



Non-native Species – Aquatic

Indicator #9002

Overall Assessment

Status: **Poor**

Trend: **Deteriorating**

Rationale: **Nonindigenous species (NIS) continue to be discovered in the Great Lakes. Negative impacts of established invaders persist and new negative impacts, including synergistic disruptions, are becoming evident.**

Lake-by-Lake Assessment

Lake Superior

Status: Fair

Trend: Unchanging

Rationale: Lake Superior is the site of most ballast water discharge in the Great Lakes, but it supports relatively few NIS. This is due at least in part to less hospitable environmental conditions.

Lake Michigan

Status: Poor

Trend: Deteriorating

Rationale: Established invaders continue to exert negative impacts on native species. *Diporeia* populations are declining.

Lake Huron

Status: Poor

Trend: Deteriorating

Rationale: Established invaders continue to exert negative impacts on native species. *Diporeia* populations are declining.

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 NIS (i.e., round goby and dreissenid mussels). An introduced virus (VHS) has caused mass die-offs of fish. *Diporeia* have become extirpated.

Lake Ontario

Status: Poor

Trend: Deteriorating

Rationale: Native *Diporeia* populations are declining in association with quagga mussel expansion. Condition and growth of lake whitefish, whose primary food source is *Diporeia*, are declining. A possible link exists between waterfowl deaths due to botulism and established NIS (i.e., round goby and dreissenid mussels). An introduced virus (VHS) has caused mass die-offs of fish.

Purpose

- To assess the presence, number and distribution of nonindigenous species (NIS) in the Laurentian Great Lakes
- To aid in the assessment of the status of biotic communities, because nonindigenous species can alter both the structure and function of ecosystems

Ecosystem Objective

The goal of the U.S. and Canada Great Lakes Water Quality Agreement is, in part, to restore and maintain the biological integrity of the waters of the Great Lakes ecosystem (United States and Canada 1987). Minimally, extinctions and unauthorized introductions must be prevented to maintain biological integrity.

State of the EcosystemBackground

At least 10% of NIS 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). In the Great Lakes, transoceanic ships are the primary invasion vector. Other vectors, such as canals and private sector activities (e.g., aquarium and bait industries), however, may play increasingly important roles.

Status of NIS

Human activities associated with transoceanic shipping are responsible for over one-third of NIS introductions to the Great Lakes (Figure 1). Total numbers of NIS introduced and established in the Great Lakes have increased steadily since the 1830s (Figure 2a). The numbers of ship-introduced NIS, however, has increased exponentially during the same time period (Figure 2b). Release of contaminated ballast water by transoceanic ships has been implicated in over 60% of faunal NIS 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 NIS introductions was recognized, finally 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, as recommended 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.

Contrary to expectations, the reported invasion rate has not declined following initiation of voluntary guidelines in 1989 and mandated regulations in 1993 (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, Figure 3) and were not required to exchange ballast, although their tanks contained residual sediments and water that would be discharged in the Great Lakes. The residual waters and sediments of these ships have been found to contain several species previously unrecorded in the basin, and 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 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).

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 (Figure 4). Conversely, the waters connecting Lake Huron and Lake Erie are an invasion 'hotspot' despite receiving disproportionately few ballast discharges (Grigorovich *et al.* 2003).

Other vectors, including canals and the private sector, continue to deliver NIS to the Great Lakes and may increase in relative importance in the future. Silver and bighead carp escapees from southern U.S. fish farms have been sighted below an electric dispersal barrier in the Chicago Sanitary and Ship Canal, which connects the Mississippi River and Lake Michigan. The 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 a second, permanent barrier in 2005.

Second only to shipping, unauthorized release, transfer, and escape have introduced NIS into the Great Lakes. Of particular concern are private sector activities related to aquaria, garden ponds, baitfish, and live food fish markets. For example, 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 is considering listing several Asian carp as nuisance species under the Lacey Act, which would prohibit interstate transport. Finally, 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.

Pressures

NIS have invaded the Great Lakes basin from regions around the globe (Figure 5), and increasing world trade and travel will elevate the risk that additional species (Table 1) 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 NIS will be introduced.

Changes in water quality, global climate change, and previous NIS introductions also may make the Great Lakes more hospitable for the arrival of new invaders. Evidence indicates that newly invading species may benefit from the presence of previously established invaders. That is, the presence of one NIS may facilitate the establishment or population growth of another (Ricciardi 2001). For example, the sea lamprey may have created enemy-free space that facilitated the alewife's invasion, and the round goby and *Echinogammarus* have thrived in the presence of previously established zebra and quagga mussels. 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, such as the crustacean *Echinogammarus* and the round goby. Evidence suggests that they have promoted the proliferation of

other nuisance species, including native and exotic weeds and blue-green algae (Skubinna *et al.* 1995; Vanderploeg *et al.* 2001).

Management Implications

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 NIS, to introduce effective safeguards, and to quickly adjust safeguards as needed. The rate of invasion may increase if positive interactions involving established NIS or native species facilitate the establishment of new NIS. 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 proven. 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 NIS, vectors, and donor and receiving regions. Without measures that effectively eliminate or minimize the role of ship-borne and other emerging vectors, we can expect the number of NIS in the Great Lakes to continue to rise, with an associated loss of native biodiversity and an increase in unforeseen ecological disruptions.

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.

Assessing Data Quality

Insert “x” under the statement that best corresponds with each data characteristic

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:						

Acknowledgments

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List of Tables

Table 1. Nonindigenous species predicted to have a high-risk of introduction to the Great Lakes. *Hemimysis anomala* was discovered in Lakes Ontario and Michigan in 2006.
Source: Ricciardi and Rasmussen 1998; Kolar and Lodge 2002; Grigorovich et al. 2003; Stokstad 2003; Rixon et al. 2005

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Figure 1. Release mechanisms for aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1840s.
Source: Mills et al. 1993; Ricciardi 2001; Grigorovich et al. 2003; Ricciardi 2006

Figure 2. Cumulative number of aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1840s attributed to (a) all vectors and (b) only the ship vector.
Source: Mills et al. 1993; Ricciardi 2001; Grigorovich et al. 2003; Ricciardi 2006

Figure 3. Numbers of upbound transoceanic ballasted (BOB) and cargo laden (NOBOB) vessels entering the Great Lakes from 1959 to 2006.

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 NIS established in the Great Lakes basin since the 1840s.

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/ncrais/glansis.html>

Figure 5. Regions of origin for aquatic NIS established in the Great Lakes basin since the 1840s.

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

Last Updated

State of the Lakes Ecosystem Conference (SOLEC) 2008

Species	Reference
Fishes	
<i>Aphanius (Atherina) boyeri</i>	Kolar and Lodge 2002
<i>Benthophilus stellatus</i>	Ricciardi and Rasmussen 1998
<i>Clupeonella caspia (cultriventris)</i>	Ricciardi and Rasmussen 1998; Kolar and Lodge 2002
<i>Hypophthalmichthys (Aristichthys) nobilis</i>	Stokstad 2003; Rixon et al. 2004
<i>Hypophthalmichthys molitrix</i>	Stokstad 2003
<i>Misgurnus anguillicaudatus</i>	Rixon et al. 2004
<i>Neogobius fluviatilis</i>	Ricciardi and Rasmussen 1998; Kolar and Lodge 2002
<i>Perca fluviatilis</i>	Kolar and Lodge 2002
<i>Phoxinus phoxinus</i>	Kolar and Lodge 2002
<i>Tanichthys albonubes</i>	Rixon et al. 2004
Cladocerans	
<i>Daphnia cristata</i>	Grigorovich et al. 2003
<i>Bosmina obtusirostris</i>	Grigorovich et al. 2003
<i>Cornigerius maeoticus maeoticus</i>	Grigorovich et al. 2003
<i>Podonevadne trigona ovum</i>	Grigorovich et al. 2003
Copepods	
<i>Heterocope appendiculata</i>	Grigorovich et al. 2003
<i>Heterocope caspia</i>	Grigorovich et al. 2003
<i>Calanipeda aquae-dulcis</i>	Grigorovich et al. 2003
<i>Cyclops kolensis</i>	Grigorovich et al. 2003
<i>Ectinosoma abrau</i>	Grigorovich et al. 2003
<i>Paraleptastacus spinicaudata trisetata</i>	Grigorovich et al. 2003
Amphipods	
<i>Corophium curvispinum</i>	Ricciardi and Rasmussen 1998
<i>Corophium sowinskyi</i>	Ricciardi and Rasmussen 1998
<i>Dikerogammarus haemobaphes</i>	Ricciardi and Rasmussen 1998; Grigorovich et al. 2003
<i>Dikerogammarus villosus</i>	Ricciardi and Rasmussen 1998; Grigorovich et al. 2003
<i>Echinogammarus warpachowskyi</i>	Grigorovich et al. 2003
<i>Obesogammarus crassus</i>	Ricciardi and Rasmussen 1998
<i>Pontogammarus aralensis</i>	Grigorovich et al. 2003
<i>Pontogammarus obesus</i>	Ricciardi and Rasmussen 1998
<i>Pontogammarus robustoides</i>	Ricciardi and Rasmussen 1998; Grigorovich et al. 2003
Mysids	
<i>*Hemimysis anomala</i>	Ricciardi and Rasmussen 1998; Grigorovich et al. 2003
<i>Limnomysis benedeni</i>	Ricciardi and Rasmussen 1998
<i>Paramysis intermedia</i>	Ricciardi and Rasmussen 1998
<i>Paramysis lacustris</i>	Ricciardi and Rasmussen 1998
<i>Paramysis ullskyi</i>	Ricciardi and Rasmussen 1998
Bivalves	
<i>Hypanys (Monodacna) colorata</i>	Ricciardi and Rasmussen 1998
Polychaetes	
<i>Hypania invalida</i>	Ricciardi and Rasmussen 1998
Plants	
<i>Egeria densa</i>	Rixon et al. 2004
<i>Hygrophila polysperma</i>	Rixon et al. 2004
<i>Myriophyllum aquaticum</i>	Rixon et al. 2004
* discovered in 2006 in Lakes Michigan and Ontario	

Table 1. Nonindigenous species predicted to have a high-risk of introduction to the Great Lakes. *Hemimysis anomala* was discovered in Lakes Ontario and Michigan in 2006.

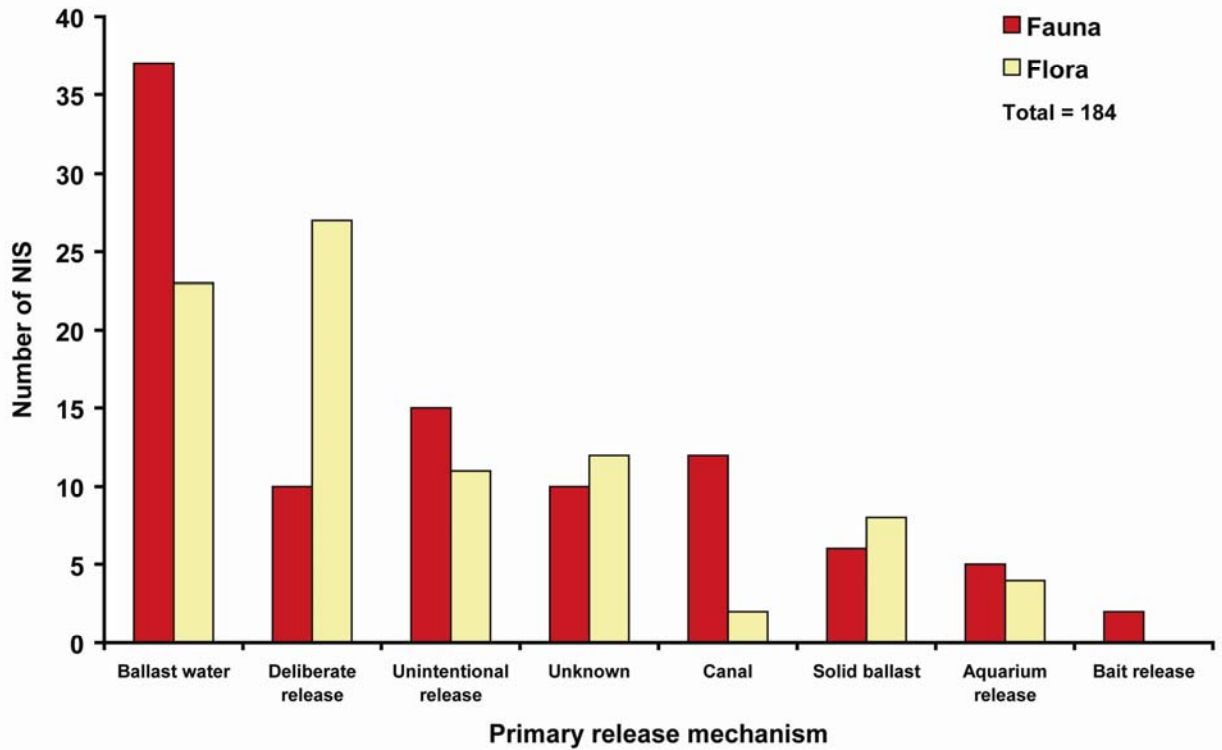


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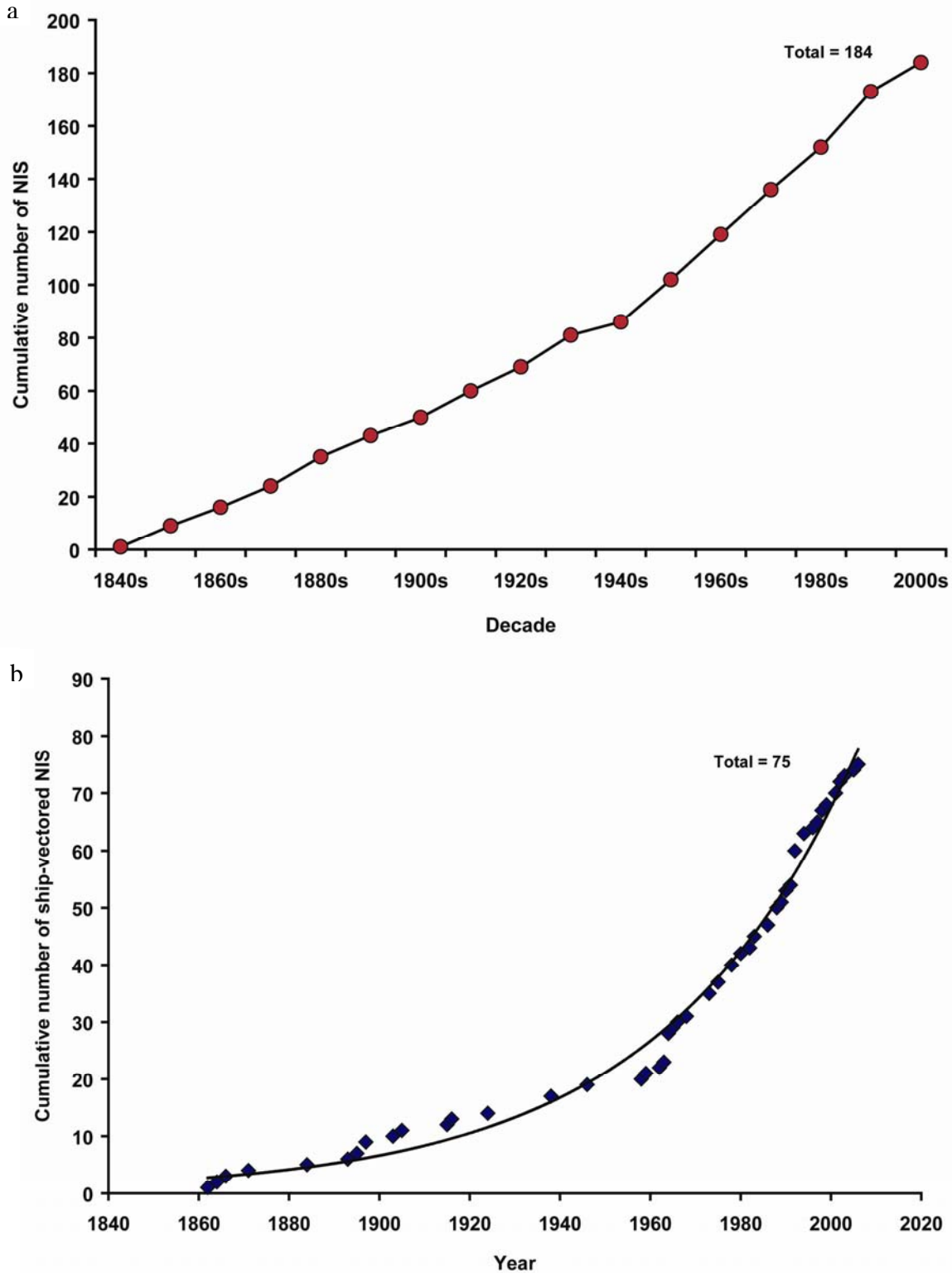


Figure 2. Cumulative number of aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1840s attributed to (a) all vectors and (b) only the ship vector.

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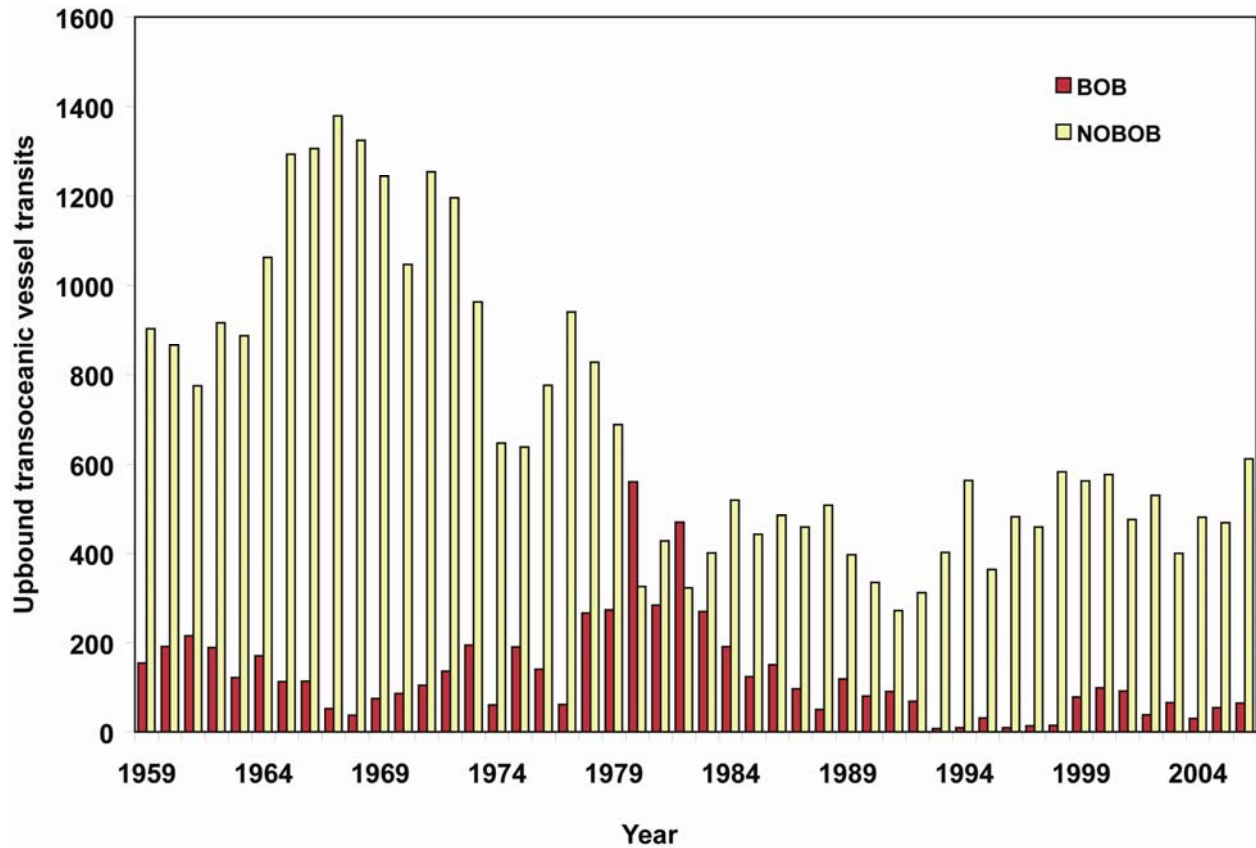


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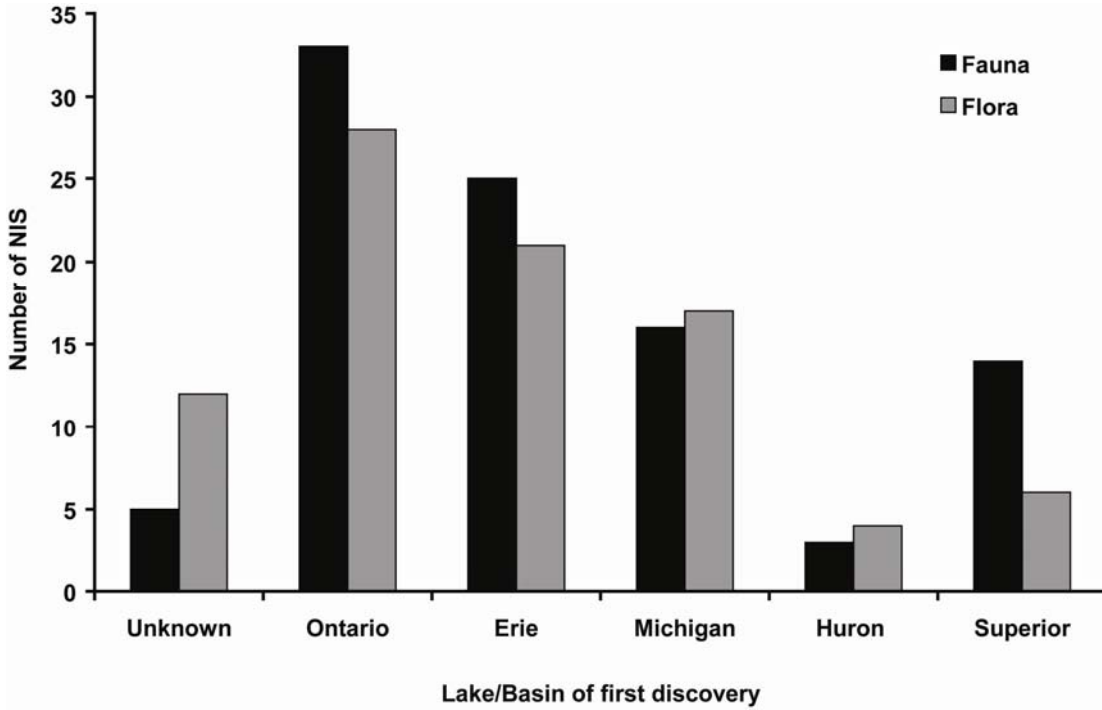


Figure 4. Lake of first discovery for NIS established in the Great Lakes basin since the 1840s. Discoveries in connecting waters between Lakes Huron, Erie and Ontario were assigned to the downstream lake. Species that were widespread at the time of discovery were assigned to the unknown category. Source: Great Lakes Aquatic Nonindigenous Species Information System, <http://www.glerl.noaa.gov/res/Programs/ncrais/glansis.html>

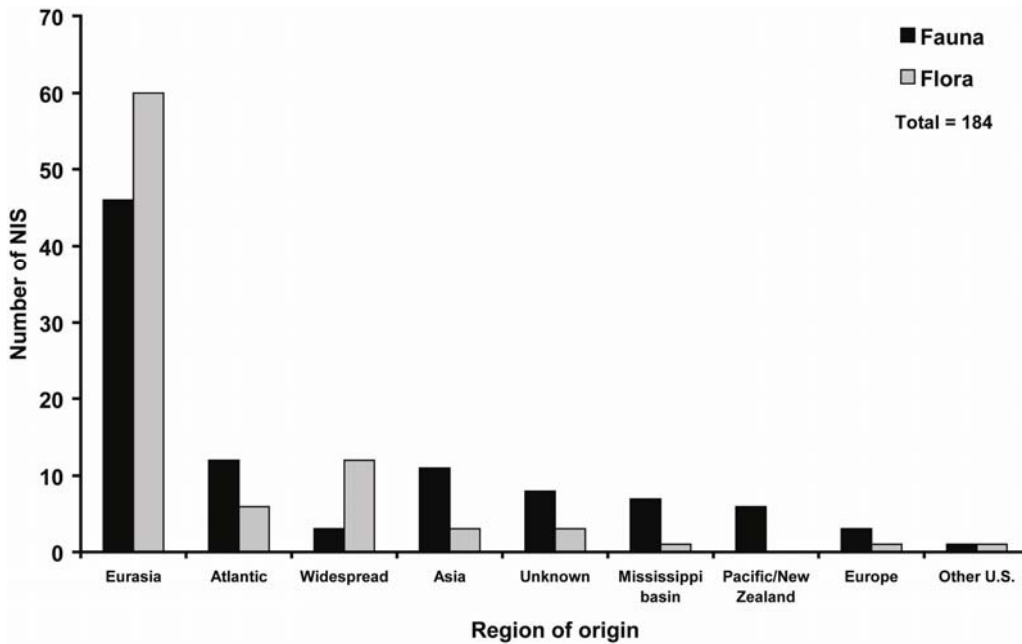


Figure 5. Regions of origin for aquatic NIS established in the Great Lakes basin since the 1840s. Source: Mills et al. 1993; Ricciardi 2001; Grigorovich et al. 2003; Ricciardi 2006