

Zebra mussels in the Great Lakes: The invasion and its implications

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by Fred L. Snyder,
David W. Garton, and
Maran Brainard, Ohio Sea
Grant College Program.
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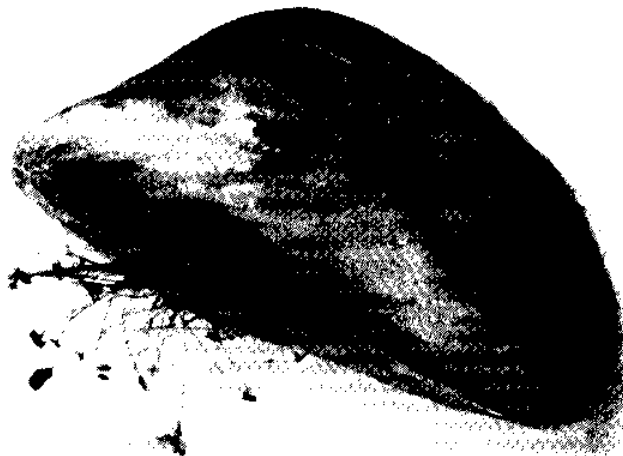
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Ohio Sea Grant
College Program
The Ohio State University
1314 Kinnear Road
Columbus, OH 43212-1194
TEL 614/292-8949
FAX 614/292-4364

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Zebra mussels (*Dreissena polymorpha*) were first discovered in the Great Lakes in 1988. Within one year, zebra mussels had colonized the surfaces of nearly every firm object in Lake Erie. Numerous populations of zebra mussels are now well established in all of the Great Lakes and are spreading into river systems outside the Great Lakes, including the St. Lawrence, Hudson, Illinois, Mississippi, Ohio, and Tennessee Rivers. Zebra mussels have been reported in several inland lakes, including Lake Wawasee in Indiana, Indian Lake in Ohio, Kentucky Lake and Dale Hollow Reservoir in Kentucky, and Balsam, Rice, and Big Bald Lakes in Ontario. Ultimately, zebra mussels will colonize most lakes and rivers in Canada and the United States.

Questions about zebra mussels abound but finding answers is much more difficult. What follows are answers to some of the more commonly asked questions about zebra mussels.



Close-up of a zebra mussel shows the tuft of byssal threads used for attachment. Particles on the ends of the threads are debris.

The invasion

Zebra mussels have been in western and central European waterways for nearly 200 years. However, comparing the Great Lakes to European lakes won't predict the impact on any Great Lake with accuracy. Europe's industries and commerce developed on water bodies already populated with zebra mussels. *Dreissena* arrived in North America to find industrialized, plankton-filled Great Lakes that supports multi-million dollar sport and commercial fisheries.

Dreissena polymorpha is a native of western Russia, near the Caspian Sea. Canals built during the late 1700s allowed the mussels to spread throughout eastern Europe. During the early 1800s, canals were built across the rest of Europe. The canals

made bulk shipping much easier but also allowed rapid expansion of the zebra mussels' range. By the 1830s the mussels had covered much of the continent and had invaded Britain.

The successful introduction of zebra mussels into the Great Lakes appears to have occurred in 1985 or 1986 when one or more transoceanic ships discharged ballast water into Lake St. Clair. The freshwater ballast, picked up in a European port, contained zebra mussel larvae and possibly juveniles. Alternately, adult mussels may have been carried in a sheltered, moist environment, such as a sediment-encrusted anchor or chain. Being a temperate, freshwater species, they found the plankton-rich Lakes St. Clair and Erie to their liking.

The zebra mussel

The mussel's reproductive cycle is one key to its rapid spread and high abundance. Egg production starts when the water temperature warms to about 54° (12°C), usually early May in Lake Erie, and continues until the water cools below 54°, generally in October. In Lake Erie, spawning (the release of eggs and sperm) peaks during July and August at water temperatures above 64° (20°C). A fully mature female mussel may produce several hundred thousand eggs per season.

Eggs are fertilized outside the mussel's body and within a few days develop into free-swimming larvae called veligers. Veligers remain suspended in the water for three to four weeks, drifting with the currents. If they don't settle onto firm objects in that time period, they die, and the vast majority actually suffer this fate.

Those that find a hard surface quickly attach themselves and transform into the typical, double-shelled mussel shape, and are then considered to be juveniles. A zebra mussel becomes sexually mature within a year. Mussels grow rapidly, nearly an inch in their first year, adding another one-half to one inch their second year. European studies report mussels may live four to six years, but in Lake Erie three years seems to be the maximum life span and the average is much less.

Zebra mussels generate a tuft of fibers known as a byssus, or byssal threads, from a gland in the foot. The byssus protrudes through the two halves of the shell. These threads attach to hard surfaces with an adhesive secretion that anchors the mussels in place. Small juveniles can actually break away from their attachments and generate new, buoyant threads that allow them again to drift in the currents and find a new surface.

Any firm surface that is not toxic can be colonized by zebra mussels. Rock, metal, wood, vinyl, glass, rubber, fiberglass, paper, plants, other mussels—the surface need only be firm. Beds of mussels in some areas of Lake Erie now contain over 30,000, and sometimes up to 70,000 animals per square meter.

Zebra mussel colonies show little regard for light intensity, hydrostatic pressure (depth), or even temperature when it is within a normal environmental range. Colonies grow rapidly wherever oxygen and particulate food is available and water currents are not too swift (generally less than six feet per second). Thus, colonies are rare in wave-washed zones except for sheltered nooks and crevices. In most European lakes the greatest densities of adult mussels occur at depths ranging from 6 to 45 feet.

Zebra mussels also colonize soft, muddy bottoms because hard objects deposited in or on the mud, such as pieces of native mussel shells, act as substrate (base) for settling veligers. As a few mussels begin to grow, they in turn serve as substrate for additional colonization. In this way, extensive mats of zebra mussels can form on soft lake bottoms.

The free-swimming veligers usually reach their greatest abundance at depths of 10 to 23 feet and usually do not descend below the thermocline, into the lower colder heavier oxygen-poor water. Veligers are the life stage most sensitive to low temperature. Juveniles are more sensitive to low temperature than adults. All life stages are sensitive to low levels of dissolved oxygen, particularly as temperature increases. Some juveniles migrate by drifting from shallow habitats occupied in late summer to deeper waters during winter.



Jim Hurst, NASA

While reported to grow nearly two inches in length, most zebra mussels are the size of a fingernail. Tiny zebra mussels (juveniles) readily attach to older ones, causing colonies to grow rapidly to depths of several inches.

Biological and ecological concerns

The feeding method of zebra mussels points to one of the growing concerns in regard to aquatic food chains. Each adult mussel is capable of filtering about one liter of water per day. Nearly all particulate matter, including phytoplankton and some small forms of zooplankton, are removed. Literature reviews suggest that zebra mussels eat mostly algae, but select primarily the 15-40 micrometer size range for consumption. Instead of passing any uneaten phytoplankton back into the water, mussels bind it with mucous into pellets called pseudofeces. Pseudofeces are ejected and accumulate among the shells in the colony. Thus, zebra mussels can remove significant amounts of phytoplankton from the water. Phytoplankton

are the food source for microscopic zooplankton, which in turn are food for larval and juvenile fishes, and other plankton-feeding forage fish supporting sport and commercial fisheries. This competition for phytoplankton, the base of the food chain, could have a long-term negative impact on Great Lakes fisheries. Other Great Lakes fisheries less dependent upon plankton as a food base may experience fewer impacts from zebra mussels.

Recent studies in Lake Erie have examined the relationship between seasonal populations of zooplankton in areas with very high zebra mussel densities. Other studies suggest that detritus, small particles of organic matter, also may have a significant role in zebra mussel feeding. Observations of the effects of zebra mussel filtration upon the food base for fish communities are still inconclusive.

Researchers as well as boaters have noted greatly increased water clarity in Lake Erie between 1989 and 1991. Shallow embayments are being recolonized by rooted, aquatic plants since turbidity no longer shades them out. A significant part of this change in clarity has been attributed to the filtering activities of zebra mussels.

Biologists were also concerned about zebra mussel colonies covering rock reefs. Most rocky areas in Lake Erie are almost completely covered with mussels several inches deep. In laboratory observation, the accumulation of pseudofeces in these beds creates a foul environment. As waste particles decompose, oxygen is used up and the pH becomes very acidic. Such poor environmental conditions potentially could hinder normal egg development of reef-spawning fish (walleye, white bass, and smallmouth bass). Results of initial American and Canadian studies indicate eggs and fry of walleye develop normally on mussel-covered reefs.

Zebra mussels are known to be intermediate hosts for a number of parasites that can also infect fishes and birds. While the European experience with *Dreissena* has not indicated a major problem with diseases or parasites, it merits further observations in North America.

Native North American mussels (family *Uniodidae*) have suffered as a result of encrustation by zebra mussels. Zebra mussels readily settle on live native mussels, sometimes several thousand zebra mussels are found on a single native mussel. In Lakes St. Clair and Erie heavy fouling by zebra mussels has severely reduced populations of native mussels. Some native mussel species are more tolerant to fouling than others, but even for these "resistant" species, zebra mussel encrustation leads to reduced energy reserves and leaves them vulnerable to other environmental stressors. In addition, a number of native mussel species are very rare and are officially listed as endangered species. As zebra mussels spread, biologists are concerned that populations of native mussels will decline, and perhaps some of the rarer species may be completely eliminated.

Industrial, commercial, & recreational concerns

The zebra mussels' proclivity for hard surfaces located at moderate water depths has made water intake structures, such as those used for power and municipal water treatment plants, susceptible to colonization. Since 1989, some plants located on the shorelines of Lake Erie have reported significant reductions in pumping capabilities and occasional shutdowns due to zebra mussel encrustment.

Several approaches to zebra mussel control on intake structures have been examined, including prechlorination, preheating, electrical shock, and sonic vibrations. Control methods that currently appear most feasible include prechlorination, ozone, potassium permanganate injection, and sand bed filtration. Prechlorination has been the most common treatment used to date; but it also raises concerns about the toxicity of chlorinated compounds to other aquatic organisms.

Zebra mussels are very sensitive to high temperatures. Researchers have obtained 100 percent mortality after five hours at 90°F, but after only 15 minutes at 104°F. Other reports show minor variation around these figures, but clearly indicate that heat can be an effective control for zebra mussel infestations. It is, however, difficult to safely apply heat to large underwater structures.

Recreational industries along Lake Erie have been impacted by zebra mussels. Unprotected docks, breakwalls, boat bottoms, and engine outdrives were rapidly colonized during 1989. There had been numerous reports of boat engines overheating due to cooling water inlets being clogged by colonies of zebra mussels. Boaters need to make frequent inspections of these areas in the future. Boats painted with approved antifouling paints containing copper have been effective in resisting zebra mussel attachment. However, copper-based paints corrode aluminum. Paints containing slow-release polymers of tributyltin (TBT) are also effective. However, these paints are banned in Michigan and restricted

in other states. For more information on approved antifouling paints, contact your state's Department of Agriculture.

Beaches are also affected by zebra mussels. By autumn of 1989, extensive deposits of zebra mussel shells could be seen on many Lake Erie beaches. The extent of these deposits varied with successive periods of high wave activity. Sharp-edged shells accumulating along swimming beaches could be a hazard to unprotected feet.

Zebra mussel control

Lakewide control of zebra mussels is simply out of the question. After two centuries of infestation, the European community hasn't been able to develop a chemical toxicant for lakewide control that isn't deadly to other aquatic life forms.

In some parts of Europe, large populations of diving ducks have actually changed their migration patterns in order to forage on beds of zebra mussels. The most extreme case occurs in Germany's Rhine River, which hosts high densities of zebra mussels. Overwintering diving ducks and coots were seen to consume up to 97 percent of the standing crop of mussels each year, although high mussel reproduction rates replenished the population each summer.

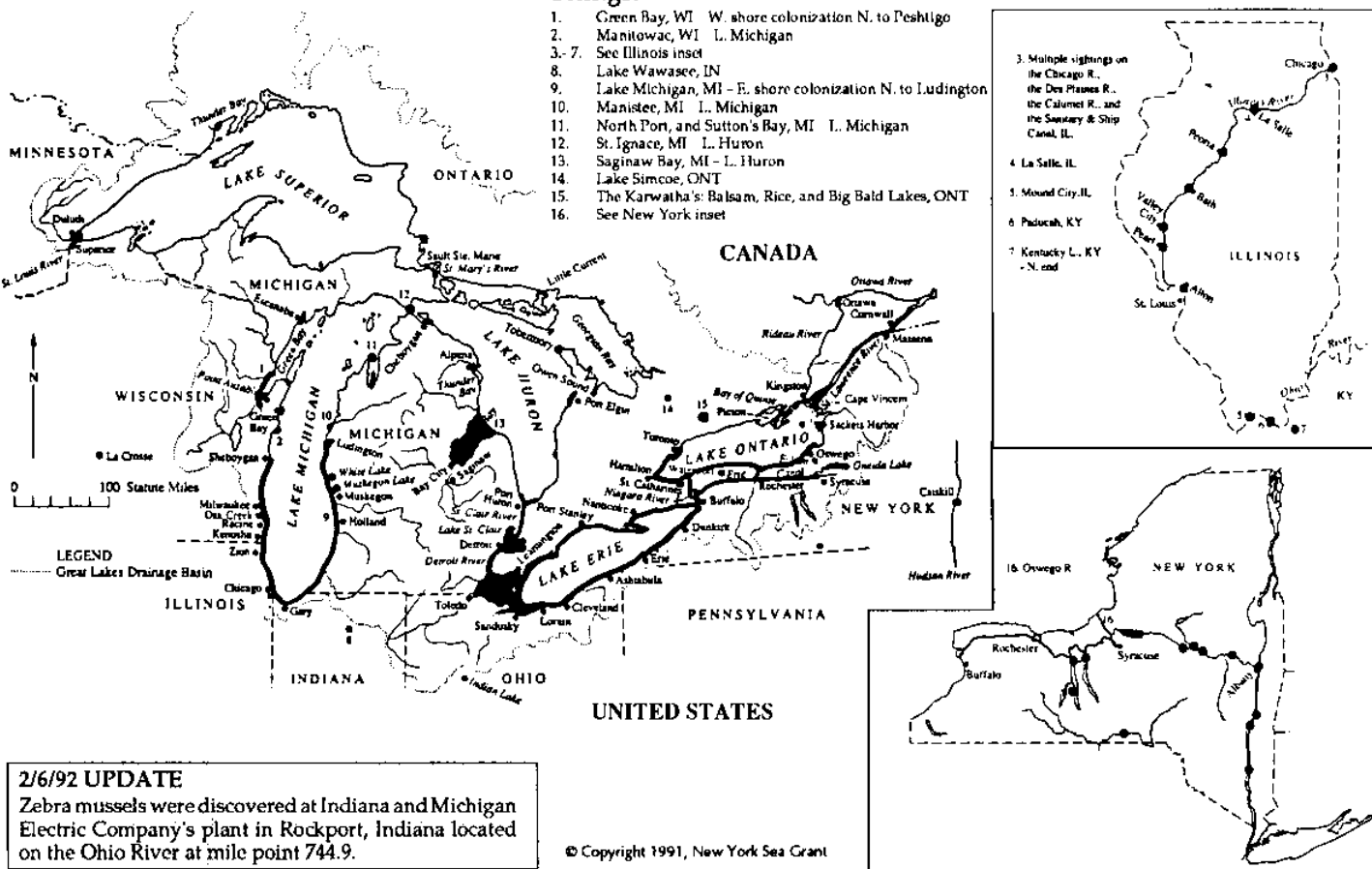
In North America, the most likely duck species that might prey on zebra mussels are scaup, canvasbacks, and oldsquaws. Populations of these species are quite low, in fact, canvasbacks are so rare they are a totally protected species. In the Great Lakes, diving ducks are migrating visitors, pausing only

Range of the zebra mussel in North America as of 26 November 1991

Compiled by New York Sea Grant with information from: Empire State Electric Energy Research Corp., Fisheries and Oceans Canada, Illinois-Indiana Sea Grant, Michigan Sea Grant, Minnesota Sea Grant, Ohio Sea Grant, Ontario Hydro, Ontario Ministry of Natural Resources, US Army Corps of Engineers, US Fish & Wildlife Service, Wisconsin Sea Grant.
 Note: The Kenosha (WI); Cheboygan (MI); Indian Lake (OH); and Ottawa (ONT) sitings were all on "moveable substrates" (boats, barges, driftwood, etc.) and DO NOT INDICATE COLONIZATION AT THIS TIME.

Sitings:

1. Green Bay, WI - W. shore colonization N. to Peshtigo
2. Manitowac, WI - L. Michigan
- 3-7. See Illinois inset
8. Lake Wawasee, IN
9. Lake Michigan, MI - E. shore colonization N. to Ludington
10. Manistee, MI - L. Michigan
11. North Port, and Sutton's Bay, MI - L. Michigan
12. St. Ignace, MI - L. Huron
13. Saginaw Bay, MI - L. Huron
14. Lake Simcoe, ONT
15. The Kawatha's: Balsam, Rice, and Big Bald Lakes, ONT
16. See New York inset



to feed during north- and southward migrations. However, Canadian researchers have documented increasing numbers of migrating ducks around Pt. Pelee (western Lake Erie), and these ducks were observed to be feeding heartily on zebra mussels. In southern Lake Michigan, zebra mussels encrusting an underwater power plant intake have attracted flocks of greater and lesser scaup. Unfortunately, some became confused and were pulled into the intake pipe and drowned. The stomachs of these dead scaup were full of zebra mussels. Therefore, North American waterfowl do feed on zebra mussels, whether or not this predation will have an impact on zebra mussel population remains to be seen.

Some fish species are likely to include zebra mussels in their diet, but research is needed to determine which species will act as predators and how many mussels they can eat. Freshwater drum, or sheepshead, are known to feed substantially on zebra mussels, and yellow perch have been seen to feed on juvenile zebra mussels, particularly when the mussels are detached and drifting.

One novel approach to controlling zebra mussel populations is by disrupting the reproductive process. As mentioned earlier, zebra mussel eggs are fertilized externally, therefore males and females must release their gametes (sperm and eggs) simultaneously. After release, zebra mussel sperm remain viable for only a short time; perhaps only a few minutes. Disrupting the synchronization of spawning by male and females will effectively reduce the numbers of fertilized eggs, and hence fewer zebra mussels will be found in the next generation. Researchers are currently studying the environmental cues and physiological pathways that coordinate spawning activity in zebra mussels.

The prodigious filtering of water by zebra mussels may increase exposure risk to humans and wildlife to organic pollutants (PCBs and PAHs). Early studies have shown that zebra mussels can rapidly accumulate organic pollutants within their tissues to levels over 300,000 times greater than concentrations in the environment or can deposit these pollutants in their pseudofeces. The fate of the chemicals depends in part on the suitability of the food source. These pollutants found in algae and sediments are persistent and can be passed up the food chain. Any fish or waterfowl consuming zebra mussels will also accumulate these organic pollutants. Likewise, human consumption of fish and waterfowl from areas with zebra mussels could risk increased exposure to these same pollutants. The implications for human health are unclear.

Spread to inland waters

Zebra mussels can spread to other inland waters either as veligers transported in water, or as adults attached to boat hulls, engines, and fish cages, or on any number of other items. Veligers attached to boats don't survive drying but they can survive in any residual water source. Waterfowl and other wildlife also may transport zebra mussels, carrying veligers and/or adults in wet fur or feathers.

Adult zebra mussels are very hardy, and with their shells closed, can survive drying for several days. In moist environments, they can survive out of the water even longer.

Before transferring a boat from a zebra mussel infested water body to inland waters, wildlife agencies urge boaters to clean boat hulls, trim tabs, outdrives, and outboard lower units or to leave the boat out of the water for 10 to 14 days. Live wells and bilges can be disinfected with one part chlorine bleach to 10 parts water for several hours. *This solution should not be discharged into lakes or streams due to its toxicity to aquatic life.* An effective alternative is to coat all boat and engine surfaces exposed to water with approved antifouling paints. Do not paint the inside of live wells or bait wells. For more information for recreational boaters, request the publication *Slow the spread of zebra mussels, and protect your boat too*, FS-054, from Ohio Sea Grant.

Veligers can be transported very easily in water used in live bait containers. Minnows or crayfish used or collected in lakes containing zebra mussels should be transferred to well water or aged chlorinated tap water before carrying them to other bodies of water.

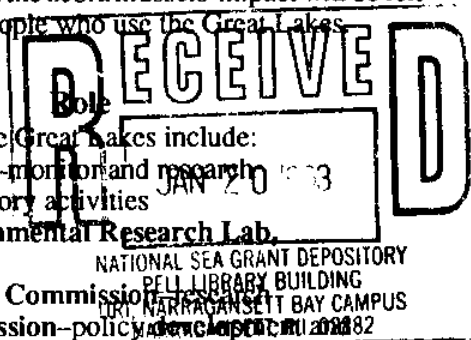
Most authorities consider the spread of zebra mussels across North America to be a certainty. The southward spread probably will be limited by average summer water temperatures above 81°F. The northward spread might be limited by soils deficient in calcium or by summer water temperatures below 54°F. This region extends from the East Coast to the West Coast and from Canada to the southernmost states.

The zebra mussel is now a permanent part of the Great Lakes environment. Increased support for research is needed to gain understanding of its effects upon the lakes' ecosystems and industries, economic implications, natural predators, spawning activity, and pollutant uptake. Theoretically, zebra mussel populations should peak a few years after initial infestation and then decline, depending upon predation and on each lake's carrying capacity. There is little doubt that the zebra mussels' impact will be felt by great numbers of people who use the Great Lakes.

Second species of *Dreissena* discovered

European (mostly Russian) literature describes several species of mussels in the genus *Dreissena* based on morphology, physiology, and geographic distribution. It was thought only one, *Dreissena polymorpha*, had been introduced into North America.

However, a second species of *Dreissena* has been discovered in North America. Its identification has not yet been confirmed but it is morphologically and genetically different. Its shell is rounder and squatter in shape than *D. polymorpha*. It is present in much lower numbers than *D. polymorpha* and is more common in Lake Ontario than in Lake Erie.



Roles of agencies in the Great Lakes include:

- U.S. Fish & Wildlife—monitor and research
- Coast Guard—regulatory activities
- Great Lakes Environmental Research Lab.
- NOAA—research
- Great Lakes Fishery Commission
- Great Lakes Commission—policy development and coordination
- Sea Grant—research, education, and technology transfer

For other publications, newsletters, conference and workshop announcements, or for advice from a local expert, contact the Sea Grant program or state natural resources management office nearest you.

- Illinois/Indiana Sea Grant Extension 708/818-2901
- Michigan Sea Grant 313/764-1138
- Minnesota Sea Grant Extension 218/726-8106
- New York Sea Grant Extension
- Zebra Mussel Clearinghouse 800/285-2285
- Ohio Sea Grant 614/292-8949
- Wisconsin Sea Grant 608/263-5371