



US Army Corps
of Engineers
Waterways Experiment
Station

Zebra Mussel Research Technical Notes

Section 1 — Environmental Testing

Technical Note ZMR-1-01

Zebra Mussels: Biology, Ecology, and Recommended Control Strategies

Background and purpose

Introduction and spread

In 1986 a ship released its ballast water into Lake St. Clair, Michigan, releasing billions of organisms that it had picked up in a freshwater port in Europe. In the ballast were the larvae of a freshwater mollusc, the zebra mussel (*Dreissena polymorpha*). This small mussel is usually no more than 5 cm long (2 in.) with characteristic zebra-like stripes (Figure 1). The zebra mussel was originally native to the Caspian Sea and Ural River in Asia. In the nineteenth century, it spread west and now occurs in most of Europe, the western portion of the Commonwealth of Independent States (formally the Soviet Union), and Turkey.

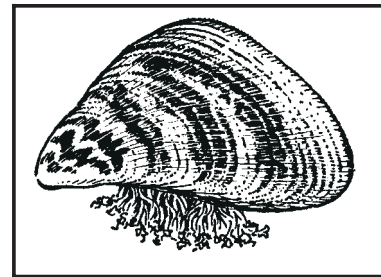


Figure 1. Adult zebra mussel
(*Dreissena polymorpha*)

Reason for concern

The zebra mussel is a macrofouler: it quickly colonizes new areas and rapidly achieves high densities. Unlike native mussels that burrow in sand and gravel, zebra mussels spend their adult lives attached to hard substratum. Under natural conditions they are found on rocks, logs, aquatic plants, shells of native mussels, and exoskeletons of crayfish. They can also attach to plastic, concrete, wood, fiberglass, pipes made of iron and polyvinyl chloride (Figure 2), and surfaces covered with conventional paints.

In 1988 and 1989, zebra mussels were first found in water intake pipes in industrial and municipal water plants in Lakes St. Clair, Erie, and Ontario. The Monroe water plant in Monroe, MI, had to temporarily suspend service when its main intake line became clogged with zebra mussels. Many power plants along Lake Erie now spend more than \$250,000 each year on control. Infestations have caused temporary power outages and difficulties in obtaining water for cooling and waste removal. Within their range, zebra mussels could render inoperable miter gates on locks, fire prevention systems that use raw water, reservoir release structures, navigation dams, pumping stations, water-intake structures, dredges, and commercial and recreational vessels. Materials and equipment, such as small-diameter pipes, seals, valves, gears, air vents, weep holes, screens, trash racks, chains, pulleys, and wire ropes, are vulnerable. When a thick layer of zebra mussels covers a metallic surface, it can cause



Figure 2. A pipe clogged by zebra mussels (provided by Peter Yates)

anoxia, reduced pH, and accelerated corrosion rates. It has been estimated that in the United States this species could cause \$5 billion in damage by the year 2000.

Spread in this country

In the summer of 1991, just three years after they were first found in Lake St. Clair, zebra mussels have been collected in the Hudson, Illinois, upper Mississippi, Susquehanna, lower Ohio, Tennessee, and Cumberland Rivers. Within a relatively short time, this species has spread throughout the eastern United States (Figure 3). Serious zebra mussel infestations will likely occur in the inland navigation system by 1992 or 1993.

Authority

The Corp's involvement with zebra mussels is based on the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, Public Law 101-646 (Congressional Record — House, 27 October 1990). The legislation required that the Secretary of the Army develop a program of research and technology development for the environmentally sound control of zebra mussels at public facilities. Public facilities include not only locks, dams, and reservoirs, but also water-pumping stations, water intakes, hydroelectric power stations, and drainage structures. In October 1991, the U.S. Army Engineer Waterways Experiment Station (WES) initiated a four-year program to develop environmentally sound control strategies for zebra mussels.

Purpose

The purpose of this technical note is to discuss the biology, ecology, and recommended control strategies for zebra mussels.

Additional information

This technical note was written by Drs. Andrew C. Miller and Barry S. Payne, U.S. Army Engineer Waterways Experiment Station (WES), and Dr. Robert F. McMahon, the University of Texas at Arlington. Contact Dr. Miller (601) 634-2141, for additional information. Dr. Ed A. Theriot, WES, (601) 634-2678, is Manager of the Zebra Mussel Research Program.

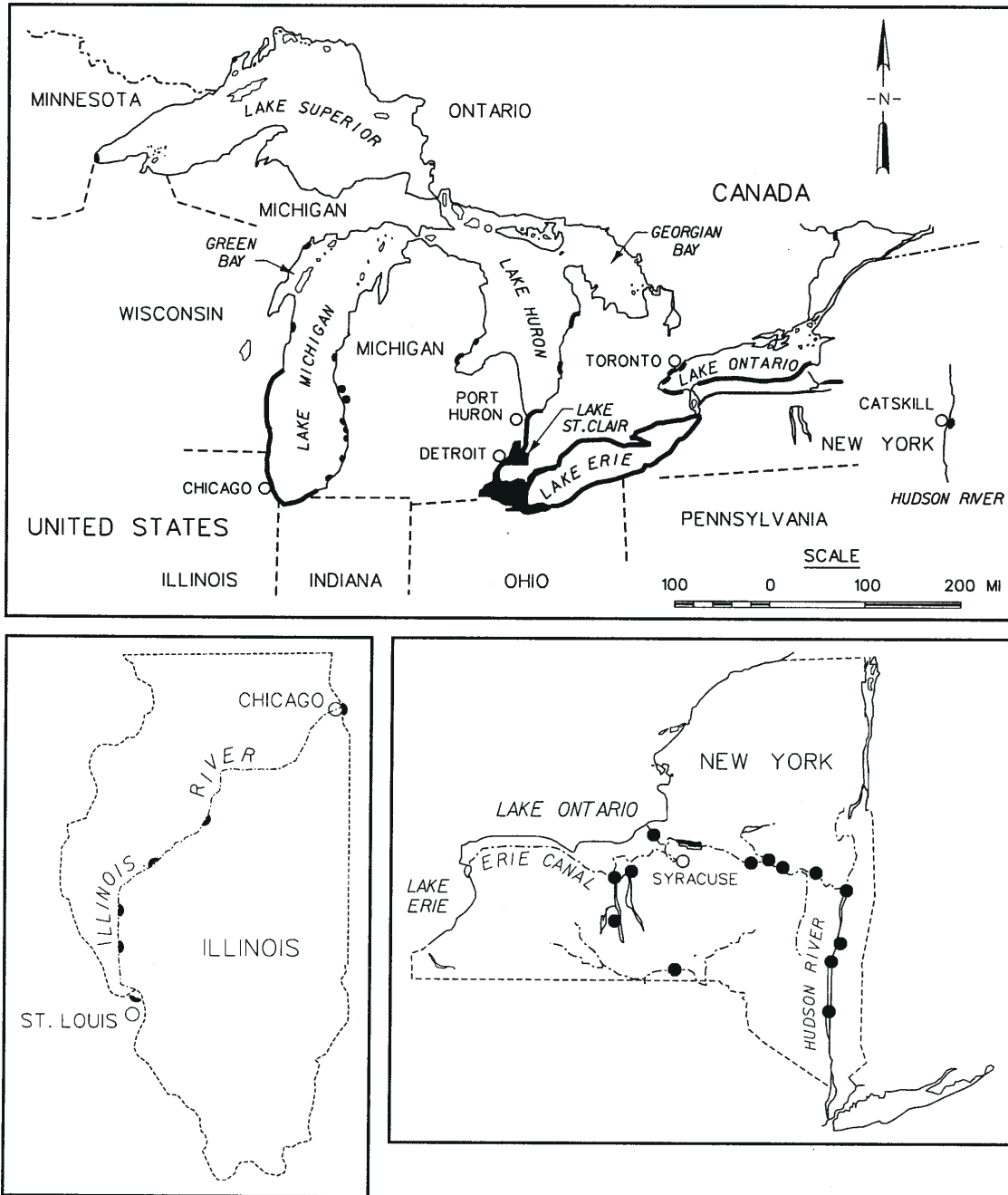


Figure 3. Distribution of zebra mussels in the United States, November 1991 (adapted from *Dreissena polymorpha* Information Review); darkened areas and solid circles indicate zebra mussel populations

Biology and ecology of zebra mussels

Physical description

Zebra mussels are bivalve molluscs related to oysters, clams, and native fresh-water mussels. They are also related to the exotic Asiatic clam (*Corbicula fluminea*), which is a biofouler in the central and southern United States. Zebra mussels can grow to 5 cm (2.0 in.), although most specimens collected in this country have been no more than 3.8 cm (1.5 in.) long. They have an elongate, somewhat pointed, thin shell usually with a zebra-like pattern of stripes. An individual mussel can attach to an object with more than 100 proteinaceous

byssal threads that are secreted from a gland at the base of its muscular foot. These threads are extremely tenacious; an attempt to remove the animal by hand usually results in breaking the shell or damaging soft tissue. Native freshwater mussels and Asiatic clams have a single, thin byssal thread that is present only in the juvenile. The zebra mussel is the only freshwater bivalve in this country that retains these threads as an adult. Byssal attachment to hard surfaces within raw water systems by large numbers of mussels is the main reason that this species causes problems in industrial and domestic water supplies.

Densities

An exotic species often achieves high densities immediately after colonizing a new habitat. For example, biologists at Detroit Edison reported that zebra mussel densities on an intake screen climbed from 200 individuals/sq m (165 individuals/sq yd) to 700,000 individuals/sq m (585,284 individuals/sq yd) in 1989. A car submerged for 8 months in Lake Erie was 90 percent covered with mussels at an average density of 45,000 individuals/sq m (37,625 individuals/sq yd). As many as 10,000 zebra mussels have been counted on a single freshwater mussel. This ability to rapidly achieve high densities makes the zebra mussel a threat to industrial and domestic water supplies.

Within 10 to 20 years of colonization, densities of zebra mussels may decline as natural predators and diseases begin to act as control agents. Densities of zebra mussels in much of Europe have declined from levels achieved within the first 10 to 15 years of introduction, and most are much less than densities now being reported from the Great Lakes.

Feeding

Zebra mussels feed on suspended particles (unicellular algae, bacteria, and fine organic detritus) using a complex arrangement of cilia. Water enters the animal through an incurrent siphon and is carried over the gill where suspended particles are filtered by cilia and are sorted according to size. Accepted particles are combined with mucus and passed to the mouth, and rejected particles are combined with mucus and ejected as pseudofeces. Zebra mussels can effectively remove particles less than 1 μm (0.0000394 in.) in diameter, while most other bivalves cannot filter objects less than 3 μm (0.000118 in.). This enables zebra mussels to feed on planktonic bacteria that are unavailable to native mussels.

This method of feeding is common in all freshwater and marine bivalves. An individual zebra mussel can filter up to 8.5 L (approximately 8 qt) of water a day. Because of their mode of feeding and their ability to achieve high densities, zebra mussel filter-feeding can increase water clarity locally. Phytoplankton, fine organic matter, and clay or silt particles are filtered out of the water and ingested or deposited as pseudofeces. By incorporating silt into feces and pseudofeces zebra mussels can greatly increase sedimentation rates in natural habitats and raw water systems. Zebra mussels are often used in Europe as water clarifiers at treatment plants.

Reproduction

Zebra mussels are mainly dioecious (a population consists mostly of males and females). When water temperatures reach 11° or 12° C (52° or 54° F), females release eggs. Females can reproduce when 12 months old or less (age at maturity decreases with growth rate; sexual maturity can be at a shell length of as low as 3 mm (about 0.1 in.)); large females are capable of producing over 1 million eggs per season. Males release sperms directly into the water and eggs are fertilized externally. The fertilized egg hatches into a free-swimming veliger larva (Figure 4) that ranges in size from 0.04 to 0.07 mm (0.0016 to 0.0028 in.). All zebra mussels do not spawn simultaneously. In waters of the United States, veligers can be found from May to October. Native freshwater mussels reproduce at a specific time, usually in the spring. In addition, native mussels usually become reproductive when they are 5 or more years old.

Early development

Newly hatched veligers have a velum that supports a ring of cilia that are used for swimming and feeding (Figure 4). Larvae tend to swim up at night and move down during the day, but are unable to swim horizontally toward specific objects. They colonize new areas by being carried passively on water currents. Veliger densities have been reported to range between 70 and 400,000 individuals/sq m (54 to 306,000 individuals/sq yd).

The veliger feeds and grows in the plankton for about 10 to 14 days. Gradually the velum begins to decrease in size and the veliger settles to the substratum and metamorphoses into a shelled juvenile. The newly settled mussel resembles an adult and is no more than 0.2 to 0.3 mm (0.0079 to 0.0118 in.) long; hence it is easily overlooked. Settlement of immature mussels takes place in areas with velocities less than 1.5 to 2.0 m/sec (4.9 to 6.6 ft/sec). However, once attached, zebra mussels can tolerate velocities greater than 2.0 m/sec (6.6 ft/sec). Zebra mussels usually attach to surfaces that are covered with a

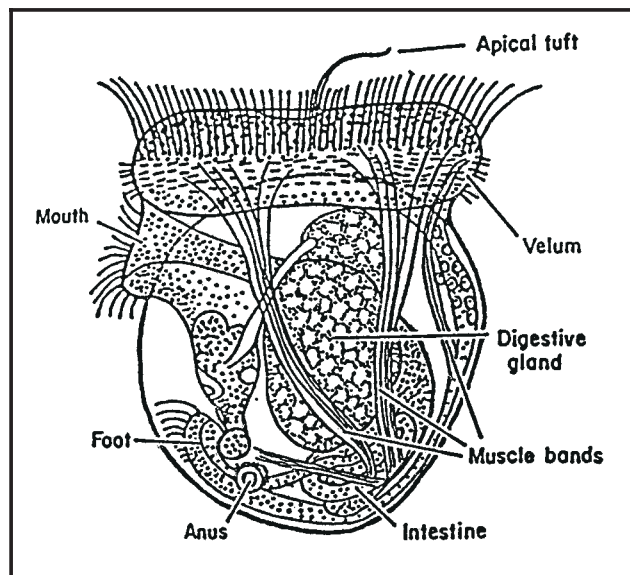


Figure 4. A veliger, or immature zebra mussel (based on a drawing in Hopkins 1990)

film of algae or bacteria. This film can develop on a clean surface within a few days.

The ability of immature zebra mussels to remain suspended in the water column for up to 2 weeks allows them to be dispersed great distances in rivers. The immature stage of most native mussels is not free-living, but must spend a developmental period on the gills or fins of a specific species of fish.

Growth

Growth rate depends on water quality and temperature and can range from 1.0 to 1.6 cm/year (0.4 to 0.6 in./year) in slow- and fast-growing populations, respectively. Maximum annual production reported for a zebra mussel population is 29.8 g of dry tissue/sq m/year (approximately 0.9 oz/sq yd). This is one of the highest recorded production rates for freshwater or marine bivalves and emphasizes the ability of these animals to quickly develop large biomass.

Locomotion

After an immature mussel settles, it can remain attached to hard substratum for life. If conditions become unsuitable, because of physical disturbance or poor water quality, zebra mussels can release from their byssal threads. Once detached from the substratum, individuals can be carried passively to new structures where they can settle and secrete new byssal threads. Zebra mussels can also crawl by extending the foot tip, anchoring it to substrate with mucus, and then contracting the muscles to pull the body forward. Small individuals are more mobile than large mussels.

The ability of zebra mussels to remain attached to boat hulls, woody vegetation, and trash is also responsible for their rapid dispersal. In addition, groups of bysally attached mussels can break loose, form dense mats, and infest new areas.

Ecology

Zebra mussels are found in freshwater lakes, embayments, and rivers. If temperature and water quality are appropriate, they tolerate velocities up to 2.0 m/sec (6.6 ft/sec). They typically are found where water temperatures range from 0° to 25° C (32° to 77° F). They have been collected in shallow waters (less than 1 m or 3.2 ft), but maximum abundance usually occurs between 2 to 14 m (6.4 to 44.8 ft). Zebra mussels are clean water inhabitants and are usually found where dissolved oxygen is greater than 90 percent saturation. They are stressed in water with less than 40 to 50 percent saturation, and 100 percent mortality occurs if there is no dissolved oxygen. Zebra mussels, like all bivalves, require calcium to construct their shell. They will not be found in water with less than 10 mg/L dissolved calcium.

Natural predators

Zebra mussels are eaten by the freshwater drum, catfish, and most sunfishes. The lake sturgeon, which is now extirpated from large rivers in the United States, eats zebra mussels. Mussels are also eaten by dabbling and diving ducks, and there have been reports of increases in waterfowl populations as a result of infestations. Although zebra mussels are consumed by a certain fish and waterfowl, it is unlikely that they will be controlled by natural predation, especially in man-made structures such as pipes or pumping plants.

Environmental considerations

Filter-feeding by zebra mussels could reduce plankton and decrease the food base for planktivorous fishes such as shad and shiners. By blanketing sediments, removing fine particulate matter, and depositing nutritious and nonnutritious particles as pseudofeces, zebra mussels could affect the density and

biomass of native clams, immature insects, and other invertebrates. Large numbers of mussels could cover spawning shoals used by riverine fishes.

Zebra mussel control Monitoring

Test substrates that can be easily removed and examined should be placed in areas where an early warning of the presence of zebra mussels is required. Since zebra mussels readily attach to most substrates, sampling for them is not difficult. Concrete blocks suspended from ropes are frequently used. A set of PVC plates secured to a rope with a weight on the bottom is a preferred method because the plates have a known surface area and are easy to examine and scrape. Since zebra mussels grow very quickly, they should be recognizable within several weeks of initial settlement.

Once collected, zebra mussels can be preserved in 10 percent buffered formalin or 95 percent alcohol (ethyl or methyl) for transporting to an authority for identification. Zebra mussels will keep for weeks if they remain cold (refrigerated) and moist. The New York Zebra Mussel Clearing House, New York Sea Grant Extension, 250 Hartwell Hall, State University of New York College at Brockport, Brockport, NY 14420-2928, (716) 395-2516, should be contacted if zebra mussels are collected outside their known range.

Appropriate control methods

The following are methods for controlling zebra mussels:

Antifoulant coatings. Toxic and nontoxic coating materials are available which can either prevent zebra mussel settlement or cause very weak byssal attachment (so that the mussels are more easily removed). These products include silicon and epoxy compounds, copper-based paints, and thermal metallic sprays. Some of these compounds can remain viable for 20 or more years. These materials can be used on structures that are difficult to clean or if there are anticipated difficulties with removal and disposal of large numbers of zebra mussels.

Limited use of biocides. Many oxidizing and nonoxidizing chemical control agents can be used to reduce or eliminate zebra mussels. Chlorine is a commonly used control agent in Europe, this country, and Canada. Continuous exposure at 0.5 mg/L will kill zebra mussels in 14 to 21 days, which is preferable to application of a concentrated "slug dose" that zebra mussels can withstand for several days by closing their shells. Chlorine can be used in pipes or ducts that contain pressure sensing or other equipment.

Mechanical cleaning. High-pressure water is very effective for removing zebra mussels from walls, trash racks, or other equipment. A suction pump attached to a mechanical scraper can be used to dislodge and vacuum zebra mussels out of an area.

Thermal shock. Zebra mussels are intolerant of elevated temperatures. Holding water at 32.5° C (90.5° F) for 3 hr causes 100 percent mortality; raising the temperature to 40° C (104° F) causes instantaneous death.

Effects of drying. Zebra mussels can be killed by exposure to hot, dry air. Their vulnerability to desiccation provides an environmentally sound control technique that is useful in many situations. Fire protection systems that use raw water could be temporarily drained and hot air forced through pipes to kill mussels. Dead shells would then have to be flushed out of the system so valves and nozzles will not be clogged.

Anoxia. Sodium-meta-bisulfate ($\text{Na}_2\text{S}_2\text{O}_5$) and hydrogen sulfide will reduce dissolved oxygen concentrations and can kill zebra mussels.

Limited use of filters. Screens or strainers on raw water systems can be installed to remove juvenile and adult zebra mussels. These screens must be removed or backwashed regularly. The downstream side of a screen often provides appropriate substratum for zebra mussels. Because of the small size of the veligers, special filters and backwash systems are required. Sand filtration systems or intakes buried in infiltration beds (that is, intake water drawn through special sediment beds) can remove zebra mussel veliger larvae from intake water.

Disposable substrates. A disposable substrate, such as netting, hemp rope, PVC pipe, or other material, can be used to protect water intake pipes or other structures where zebra mussels are likely to settle. If placed properly, zebra mussels will attach to these materials before reaching important pipes or machinery. When covered with zebra mussels, substrates can be removed and disposed of properly. If these substrates reduced maintenance requirements by even modest amounts, for example, 10 or 20 percent, their use could be justified.

Disposal of zebra mussels Finding places to dispose of large quantities of zebra mussels may be difficult. Landfill operators may not accept dead zebra mussels because of their odor. It may be possible to hold zebra mussels temporarily until the odor dissipates and then take them to a landfill. Large volumes of zebra mussels should not be disposed of in a waterway. If they are, a National Pollutant Discharge Elimination System (NPDES) permit, not a section 404 permit (zebra mussels cannot be considered dredged material), would be required. Zebra mussels that are scraped from underwater surfaces can be left in the water where they will wash away.

Beneficial uses of zebra mussels Zebra mussels, like dredged material, may have some commercial value. These beneficial uses, when fully evaluated, could be implemented to reduce disposal costs. Under certain conditions it is possible that zebra mussels could be used as fertilizers, sources of calcium carbonate, a fowl feed supplement, or fill material. Perhaps their best use would be as water clarifiers.

Concluding comments The U.S. Army Corps of Engineers is a construction and operation agency. Therefore, it will emphasize its engineering expertise to devise appropriate zebra mussel control strategies. A successful strategy must consider costs, effectiveness, environmental compliance, and the safe and continued operation of the facility. The search for environmentally sound control methods for zebra mussels will represent a great environmental challenge for planners, engineers, and biologists.

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