Non-native Species – Aquatic

Indicator #9002

Overall Assessment

Status: **Poor**
Trend: **Deteriorating**
Rationale: **Non-indigenous species (NIS) continue to be discovered in the Great Lakes. Negative impacts of established invaders persist and new negative impacts 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).

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).

Purpose

- To assess the presence, number and distribution of non-indigenous species (NIS) in the Laurentian Great Lakes
- To aid in the assessment of the status of biotic communities, because non-indigenous 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 Ecosystem

Background

Nearly 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, however, are also utilized by NIS with potential to harm biological integrity.

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 70% of faunal NIS introductions to the Great Lakes since the opening of the St. Lawrence Seaway in 1959 (Grigorovich *et al.* 2003).

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 Nonindigneous Aquatic Invasive Species Act has been drafted and awaits Congressional reauthorization.

Contrary to expectations, the reported invasion rate has increased following initiation of voluntary guidelines in 1989 and mandated regulations in 1993 (Grigorovich *et al.* 2003, Holeck *et al.* 2004). 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.

Recent studies suggest that the Great Lakes may vary in

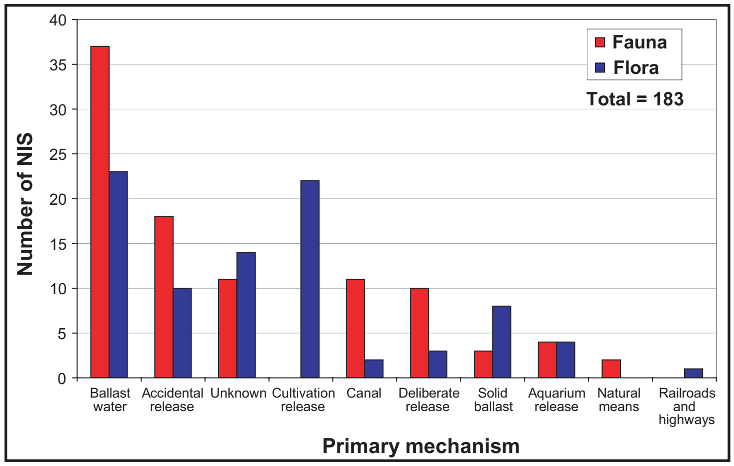

Figure 1. Release mechanisms for aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1830s.
Source: Mills *et al.* 1993; Ricciardi 2001; Grigorovich *et al.* 2003; Ricciardi 2006

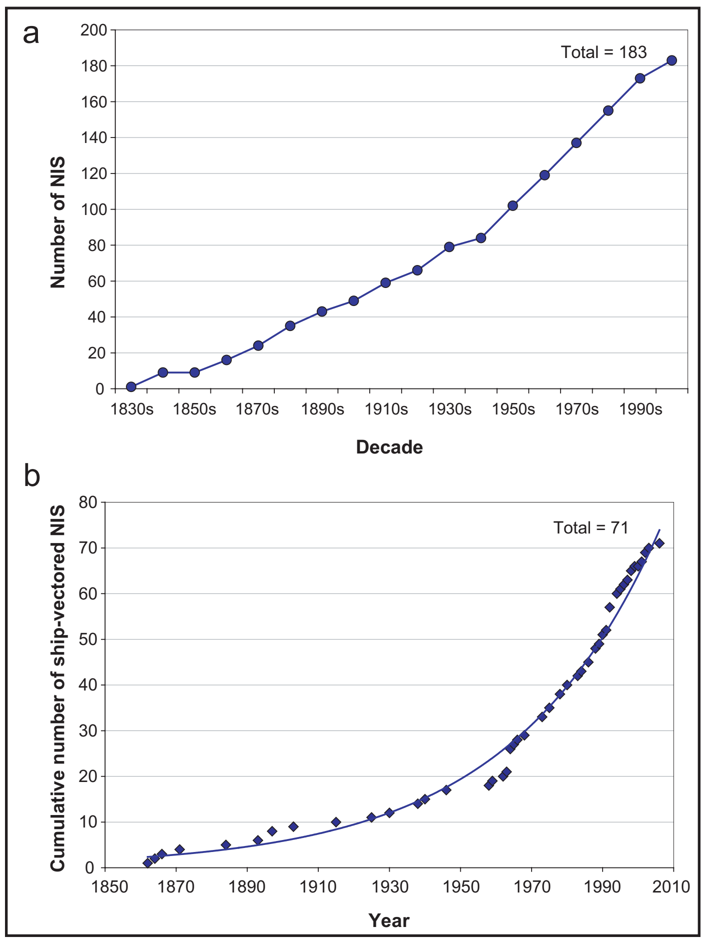

Figure 2. Cumulative number of aquatic nonindigenous (NIS) established in the Great Lakes basin since the 1830s attributed to (a) all vectors and (b) only the ship vector.
Source: Mills *et al.* 1993; Ricciardi 2001; Grigorovich *et al.* 2003; Ricciardi 2006

vulnerability to invasion in space and time. Lake Superior receives a disproportionate 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). Ricciardi (2001) suggests that some invaders (such as *Dreissena* spp.) may facilitate the introduction of coevolved species such as round goby and the amphipod *Echinogammarus*.

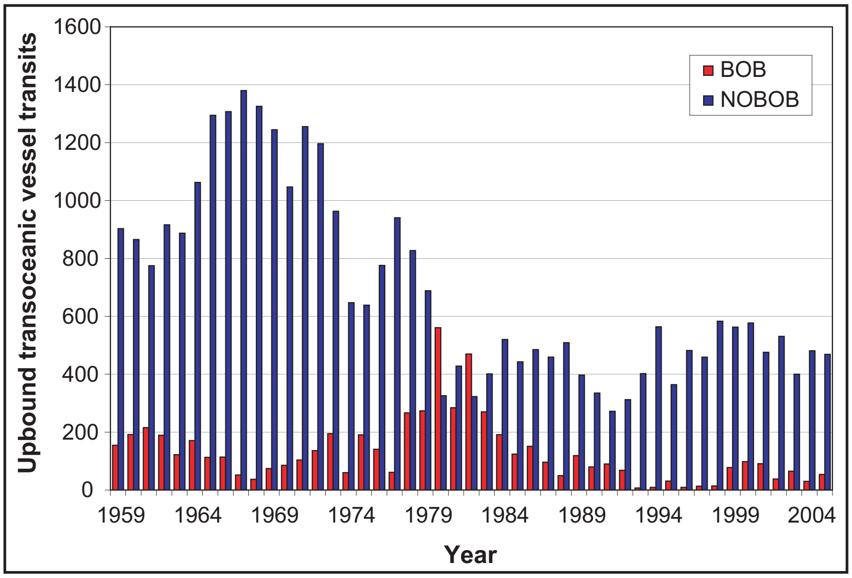

Figure 3. Numbers of upbound transoceanic vessels entering the Great Lakes from 1959 to 2002.

Source: Colautti *et al*. 2003; Grigorovich *et al*. 2003; Holeck *et al*. 2004

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.

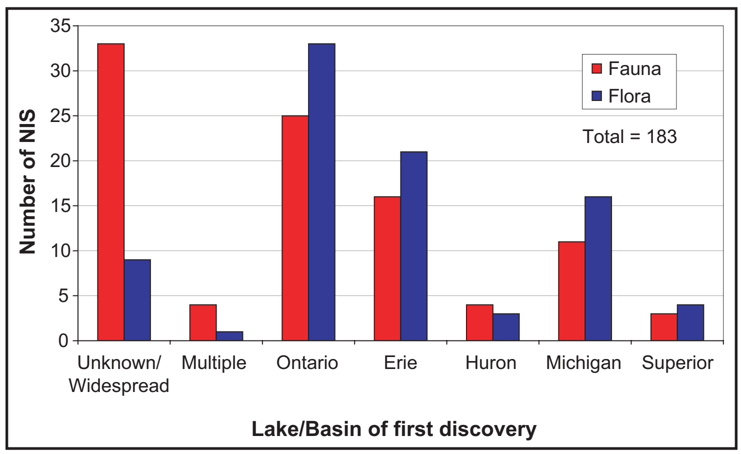

Figure 4. Lake of first discovery for NIS established in the Great Lakes basin since the 1830s.

Discoveries in connecting waters between Lakes Huron, Erie and Ontario were assigned to the downstream lake.

Source: Grigorovich et al. 2003

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. 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 of another (Ricciardi 2001). For example, round goby and *Echinogammarus* have benefited from 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.

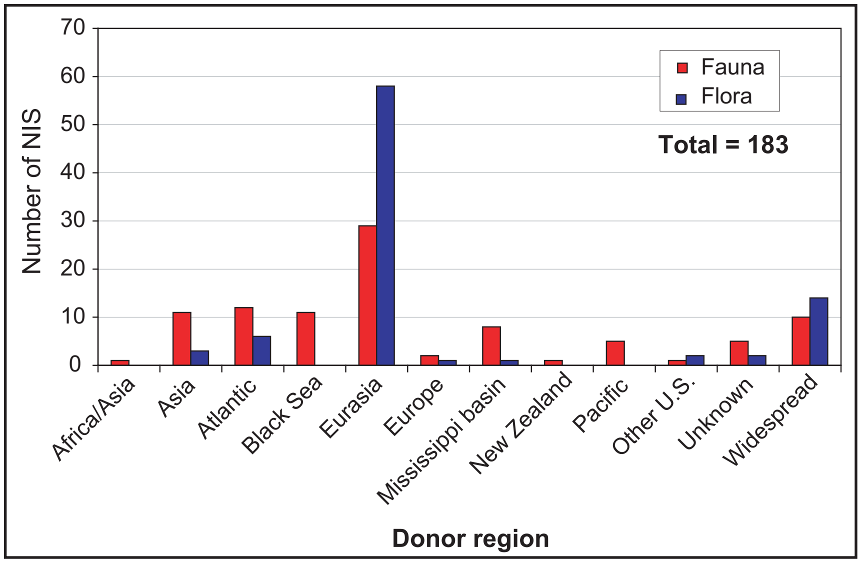

Figure 5. Regions of origin for aquatic NIS established in the Great Lakes basin since the 1830s.
Source: Mills *et al.* 1993; Ricciardi 2001; Grigorovich *et al.* 2003; Ricciardi 2006

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 entry 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.

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 unpredicted 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.

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

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

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