The Biology, Invasion and Control of the Zebra Mussel (*Dreissena polymorpha*) in North America

By
Leann Maxwell

Edited
J. Joseph Homburger
Willard N. Harman

Biological Field Station
Cooperstown, New York
Occasional Paper No. 24

Otsego Lake Watershed Planning
Report No. 3
February, 1992

Biology Department
State University College Oneonta

EDITORS NOTE

This contribution has been derived from a manuscript written by a graduate student enrolled in Bio 487, Topics in Aquatic biology, taught Fall Semester 1991. It is one of 14 papers (one per week) required of students in the course. It represents a brief literature search including materials gathered from the Second International Zebra Mussel Research Conference in Rochester, N. Y. 19-22 November 1991. It has all the limitations typical of student contributions, but in our opinion does offer an excellent overview of the concerns at hand. (Perhaps because of an over-reliance O'Neill and Mac Neil, 1991 [see references]).

Those seriously concerned with the impact of Zebra Mussels should contact The N.Y.State Sea Grant Program, N. Y. Zebra Mussel Information Clearinghouse, SUNY College at Brockport 14420-2928. Telephone (716) 395-2516 for further, and continuously updated information.

INTRODUCTION

The zebra mussel, Dreissena polymorpha, (Cyrenodonta: Dreissenacea) is the most recently introduced bivalve species to North America and many of its life-history characteristics make it highly invasive (Thorp and Covich, 1991). It is assumed the zebra mussel, a black and white striped bivalve mollusk, made its way from Central and Eastern Europe into North American waters through the discharge of international shipping ballast water. Since its first Great Lakes discovery in Lake St. Clair in June 1988, the zebra mussel has spread rapidly into and throughout Lake Erie, becoming one of the dominant organisms in the Lake's western basin. The mussel has recently been found in the Niagara River, along the southwest and northeast shores of Lake Ontario, and in locks of the St. Lawrence Seaway (New York State Senate Task Force on Zebra Mussels and New York Sea Grant, 1990). The zebra mussel has the potential to foul municipal, electric power generation and industrial water intake facilities; to disrupt food webs and ecosystem balances; and to interfere with sport and commercial fishing, navigation, recreational boating, beach use and agricultural irrigation throughout North American fresh waters (O'Neill and MacNeill, 1991). In fact, rough damage estimates for the Great Lakes alone run to $4 billion (Roberts, 1991) or $5 billion (Anonymous, 1991). It is believed that zebra mussels will have invaded nearly every waterway in North America within the next 20 years (Anonymous, 1991).

BIOLOGY OF THE ZEBRA MUSSEL

Zebra mussels are small (3.5-5.0 cm) bivalve mollusks with elongated shells typically marked by alternating light and dark bands. As its scientific name polymorpha implies, the species shows considerable genetic and morphological plasticity, particularly in its marking and coloration patters (Feinberg, 1979). Specimens with few markings, with herringbone pattern, with stippled patterns or radial striping are quite common. Soviet studies suggest the presence of discrete morphological and physiological ecotypes or phenes (races) of Dreissena. Early Soviet studies described at least five species (O'Neill and MacNeill, 1991).

Zebra mussels secrete durable elastic strands, called byssal threads, by which they can securely attach to nearly any surface, forming barnacle-like encrustations. Because of an affinity for water currents, zebra mussels extensively colonize water pipelines and canals, often severely reducing the flow of water and, upon death, imparting a foul taste to drinking water (Ellis, 1978).

Zebra mussels will colonize lakeshores and riverbanks where they attach to rock or gravel substrates forming dense reef-like mats. They can even attach themselves to the shells of other mussels and clams. In some European lakes, colony densities exceeding 100,000/m^2 have been reported with 15 cm deep shell accumulations from dead mussels on the lake bottom within two years (O'Neill and MacNeill, 1991). Thorp and Covich (1991) state that zebra mussel population densities range from 7,000 to 114,000/m^2 and standing crop biomasses from 0.05 to 15 kg/m^2. In fact, in 1988, biologists at the Detroit Edison plant on western Lake Erie counted 200 zebra mussels/m^2 on the intake screen and in the following year (1989), the number had increased to 700,000 (Roberts, 1991). To aid in illustrating the increased significance of present-day mussel invasions, it should be noted that according to Burky (1983), Stanczykowska (1976) reported that population densities of zebra mussels can approach only 2,000 clams/m^2. Looking at today's figures of zebra mussel population densities, we can easily see what a tremendous problem their numbers are becoming.

Zebra mussels are generally found within 2 to 7 meters of the water surface but may colonize to depths up to 50 meters. Colonization depths vary from lake to lake, but appear to be determined by light intensity, water temperature, and availability of food. Zebra mussels can tolerate a fairly wide range of environmental conditions. They prefer water temperatures between 20° and 25°C (68° and 77°F) and water currents 0.15 to 0.5 meters/second for proper growth. While normally considered a freshwater species, the zebra mussel can adapt to and inhabit brackish areas ranging from 0.2 to 2.5 parts per thousand (ppt) total salinity in estuarine habitats. European studies indicate occasional sightings of zebra mussels in total salinities exceeding 12 ppt (O'Neill and MacNeill, 1991).

In Europe, mussel densities tend to be higher in large lakes (surface areas greater than 485 hectares) with depths exceeding 35 meters, which are not overly enriched but which have a high calcium content, generally greater than 12 ppm. Conditions generally considered as unsuitable for growth are water temperatures below 7° C (45°F) or above 32°C (90°F), water currents greater than 2 meters/second or rapid water level fluctuations. Zebra mussels can withstand desiccation for two to three days depending on atmospheric humidity (O'Neill and MacNeill, 1991).

On November 21, 1991 at the Second International Zebra Mussel Research Conference held in Rochester, New York data was presented which suggested relative humidity that dewatering to kill zebra mussels would require three-four days at 25°C. At 15°C, it would require 7-9 days below 75% (RH), but 23 days above 95% RH. At 5°C, minimal time for 100% kill would be 11 days and is likely to exceed 30 days above 95% RH. Thus, the most appropriate time for application of dewatering to control zebra mussels is mid-summer when elevated ambient temperatures would induce rapid kills. At lower ambient temperatures, application of dry and/or heated air to dewatered components may be required to produce acceptable kill rates. (MacMahon etal, 1991).

The zebra mussel has a reproductive strategy unique to freshwater mussels which is responsible for its rapid population expansion in Europe and the Great Lakes (O'Neill and MacNeill, 1991). Sexual maturity is typically reached at age two but may occur in the first year at a size of 3 to 5 mm. Zebra mussels are separately sexed, but some hermaphroditism has been reported. Mature mussels can produce 30,000 to 40,000 eggs per year. At least one European study has indicated that a 30 mm female can produce, on average, up to 1,000,000 eggs per year. Egg production can occur in either asynchronous or synchronous batches enabling individuals to spawn several times during the spawning season. Spawning activity may extend throughout the year in warm, productive waters (Anonymous, 1991; O'Neill and MacNeill, 1991; Otter, 1991; Roberts, 1991; and Thorp and Covich, 1991).

Although poorly understood, the reproductive cycle is apparently influenced by environmental cues such as water temperature, phytoplankton abundance and species composition, and mussel population density. Evidence from Lake Erie suggests that reproductive activity may be cued by such seasonal phytoplankton dynamics as blooms and algal species succession. Spawning patterns may show considerable year-to-year variations. Recent studies from

Lake Erie suggest that cool water temperatures, storm events, increased turbidity, and increased population densities can delay spawning resulting in possible synchronous spawning activity. Spawning may also be induced by the presence of mussel gametes in the water (O'Neill and MacNeill, 1991).

Unlike all other North American bivalve species, the zebra mussel releases sperm and eggs to the surrounding medium such that fertilization is completely external. A free-swimming planktonic veliger larva hatches from the egg and remains suspended in the water column where it feeds and grows for eight to ten days before settling to the substratum. Veligers are active swimmers and are also transported by water currents, enabling them to disperse considerable distances from their parent colonies (Thorp and Covich, 1991).

Within three weeks of hatching, the young mussels reach the "settling stage," where they can attach to bedrock, cobble, bottom debris or manmade objects such as boat hulls, breakwaters, and water intake pipes. At this life-cycle phase, the settling larvae can experience mortalities exceeding 99%, primarily from hypoxia (oxygen deficiency), temperature shock, and failure to locate a suitable attachment substrate (which could result in larval sinking into bottom sediments or into deeper, colder water with lower productivity (O'Neill and MacNeill, 1991; Thorp and Covich, 1991).

During the first year of life, young mussels are capable of active crawling along the substrate at speeds over 3.8 cm/hour until they find a suitable location to attach with small, temporary byssal fibers. With age, the mussels develop extensive byssal fibers (up to 200 byssal fibers) and, for the most part, become sessile. Younger, overwintering mussels can detach from their temporary byssal fibers and migrate to deeper, warmer waters to escape from cold temperatures and ice scour. During the first growing season, young zebra mussels may reach 5 to 10 mm in length (O'Neill and MacNeill, 1991; Roberts, 1991; and Thorp and Covich, 1991).

The life span of a zebra mussel is highly variable depending on a number of environmental conditions. Lifespans average around 3.5 years but can reach 8 to 10 years in some less productive European localities (O'Neill and MacNeill, 1991). Thorp and Covich (1991), however, state that zebra mussels typically have life spans from 5 to 6 years.

Typically, when the zebra mussel is introduced outside its native range, the relocated population undergoes a rapid increase in number, often by a factor of 2 to 3, lasting for several years after the initial introduction, followed by a marked reduction in population size and subsequent population oscillations. However, in Sweden the population of zebra mussels has not yet declined after more than 11 years. The zebra mussel population expansion in Lake Erie appears to be more aggressive than in Europe, most likely due to the lake's highly suitable chemical, biological, and thermal properties (O'Neill and MacNeill, 1991).

Overall, according to Thorp and Covich (1991), the life-history traits of a high growth rate throughout life, high fecundity, short life spans, and the capacity for both adult and larval stage downstream dispersal make the zebra mussel a highly invasive species. Morton (1969) adds that the possession of a free-swimming veliger larva, a unique feature of freshwater bivalves, and the ability to attach itself by means of byssal threads in situations normally unoccupied by other bivalves, are important elements in its success.

THE ORIGIN, INTRODUCTION, AND INVASION OF THE ZEBRA MUSSEL

The zebra mussel, which is native to the drainage basins of the Black, Caspian, and Aral Seas, was introduced into several European freshwater ports during the late 1700's. Within 150 years of its introduction, the zebra mussel was found throughout European inland waterways. Current estimates of the spread of the zebra mussel in inland waters of the United States suggest that it will spread at a much faster rate than in Europe (MRB Group, 1991).

Although the actual pathway of the mussel's introduction to North America is unknown, it is believed that ships originating from overseas freshwater ports where the mussel is found carried the mussel in freshwater ballast which was discharged into freshwater ports of the Great Lakes (Roberts, 1991). Although adult mussels are capable of attaching to the hulls of ships, their transoceanic transport in this manner is unlikely since the mussels cannot survive the high total salinity in open ocean saltwater for the time required for a transatlantic crossing (O'Neill and MacNeill, 1991). Barry Payne has suggested that anchors and anchor lines kept in cool moist chain lockers of vessels may well have been a transport method (MacMahon _et al_, 1991). However, for reasons that are not fully understood, the zebra mussel survived and the population has since exploded (Roberts, 1991).

The zebra mussel was first discovered in the Great Lakes Basin in Lake St. Clair in June 1988. Judging from its small size, it was theorized that the mussels were introduced into the lake sometime in 1985 or early 1986 (MRB Group, 1991). The first confirmed sighting in the western basin of Lake Erie was in July 1988. Extensive colonies of up to 30,000 to 40,000 individuals/m^2 were reported in the western basin of Lake Erie in the summer of 1989 by the Ontario Ministry of Natural Resources (MRB Group, 1991; O'Neill and MacNeill, 1991; and Robert, 1991).

By September 1991, the mussel was found in all five of the Great Lakes; their connecting waterways; the St. Lawrence River; the western two-thirds of the Erie Canal; the eastern end of the Mohawk River; Cayuga and Senaca Lakes; the upper Susquehanna River in Johnson City, New York; the Hudson River between Albany and Red Hook, New York; the Illinois River; the Mississippi River between its confluence with the Illinois River and St. Louis, Missouri; the upper Mississippi River near La Crosse, Wisconsin; the Tennessee River near the Kentucky border; and the Ohio River near Mound City, Illinois (O'Neill and MacNeill, 1991). In addition, according to MRB Group (1991), in the spring of 1991, zebra mussels were confirmed in the Hudson River as far south as Catskill, New York - about five years ahead of the earlier predicted schedule. Figure

1 illustrates the North American range of the zebra mussel as of September 21, 1991 (O'Neill and MacNeill, 1991).

According to O'Neill and MacNeill (1991), biologists believe that the interbasin transport of the zebra mussel from the Great Lakes system into inland fresh surface waters is taking place via natural and human influenced dispersal vectors, and that the mussels will ultimately infest most areas of North America south of central Canada and north of the Florida panhandle. In a different report (Anonymous, 1991), O'Neill expects that within two or three decades, the zebra mussel will have spread from central Canada to the Texas and Florida panhandles and from Maine to the West Coast.

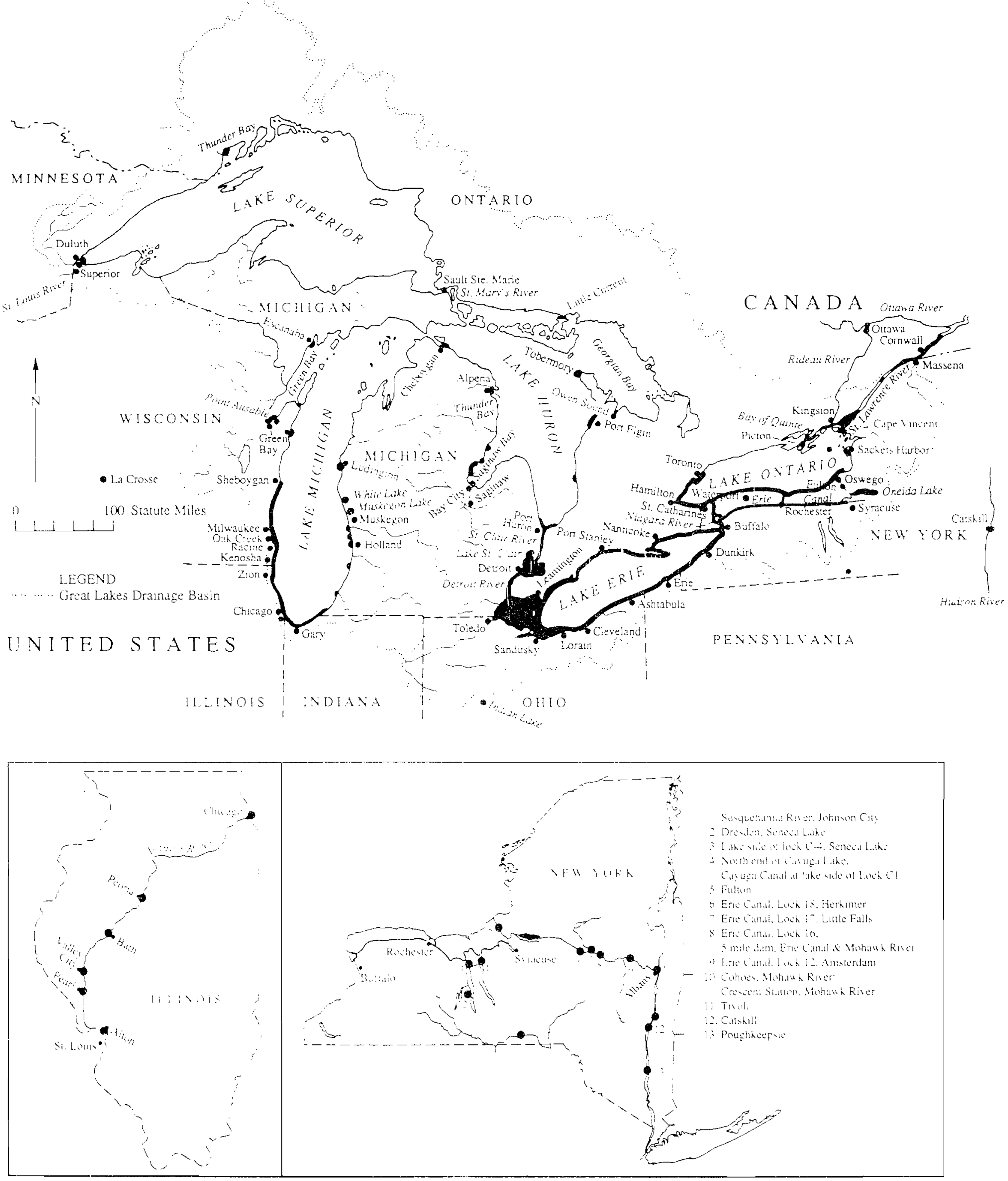
This increased dispersal of zebra mussels will most likely be greatly enhanced by interlake transport of veliger larvae in ship ballast and adult and juvenile mussels attached to ship and recreational boat hulls. There is concern that the range expansion of the zebra mussel will be further facilitated by the transport of veligers by commercial bait transport, in anglers' bait bucket water and recreational boat engine cooling water, transport of juveniles and adults by waterfowl and by attachment to crayfish and turtles (O'Neill and MacNeill, 1991).

BIOLOGICAL IMPACTS OF THE ZEBRA MUSSEL

Zebra mussels use siphons and a ciliated gill system to filter small particles such as phytoplankton, small zooplankton, and bits of detritus out of water drawn into the mussel's mantle cavity (Thorp and Covich, 1991). Laboratory studies indicate that the

North American Range of the Zebra Mussel

as of 21 September 1991



mussels can efficiently filter food particles down to 0.7 um, but preferentially select particles between 15 to 40 um as food. Rotifers as large as 450 um can be retained and eaten (O'Neill and MacNeill, 1991). In a study by MacIsaac and Sprules (1991), it was demonstrated that large veligers in western Lake Erie have higher filtration rates than small individuals, and some are capable of ingesting particles as large as 11 um. Zebra mussels can also filter and consume their own veligers. Particles of unsuitable size or chemical composition that are not ingested are coalesced into a mucus bolus (pseudofeces) and subsequently discharged (O'Neill and MacNeill, 1991).

Filtration rates are determined by food particle concentration and sizes, water temperatures, hunger state, and mussel body size. On average, a 25 mm long zebra mussel can filter one liter of water per day. However, filtration rates up to two liters per day under optimal conditions have been observed. European studies indicate that the filtration ability of zebra mussels can dramatically increase lake water clarity. Since the introduction of zebra mussels into Lake Erie, researchers have observed a two- to three-fold increase in water clarity and a significant reduction in chlorophyll^a content (O'Neill and MacNeill, 1991). In fact, it has been stated that zebra mussels filter phytoplankton out of the water with such efficiency that visibility in Lake Erie is now about 30 feet down, where formerly it was only 1.5 feet. The extent that changes in Lake Erie's clarity and productivity can be attributed directly to zebra mussel filtration remains unknown and it is still too early to know how the mussels will affect the ecology of the waterways they invade (Anon., 1991).

Because the zebra mussel filters huge quantities of water, filtering out most of the phytoplankton, the biggest concern is that it will disrupt the lower food web, with effects reverberating up the food chain. Since phytoplankton and detritus are major food sources involved in food webs, fisheries-related impacts could result from zebra mussel filtration activity (Roberts, 1991). Excessive removal of phytoplankton and detritus from the water column could cause a decline in zooplankton species which feed upon those food particles. Small zooplankton are also eaten by zebra mussels. Larger zooplankton and larval fish of all species preying on small zooplankton could face reduced survival as mussel populations expand, suggesting other food web impacts. In addition, extensive deposition of mussel pseudofeces on the lake bottom could favor the proliferation of benthic fish and invertebrate species. The changes in water transparency and the selective survival of benthic algae in mussel pseudofeces could favor a shift towards increased importance of benthic algae in the Great Lakes (O'Neill and MacNeill, 1991).

Because zebra mussels settle on rock cobble for attachment, there is concern that extensive colonization of shoal areas could impair reproduction of certain fish species which spawn only on rocky bottom habitats. Some biologists are concerned that decomposing mussel pseudofeces could reduce water quality in and around fish egg masses on shoals, reducing egg survival. In addition, increased water clarity may reduce the ability of larval fish to avoid predation. This also makes zooplankton more visible to fish predators (O'Neill and MacNeill, 1991). Walleye, white bass, and lake trout are directly endangered, as zebra mussels have encrusted their prime spawning beds (Fitzsimons et al., 1991). This is important due to the fact that walleye fishing in Lake Erie alone is a $900 million-a-year business (Roberts, 1991). So far, however, the walleye, white bass, and lake trout production in mussel-encrusted shoals appear relatively unaffected and recent populations have been stable (Fitzsimons et al., 1991; O'Neill and MacNeill, 1991; and Roberts, 1991).

Although zebra mussels are not considered as common parasitic vectors in Europe, they could potentially increase the spread of certain parasites, particularly as the mussel rapidly colonizes throughout North America (O'Neill and MacNeill, 1991).

Native mussel populations may be adversely impacted by competition for food and space by the large numbers of zebra mussel colonies reported in areas of the Great Lakes. There are indications that native unionid clam populations in Lake St. Clair are disappearing rapidly as zebra mussel colonization increases. Numerous live and dead unionids have been observed covered with extensive growths of zebra mussels. Many unionids appear to die as zebra mussel colonies interfere with host shell movements or cause shell damage (O'Neill and MacNeill, 1991).

ZEBRA MUSSEL IMPACTS ON WATER TREATMENT FACILITIES

A major impact of zebra mussel infestations is the fouling of raw water intakes such as those at drinking water, electric generation and industrial facilities (O'Neill and MacNeill, 1991). Water intake structures serve as excellent habitats for zebra mussel colonization. The continuous flow of water into intakes carries a continuous source of food and oxygen, carries away wastes, and the structures themselves protect the mussels from predation and ice scour (MRB Group, 1991).

The presence of zebra mussels in a raw water main is usually first detected by the discharge of shells into the facility's raw water well or forebay (O'Neill and MacNeill, 1991). Once in a drinking water facility, the main impacts associated with zebra mussel colonization are: loss of intake head; obstruction of valves; decay of highly proteinaceous mussel flesh; obnoxious and dangerous methane gas production; imparting a foul taste and odor to the water; and electro-corrosion of steel and cast iron pipelines (Giacomo et al., 1991 and MRB Group, 1991).

A similar fouling problem can occur in power plants and industrial water systems which use infested water as their raw water supply. Condenser and heat exchanger tubing can become clogged, leading to loss of heat exchange efficiency and overheating. Service water (e.g., fire protection, bearing lubrication/ transformer cooling, etc.) lines can also become clogged resulting in potential damage to vital plant components and possible safety hazards if sprinkler systems fail to operate correctly (O'Neill and MacNeill, 1991).

IMPACTS ON NAVIGATION AND RECREATIONAL BOATING

Zebra mussels can adversely affect commercial navigation and recreational boating. Zebra mussels, by attaching to hulls, increase the amount of drag, reduce a boat's speed, and increase fuel consumption. Growth of larval mussels drawn into a boat's engine cooling water intake may affect the cooling system and lead to overheating and possible engine damage.

Commercial and recreational navigation can also be affected if marker buoys sink due to the weight of mussel colonizations. There is also concern that navigation canals can also be negatively impacted by mussel colonization in lock systems.

The zebra mussel can also negatively affect docks and piers. Large colonies can encrust pilings and ladders, making them difficult to tie up to and speeding corrosion as a result of mussel waste excretions. Mussels can attach to floating dock systems, adding 20 to 30 pounds/m^2. Dock systems that are left in the water year-round could be destabilized or sunk due to mussel colonization (O'Neill and MacNeill, 1991).

IMPACTS ON RECREATION

Recreational use of beaches in infested areas may be impacted by mussel colonization of cobble in shallow near-shore areas and by the littering of beaches by washed-up shells. Bathers on some Great Lakes beaches are currently using beach/bathing footgear to prevent cuts from zebra mussel shells. The foul odors resulting from the decomposition of mussels can also have an adverse effect on the enjoyment of shoreline recreational activities (O'Neill and MacNeill, 1991).

BIOLOGICAL CONTROL OF ZEBRA MUSSELS

Although larval and adult zebra mussels, which offer a high nutritional value to predators, are regularly consumed by several species of fish in Europe, the overall impact upon mussel populations is believed to be insignificant in most cases. Veliger and post-veliger larvae are also preyed upon by fish, but this loss is estimated at only about 5%. In some European lakes, crayfish predation on mussels one to five mm long is considerable with adult crayfish consuming over 100 mussels/day. However, crayfish are believed to be ineffective predators in deeper lakes due to cooler water temperatures. Some studies have indicated that over 90% of the diets of the roach, a Eurasian fish species, is composed of zebra mussels. *Dreissena* populations have been noted to decrease in Europe because of predation by overwintering diving ducks (*Aythya ferina* and *A. fuligula*) and coots (*Fulica atra*). Mean consumption by waterfowl every winter is 97%. Regular counts of larvae show fluctuations without a special trend on a low level, elucidating a predator controlled equilibrium. (WA/2, 1991). In the Great Lakes, the role of certain fish species such as carp, eels, and sheepshead may become increasingly important as a biological control agent (O'Neill and MacNeill, 1991).

Molloy and Griffin (1991) initiated a research project in April, 1991, which focuses on the development of a biological method for controlling zebra mussels. Over 260 different microorganisms are being tested in the laboratory over a two year period to identify those which are lethal to attached zebra mussel life stages. These control microorganisms will not be natural parasites of zebra mussels, but rather naturally occurring soil and water microbes, which just happen to be lethal to zebra mussels when the mussels are exposed to artificially high densities of the microbe. A microorganism which at artificially high densities is poisonous to zebra mussels undoubtedly exists in nature, and the proposed research is designed to identify it.

The value of zebra mussels as a human food source is doubtful because of their small size; a strong byssal attachment which would make them difficult to harvest; a possible tendency to serve as parasitic vectors to humans; and due to the mussel's filter feeding, they may cause bioaccumulation of toxic substances, making the mussels unfit for human consumption (O'Neill and MacNeill, 1991).

PHYSICAL CONTROL OF ZEBRA MUSSELS

Experience in Europe and the Soviet Union demonstrates that it is best to eliminate the zebra mussel in water pipelines at the veliger stage or before the most rapidly growing post-veliger specimens are able to pass uninhibited into the intake pipeline (MRB Group, 1991).

The first, and most evident, method for controlling zebra mussel infestation of raw water use facilities is to prevent entry of the mussel into such water systems (exclusion). This can be accomplished by the use of strainers and filters to prevent the entry of larval, juvenile, and adult mussels. The effectiveness of exclusion depends upon the mesh size and traveling and stationary screens and the size of the mussel.

Another method to control zebra mussel colonization is to maintain intake and distribution systems at flow velocities above which zebra mussels cannot attach. Anything that causes either a significant drop in flow or an eddying effect which would allow for increased mussel settlement and subsequent colonization should be avoided.

Physical scraping of mussels from water systems is also a viable method for control. Scraping is most effective in large conduits where mussels are found in high concentrations, where access for personnel and equipment is available, and where the conduit can be taken out of service for long enough periods of time that divers can remove the accumulated mussels. This method, however, is very expensive in terms of labor and lost production (O'Neill and MacNeill, 1991).

At the Second International Zebra Mussel Research Conference of November 19-22, 1991, in Rochester, New York, the following physical control methods were discussed. (For additional information pertaining to these topics, review the papers as cited in the reference section of this report.)

1. Design of Pipe-Crawling Vehicles for Zebra Mussel Control (Martin *et al.*, 1991)

2. Application of Centrifugal Separators for Control of Zebra Mussels in Raw Water Systems (Smythe et al., 1991)
3. Application of Low Voltage Electric Fields to Deter Attachment of Zebra Mussel to Structures (Smythe et al., 1991)
4. Effect of Ultraviolet-B Radiation (280-320 nm) on Survivorship of Zebra Mussel Larvae (*Dreissena polymorpha*): A Potential Control Strategy (Chalker-Scott et al., 1991)
5. Zebra Mussel Control Using Acoustic Energy (Menezes, 1991)
6. Control of Zebra Mussel Fouling by Coatings (Smithee and Kovalak, 1991)

Organometallic antibiofouling coatings such as tributyltin oxide (TBTO) may be effective in preventing zebra mussel attachment to pipes, boat hulls, and buoys, but are relatively expensive, difficult to apply, must be reapplied frequently and may result in negative environmental impacts on nontarget species as the coatings peel off or disintegrate into the surrounding waters and accumulate in sediments. Other coatings, such as copper paints or epoxies, zinc galvanizing, or silicone-based coatings may also be useful in minimizing zebra mussel attachment and growth without the environmental consequences caused by TBTO (O'Neill and MacNeill, 1991 and Smithee and Kovalak, 1991).

CHEMICAL CONTROL OF ZEBRA MUSSELS

Chemical control strategies generally fall into two categories: compounds which oxidize the mussels' organic material rather than acting in a toxic manner (e.g., chlorine, chlorine dioxide, ozone, potassium permanganate, hydrogen peroxide, chloramine) and chemicals which have a toxic effect on the mussels (e.g., molluscicides, copper sulfate, some metallic ions)

Chemical control strategies may be applied once per year at the end of the mussel spawning season; periodically throughout the spawning season; frequent intermittent treatment with relatively high concentrations of chemicals; and continuously with lower concentrations of chemical throughout the spawning season to prevent all settlement and colonization within the system. Molluscicides involve seasonal or periodic treatment of nonpotable water systems in which some colonization can be tolerated. Oxidizing chemicals may be used for short-term seasonal or periodic usage in systems with an immediate discharge to the environment. In potable water systems where little or no colonization can be tolerated because of potential human health impacts, oxidizing chemicals may be suitable for intermittent or continuous treatment.

Experiments in the Soviet Union have indicated that electrolytically dissolved metal ions in water may be used in low discharge pipelines and in underground and other inaccessible conduits to eliminate zebra mussels. When using metallic ions, larger mussels can be expected to exhibit a greater negative response due to incomplete hermetic sealing of their shells.

Chlorine is also a proven method for controlling zebra mussel populations. Concentrations in the range of 0.25 mg/L to 1.0 mg/L total residue chlorine (TRC) for two to three weeks has been found to be effective in killing 95%-100% of zebra mussels. There is a concern for negative effects of chlorine on nontarget species in discharge receiving waters. Therefore, dechlorination at the point of discharge is usually required (O'Neill and MacNeill, 1991).

Chlorine treatment of public drinking water supplies at the intake also needs to be carefully evaluated in terms of trihalomethane generation. Federal and State drinking water standards for surface water supplies call for filtration prior to disinfection with chlorine, in part, to eliminate trihalomethanes (carcinogens) which are produced when chlorine reacts with organic matter in water.

At the Second International Zebra Mussel Research Conference of November 19-22, 1991, in Rochester, New York, the following chemical control methods were discussed. (As before, for additional information pertaining to these topics, review the papers as cited in the reference section of this report.)

1. Testing of Candidate Molluscicides on the Zebra Mussel (Fisher and Dadrowska, 1991)
2. Effects of Potassium, Chloramine, and Chlorine Dioxide on Control of Adult Zebra Mussels (Matisoff *et al.*, 1991)
3. The Toxicity of Potassium Chloride to Zebra Mussel Veligers and Select Nontarget Organisms (Fisher *et al.*, 1991)
4. The Use of Endod, *Phytolacca dodecandra* (Lee and Lemma, 1991)
5. Effect of Lithium/Hydrazine Water Chemistry of Short-Term Survival of Zebra Mussel (Evans and Coughlin, 1991)

OXYGEN DEPRIVATION CONTROL OF ZEBRA MUSSELS

Since zebra mussels breathe oxygen as they draw over their gills, oxygen deprivation, accomplished by sealing water intakes and isolated internal distribution lines, can be used as a control method. Because the mussels utilize oxygen most efficiently at 20°C (68°F), oxygen deprivation tends to work best in summer. Two or three days exposure to anaerobic water at 23° to 24°C (73.5° to 75°F) will result in 100% mortality (O'Neill and MacNeill, 1991).

THERMAL CONTROL OF ZEBRA MUSSELS

Experience in Europe and the Soviet Union indicates that one of the most efficient environmentally sound and cost effective methods of controlling zebra mussel colonization is the systematic, periodic flushing of water systems with heated water. Water temperatures must exceed 37°C (98.6°F) for approximately one hour to ensure 100% mortality for mussels acclimated to 10°C (50°F) water temperatures (O'Neill and MacNeill, 1991).

PERSONAL CONTROL OF THE ZEBRA MUSSEL

According to the New York State Senate Task Force on Zebra Mussels and New York Sea Grant (1990), we can all help to slow the spread of the zebra mussel and to prevent our own equipment from being fouled by taking the following steps:

1. Drain all bilge water, live well, and bait buckets before leaving an infested waterway. Leftover bait should not be transported from infested to uninfested waterways.
2. Thoroughly inspect the boat's hull, trailer, etc. Scrape off any zebra mussels present.

3. Thoroughly flush hulls, outdrive units, live wells, bilges, trailer frames, anchors, ropes, bait buckets, raw water engine cooling systems, and other boat parts and accessories using hot (140°F or hotter) water, <u>OR</u> use a 10% solution of household chlorine bleach and water or a hot saltwater solution and follow with a clean water flush to remove any chlorine or salt residues. These solutions should not be used where they will run off into surface waters or storm sewers because they can be harmful to the environment.
4. Boats and trailers should be allowed to dry thoroughly in the sun before being transported to uninfested waterways.

REFERENCES

Anonymous. 1991. Researchers Discuss Zebra Mussel Threat, p. 5. In Oneonta, New York, Daily Star Newspaper, Wed. Nov. 20, 1991.

Burky, A. J. 1983. Physiological Ecology of Freshwater Bivalves, p. 281-308. In K. M. Wilbur and W. D. Russel-Hunter (ed.), The Mollusca, Vol. 6: Ecology. Academic Press, Inc. 694 p.

Chalker-Scott, L., J. D. Scott, C. Dunning, and K. Smith. 1991. Effect of Ultraviolet-B Radiation (280-320 nm) on Survivorship of Zebra Mussel Larvae (Dreissena polymorpha): A Potential Control Strategy, p. 35. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N.Y.

Ellis, A. E. 1978. British Freshwater Bivalve Mollusca: Keys and Notes for the Identification of Species. Academic Press. 109 p.

Evans, D. W. and L. M. Coughlin. 1991. Effect of Lithium/Hydrazine Water Chemistry on Short-Term Survival of Zebra Mussel, p. 46. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Feinberg, H. S. (ed.) 1979. Simon and Schuster's Guide to Shells. Simon and Schuster. 512 p.

Fisher, S. W. and H. Dabrowska. 1991. Testing of Candidate Molluscicides on the Zebra Mussel, p. 37. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N.Y.

Fisher, S. W., K. R. Polizotto, and B. Schneider. 1991. The Toxicity of Potassium Chloride to Zebra Mussel Veligers and Select Nontarget Organisms, p. 38. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Fitzsimons, J. P., J. Leach, S. Nepzy, and V. W. Cairns. 1991. Zebra Mussels and Their Effects on Fish Spawning in Lake Erie, p. 19. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Giacomo, S., R. Cavalcoli, and M. Cavalcoli. 1991. Case Studies for the Engineering of Mussel Control Facilities in Raw Water Intake Systems, p. 24. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Lee, H. H. and A. Lemma. 1991. Towards the Mitigation of Zebra Mussels and Asiatic Clams: The Use of Endod, Phytolacca dodecandra, p. 24. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

MacIsaac, H. J. and W. G. Sprules. 1991. Filtering Impacts of Larval and Adult Zebra Mussels in Western Lake Erie, p. 18. In

Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N.Y.

McMahon, Robert F., Barry S. Payne and Thomas Ussery. 1991. Effects of Temperature and Relative Humidity on Desiccation Resistance in Zebra Mussels (Dreissena Polymorpha): Is Aerial Exposure a Viable Control Option? In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Martin, B. and S. E. Landsberger. 1991. Design of Pipe-Crawling Vehicles for Zebra Mussel Control, p. 32. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Matisoff, G., A. Greenberg, G. Gubaznich, and J. Ciaccia. 1991. Effects of Potassium, Chloramine, and Chlorine Dioxide on Control of Adult Zebra Mussels, p. 37. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Menezes, J. 1991. Zebra Mussel Control Using Acoustic Energy, p. 36. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Molloy, D. P. and B. Griffin. 1991. Biological Control of Zebra Mussels: Screening for the Lethal Microorganisms, p. 30. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Morton, B. 1969. Studies on the Biology of Dreissena polymorpha Pall.: I. General Anatomy ad Morphology. Proceedings of the Malacological Society of London 38 (4): 301-321.

MRB Group. 1991. The Impact of Zebra Mussel Infestations on Public Water Supplies: A Summary Report (Sept., 1991). MRB Group Engineering, Architecture and Surveying, P. C., Rochester, N. Y. 5 p.

O'Neill, C. R., Jr. and D. B. MacNeill. 1991. The Zebra Mussel (Dreissena polymorpha): An Unwelcome North American Invader. Sea Grant. Cornell Cooperative Extension, State University of New York. Coastal Resources Fact Sheet, Nov. 1991.

Otter, T. 1991. Biology of Zebra Mussel Sperm,. p. 5. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Roberts, L. 1990. Zebra Mussel Invasion Threatens U. S. Waters. Science Vol. 249 (Sept., 1990): 1370-1372.

Smithee, R. D. and W. P. Kovalak. 1991. Control of Zebra Mussels Fouling by Coatings, p. 36. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Smythe, A. G., C. L. Lange, J. F. Doyle, and P. M. Sawyko. 1991. Application of Low Voltage Electric Fields to Deter Attachment of Zebra Mussel to Structures, p. 34. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Smythe, A. G., C. L. Lange, T. M. Short, and R. Tuttle. 1991. Application of Centrifugal Separators for Control of Zebra Mussels in Raw Water Systems, p. 33. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.

Thorp, J. H. and A. P. Covich. 1991. Ecology and Classification of North American Freshwater Invertebrates. Academic Press, Inc. 911 p.

Walz, N. 1991. New Invasions, Increase, and Ecological Equilibrium of Dreissena Polymorpha Populations in Central and Southern Europe Lakes and Rivers. In Second International Zebra Mussel Research Conference, Nov. 19-22, 1991, Rochester, N. Y.