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Zebra mussel migration to inland lakes and reservoirs: A guide for lake managers

Ohio Sea Grant College Program

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The Great Lakes Sea Grant Network is a cooperative program of the Illinois-Indiana, Michigan, Minnesota, New York, Ohio, and Wisconsin Sea Grant programs. Sea Grant is a university-based program designed to support greater knowledge and wise use of the Great Lakes and ocean resources.

Through its network of advisory agents, researchers, educators and communicators, the Great Lakes Sea Grant Network supplies the region with usable solutions to pressing problems and provides basic information needed to better manage the Great Lakes for both present and future generations.

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Since the introduction of zebra mussels (*Dreissena polymorpha*) from Europe into Lake St. Clair in 1986, they have spread to all the other Great Lakes and the inland navigation system of major rivers, notably the Cumberland, Mississippi, Ohio, Susquehanna, Hudson and Tennessee rivers. They have recently been sighted in some small inland lakes and reservoirs, and it is generally believed that they will soon spread to many others. Which environmental factors are most important in determining whether a lake can support large populations of zebra mussels? What will be the ecological and economic impacts of zebra mussels in inland lakes and reservoirs? What can be done to prevent and mitigate the spread of zebra mussels? The purpose of this publication is to summarize current views on these topics to aid resource managers in planning.

Lake conditions most likely to support zebra mussels

Moderately hard-water lakes with calcium (Ca^{2+}) concentrations above 12 mg/L, alkalinity above 50 mg $CaCO_3$/L and pH above 7.2 provide the necessary chemical environment for adult zebra mussels. Zebra mussels will tolerate oxygen concentrations as low as 25 percent saturation (about 2 mg/L at 25°C), but they die in anoxic water. Lakes with prolonged periods above 54° F (12°C) and with maximum temperatures of 64-74°F (18-23°C) provide optimum conditions for growth and reproduction. Development of large populations of zebra mussels also depends on sufficient hard substrate onto which the adults can attach, as well as an abundant edible phytoplankton community. For example, the western basin of Lake Erie, with Ca^{2+} concentrations above 30 mg/L, alkalinity of 86 mg $CaCO_3$/L, pH of 8.4, mean temperatures around 68°F and a rocky bottom, is able to support massive populations of zebra mussels; more than 100,000 adults/m^2 have been reported in some places.

Although these are the optimum conditions for production of large populations, managers need to recognize that zebra mussels readily adapt to a wide range of conditions. In Europe, their range extends from the southern parts of Sweden to the Mediterranean shores. Recent physiological studies indicate that zebra mussels are more tolerant of mild salinity and wide swings of temperature than many indigenous bivalve mollusks, indicating that they may successfully invade some regions that offer only marginal environments to other mollusks. Zebra mussels are genetically diverse and readily produce genetic variants, a characteristic that permits them to invade a wide variety of habitats and that may permit them to expand their limits of tolerance.

Recent field and laboratory studies report that calcium and alkalinity are the major factors that determine growth and reproductive success of zebra mussels. Zebra mussels require Ca^{2+} concentrations greater than 12 mg/L to establish significant populations, which is considerably higher than required by other bivalve mollusks (typically 3-4 mg/L). Adult mussels are unable to survive in aquaria below 3.6 mg Ca^{2+}/L and an alkalinity of 4.7 mg $CaCO_3$L. Larval veligers are more sensitive to low calcium and alkalinity than adults.

Mussels are sensitive to acidic waters, too. Below pH 6.8, adult zebra mussels have a net loss of calcium, sodium and potassium to the surrounding water; however, they are able to adapt to mildly acidic conditions. After several days at pH 5.5-6.0, adults adapt to these conditions and their net rate of ion loss decreases. Zebra mussels are unable to withstand prolonged periods below pH 5.2 and eventually die because of ionic imbalance. Veligers are more sensitive to low pH than adults.

Temperature is another factor that can limit the extent of zebra mussel colonization. Each mature female produces several hundred thousand eggs during the breeding season, which occurs when the water temperature is above 54°F (12°C). The longer this period the more successful colonization is likely to be. Adults are unable to survive prolonged exposure to temperatures above 90°F (32°C). They can tolerate temperatures as low as 32°(0°C), provided they do not freeze.

Ecological effects of zebra mussels in inland lakes

Zebra mussels graze on several species of algae at different rates and can remove large portions of the phytoplankton community from the water column, greatly increasing water clarity. Zebra mussels graze on particles greater than 0.00004 in. (1μm) in size. Free-living bacteria are smaller than this and apparently are not grazed by zebra mussels. These mussels graze on algae, protozoans and rotifers, but not indiscriminately. Recent investigations in Saginaw Bay indicate that zebra mussels establish abundant populations most readily in regions with large populations of diatoms and small edible green algae. Zebra mussels appear to graze on large filamentous blue-green algae and colonial algal forms less readily, and they greatly decrease their filtering rate in the presence of toxins released from certain blue-green algae (even if those algae aren't present).

The particles zebra mussels filter and eat are digested and released through the exhalant siphon as fecal material, which rapidly decomposes. The particles zebra mussels filter and reject are coated with mucous and expelled through the inhalant siphon as pseudofeces, which sink and decompose slowly at the sediment surface. The net effect of zebra mussels on the benthic (bottom-dwelling) community is unclear; some organisms benefit from their presence, others are harmed. Gammarid amphipods feed on feces and pseudofeces and seem to benefit from the increased food supply on the bottom of the lake. On the other hand, zebra mussels compete with other organisms (e.g. mysid decapods) for the same plankton resources. Populations of burrowing unionid clams have been nearly eliminated from Lake St. Clair because of zebra mussels that attach to the exposed portion of their shells.

Recent studies indicate that zebra mussels may mobilize toxic materials from the sediments into the food chain in two ways. When zebra mussels filter algae to which toxic materials are sorbed, they either ingest these toxic algae or release them in pseudofeces. Zebra mussels are capable of accumulating toxic compounds (PAHs and PCBs) in their fatty tissues, reaching concentrations 50,000 times greater in concentration than the surrounding water and about 10 times greater than other invertebrates. If edible fish begin to eat zebra mussels in large quantities, biomagnification of these accumulated toxic organic materials could increase the toxic load to humans. Also, zebra mussels provide a new mechanism of introducing toxins to the food chain, as amphipods that graze on pseudofeces containing toxin-sorbed algae are then eaten by fish.

Removal of significant proportions of plankton at the base of the food chain will diminish the energy available for fish production. Inland lakes that support large populations of zebra mussels may experience a diminished fish yield, especially of fish feeding in the open water. On the other hand, stimulation of the benthic community may increase the productivity of bottom-dwelling fish. Open-water piscivorous fish may change their feeding habits to prey more on benthivorous fish or may decrease in production. As water clarity increases, changes in fish populations may occur as conditions become more favorable for "clear-water" fish (e.g. pike) and less favorable for "turbid-water" fish (e.g. walleye). Increased water clarity will increase the light penetration into the water, increasing growth of aquatic weeds, providing increased habitat for fish that prefer to spawn and hide in weed beds (e.g. sunfish).

Increased water clarity can also cause community and ecosystem changes. Abundant growth of these aquatic weeds will oxygenate the bottom waters, further supporting benthic community life. Recent studies indicate that zebra mussels increase the remineralization and recycling rate of nitrogen and phosphorus, providing an increased availability of nutrients such as nitrate and phosphate, essential for growth of benthic organisms.

Economic impact of zebra mussels on inland lakes

Hydroelectric power plants, municipal drinking water facilities and other water-using industries are likely to be most heavily impacted by zebra mussel populations. Mussels colonize the surfaces of pipes, diminishing the flow rate through water intake pipes. Unless preventive measures are taken, larval zebra mussels colonize the interior parts of turbines and other equipment, leading to costly repairs. Preventive measures such as retrofitting backwash filters or pre-chlorination devices for water intake pipes are also costly. Great Lakes industries have spent millions of dollars combating and preventing zebra mussel damage.

Zebra mussels can also attach to water intake pipes of boats, preventing sufficient flow of coolant water, leading to engine failure. Mussel attachment to boat hulls increases drag and decreases fuel efficiency. Removal of mussels from boat hulls can be time-consuming and costly. Anti-fouling paints are expensive; some are highly toxic, heavily regulated and need to be applied by a licensed specialist.

The full economic impact of zebra mussels is still under investigation. Recent studies report that zebra mussels hasten the corrosion rate of iron and steel structures at the point of attachment. Enhanced growth of aquatic weeds resulting from increased water clarity has led to taste and odor problems in drinking water supplies, necessitating more expensive and aggressive water treatment procedures.

Prevention and remediation of the zebra mussel invasion

Boat and barge traffic is the major vector spreading zebra mussels inland from the Great Lakes through the inland waterways. From these inland waterways, it is expected that zebra mussels will be carried unwittingly to inland lakes and reservoirs on the hulls of boats. They also may be carried in live wells and bait buckets, on fish nets and possibly by waterfowl and other wildlife moving from infested waters.

Controlling the movement of contaminated boats appears to be the only significant means of preventing, or at least slowing, the spread of zebra mussels from infested waters. The most effective and least environmentally damaging method of control is to drain the boat thoroughly and let it dry for several days before transferring it to other waters. Although the veligers are sensitive to drying, individual adult mussels are very hardy and can survive at least several days out of water, especially in moist environments. Washing the boat with hot water (at least 110°F; 42°C) using a high pressure hose is also effective in removing zebra mussels attached to boat surfaces. Inspection of boat hulls and scrubbing have a limited effectiveness because very young mussels are difficult to detect, often being smaller and more transparent than a sesame seed.

Zebra mussels are sensitive to potassium and to modest amounts of chlorine bleach (one part bleach to ten parts water). Chlorine bleach is useful for disinfection of live wells and bilges. Although dipping boats into holding ponds of potassium chloride or chlorine bleach for several hours has been contemplated as a means of decontaminating boat hulls, this is generally not considered feasible because both the economic and environmental costs may outweigh the benefits. Chemical treatments are expensive in the large quantities required and can damage some boat equipment. Disposal of large quantities of chemicals is problematic because of toxicity to aquatic life. For more information, boaters should request the publication *Slow the Spread of Zebra Mussels, and Protect Your Boat, Too*, FS-054, from Ohio Sea Grant.

What can be done to remove zebra mussels once they have become established in a lake? Much current research is directed at identifying procedures of reducing or removing zebra mussel populations from lakes. Adult zebra mussels are resistant to toxins generally used to remove mollusks. Molluscicide concentrations sufficient to kill zebra mussels do considerable damage to other forms of aquatic life and are considered an inappropriate means of control. Biological control seems also to be inadequate. Diving ducks are natural predators of these mussels, but their numbers are insufficient to control massive populations. Some fish (e.g. yellow perch) are learning to eat zebra mussels, but so far fish do not consume them to the extent sufficient to control large populations.

Whole-lake control may be possible for impoundments that can be drawn down over winter. Although a draw-down cannot be done on all inland lakes and reservoirs, it is a procedure that needs to be explored as a possible means of control in those lakes that can be drawn down.

NOTE TO READERS

Because research is on-going and zebra mussels readily adapt to a wide range of conditions, this publication will be updated to incorporate new information as appropriate.

Aquatic nuisance species and Sea Grant

Kelly Kershner, Ohio Sea Grant Communications

In 1869, it was purple loosestrife. In 1873, alewife and chinook salmon. In 1879, common carp.

Exotics are nothing new in the Great Lakes. Scientists believe the sea lamprey led the way back in the 1830s. Today, scientists estimate that 136 foreign plants, fish and mollusks make the Great Lakes home.

Perhaps the most definitive zebra mussel characteristic is a seeming urge to roam. They're native to the Ponto-Caspian region of western Russia. But with the construction of canals across Europe in the 1700s and 1800s, they rapidly expanded their range. By the 1830s, zebra mussels covered much of the continent and had invaded Great Britain.

Today, zebra mussels have made their mark on the Great Lakes. Since their discovery in Lake St. Clair in 1988, the tiny striped mollusks have spread rapidly to all of the Great Lakes and inland waters in 18 states and two provinces. No matter where it colonizes, Lake Erie—with its shallow, warm, nutrient-enriched environment—is expected to always be the most significantly affected of the Great Lakes.

Zebra mussels have also affected the environment in significant ways. So far, scientists have learned that zebra mussels are prodigious filter feeders—they remove tiny organisms from the water column at the rate of about a liter per day. Since the invasion, water clarity in Lake Erie has increased almost six-fold, allowing rooted aquatic plants to flourish and even clog harbors. Diatoms and rotifers -microscopic plants and animals at the base of the aquatic food chain—have been reduced by as much as 80 percent in some areas.

Also, scientists have learned that the zebra mussel, though small, is dangerous. In parts of Lake Erie and Lake St. Clair where zebra mussels and native clams are both present, the native clams are now almost gone.

Further, data suggest that zebra mussels' fatty tissues allow them to accumulate toxic chemicals at levels 10 times higher than native mussels. When eaten, zebra mussels pass this contaminant burden on to fish and on to small, shrimp-like organisms called gammarids, which eat both zebra mussel waste products and dead mussel tissue.

Still unclear in all of this are the implications—for fisheries, biodiversity and pollution. Do zebra mussels hurt the walleye fishery by stealing food from the smaller fishes that walleye feed on? Will zebra mussels cut a simplifying swath through the complex ecosystem, doing to lakes what purple loosestrife has done to marshes? Will zebra mussels pass super-concentrated pellets of pollutants back up the food chain? Scientists seek answers to these and other questions.

Zebra mussels pose a complex set of challenges, both now and for the future. The spread is continuing and mussel densities at Lake Erie water intakes are approaching 1 million per square meter. To meet those challenges, research must continue. Control methods must be developed, tested and made affordable. Industries, marinas—all those directly affected by zebra mussels—must have a direct line to the latest information. The general public must get involved — even simple precautions will help slow the spread.

That's where Sea Grant comes in.

Sea Grant is a bridge between government and academia, scientist and private citizen. Sea Grant is a commitment to solve coastal problems and develop marine resources. It's a bond uniting 29 state programs, 300 colleges and universities and millions of people. It's a partnership with a purpose—to help Americans understand and more wisely use our precious Great Lakes and ocean waters.

Sea Grant scientists make progress on the important marine issues of our time. Extension agents quickly take this information out of the laboratory and into the field, working to help save a coastal business, a fishery, sometimes even a life. A dedicated corps of writers and communications specialists spreads the word to the public. And Sea Grant educators bring the discoveries into the nation's schools, using them to pioneer new and better ways of teaching, helping to create a new generation of scientifically literate Americans.

Together, separate elements create a cohesive whole, ensuring that Sea Grant meets the challenges of its mandate.

Sea Grant's strength is its ability to meet problems head-on and efficiently solve them.

Today, one of those challenges is zebra mussels. Sea Grant is meeting this challenge. Proceeding as it always has, Sea Grant is drawing on a wealth of scientific expertise to develop feasible solutions. But it's also keeping the public informed in all the effective and innovative ways the collective creativity within Sea Grant can generate.

For more information about Sea Grant's work on zebra mussels, contact the program nearest you. For a list of resources available from the six Sea Grant programs in the Great Lakes Sea Grant Network, request a copy of *A Great Lakes Sea Grant resource list on zebra mussels and other nonindigenous species.*

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Other U.S., state and Canadian agencies are also working on this issue. Some of the agencies working as a Great Lakes panel on nonindigenous species include:

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

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Range of the zebra mussel in North America
as of August/September 1993

Compiled by New York Sea Grant with information from: Empire State Electric Energy Research Corp., Fisheries and Oceans Canada, Great Lakes Sea Grant Network, Illinois Natural History Survey, Ontario Hydro, Ontario Ministry of Natural Resources, Tennessee Valley Authority, US Army Corps of Engineers, US Fish & Wildlife Service, and utilities and others throughout North America.