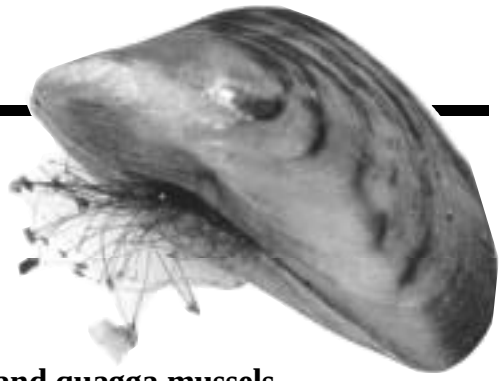
Zebra mussels in North America

The invasion and its implications



Ohio Sea Grant College Program
The Ohio State University
1314 Kinnear Road
Columbus, OH 43212-1194
614/292-8949
Fax 614/292-4364
http://www-ohiosg.osc.edu/OhioSeagrant

Sea Grant is a program within the National Oceanic and Atmospheric Administration (NOAA), Department of Commerce. Ohio Sea Grant is one of 29 state programs nationwide that work to improve the wise use and management of marine and Great Lakes resources for public benefit. Sea Grant uses university expertise in research, education, and technology transfer to help solve the problems and challenges of the oceans and the Great Lakes.

By Fred.L.Snyder, Maran Brainard Hilgendorf, and David W. Garton.

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Zebra mussels (*Dreissena polymorpha*) were first discovered in Lakes St. Clair and Erie in 1988. They quickly colonized much of the hard substrate found in waters deeper than 3 feet in western Lake Erie. As of July 1996, zebra mussels have been found in all of the Great Lakes and in waterways in 19 states and two provinces. Major river systems that now have zebra mussels include the St. Lawrence Seaway and the Hudson, Illinois, Mississippi, Ohio,Arkansas, and Tennessee Rivers.

Zebra mussels also have been reported in a growing list of inland lakes including Lake Champlain and lakes in Indiana, Michigan, Ohio, and Ontario.

In 1991, a second species of *Dreissena* was discovered in North America. Quagga mussels (*Dreissena bugensis*) have been found in the St. Lawrence Seaway, Lake Ontario, Lake Erie, and Saginaw Bay in Lake Huron. The percentage of the total *Dreissena* population composed of quagga mussels is increasing noticeably in some areas.

It is not clear when, how far, and into which waterways the zebra and quagga mussels will spread. The zebra mussel has spread faster and farther than expected. Its southward spread was thought to be limited in areas with average summer water temperatures above 81°F (27°C) but recent research shows that individual mussels adjust well to warmer temperatures. The northward spread might be limited by soils deficient in calcium or by summer water temperatures below 54°F (12°C).

Questions about zebra and quagga mussels abound, but finding answers is a difficult task. The following information answers some of the more commonly asked questions about zebra and quagga mussels.

The invasion

Dreissena polymorpha and *Dreissena bugensis* are native to an area in the Ukraine and Russia near the Black and Caspian Seas. 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, which made bulk shipping much easier but also allowed rapid expansion of the zebra mussel's range. By the 1830s, the mussels had covered much of the continent and had invaded Britain.

The 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 ballast, which is water ships carry to balance the vessel when they aren't fully loaded, may have contained zebra mussel larvae and possibly juveniles; or, adult mussels may have been carried in a sheltered, moist environment, such as a sediment-encrusted anchor or chain. The faster speed of today's ships provides exotic species a better chance of surviving the trip across the Atlantic. Being a temperate, freshwater species, the zebra mussels found the plankton-rich Lakes St. Clair and Erie to their liking.

Zebra and quagga mussels

The rapid spread and abundance of both mussels can be partly attributed to their reproductive cycles. A fully mature female mussel may produce up to one million eggs per season. Egg release starts when the water temperature warms to about 54°F (12°C) and continues until the water cools below 54°F. In Lake Erie, spawning may begin as early as May and end as late as October, but it peaks during July and August at water temperatures above 68°F (20°C).

Eggs are fertilized outside the mussel's body and within a few days develop into free-swimming microscopic larvae called veligers that soon develop miniature bivalve shells. Veligers swim and feed by using their hair-like cilia for 3 to 4 weeks, drifting with the currents. If they don't settle onto firm objects in that time, they die; the vast majority actually suffer this fate. It is estimated that only 1 to 3 percent survive this planktonic period of life. Those that find a hard surface quickly attach with sticky, secreted threads; they are then considered juveniles.

Mussels become adults when they reach sexual maturity, usually within a year. They grow rapidly, nearly an inch in their first year, adding another 1/2 to 1 inch their second year. European studies report mussels may live 4 to 6 years. Three years seems to be the maximum life span in Lake Erie, but there is insufficient data to know what to expect in other North American bodies of water.

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 near the hinge. These threads attach to hard surfaces with an adhesive secretion that anchors the mussels in place. Small juveniles can actually shed their threads where they attach to the body, leaving the threads attached to the substrate. They then secrete new, buoyant threads that allow them to drift again with the currents and find a new surface.

Zebra mussels can colonize any surface that is not toxic — rock, metal, wood, vinyl, glass, rubber, fiberglass, paper, plants, or other mussels. Beds of mussels in some areas of Lake Erie now contain more than 30,000 — and sometimes up to 100,000 — mussels per square meter. Zebra mussels can colonize soft, muddy bottoms when hard objects deposited in or on the mud — such as pieces of native mussel shells or grains of sand— serve as a substrate (base). As a few mussels begin to grow, they in turn serve as substrate for additional colonization, forming what is known as a "druse." Individual zebra and quagga mussels can also live directly on a muddy or sandy bottom.

Dreissena arrived in North America and rapidly colonized industrialized, plankton-filled Great Lakes, which support multi-million-dollar sport and commercial fisheries.

Zebra mussel colonies show little regard for hydrostatic pressure (depth), or even temperature when it is within a normal environmental range. The life stage most sensitive to low temperature is the veliger, and juveniles are more sensitive than adults. All life stages are sensitive to low levels of dissolved oxygen, particularly as temperature increases. Colonies grow rapidly wherever oxygen and particulate food are available and water currents are not too swift (generally less than 6 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. Quagga mussels appear more tolerant of low temperatures and extreme depths than zebra mussels.

Biological and ecological concerns

Zebra mussels alter and redirect the pathways of aquatic food webs. Literature reviews suggest that they eat mostly algae in the 15-40 micrometer size range. They use cilia on their gills and body to pull lake water into the shell cavity through an 'incurrent siphon' (a tube-like device) and extract particulate matter by allowing it to stick to mucus that is then moved by other cilia into the mouth. The newly particle-free water is then discharged out the 'excurrent siphon' as are feces from the intestine and urine from the kidneys. Each adult mussel is capable of filtering 1 or more liters of water each day. They remove nearly all particulate matter to which they have access, including phytoplankton and some small forms of zooplankton, including their own veligers. Any undesired (or distasteful) particulate matter is bound with mucus into loose pellets called "pseudofeces" that are ejected back out the incurrent siphon and accumulate among the shells in the colony.

By removing significant amounts of phytoplankton from the water, zebra mussels reduce the food source for microscopic zooplankton, which in turn are food for larval and juvenile fishes as well as forage fish species that support sport and commercial fisheries. This competition for phytoplankton, the base of the food web, could have a long-term negative impact on Great Lakes fisheries. Because of difficulties measuring the rate of delivery of algae from the upper waters where it grows to the bottom where zebra mussels can reach them, investigations of the effects of zebra mussel filtration upon the food base for fish communities are still inconclusive.

Most rocky areas in Lake Erie are almost completely covered with mussels several inches deep, and about 25 percent of the soft-bottomed areas are also covered. In laboratory observation, the accumulation of pseudofeces in these beds creates a foul environment. As waste particles decompose, oxygen is used up, the pH becomes very acidic, and toxic byproducts like ammonia and hydrogen sulfide are produced. Biologists initially were concerned that poor water quality on spawning reefs could hinder normal incubation of eggs for species such as walleye and white bass. However, large hatches of walleye documented in Lake Erie in 1990, 1991, 1993, and 1996 suggest that the flushing action of water currents are sufficient to prevent environmental deterioration.

Zebra mussels readily encrust native North American mussels (family *Uniodidae*). 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 vulnerability to other environmental stressors, such as extreme water temperatures, lack of food, or parasites and disease. 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.

Zebra mussels have contributed to the increase in Lake Erie's water clarity, which began with the initiation of phosphorus abatement programs in the 1970s. Shallow embayments are being recolonized by rooted, aquatic plants, since turbidity no longer shades them out. According to Dr. Ruth Holland Beeton, who conducted research near Stone Laboratory on Lake Erie in the 1970s before phosphorus abatement programs, water clarity was approximately 3 feet, improved to 6 to 10 feet in the 1980s after a decade of reduced phosphorus inputs, and improved again to 10 to 17 feet in the early 1990s, after zebra mussels colonized the area.

Noxious blue-green algae blooms are not likely to be reduced by zebra mussel filtration. During recent *Microcystis* blooms in western Lake Erie and in Saginaw Bay, zebra mussels were observed rejecting the clumps of *Microcystis* pulled into their siphons. In addition, algae is digested by zebra mussels more rapidly than it decomposed before the mussels arrived. This results in more rapid recycling of phosphorus and nitrogen, which provides more nutrients to stimulate the growth of new algae. Recent increases in growth rates of *Cladophora*, a filamentous green algae that attaches to rocks, and *Lyngbya*, a filamentous blue-green algae found among the mussel beds in Lake Erie, are thought to have resulted from this process.

The prodigious filtering of water by zebra mussels may increase human and wildlife exposure to organic pollutants (PCBs and PAHs). Early studies have shown that zebra mussels can rapidly accumulate organic pollutants within their tissues to levels more than 300,000 times greater than concentrations in the environment. They also deposit these pollutants in their pseudofeces. These persistent contaminants can be passed up the food chain so that any fish or waterfowl consuming zebra mussels may also accumulate these organic pollutants. Likewise, human consumption of these same fish and waterfowl could result in further risk of exposure. The implications for human health, however, remain unclear.

Clear waters do not necessarily mean safe, clean waters. Zebra mussel's activities may make toxic substances available to new organisms in the food chain. Because zebra mussel feces and pseudofeces stay at the bottom of the lake, zebra mussels transfer plankton to the benthos, where they create a potentially tainted food supply for benthic organisms, such as gammarid amphipods.

Industrial, commercial, and recreational concerns

The zebra mussel's proclivity for hard surfaces located at moderate 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 in areas of extensive zebra mussel colonization have reported significant reductions in pumping capabilities and occasional shutdowns.

Prechlorination has been the most common control treatment used to date because it is already approved by the Environmental Protection Agency to control biofouling in intakes. However, chorination raises concerns about toxicity to other aquatic organisms when chlorine reacts with organic compounds in the water and forms other chlorinated compounds, such as chloroform. Potassium permanganate is an increasingly popular alternative, especially for drinking water sources where chlorinated byproducts are a health concern. Other control strategies in use include proprietary molluscicides, ozone, antifouling coatings, and sand bed filtration. Control methods like electrical currents, sonic vibration, and oxygen deprivation are being investigated but are not yet in general use. Some thermal electric plants currently are experimenting with the diversion of waste heat into intake structures to kill zebra mussels or prevent settlement.

Recreation-based industries along Lake Erie have also been impacted by zebra mussels. Unprotected docks, breakwalls, boat bottoms, and engine outdrives were rapidly colonized beginning in 1989. Consequently, there were numerous reports of boat engines overheating due to colonies of zebra mussels clogging cooling water inlets and mussels colonizing boat hulls. The proper use of antifoulling coatings has been shown to reduce hull and engine fouling.

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

Zebra mussel control

Lake-wide control of zebra mussels is not feasible. The European community, after two centuries of infestation, and the Great Lakes community, after years of infestation, haven't been able to develop a chemical toxicant for lake-wide control that isn't deadly to other aquatic life forms.

In some parts of Europe and on Lake Erie, large populations of diving ducks have actually changed their migration patterns in order to forage on beds of zebra mussels. The most extreme case occurred on Germany's Rhine River. Overwintering diving ducks and coots consumed up to 97 percent of the standing crop of mussels each year. High mussel reproduction rates, however, replenished the population each summer.

In North America, the species most likely to prey on relatively deep beds of zebra mussels are scaup, canvasbacks, and old squaws. But populations of these species are quite low. In the Great Lakes, diving ducks are migrating visitors, pausing only to feed during north- and southward migrations. However, wildlife biologists and bird watchers alike have noted increasing numbers of diving ducks on western Lake Erie during migration. This appears to be in response to the increased food supply provided both by zebra mussels and the submerged aquatic plants growing in the now-clear water. In southern Lake Michigan, zebra mussels encrusting an underwater power plant intake attracted flocks of lesser scaup. Unfortunately, some were pulled into the intake pipe and drowned. The stomachs of these dead scaup were full of zebra mussels. Mallard ducks, although they do not dive, also are frequently observed foraging on zebra mussels on shoreline rocks and shallow structures.

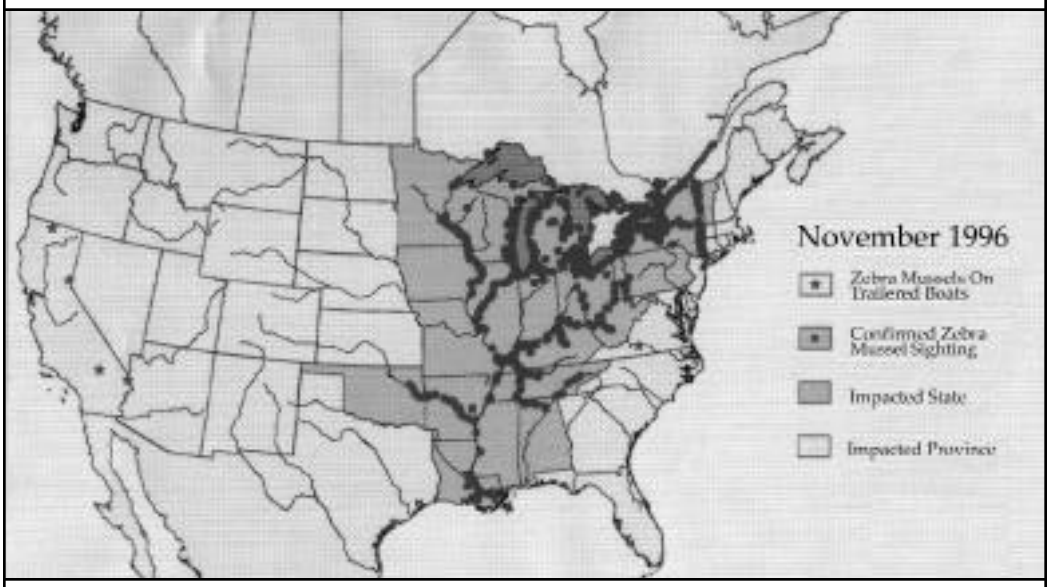
Among fish species, freshwater drum feed heavily on zebra mussels, as do the recently introduced round gobies. Yellow perch feed on juvenile mussels during autumn when the mussels are detached and drifting. Other fishes that feed on zebra mussels include catfish and carp. Regardless of this growing list of zebra mussel predators, biological control has been ineffective in the Great Lakes.

One novel approach to controlling zebra mussel populations is by disrupting the reproductive process. 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 males and females may effectively reduce the numbers of fertilized eggs. Researchers are currently studying the environmental cues and physiological pathways that coordinate zebra mussel spawning activity.

Exotic species are nothing new in the Great Lakes. Scientists believe the sea lamprey led the way back in the 1830s. Since then, scientists have identified 136 plant, fish, and mollusk species that have been introduced.

Because of its shallow, warm, nutrient-rich environment, Lake Erie will always support significant populations of zebra and quagga mussels.

Zebra Mussel *(Dreissena polymorpha)* Distribution in North America



These data are a part of the U.S. Geological Survey Biological Resources Division's Nonindigenous Aquatic Species Data Base located in Gainesville, Florida.Information is collected from federal, state, and private agencies and is available upon request (352/378-8181).

For other publications or advice from local experts, contact the Sea Grant program or state natural resources management office nearest you.Phone numbers of several Sea Grant programs follow.

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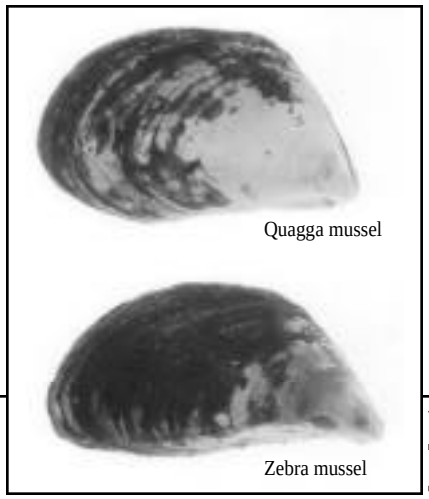
Sea Grant Nonindigenous Species (Internet Site)
http://www.ansc.purdue.edu/sgnis/

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, aquatic weeds, or other surfaces. Veligers are small — about the size of the period at the end of this sentence — and may be able to survive in any residual water source.

Adult mussels are very hardy and can survive out of water for extended periods depending upon temperature, humidity, wind, and sunlight. Maximum out-of-water survival time in ideal conditions is about 10 days for adults and 3 days for newly settled juveniles.

By 1995, California Agriculture Station inspectors had found zebra mussels on six boats that had been transported overland from the Great Lakes; two of which were transporting live mussels.



Dave Dennis

Zebra mussels and Quagga mussels

Zebra mussels (*Dreissena polymorpha*) were accidentally introduced into the Great Lakes in the mid-1980s. Quagga mussels *(Dreissena bugensis)*, an East European relative of the zebra, was found in the colder depths of Lake Ontario in 1991, across the bottom of Lake Erie in 1992, and in Saginaw Bay in Lake Huron. This table contrasts the characteristics of the two species.

	ZEBRA MUSSELS	QUAGGA MUSSELS
Shell	Triangular shape Obvious ridge between side and bottom Sides merge with bottom Byssal (ventral) side flat	Rounder sides Ridge lacking Byssal side rounded
Color	Variable colors and patterns Usually dark	Pale near hinge Dark concentric rings on the shell
Byssal	Large groove in middle of flat side; allows tight hold on rocks	Small byssal groove near the hinge
Depth in Lake	3 to 98 feet (1-30 m) Maximum 33 feet (10 m); rare below 50 feet (15 m.)	3 to 351 feet (1-107 m) Commonly found down to 98 feet (30 m.)
Temperature	32°to 86°F (0°to 30°C)	32°to 86°F (0°to 30°C)
Tolerance	54°to 68°F (12°to 20°C) preferred	39°to 68°F (4°to 20°C) preferred
Reproductive Temperature	Young present at 57°to 68°F (14°to 20°C)	Young present as low as 46°F (8°C)
Growth	Up to 1 inch (25 mm)/year	Up to 0.8 inch (20 mm)/year

Source:
Ontario Ministry of Natural Resources with an update by Dr. Robert Heath, Kent State University.

An interagency Great Lakes task force recommends the following to prevent further spread of zebra mussels:

- Remove any visible vegetation from items that were in the water, including the boat's hull, propeller, trailer, and all equipment. (Zebra mussels readily attach to aquatic vegetation.)
- Flush the engine cooling system, live wells, and bilge with hot water. Rinse any other areas that get wet, such as water collected in trailer frames, safety light compartments, boat decking, and the lower portion of motor cooling systems. Water hotter than 110°F will kill veligers, and 140°F will kill adults. If hot water is not available, use tap water. Do not use salt and chlorine water mixtures, as both are very toxic to other organisms and may also damage your equipment.
- Examine the boat exterior for mussels if it has been docked in infested waters. If mussels are found or the exterior is heavily fouled by algae, either clean fouled surfaces or leave the boat out of the water for at least 5 days before entering uninfested waters. Any mussels scraped off should be bagged and discarded in the trash.

  If your gear feels gritty, then young microscopic mussels may be attached.
- Do not re-use bait. Empty your bait bucket on land. Never release live bait in lakes or streams. Viligers may be transported easily in water used in live bait containers. Minnows or crayfish taken from lakes containing zebra mussels should be transferred to well water or aged chlorinated tap water before carrying them to other bodies of water.

Be advised that these recommendations are still being studied by researchers and resource managers; therefore, the recommendations may change.

The zebra mussel is now a permanent part of the Great Lakes, many major river systems, and inland lakes. It continues to spread rapidly throughout major river basins. Increased support for research is needed to gain understanding of its natural predators, spawning activity, and pollutant uptake, as well as its effects upon ecosystems, industries, and local economies.

Theoretically, zebra mussel populations should peak a few years after initial infestation and then decline, depending upon predation and upon each water body's carrying capacity. It is not certain whether or not this has occurred yet in any North American waters. There is little doubt that the zebra mussel's impact will be felt by everyone who uses our nation's inland waters.

Thanks to generous printing donations made by Brunswick Marine to Ohio Sea Grant, several other fact sheets on nonindigenous species are available free. Other species-specific fact sheet cover the ruffe, the goby, and the spiny water flea. Other fact sheet present boaters concerns with zebra mussels, inland managers concerns with zebra mussels. and consequences of zebra mussels to the native mussel population.
For more information, contact Ohio Sea Grant.