INTRODUCTION

Zebra mussels *(Dreissena polymorpha)* are exotic, freshwater bivalves that were inadvertently delivered to U.S. waters around 1986 through the discharge of European shipping ballast water. They reproduced and colonized the Great Lakes for two years before they were sighted in July 1988 in Lake St. Clair near Detroit, Mich. The 1-to 2-inch-long striped mollusks originated in the drainages of the Black, Caspian and Aral seas. Since their arrival, they have spread rapidly throughout the Great Lakes and into several river systems of the eastern United States, including the Ohio, Illinois, Mississippi, Mohawk, Hudson, Susquehanna, Tennessee and Arkansas rivers.

Zebra mussel colonization of water-intake pipes, boats, docks, piers and other structures in the Great Lakes region has already cost millions of dollars. Some speculate that it's only a matter of time until they spread throughout most of the United States. If they colonize the mid-Atlantic, they could interfere with municipal and industrial water users, sport and recreational fisheries, food webs, navigation, recreational boating and beach use.

THE MID-ATIANTIC REGION

The Mid-Atlantic Sea Grant region includes New York, New Jersey, Delaware, Maryland, Virginia and North Carolina. To date, zebra mussels have not forged into any of these states except New York, which has been combating the mollusks since 1988. This fact sheet does not address the status of zebra mussels in New York. Rather, it looks at the prospect of the mussel moving into other states in this region and how the area might offer a different and more variable environment than the Great Lakes.

The eastern portion of the mid-Atlantic is comprised of expansive estuaries. The Chesapeake Bay, Delaware Bay and Albemarle/Pamlico estuarine system represent more than half of the East Coast estuarine waters. This large system is dynamic, often experiencing rapid fluctuations in temperature and salinity. Freshwater resources are also plentiful. The region is composed mostly of Atlantic-bound drainages and a few watersheds in the western portions of Maryland, Virginia and North Carolina that feed the Mississippi River network. There are very few natural lakes within the region, but thousands of man-made impoundments lie within these drainages, including farm ponds, aquaculture facilities, drinking water supplies, detention facilities for water quality or flood control, and recreational or multipurpose lakes.

CONCERNS

Zebra mussels can securely attach to nearly any surface by secreting durable elastic strands called byssal fibers. They colonize to form barnaclelike encrustations. And because of their affinity for water currents, zebra mussels can colonize water pipelines and canals, often severely reducing the water flow and, upon death, imparting a foul taste to drinking water. The intake pipes at drinking water, power generation and industrial facilities serve as excellent habitat for the mussels. The water flow provides a continuous source of food and oxygen and carries away wastes, while the structures themselves protect the colonies from predation.

Once in a drinking water treatment facility, zebra mussels can colonize any surface within the distribution system up to the first oxidation or filtration stage, including intake mains, raw wells, screen house walls. traveling or stationary screens, strainers and settling tanks. Colonization can cause loss of intake head, valve obstructions, putrescence from the decay of protein-rich mussels, obnoxious methane gas and increased corrosion of steel and cast iron pipe.

A similar fouling problem can occur

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in power plant and industrial water systems. The mussels can clog condenser and heat exchanger tubing, leading to loss of heat exchange capacity and overheating. They can also block service water lines for fire protection or lubrication and/or cooling of bearings and transformers, potentially damaging vital plant components or creating safety hazards if sprinkler systems fail.

Recreational boating cart be another zebra mussel casualty. Attached to boat hulls, the mussels increase drag, thus reducing fuel efficiency and speed. Larval mussels drawn into a boat's engine-cooling water intake may grow and obstruct the system, leading to overheating and possible engine damage. Shells drawn into the engine could abrade cooling system parts, especially impellers.

Zebra mussels also attach to docks, marker buoys, ladders, pilings and ropes. Their waste excretions hasten the corrosion of these structures, and dense colonies can even sink buoys and floating docks. Colonization of lock systems may negatively impact navigation canals.

Recreational beaches in infested areas may be littered with shells washed up by storm waves. Some Great Lakes beachgoers use footgear to prevent cuts. Dead mussels produce odors that also detract from the enjoyment of the shoreline.

Further, zebra mussels can biologically impact the environment. An adult zebra mussel filters on average 1 liter of water per day using siphons and a ciliated gill system, but rates of up to 2 liters per day have been observed. They feed on small phytoplankton and zooplankton (microscopic plants and animals) in lakes and detritus (decaying leaf matter) in rivers. They can also filter and consume their own larval stage. called veligers. Particles of an unsuitable size or chemical composition are not ingested: rather, they are consolidated and discharged as pseudofeces. European studies indicate that zebra mussel filtration can dramatically increase lake water clarity. Since the mussels were introduced into the western and central basin of Lake Erie, water clarity has increased dramatically and the chlorophyll a content (photosynthetic pigment found in algae) has decreased. But the extent to which changes in the lake's clarity and productivity can be attributed to zebra mussel activity is still unknown.

Although filtration may improve water clarity, the phytoplankton and detritus removed by zebra mussels are important links in lake and riverine food webs. Therefore, filtration could negatively impact fisheries. In lakes, excessive removal of phytoplankton could cause a decline in zooplankton species that eat phytoplankton. Zebra mussels also eat small zooplankton, possibly reducing their numbers and the survival of larger zooplankton and larval fish that feed on them. This in turn could affect higher trophic species within the food chain. Similar to lakes, excessive removal of detritus from rivers may cause a decline in aquatic insects and other detrital consumers, which are an important food source for many fish. Growing mussel populations could alter vital links in the food web. In addition, clearer water could make zooplankton more visible to fish predators and reduce the ability of larval fish to avoid predation.

Native mussel populations may be endangered by the sheer numbers of zebra mussel colonies competing for food and space. In Lake St. Clair, zebra mussel colonization has coincided with the rapid disappearance of the native unionid clam population. Numerous live and dead unionids have been found covered with mussel growths. Many unionids appear to die as zebra mussel colonies interfere with host shell movements or damage the shell edges.

REPRODUCTION

The zebra mussel has a reproductive strategy unique to freshwater mussels, which is responsible for its rapid expansion in Europe and the Great Lakes.

Sexual maturity is typically reached at age 2 but may occur in the first year at a size of 3 to 5 millimeters (mm). Zebra mussels are separately sexed, but some hermaphroditism has been reported. Mature female mussels can produce 30,000 to 40,000 eggs per year, although some produce up to 1 million eggs annually. Based on these observations, they may have the highest fecundity among freshwater mollusks. Young, frirst-year mussels as small as 3 mm may produce as many as 6,000 eggs per year. Individuals are able to spawn several times a season, and spawning activity appears to occur year-round in warm, productive waters, such as those in Tennessee and Mississippi.

Although poorly understood, the reproductive cycle is apparently influenced by local environmental cues, such as water temperature, mussel population density, phytoplankton abundance and species composition. Spawning patterns can show considerable year-to-year variations. Studies from Lake Erie suggest that cool water temperatures, storms, elevated turbidity and increased population densities can delay spawning, possibly causing the mussels to spawn simultaneously. The presence of mussel gametes (sex products) in the water may also promote spawning.

BIOLOGY

Two to three days after water temperatures have reached 14-16 C, a fertilized zebra mussel egg becomes a planktonic larvae known as a veliger. Traveling veligers search for food for two to three weeks, often covering considerable distances. Within three weeks of hatching, they reach their "settling stage"' and attach to bottom debris or other solid surfaces in the water. But mortalities of settling larvae can be very high due to hypoxia, temperature shock or failure to locate a suitable attachment substrate.

During their first year of life, zebra mussels are able to crawl along substrates at speeds of 3.8 cm per hour in search of a more suitable location to attach. Juveniles can attach by secreting a few temporary byssal threads, which they can detach later to move elsewhere. Sessile mussels develop byssal fibers and remain stationary in most cases. However, larger mussels may be able to detach. During winter, the young mussels migrate to deeper, warmer waters to escape cold surface temperatures. Their life spans are highly variable, depending on environmental conditions, but they can live up to five years and sometimes longer.

PREDATION

Predation of Great Lakes zebra mussels by other animals has not significantly changed the size of their colonies. The freshwater drum and a few other species of fish, crayfish and diving ducks have been unable to significantly reduce their populations. In some European lakes, crayfish predation of the mollusks has been substantial. But zebra mussels attach to any firm surfaces in water, including crayfish, and they can severely limit the mobility of their host.

Typically, when *Dreissena* is introduced to a suitable area outside of its native range, a population will establish and grow rapidly, often by a factor of two or three. This explosive growth usually lasts several years, followed by a marked reduction in size and subsequent oscillations. In western and central Lake Erie, zebra mussel populations appear to have peaked and are starting to decrease as a result of crowding for food and space. As their numbers thin out, predation will likely have a greater impact.

ENVIRONMENTAL REQUIREMENTS

Zebra mussels are capable of withstanding a wide range of environmental parameters. Even though they are a freshwater mollusk. they have demonstrated an ability to acclimate to salinities of 10-12 parts per thousand (ppt) for short periods. Temperature has a bearing on this ability. If zebra mussels are removed from fresh water and gradually exposed to fairly low salinities of 2-3 ppt, their mortality will significantly increase once water temperatures exceed 10 C. Rapid temperature fluctuations, characteristic of estuarine environments, also inhibit their salinity tolerance. Physiological differences may further affect the mussels' ability to tolerate salinity.

Zebra mussels begin to grow at temperatures from 6-12 C and continue up to 33 C. The maximum temperature of extended exposure is unknown, but it likely exceeds 30 C. Spawning takes place in temperatures from 12-23 C, but laboratory tests have concluded that the optimal temperature for nurturing zebra mussel larvae is 17-18 C.

The mussels are intolerant to prolonged exposure to acidic waters. They prefer basic waters with a pH in the range of 8-10 and generally do not persist in waters with a mean pH below 7.9. All freshwater mussels need calcium to grow and build shells, but zebra mussels tend to require higher calcium concentrations than other freshwater bivalve species. Research has shown that zebra mussels are unable to maintain a balance between uptake from the water and metabolic loss of calcium if concentrations drop much below 12-14 milligrams per liter (mg/1).

The optimal range of dissolved oxygen concentrations for zebra mussels is 8-10 mg/1 As dissolved oxygen concentrations begin to drop, they consume less oxygen, However, they typically do not colonize waters with continual concentrations of 4 mg/1 and less, due to respiration difficulty.

The mussels are most often found within 2-7 meters of the water surface. However, they are able to colonize at depths of up to 50 meters. Since flowing waters provide a continuous source of food and oxygen and carry away their waste, velocities of 0.5-0.7 meters per second (m/s) are optimal for colonization. Velocities greater than 2 m/s inhibit their feeding and growth. They are also fairly intolerant of rapid fluctuations in water levels. The mussels generally withstand drying for only a few days, depending on atmospheric humidity. And they prefer very firm substrates, such as rock, wood, gravel, shells, concrete, metal or plastic for attachment. They can attach to most any surface, however, including sand, rope or even aquatic weeds and grasses.

DISPERSAL

Three natural and 20 human-related disposal mechanisms have been identified for zebra mussels. Natural mechanisms include currents, birds and other animals, such as beavers, muskrats, turtles, fish and crayfish. Of all animals, birds are believed to be the most significant transporter. They can move zebra mussel adults, larvae or eggs that attach to their plumage, legs or feet; relocate them internally after consumption and subsequent defecation or regurgitation; and directly transport them in their beaks.

But many human activities can disperse the mollusks more rapidly than natural mechanisms. And in some cases, humans have built canals and waterways that aided natural dispersal. Construction of shipping canals helped zebra mussels migrate from their place of origin in western Russia into European fresh waters in the late 1700s. The transport and discharge of ballast water is another dispersal method that was believed to be responsible for introducing zebra mussels and other non-native species into the Great Lakes from Europe.

Mussels can also be transported by attaching to boat trailers, vessel hulls, hull openings or recreational boat and motor components, such as outdrive units, trim plates, transducers. prop guards, propellers, shafts and anchors. Fisheries-related dispersal includes movement of fish cages, fish stocking water, fish bait, bait-bucket water and fishing gear, such as tackle, nets or traps. Other means of dispersal are recreational dive equipment and water discharged from aquariums, fire trucks, research projects and amphibious plane pontoons.

CONTROL MEASURES

Numerous methods for controlling the infestation of water-intake systems have been developed in Europe, Russia and the Great Lakes. For instance, filter systems or high water velocities (above 2 2.5 m/s) can deter the mussels from entering and attaching to water intakes; scraping can remove mussels already attached organometallic anti-biofouling coatings and electrical currents can discourage them from attaching to pipes; and reducing oxygen in the water, flushing water systems with hot water or treating intake water with copper sulfate, chlorine, ozone or other chemicals can kill adult and larval mussels. Scientists continue to develop new control methods.

The choice of a control method depends on many site-specific variables, including the type of water-intake facility: use of the intake water intake pipe size, length and accessibility; federal and state environmental regulations: and zebra mussel population densities.

WHAT'S DIFFERENT ABOUT THE MID-ATLANTIC?

COLONIZATION RISK

Assessing the risk of colonization appears to be site-specific. Two major factors should be considered: mechanisms by which zebra mussels can be introduced to an area and the mollusks' ability to survive the environmental conditions of that area. Determining their ability to survive requires a close examination of several environmental parameters. A number of mid-Atlantic environments are at risk of colonization, and each should be individually examined to gauge its risk. A few areas within the region have distinct environmental characteristics that qualify them as suitable or unsuitable for colonization. However, it is difficult to make basic generalizations about the risks involved for the entire region.

Similar to other systems. the estuaries of the mid-Atlantic typically undergo fairly rapid temperature and salinity fluctuations, especially after a rain. Zebra mussels can tolerate significant salinity concentrations for short periods of time. But they are unable to colonize, reproduce and proliferate in highly saline waters, especially estuarine environments. Therefore it is unlikely that dense inhibitory colonies of these mussels will establish in the mid-Atlantic estuaries. But the mussel is constantly evolving through the process of natural selection, and it may develop a greater tolerance for higher salinities. European and Russian studies indicate that other species of *Dreissena* have greater salinity tolerences.

Summertime surface-water temperatures usually exceed the preferred range for zebra mussels in the southern reaches of the mid-Atlantic, especially in the shallower, low-salinity fringes of the estuaries and lakes. And in many of these areas, the deeper,cooler waters that the mollusks are more likely to colonize often have dissolved oxygen concentrations below desired levels. Another important characteristic is the drastic reduction in suitable attachment substrates for zebra mussels as the Atlantic-bound rivers of the mid-Atlantic approach the estuaries. The region is well-known for the blue crab populations in its estuaries, and the male crabs that visit the low-salinity waters will likely enjoy feeding on zebra mussels.

The acidity of mid-Atlantic inland waters depends on the acidity of rainfall and bedrock composition, whereas the acidity or pH of estuarine waters is more dependent on salts, which act as buffers. Acidic waters, such as the Pine Barrens of southern New Jersey or the Great Dismal Swamp of southern Virginia and North Carolina. would not serve as suitable mid-Atlantic environments for zebra mussels.

A large number of lakes are classified as eutrophic within the region, with the highest concentration occurring in the warmer southern portion. These algae-rich bodies of water would provide plenty of food for zebra mussels. Extremely eutrophic waters with very high nutrient loadings would not be suitable. Many lakes within the southern region have calcium concentrations too low to support healthy populations. But there are isolated limestone deposits scattered throughout the entire mid-Atlantic. Limestone (calcium carbonate) can dissolve, raising calcium concentrations in the water and creating a suitable climate for zebra mussels.

ROUTES OF ENTRY

Zebra mussels have several potential routes into the region's waters. They are rapidly encroaching on the mid-Atlantic estuaries from the Susquehanna, a tributary of the Chesapeake Bay. And even though the mussels are not likely to establish in these estuaries, they can survive salinities of up to 12 ppt for several days, enabling them to attach to barges or other slow-moving vessels and travel through the estuarine fringes into the mouths of uninfested freshwater rivers. Once there, barge and boat traffic will provide them with an easy means of dispersing to other tributaries within the associated watersheds.

The Susquehanna is not the only route of entry into the Chesapeake Bay. The zebra mussels could also be introduced by the discharge of infested shipping ballast water. The Chesapeake Bay is linked to the Delaware Bay by the Chesapeake and Delaware (C&D) Canal; it's also linked to North Carolina's Albemarle/Parnlico estuarine system by several man-made canals, including the Intracoastal Waterway, These connections make all drainages feeding the mid-Atlantic estuaries vulnerable to a Chesapeake Bay introduction.

The Delaware River, which lies just west of the already infested Hudson River, will provide easy access into New Jersey and the Delaware Bay if it becomes colonized. The Potomac River drainage lies just southwest of the Susquehanna drainage and extends into southern Pennsylvania. if zebra mussels are transported into the Potomac River system, they will move easily into nonhwestern Maryland. south into northern Virginia and

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on to the Chesapeake Bay. They are also in the Ohio River system. The New River forms in northwestern North Carolina, travels through western Virginia and finally drains into the Ohio River at the border between West Virginia and Ohio. Deep Creek Lake at the far western tip of Maryland feeds the Youghiogheny River, which is also a tributary of the Ohio River. Therefore, movement of zebra mussels upstream through the Ohio River network exposes western Virginia as well as small portions of North Carolina and Maryland. Currently in the Tennessee River, upstream movement of zebra mussels threatens the far-western drainages of North Carolina.

KEY DISPERSAL Mechanisms

Many of the mid-Atlantic region's larger lakes serve recreational uses for residents and visitors from other parts of the country. Of most concern are people who bring their boats from states where zebra mussel invasion has already occurred. such as Michigan, Illinois, Ohio, Pennsylvania and Tennessee.

Water is regularly transpoteded to mid-Atlantic drainages from river networks, including the Mississippi and Tennessee, through the sale of fish for bait and for stocking aquiculture operations. Preliminary investigation has shown that fish producers generally use well water to fill their live-haul trucks for transport. and many fish ponds are filled with well water or are located in very small upstream tributaries that are fed by watershed runoff rather than streams or rivers. However, this is not true in all cases. and the potential for zebra mussel adults. larvae or eggs attaching to the fish must also be considered.

POTENTIAL IMPACTS

Numerous drinking water plants, industries. pulp and paper mills, power generation facilities, processing plants, golf courses and agricultural operations draw water from rivers, streams and reservoirs in the mid-Atlantic region. Many of these users have already incurred zebra mussel expenditures by monitoring for their arrival and developing plans of action for a potential colonization. The possible costs of an invasion to these water users is even more significant.

Shoreline property owners within the mid-Atlantic region would likely be impacted by zebra mussels that colonize docks, piers, pilings and other shoreline structures. Boat owners would be burdened by preventing and repairing damage to motor intake lines that are clogged and hulls and other exposed surfaces that are fouled. The Intracoastal Waterway provides a vital commerce link for the East Coast. Barge traffic carries seafood, gravel, fertilizers, fuel and other products through numerous ports along the waterway and connecting river systems. There are also many recreational uses of the waterway, including pleasure boating, sailing and yachting. Navigation through the region could be inhibited by zebra mussels colonizing locks, bridges and other structures.

The mid-Atlantic supports several important commercial and recreational fisheries. Each year. recreational anglers spend millions of dollars on fishing licenses, bait, tackle and guided tours. The region could suffer economically if a zebra mussel infestation caused severe reductions in fisheries. Even though they have not yet reached the mid-Atlantic, some local economies have already suffered where lakes were temporarily closed to boaters for fear of an invasion.

Close to 300 species and subspecies of freshwater mussels are found in the United States, but the Southeast has the greatest diversity. Human activities have already placed considerable stress on these mussels. A few species are considered extinct and many others are listed as endangered or threatened. According to the U.S. Fish and Wildlife Service, if the zebra mussel establishes itself in reservoirs and larger rivers throughout the eastern United States, at least 20 additional freshwater species could become extinct. Their extinction would probably be a direct result of competition for food and space, coupled with existing stresses. If mid-sized and smaller rivers are also colonized by zebra mussels, the death toll is expected to rise even higher.

MONITORING

Unlike the Great Lakes region, the mid-Atlantic has the opportunity to prepare for zebra mussels. As part of the plan for preparedness, these states are keeping abreast of the mussel's migration, establishing a plan of action to minimize the economic and environmental impacts upon arrival and monitoring to detect its presence. The U.S. Fish and Wildlife Service maintains art inventory of all zebra mussel monitoring within the United States. Federal and state agencies use this information to track the mussel's distribution and to provide an early warning to resource managers, scientists and at-risk water users. The spread should be tracked by monitoring at the edge of the zebra mussel range. Planktonic veligers are likely the first life stage to colonize a new area, although adults may be transported by boat or barge. For early detection, sampling should cover all of its life stages, from veligers to settled adults. Veligers are detected by planktonic sampling, settling juveniles are picked up by smooth settlement plates and settled adults are detected by regular inspections of hard surfaces. Most first sitings of zebra mussels have been reported by informed citizens. Therefore, public education is an effective method of early detection.

Once a population has arrived, continuous monitoring data cart reveal how it is developing and expanding. Sampling should occur at intervals that span the entire spawning season. Any

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method of collection is suitable, although a standard protocol is best for comparing data from different locations. Measurements of population density can be used to investigate local environmental factors that may influence the mussel's success and to track its movement. Continuous monitoring data can help a facility assess the need, timing and efficacy of control measures.

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