Indicator: Invasion of Zebra Mussels (*Dreissena polymorpha*) and Quagga Mussels (*Dreissena bugensis*)

Background

Zebra mussels (*Dreissena polymorpha*) are bivalve mollusks approximately 1 to 5 cm long that live in freshwater lakes (Figure 1). They siphon and filter phytoplankton and organic sediment from water with staggering efficiency, and have the ability to permanently attach to hard substrates. Zebra mussels are not native to the Great Lakes. Their free-swimming larvae (called "veligers," referring to the presence of a velum, a larval organ of feeding and locomotion) arrived via ballast from commercial ships. This ballast is composed of water, stones, plants and sediment taken up by the ship somewhere in its journeys to stabilize the vessel during travel without heavy loads; it is discharged elsewhere along with any organisms associated with the ballast as the ship is loaded with cargo. The mussels are from the Black and Caspian seas, and the Sea of Azov, but they have invaded many Russian and European waterways within the last 200 years.

*Figure 1. Zebra mussel (*Dreissena polymorpha*) cluster from the Detroit River (Photo credit: Center for Great Lakes and Aquatic Sciences).*

One of the most disturbing and direct consequences for the Great Lakes ecosystem from the recent invasion of zebra mussels is the local extirpation of the native mussel populations. These beneficial members of the Great Lakes ecosystem belong to the family Unionidae. They live in mud or sandy sediment. Before the arrival of zebra mussels, there were approximately 40 species of native mussels in the Detroit River and approximately 20 in Lake St. Clair. Nalepa et al. (1996) collected Unionidae from 29 sites in Lake St. Clair in 1986 (before the first zebra mussels were found), 1990, 1992, and 1994. They collected 281 (18 species), 248 (17 species), 99 (12 species), and 6 (5 species) native mussels in the four years, respectively, which shows the devastating impact to native mussels. Zebra mussels attach themselves to unionids by byssal threads. The zebra mussels interfere with the unionid mussels' ability to open and close their shells (Figure 2). This prohibits the unionids' ability to burrow. The zebra mussels also consume the algae and suspended sediment that the unionids would otherwise filter from the water.

Zebra mussels alter the nutrient cycling of the aquatic ecosystem. They filter sediment and food particles out of the water. The solid waste particles (feces and pseudofeces) are much larger than the food particles eaten, and build up on the lake bottom, thereby transferring energy from the pelagic (open water) to the benthic (bottom) zone. Pseudofeces are materials that collect on the zebra mussel's gills and are rejected before entering the gut. Through filtration, zebra mussels clarify the water and decrease local algal densities (Mellina et al. 1995; see Water Clarity indicator).

Experiments at the Great Lakes Environmental Research Laboratory (GLERL) in Ann Arbor, Michigan with water from Lake Erie have shown that zebra mussels reject inedible phytoplankton. Many species of bluegreen algae are apparently distasteful to aquatic biota. The mussels' selective feeding habits seem to promote and maintain *Microcystis* blooms, which at high levels can be toxic to aquatic life (Vanderploeg et al. 2001; see Algal Blooms in Western Lake Erie indicator). Using special video equipment, GLERL showed that mussels filter any water, but expel only *Microcystis* back into the water. Thus, the competitors of *Microcystis* are removed. The mussels' excreted waste products are rich in nutrients (phosphate and ammonia) derived from their phytoplankton food. These nutrients, in turn, serve to fertilize further phytoplankton growth, especially growth of *Microcystis*.

Figure 2. Native mussel shell with attached zebra mussels (Photo credit: U.S. Fish and Wildlife Service).

Zebra mussels accumulate contaminants such as polychlorinated biphenyls (PCBs) as they filter water and take in algae, as well as suspended sediment particles that have associated contaminants. Their tissues accumulate and store some of the contaminants, but some are carried out in the feces and accumulate in the bottom sediment. Dreissenids are so abundant that they can produce large amounts of contaminated feces. These feces are then consumed by benthic invertebrates such as *Gammarus fasciatus*, a shrimp-like crustacean. These organisms are, in turn, important food for fish, which then acquire the contaminants. These same contaminants are ultimately transferred further up the food web to organisms such as waterfowl, hawks and eagles, as well as people.

Zebra mussels have also had a large economic impact on the Great Lakes. Many power plants and water users have had to spend millions of dollars cleaning out zebra mussels from their facilities. In addition, more money has been spent on retrofitting facilities with devices to keep zebra mussels out and to monitor for them. These costs get passed along to the consumers.

Status and Trends

The zebra mussel is now well established throughout the Great Lakes and the Mississippi River watershed, while the related invasive quagga mussel (*Dreissena rostriformis bugensis*) is currently limited to the southern Great Lakes and the St. Lawrence River. Zebra mussels were first found in Lake St. Clair in June 1988 and probably arrived in 1986 (Hebert et al. 1989). The first quagga mussel was found in the Erie Canal in 1989, but was not recognized as a distinct species until 1991 (May and Marsden 1992). It does not have the tolerance for warm water and desiccation that zebra mussels do (Ricciardi et al. 1995) and its range is currently much more limited. However, quagga mussels have become the dominant dreissenid species in many areas once dominated by zebra mussels. Quagga mussels generally are able to live under wider environmental conditions than zebra mussels (Baldwin et al. 2003; Mills et al. 1996; Ricciardi and Whoriskey 2004). There is evidence that suggests quagga mussels could outcompete zebra mussels in more shallow, warm locations, or that hybridization may occur. Although morphological intermediates between the two species do occur, the frequency of hybridization was found to vary by basin. In 2004, D.R. Barton et al. (University of Waterloo, unpublished data) found specimens that had physical features intermediate between zebra mussels and quagga mussels at 31% of the stations sampled in the western basin, but only at 4% of those sampled in the central basin, and none in the eastern basin.

The U.S. Geological Survey (2007) has compiled annual distribution data that it obtained from many sources throughout the zebra mussel range (Table 1). Within one year of the initial discovery in Lake St. Clair in 1988, zebra mussels had become established along southern Lake Erie, western Lake Ontario and into the St. Lawrence River probably by way of commercial barges. By 1990, they had colonized Saginaw Bay and southern Lake Michigan. Surveys conducted in 1991 showed that the species colonized along the Mississippi River and the western portion of Lake Michigan, and by 1992 they were observed throughout the Mississippi River watershed. During this period, ships were observed with thousands of zebra mussels attached to their hulls, and barge ships were still the most significant mode of dispersal (Keevin et al. 1992). Rapid population growth and range expansion continued, but slowed down in 1993/1994. At this time, increases in density were found in the Detroit River and western Lake Erie, and expansion of inland lakes began in earnest. By 1994, they were in 10 inland lakes in Michigan. The 1995 survey showed an exceptional expansion in the number of inland lakes colonized by zebra mussels bringing the number to 29. From the late 1990s into the 2000s, zebra mussel densities continue to be high, with high numbers even appearing on soft substrate (Berkman et al. 2000), and quagga mussels are expanding their range in local areas.

Table 1. A summary of the history of zebra and quagga mussels in western Lake Erie and the Detroit River.

Time Period	Zebra and Quagga Mussel Population
1986	Arrival of zebra mussels from ballast as veligers or adults
1988	First established zebra mussel population confirmed in Lake St. Clair
1989	First quagga mussel sighted in Lake Erie
Early 1990s	Peak zebra mussel density and impact on ecosystem
Mid- to late 1990s	Leveling off of zebra mussel population, but more colonization on soft substrate; densities of quagga mussels increasing
2000s	Quagga mussels displacing zebra mussels in some warm littoral areas previously dominated by zebra mussels; quagga mussels reach their peak density in the central basin in 1998 and in the eastern basin in 2002
2004	Zebra mussels only common in the western basin; quagga mussel population numbers declining, but still remain highest in the eastern basin

As of January 2007, zebra mussels have been documented in all of the Great Lakes and in 225 inland lakes in Michigan (USGS 2007). The rate of inland expansion has declined considerably since 1998. The spread of zebra mussels is much faster in shipping routes and much slower across isolated bodies of water. Johnson et al. (2006) reported a peak invasion of inland lakes in 1993-1995 and another in 1998. Oakland County is the most invaded inland region in the state.

Quagga mussels dominate the soft substrates in the eastern basin of Lake Erie, which is the deepest of the three basins. Patterson et al. (2005) found that quagga mussels are present at all depths, but are most commonly found between 18 and 23 meters. The abundance of quagga mussels began increasing in 1992, at approximately the same time that zebra mussels reached their peak density in Lake Erie. Quagga mussel numbers continued to rise in all three basins, with the eastern basin exhibiting the greatest rise in abundance (Patterson et al. 2005). Population numbers leveled off in the central basin in 1998 and started to decline in subsequent years; densities in the eastern basin began to decline in 2002 (Patterson et al. 2005). In 2004, quagga mussels were present at approximately 65% of the 283 stations sampled and accounted for 93% of the total mussel mass (D.R. Barton et al., University of Waterloo, unpublished data). By this time, zebra mussels were common only in the western basin.

Management Next Steps

The management of all invasive species must center on prevention, as it is the most successful and economically viable method for ecosystem protection. The governments of the United States and Canada, as well as the eight Great Lakes states and the provinces of Ontario and Quebec, must stop the introduction of all exotic species into the Great Lakes. Stopping ballast water inputs of exotic species must be a priority. In 1997, the estimated cost of zebra mussels to raw-water dependent infrastructure at 339 facilities (e.g., power plants, drinking water treatment plants, etc.) was $69 million (O'Neill 1997).

Currently, trailered-boating is the main mode of dispersal of zebra mussels into inland lakes. Attention to geographic human activity patterns (where boaters are traveling from one body of water to another) can help predict future large-scale colonization of other invasive species (Padilla et al. 1996). Boaters that travel among numerous bodies of water must be informed of the risk that their watercraft can transport mussels to inland lakes. Information must be widely available that boats that have been in waters containing zebra and quagga mussels must be cleaned with heated spray. Boater education and awareness is essential to prevent the further spread of zebra mussels. The Lewis and Clark Project, spearheaded by the Pacific States Marine Fisheries Commission, has shown leadership in preventing the westward spread of zebra mussels. Its six-step program could help prevent invasion of inland lakes in the Great Lakes region. The program includes regional publicity, a containment strategy whereby new invasions could be identified quickly, and quarantine plans (ANS Task Force 2004).

Immediate conservation action must occur to locate and protect existing native unionid populations. Some researchers (e.g., Ricciardi et al. 1998; Cope and Waller 1995) have suggested capture and relocation projects, as this holds the most promise in terms of creating sustainable populations of native mussels. Such capture and relocation projects must be closely coupled with sound research to be most effective. A project at Metzger Marsh, Lake Erie removed unionids for a 3-year period and successfully returned them when the marsh was dewatered (Nichols and Wilcox 2002). Although low recruitment continues to threaten the population, it does show the importance of soft marsh sediment and warm temperatures to unionid burrowing and separation from zebra mussels. These isolated populations of native mussels are vulnerable to water level fluctuations and attention to this must occur so that diverse unionid populations do not move to deeper waters where mortality from zebra mussels on the harder substrates could occur. Ricciardi et al. (1998) also reiterate that management must focus on whole watersheds and not on single, rare species.

Research/Monitoring Needs

Continued research is needed to improve our understanding of food web changes and dynamics, as well as nutrient and contaminant cycling through time. It is not clear if the recent patterns interpreted from the data regarding the invasion of Dreissenids represent actual trends or simply year-to-year variation. Therefore, regular monitoring at particular locations is necessary. There is a need to further understand the potential spread of quagga mussels from the deep water zone to the more coastal areas and the possible occurrence of hybridization between the two species. Other research needs include obtaining a greater understanding of potential ecosystem control strategies, where the probability of colonization events can be reduced (Illinois River Biological Station 2007).

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Links for More Information

U.S. Geological Survey. Zebra mussel basic biology and impact: http://www.glsc.usgs.gov/main.php?content=research_invasive_zebramussel&title=Invasive%20Invertebrates0&menu=research_invasive_invertebrates

U.S. Geological Survey. Dreissena facts and figures: http://cars.er.usgs.gov/Nonindigenous_Species/Zebra_mussel_FAQs/Dreissena_FAQs/dreissena_faqs.html#Q9

The National Oceanic and Atmospheric Association (NOAA). The zebra mussel connection: Nuisance algal blooms, Lake Erie anoxia, and other water quality problems in the Great Lakes: http://www.glerl.noaa.gov/pubs/brochures/mcystisflyer/mcystis.html

The National Oceanic and Atmospheric Association (NOAA). The origin of the Great Lakes zebra mussels: http://www.research.noaa.gov/spotlite/archive/spot_zebramussels.html

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