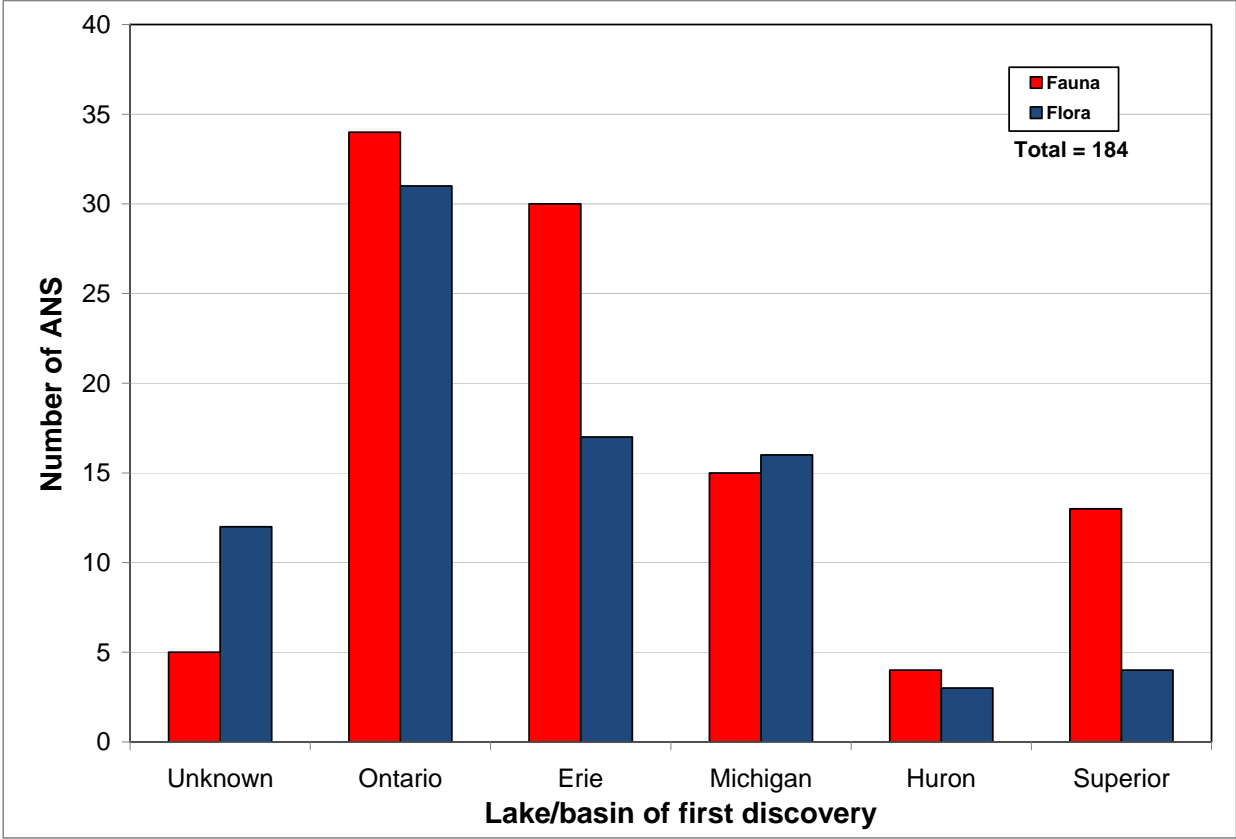
**Figure 2.** Cumulative number of aquatic nonindigenous species (ANS) established in the Great Lakes basin since the 1830s attributed to (a) all vectors and (b) only the ship vector.

Source: Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.

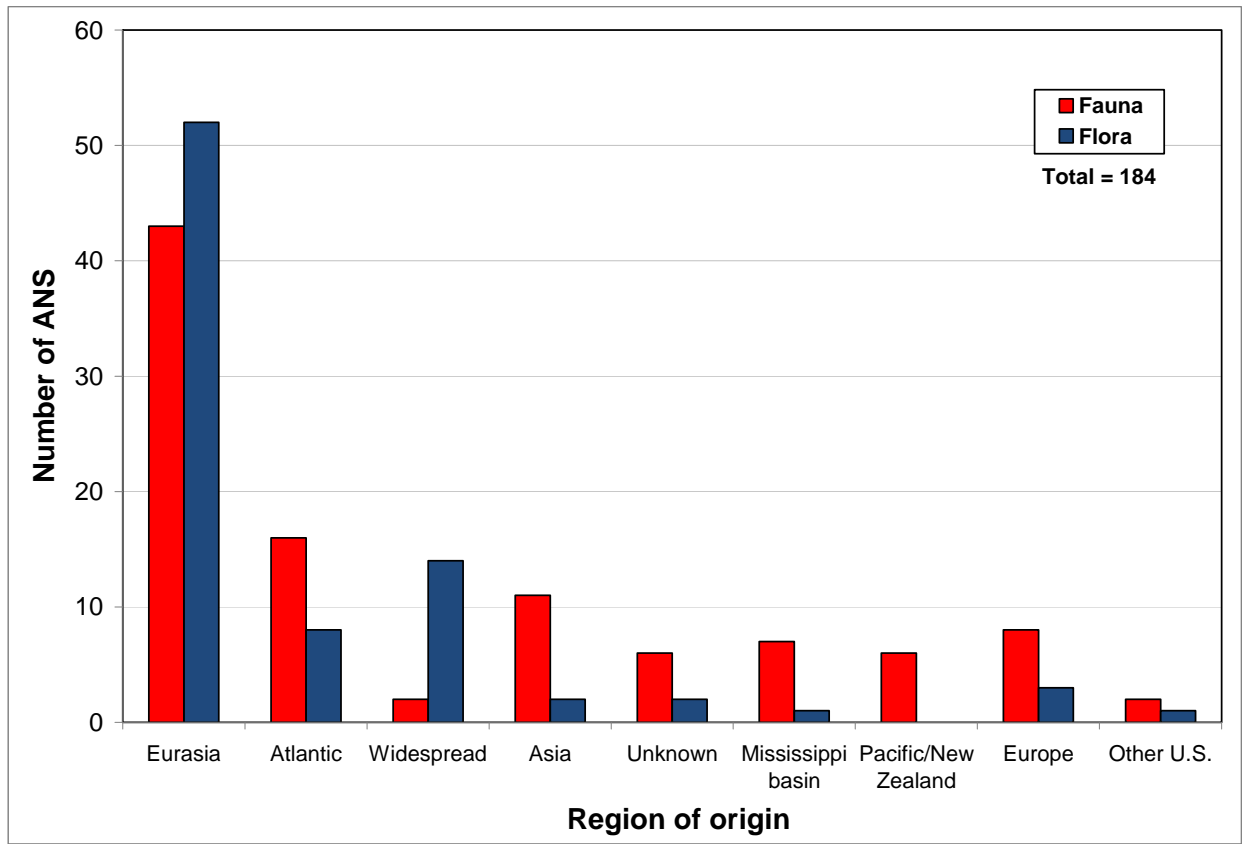


**Figure 3.** Numbers of upbound transoceanic ballasted (BOB) and cargo laden (NOBOB) vessels entering the Great Lakes from 1959 to 2010.

Source: Colautti et al. 2003; Grigorovich et al. 2003; Holeck et al. 2004; Saint Lawrence Seaway Development Corporation Annual Traffic Reports, <http://www.greatlakes-seaway.com/en/seaway/facts/traffic/index.html>.



**Figure 4.** Lake of first discovery for ANS established in the Great Lakes basin since the 1830s. Discoveries in connecting waters between Lakes Huron, Erie, and Ontario were assigned to the downstream lake. Species that were widespread at the time of discovery were assigned to the unknown category.  
 Source: Great Lakes Aquatic Nonindigenous Species Information System,  
<http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html>.



**Figure 5.** Regions of origin for aquatic ANS established in the Great Lakes basin since the 1830s. Source: Great Lakes Aquatic Nonindigenous Species Information System, <http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html>; Grigorovich et al. 2003; Mills et al. 1993; Ricciardi 2001; Ricciardi 2006.