Nonindigenous Species (NIS)

State of the Ecosystem

Nearshore and coastal waters provide habitat for all 184 nonindigenous species (NIS) introduced to the Great Lakes since 1840; none are restricted exclusively to offshore areas. These habitats have been profoundly altered by NIS, with effects ranging from uprooting of wetland plants by common carp to direct and indirect creation of microhabitats by Dreissenid mussels. The status of Great Lakes nearshore waters with respect to NIS is **poor**. Since 1996, eighteen new NIS (Table 1) have been discovered – a rate of 1.5/year. This rate is higher than the long-term discovery rate (1.1/year since 1840), but lower than the rate since the opening of the St. Lawrence Seaway in 1959 (1.8/year) (Figure 1). Despite the slightly lower discovery rate in the last decade, any increase in the number of NIS in the Great Lakes represents a **deteriorating** trend since additional NIS may portend further disruption of existing food webs, in many cases in unpredictable and/or undesirable ways.

Of the eighteen NIS introduced since 1996, twelve are attributed to the ship vector and nine are native to Eurasia--proportions consistent with historical patterns (Kelly et al. 2008). Lake Michigan and Lake Ontario were first discovery sites for seven and six species, respectively; Lake Erie, Lake St. Clair and connecting waters hosted four; and Lake Superior harbored one—*Gammarus tigrinus*—which was also found in Lake Huron one year later. This distribution is generally consistent with historical patterns (Figure 2), although discoveries have become more prevalent in Lake Michigan in recent years. Species discovered since 1996 that have the greatest potential to disrupt Great Lakes nearshore ecosystems are *Cercopagis pengoi* (discovered 1998), viral hemorrhagic septicemia (VHS)(discovered 2005), and *Hemimysis anomala* (discovered 2006). *Cercopagis*, present in Lakes Ontario, Erie, and Michigan, preys on zooplankton, impacts native zooplankton species community composition, and competes with planktivorous fish for food. VHS, a virus originally believed to affect only salmonid species, is responsible for die-offs of muskellunge, smallmouth bass, northern pike, freshwater drum, gizzard shad, yellow perch, round goby, lake whitefish, Chinook salmon, and walleye in all the Great Lakes except Lake Superior. *Hemimysis*, a mysid shrimp that has become established in Lakes Ontario, Michigan, and Erie, was predicted to invade the Great Lakes because of its likelihood of surviving transport in ship ballast water and its extensive recent invasion history in Europe (Ricciardi and Rasmussen 1998). *Hemimysis* is a shallow water mysid that resides at depths from 0.5 to 50m (generally 6 to 10m) (Salemaa and Hietalahti 1993), whereas the Great Lakes native *Mysis relicta* prefers deeper waters. *Hemimysis* has the potential to be both a food competitor with young fish and a food source for older fish.

No new fish species have been discovered since 1996, but several fish diseases are cause for concern. Viral hemorrhagic septicemia (VHS), largemouth bass virus (LMBV), and spring viremia of carp (SVC) have each caused die-offs of fish in recent years. The VHS virus affects many (>40) fish species and appears to have significant potential for further spread in and around the Great Lakes. Concern about the transfer of VHS to other waters led to regulation of the baitfish industry in all U.S. Great Lakes states; baitfish that are to be transported to waters other than those in which they were collected must be certified disease free. SVC has caused large die-offs of ornamental koi in aquaculture facilities in Virginia and North Carolina. Carrier carp have been isolated from the Calumet-Sag Channel (Lake Michigan basin) that connects Lake Michigan to the Mississippi drainage and from Hamilton Harbor, Lake Ontario. LMBV has been detected in fish in Lake St. Clair and the Bay of Quinte, Lake Ontario although no large fish kills have been reported to date in the Great Lakes basin. Large kills have occurred in several southern states and appear to be related to thermally stressed fish. In addition to viruses, five protozoa and one bacterium have been discovered since 1996. This shift in the pattern of discovery toward microscopic organisms likely reflects greater research efforts to identify new NIS.

Pressures

Ballast water discharge. New regulations (Canada 2006; United States 2008) require transoceanic ships declaring no ballast on board to flush their ballast tanks with saline water, but the method does not provide 100% efficacy. While planktonic organisms will be flushed or killed with close to 100% efficiency (Gray et al 2007), species with resistant life stages may still gain entry. Also, NIS may still be transferred within the Great Lakes by "lakers"—vessels that do not leave the Great Lakes-St. Lawrence Seaway system but do transfer ballast water between Great Lakes ports (Rup 2008). New ballast water treatment technologies (heat, UV light, chemicals, and filtration) show promise for both oceangoing and lake vessels, particularly when used in combination, although their application to Great Lakes conditions needs further attention.

Other vectors. NIS may continue to be introduced and spread by other vectors. Baitfish may contain more than one species, including NIS like round gobies. In addition, infected baitfish could vector VHS to inland lakes. Asian carp species (bighead, silver) from the Mississippi drainage still threaten to enter Lake Michigan through the Chicago Sanitary and Ship Canal, despite the presence of an electric barrier. Growth in aquaculture, live gardens, and the aquarium trade increase the risk that NIS will be introduced either intentionally or unintentionally (Cohen et al. 2007).

Synergistic effects. Combined effects of water quality change, climate change, and facilitative interactions between NIS may increase the pressures exerted on nearshore waters of the Great Lakes. NIS may act in concert with one another with results that are more severe than the effect of any NIS alone (Ricciardi 2001, 2005). For example, recurring outbreaks of avian botulism resulting in the deaths of large numbers of waterfowl in Lakes Erie and Ontario are thought to result from the combined effects of Dreissenid mussels and round gobies. It has been suggested that mussels, through deposition of pseudofeces, create environmental conditions that promote the pathogenic bacterium, and round gobies, through their ingestion of mussels, transfer bacterial toxin from the mussels to higher levels of the food web (Yule et al. 2006). Warming temperatures and changing water quality (e.g. increasing clarity, declining nutrients) may enhance the success of established NIS that have a broader range of environmental tolerance as compared with native species.

Range expansions of established NIS. Although there have been no new vascular plant discoveries in the Great Lakes since 1996, several established invasive plant species continue to spread. Since 1996, new records of purple loosestrife have been documented in all Great Lakes states except Indiana and Illinois (USGS 2008). Purple loosestrife replaces cattail and other native wetland plants resulting in the alteration of the structure and function of wetlands. Large infestations reduce native foods and cover for wildlife and can impede water flow. *Phragmites australis*, or common reed, is also spreading throughout the Great Lakes basin. Recent research demonstrates the presence of two genotypes—one native and one invasive. It is the invasive European genotype that has expanded its range in the Great Lakes basin in areas such as Lake St. Clair; Long Point, Lake Erie; and Green Bay, Lake Michigan. *Phragmites* forms dense monospecific stands, altering native wetland plant and wildlife communities. Additional macrophytes including *Hydrilla verticillata* and *Cabomba caroliniana* are currently found in water adjacent to the Great Lakes, and could pose significant problems in shallow wetland areas if introduced.

Dreissenid mussels have continued to expand their range, with quagga mussels replacing zebra mussels in numerous nearshore and offshore habitats in Lakes Erie, Michigan, and Ontario. Dreissenid mussels may be partially responsible for lack of improvement in nearshore water quality despite distinct improvements in offshore waters due to declines in phosphorus loadings. Hecky et al. (2004) suggest that Dreissenids sequester phosphorus in nearshore areas through their filtering activity and through deposition of pseudofeces (nearshore shunt hypothesis).

Management Implications

The introduction of each new NIS adds ever-increasing complexity to Great Lakes food webs. Before the effects of any one invader are known, another arrives, confounding research results and forcing modification of previously successful management strategies in the face of uncertainty. Prevention of new introductions will require aggressive vector management (e.g. ballast water exchange, to be replaced by ballast water treatment, for all vessels) coupled with continued monitoring to determine the efficacy of preventative measures. New ballast water regulations for transoceanic NOBOB vessels should reduce the risk of introduction of new NIS in Great Lakes waters, but interlake transfer of ballast water by vessels that do not leave the Great Lakes will continue to spread existing NIS among the lakes. Transfer of unexchanged ballast water to the Great Lakes by vessels originating from coastal ports of North America must also be explored. Some species, including the amphipod *Gammarus tigrinus*, may have entered the lakes via ballast discharge from a coastal vessel. Nearshore and coastal habitats in the Great Lakes continue to be significantly impacted by NIS and are areas that require increased attention by scientists, managers, and policymakers.

Comments from the author(s)

To better assess nearshore and coastal waters, facilitative and/or synergistic effects should be assessed. Data access is typically quite good; NOAA's Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS) provides reliable information. Endpoints that would infer achievement of good quality nearshore waters are no new NIS discoveries, a decrease in the discovery rate, and confinement of existing NIS to current distributions (no spread). It must be acknowledged, however, that time lags between introduction and discovery of NIS could result in further finds of NIS in the Great Lakes even after the vectors responsible for their introduction have been muted or eliminated.

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Information Sources
Cohen, J., Mirotchnick, N., and Leung, B. 2007. Thousands introduced annually: the aquarium pathway and non-indigenous plants in the St. Lawrence Seaway. Frontiers in Ecology and the Environment 5:528-532.

Gray, D.K., T. Johengen, D.F. Reid and H.J. MacIsaac. 2007. Efficacy of open-ocean ballast water exchange as a means of preventing invertebrate invasions between freshwater ports. Limnol. Oceanogr. 52:2386-2397.

Grigorovich, I.A., Colautti, R.I., Mills, E.L., Holeck, K.T., Ballert, A.G., and MacIsaac, H.J. 2003. Ballast-mediated animal introductions in the Laurentian Great Lakes: retrospective and prospective analyses. Can. J. Fish. Aquat. Sci. 60:740-756.

Kelly, D.W., G. Lamberti and H.J. MacIsaac. 2008. Laurentian Great Lakes as a case study of biological invasion. In: ISIS Bioeconomics of Biological Invasions. R. Keller, M. Lewis and D. Lodge (eds). (in press)

Mills, E.L., Leach, J.H., Carlton, J.T., and Secor, C.L. 1993. Exotic species in the Great Lakes: A history of biotic crises and anthropogenic introductions. J. Great Lakes Res. 19(1):1-54.

Ricciardi, A. 2001. Facilitative interactions among aquatic invaders: is an "invasional meltdown" occurring in the Great Lakes? Can. J. Fish. Aquat. Sci. 58:2513-2525.

Ricciardi, A. 2005. Facilitation and synergistic interactions among introduced aquatic species. *In* Invasive Alien Species: A New Synthesis. Eds, H.A. Mooney, R.N. Mack, J. McNeely, L.E. Neville, P.J. Schei, and J.K. Waage. Pp. 162–178. Washington, DC: Island Press

Ricciardi, A. 2006. Patterns of invasions in the Laurentian Great Lakes in relation to changes in vector activity. Diversity and Distributions 12:425-433.

Ricciardi, A., and Rasmussen, J.B. 1998. Predicting the identity and impact of future biological invaders: a priority for aquatic resource management. Can. J. Fish. Aquat. Sci. 55:1759-1765.

Rup, M. 2008. Examination of ballast water movement by domestic vessels in the Great Lakes as vector of introduction or spread of aquatic nonindigenous speices. BSc thesis, University of Windsor. 25p.

Salemaa, H. and Hietalahti, V. 1993. *Hemimysis anomala* G. O. Sars (Crustacea: Mysidacea) – immigration of a Pontocaspian mysid into the Baltic Sea. Annales Zoologici Fennici 30(4): 271-276.

USGS. 2008. Nonindigenous Aquatic Species Database, Gainesville, FL. http://nas.er.usgs.gov

Yule, A.M., Austin, J.W., Barker, I.K., Cadieux, B., and Moccia, R.D. 2006. Persistence of *Clostridium botulinum* neurotoxin Type E in tissues from selected freshwater fish species: implications to public health. J. Food Prot. 69: 1164-1167.

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Table 1. NIS discovered in the Great Lakes since 1996.

Year	**NIS**	**Common Name**	**Region of Origin**	**Lake of First Discovery**	**Vector**
1996	*Heteropsyllus nr. nunni*	harpacticoid copepod	Atlantic North America	Lake Michigan	Shipping
1997	*Acineta nitocrae*	suctorian	Eurasia	Lake Erie	Shipping
1998	*Cercopagis pengoi*	fish-hook waterflea	Ponto-Caspian	Lake Ontario	Shipping
1998	*Schizopera borutzkyi*	harpacticoid copepod	Ponto-Caspian	Lake Michigan	Shipping
1999	*Daphnia lumholtzi*	waterflea	Africa	Lake Erie	Unintentional release
1999	*Nitokra incerta*	harpacticoid copepod	Ponto-Caspian	Detroit River	Shipping
2000	*Heterosporis sp.*	microsporidian	Unknown	Lake Ontario	Unknown
2001	*Gammarus tigrinus*	amphipod	Atlantic NA	Lake Superior	Shipping
2001	*Psammonobiotus communis*	testate amoeba	Ponto-Caspian	Lake Ontario	Shipping
2001	*Rhabdovirus carpio*	SVC spring viraemia of carp	Eurasia	Lake Michigan	Unknown
2002	*Cylindrospermopsis raciborskii*	cyanobacterium	South America	Lake Michigan	Unknown
2002	*Piscirickettsia cf. salmonis*	muskie pox	Unknown	Lake St. Clair	Unknown
2002	*Psammonobiotus linearis*	testate amoeba	Ponto-Caspian	Lake Ontario	Shipping
2002	*Psammonobiotus sp.*	testate amoeba	Ponto-Caspian	Lake Ontario	Shipping
2002	Ranavirus sp.	largemouth bass virus (LMBV)	Unknown	Lake Michigan	Unintentional release
2003	*Enteromorpha flexuosa*	green alga	Widespread	Lake Michigan	Shipping
2005	Novirhabdovirus sp.	Viral Hemorrhagic Septicemia (VHS) virus	Atlantic North America	Lake Ontario	Shipping
2006	*Hemimysis anomala*	mysid shrimp	Ponto-Caspian	Lake Michigan	Shipping

Figure 1. Cumulative number of aquatic NIS discovered in the Great Lakes basin since 1840. Source: Mills et al. 1993; Ricciardi 2001; Grigorovich et al. 2003; Ricciardi 2006.

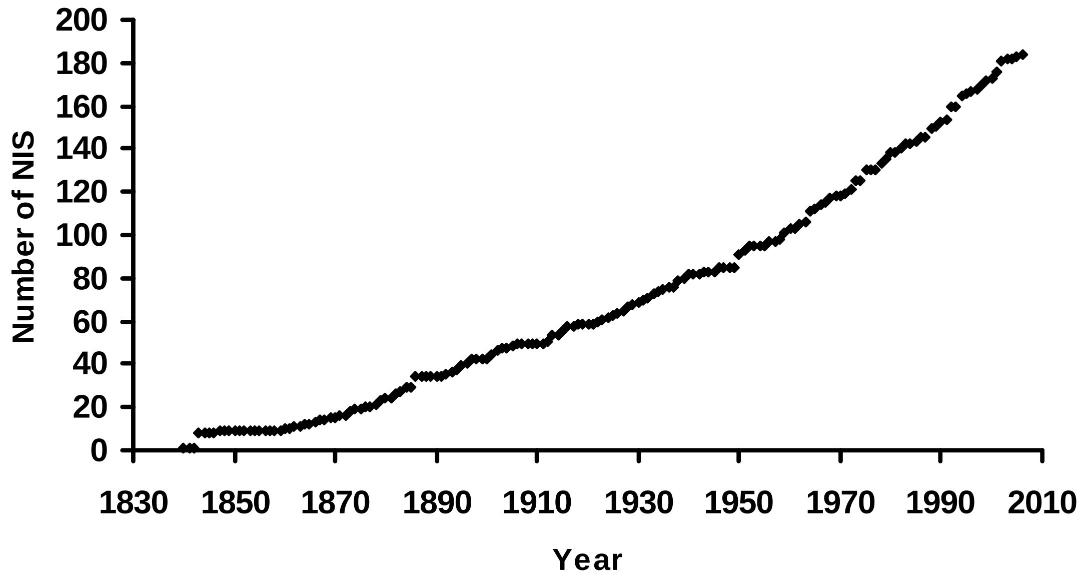

Figure 2. Location of first discovery for NIS in the Great Lakes since 1840. Discoveries in connecting waters between Lakes Huron, Erie, and Ontario were assigned to the downstream lake. Species that were widespread at the time of discovery were assigned to the unknown category. Source: Great Lakes Aquatic Nonindigenous Species Information System (http://www.glerl.noaa.gov/res/Programs/ncrais/glansis.html)