NEW JERSEY SEA GRANT
EDUCATION AND OUTREACH PROGRAM

ZEBRA MUSSEL CURRICULUM SUPPLEMENT

NJSG-95-037

J. Tiedemann, K. Lynch,
C. Antonucci, et. al.
Title: New Jersey Sea Grant Education and Outreach Program Zebra Mussel Curriculum Supplement

Author(s): J. Tiedemann, K. Lynch, C. Antonucci, et al.

Author(s) Department and University: NJ Sea Grant Education and Outreach
Date of Publication: 1995
Publication Number: NJSG-95-307

Abstract

The New Jersey Zebra Mussel Curriculum Supplement, developed by the NJ Sea Grant Education and Outreach Program, is intended for use with the previously published Virginia Sea Grant Marine Advisory Program's Invasion of Exotic Species: Stop the Zebra Mussel curriculum package. It is designed to provide New Jersey students with the opportunity to identify the susceptibility of New Jersey waterbodies to the introduction and invasion of zebra mussels using actual water quality data collected throughout the state. Additional literature on zebra mussel life history, physiology, and spread through waterbodies in North America has been included in order to provide background information for teachers and students.

Not intended for wide distribution. Quantities are extremely limited. For additional information contact: Kerri Lynch at 908-872-1300
Showing Our Mussel

The Great Lakes Sea Grant Network Report on Zebra Mussel Research and Outreach

Sea Grant Zebra Mussel Report Feb-95
An Update of Research and Outreach
is available for $5.00 from
Ohio Sea Grant 1314 Kinnear Rd
Columbus, OH 43212
Acknowledgments

Sea Grant draws on university expertise in research, education and technology transfer to promote wise use and management of marine and Great Lakes resources for the public benefit. Sea Grant reaches its audiences through direct interaction, mass media and other modes of communication such as fact sheets, journals, videos and newsletters.

The Ohio Sea Grant College Program is one of 29 programs in the National Oceanic and Atmospheric Administration's (NOAA) National Sea Grant College Program in the Department of Commerce. There is a Sea Grant program in every coastal state, except for Pennsylvania, and in Puerto Rico. For more information, contact the Sea Grant program nearest you or the National Sea Grant office.

Funding for this report is provided primarily through grants from National Sea Grant (grant number NA16RG0271-01 for project A/2M-1, and grant number NA90AA-D-SG496 for project M/P-2), with matching funds provided by the Ohio Board of Regents and The Ohio State University. The zebra mussel outreach project (A/2M-1) is a Great Lakes Sea Grant Network project, with Illinois-Indiana, Michigan, Minnesota, New York, Ohio and Wisconsin Sea Grant programs participating.

Jeffrey M. Reutter, Director
Leroy J. Hushak, Associate Director/Advisory Service Leader
Maran Brainard Hilgendorf, Communications Coordinator
Kelly Kershner, Writer
Sue Abbati, Graphic Designer

This report was prepared by the Ohio Sea Grant College Program for the Great Lakes Sea Grant Network and the National Sea Grant College Program.

Ohio Sea Grant College Program
The Ohio State University
1314 Kinnear Road
Columbus, OH 43212-1194
614/292-8949
Fax 614/292-4364

Additional copies of Showing Our Mussel: The Great Lakes Sea Grant Network Report on Zebra Mussel Research and Outreach are available from Ohio Sea Grant for $5.00.

ISBN 1-883756-01-4

© December 1993 by The Ohio State University.
Contents

2 Preface by Bernard Griswold, National Sea Grant
3 Foreword by Jeffrey M. Reutter, Ohio Sea Grant
5 Exotics & the Great Lakes
7 Zebra mussel distribution
9 What is Sea Grant?
10 Sea Grant Research
13 Research projects
13 Biology/Life History of Nonindigenous Species
16 Ecosystem Effects of Nonindigenous Species
28 Socio-Economic Analyses: Cost and Benefits of Nonindigenous Species
30 Control and Mitigation of Nonindigenous Species
34 Prevention of Introduction of Nonindigenous Species
35 Reducing the Spread of Established Nonindigenous Species
37 Newly funded research projects
37 Biology/Life History of Nonindigenous Species
38 Ecosystem Effects of Nonindigenous Species
39 Socio-Economic Analyses: Cost and Benefits of Nonindigenous Species
40 Control and Mitigation of Nonindigenous Species
41 Sea Grant outreach
43 Just the facts
45 Mussel busters
47 Musseling in on research
49 Dial-A-Mussel
51 Zebra mussels & the bottom line
52 May I see some I.D., please?
53 A picture is worth...
54 Zebra mussels 101
56 Getting the scoop
57 An exotic exhibit
59 On the lookout
61 Q & A
63 Mussels and the Mississippi
65 Researchers
68 Sea Grant offices
69 Publications

Summary
For a summary of this report, read the introductory stories on pages 2-9.
An overview of the research projects is provided on pages 10-12.
An overview of the outreach projects is provided on pages 41 and 42.
Since the mid-1980s, when the zebra mussel was first discovered in the Great Lakes basin, the National Sea Grant College Program has played a leading role in the federal response to the problem. Sea Grant outreach personnel were among the first to recognize the enormous potential for adverse ecological and economic impacts and helped generate a quick response. This took the form of interagency research planning and development of control legislation for nonindigenous aquatic nuisance species.

Through its long-standing partnership with academia and a competitive peer-reviewed research process, Sea Grant researchers have been able to address more basic areas of research, which the more mission-driven agencies are unable to do. Sea Grant’s nonindigenous species research covers wide-ranging topics, from manipulating zebra mussels’ reproductive physiology as a possible means of control, to modeling ballast exchange at sea for control of aquatic animals while maintaining ship stability and safety. This work complements the research of other agencies and the interagency research plan for nonindigenous aquatic nuisance species.

At the same time, Sea Grant outreach efforts are the basic avenues by which water users learn about ways to predict the arrival of zebra mussels and combat them once they’re established. This is increasingly important as zebra mussels continue to spread throughout the United States.

It is our intent that this report provide the reader with accomplishments to date and a synopsis of the program up through the funding of new research projects in the 1993 fiscal year.

Bernard Gaussoin, Ph.D.
Division Director
National Sea Grant College Program

Nonindigenous Species Control Act

AQUATIC NUISANCE PREVENTION AND CONTROL,
PUBLIC LAW 101-646—NOV. 29, 1990

To prevent and control infestations of the coastal inland waters of the United States by the zebra mussel and other nonindigenous aquatic nuisance species.
As regional leaders in education, environmental communications and technology transfer, we recognized our duty to devote all available resources to this critical problem. We also recognized our responsibility to focus the vast university-based research expertise at the region's academic institutions on the zebra mussel issue and to cooperate and collaborate with federal programs to develop a comprehensive, coordinated nonindigenous species research agenda.

The U.S. Great Lakes Nonindigenous Species Coordinating Committee was formed to foster cooperation and collaboration and to develop the coordinated research agenda. The U.S. Great Lakes Nonindigenous Species Coordinating Committee was formed to foster cooperation and collaboration and to develop the coordinated research agenda. In addition to the six Great Lakes Sea Grant programs, the committee included the Great Lakes Environmental Research Laboratory (GLERL) of NOAA, the National Fisheries Research Center of the U.S. Fish and Wildlife Service, the Cooperative Institute for Limnology and Ecosystems Research (CILER), the U.S. Environmental Protection Agency, the Great Lakes Commission, the Great Lakes Fishery Commission, the U.S. Coast Guard and the U.S. Army Corps of Engineers. Later, this committee expanded to become the Great Lakes Panel on Exotic Species of the Aquatic Nuisance Species Task Force.

This report briefly summarizes the zebra mussel research and outreach efforts of the National Sea Grant College Program. It includes brief descriptions of all research projects funded by National Sea Grant with the special zebra mussel appropriations and all research projects funded by the local Sea Grant programs in the Great Lakes. This information should be useful to elected officials, decision makers, scientists, businesses and industries, students and the general public.

Jeffrey M. Boudier, Ph.D.
Director
Ohio Sea Grant College Program

The Great Lakes Sea Grant Network
Wisconsin Sea Grant Institute
Ohio Sea Grant College Program
Minnesota Sea Grant College Program
Illinois-Indiana Sea Grant Program
Michigan Sea Grant College Program
New York Sea Grant Institute
Exotics & the Great Lakes

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. Since then, however, a host of others have followed, everything from plants to fish to mollusks. Today, scientists estimate that 136 foreign travelers make their home in the Great Lakes.

About half of these travelers are from Europe, according to scientists Joseph Leach, William Mills and James Carlton, who've completed a survey of Great Lakes exotics. These species made the trip to America by stowing away in the ballast water of ocean-going vessels. When the vessels dumped their ballast into the Great Lakes, the travelers had a new home. Evidence indicates that the Great Lakes' most famous recent invader, the zebra mussel, got its start that way.

Zebras mussels look like small clams and are about the size of a thumbnail. A small tuft of fibers — called byssal threads — protrude from the hinge on their bodies. These fibers allow the mussels to attach to any hard surface — including other mussel. Female mussels can reach maturity in less than a year. Once mature, they can produce more than one million eggs per year. The eggs hatch into free-swimming larvae — called veligers. Veligers can remain in the water column for more than a month before settling and attaching. During this time, they can be transported great distances by currents. Once they settle, they begin to filter the water — up to a liter per day — using plankton for food.

But perhaps the definitive zebra mussel characteristic is a seeming urge to roam. History tells us that zebra mussels have always been on the move. They're native to the Pontic-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 mussels have spread rapidly. Because of its shallow, warm, nutrient-enriched environment, Lake Erie is, was, and probably always will be the most significantly affected of the Great Lakes; however, to date, zebra mussels have spread to all of the Great Lakes and waterways in 18 states and the provinces of Ontario and Quebec. They've cost municipal and industrial water facilities millions of dollars in cleanup and control costs. They've disrupted Great Lakes recreation, causing thousands of dollars in damage to boats, docks, buoys and beaches.

Over the next decade, scientists estimate that the cost of the zebra mussel invasion for Great Lakes water users could go as high as $5 billion.

Zebra mussels have also affected the environment in other significant ways. So far, Sea Grant 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 damaging to other organisms. In parts of Lake Erie and Lake St. Clair, where zebra mussels and native clams were both present, the native clams are now almost gone.

In addition, data suggest that zebra mussel's 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.

To further complicate things, a second zebra mussel species, Dreissena bugensis, or "quagga" mussel, has been found in Lake Erie, Lake Ontario and the St. Lawrence River. This mussel can colonize much deeper habitats than Dreissena polymorpha — it's the only zebra mussel found below 110 meters. Also, it is lighter in color than the more famous black and brown striped zebra mussel. Another difference is substrate preference. Unlike "standard" zebra mussels, quaggas have been found on soft surfaces such as sand and mud.
The Great Lakes basin is home to 22 million Americans, 9 percent of the total U.S. population. The eight Great Lakes states are home to 30 million Americans.

- The Great Lakes basin covers 94,000 square miles and is larger than the states of New York, New Jersey, Connecticut, Massachusetts, Vermont and New Hampshire combined.

- The Great Lakes shoreline covers more than 11,000 miles — a distance equal to almost 45 percent of the Earth’s circumference.

- The Great Lakes contain 6 quadrillion gallons of fresh water. That’s about 20 percent of the world’s fresh surface water and 95 percent of the U.S. supply.

- Each day, 655 billion gallons of Great Lakes water are used for various purposes — 94 percent of this water produces 20 billion kilowatt-hours of electricity by passing through hydroelectric plants and returning to the Great Lakes ecosystem.

- About 25 million people get their drinking water from the Great Lakes and the St. Lawrence River.

- The 145 U.S. and Canadian ports and terminals on the Great Lakes and St. Lawrence Seaway move more than 200 million tons of commodities each year.

- In 1986, about 17 percent of U.S. manufacturing industries were located in the Great Lakes basin.

- In 1988, there were more than 3.5 million registered recreational boats in Great Lakes states — a third of all registered watercraft in the country.

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.

Much progress has been made, however. In the laboratory, researchers have been able to artificially induce zebra mussel spawning. If large mussel populations in the wild could be “tricked” into spawning at inappropriate times, this could be a promising control technique.

Also, research has shown that potassium, bromine, ozone and ultraviolet light are potential control strategies — and possible alternatives to chlorine. Currently, more than 30 compounds are also being studied to determine their environmental impact and effectiveness against zebra mussels. Chlorine is currently the most popular control strategy, but increased chlorination clearly contradicts the efforts of the Great Lakes community to reduce the amount of chlorine entering the ecosystem.

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 these 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.

In short, there must be a coordinated campaign against zebra mussels through research, education, communication and information transfer. Clearly, zebra mussels are a national problem and no longer just a Great Lakes issue. This problem demands an effective solution.

That’s where Sea Grant comes in. ▲

SOURCES:
The Great Lakes Economy: Looking North and South, prepared by the Federal Reserve Bank of Chicago and the Great Lakes Commission.
Zebra mussel distribution
compiled by New York Sea Grant with information from industries, agencies and Sea Grant programs throughout North America.

North American Range of the Zebra Mussel (*)
as of 18 January 1991

North American Range of the Zebra Mussel (*)
as of 15 October 1992
Zebra mussel distribution

North American Range of the Zebra Mussel (*)
as of 15 December 1993

1. Hog's Back Lock, Rideau River, Ottawa, ONT
2. Burnt's Rapid Locks, Rideau River, Ont
3. Lower Rideau Lake, ONT
4. Opinicon Lake, ONT
5. Big Rideau Lake, ONT
6. Owen Sound Harbour, ONT
7. Collingwood Harbour, ONT
8. Mississagi Strait, ONT
9. Burt Lake, Crooked Lake, Paradise Lake,
   Pickerel Lake, Walloon Lake, Michigan
10. Houghton Lake, Michigan
11. Cass Lake, Walled Lake, Michigan
12. Belleville Lake, Michigan
13. Lake Paw Paw, Michigan
What is Sea Grant?

Some have called it a commitment. Others call it a bridge, a bond, a partnership.

Congress called it Sea Grant. A national program created in 1966, Sea Grant is all of these things. It’s a commitment to solve coastal problems and develop marine resources. It’s a bridge between government and academia, scientist and private citizen. 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 today is what Congress intended — an agent for scientific discovery, technology transfer, economic growth and social understanding.

It’s happening all over. Every day. 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. National Sea Grant Director David Duane describes it this way: “Being a marine program, the boundaries between such traditional elements of Sea Grant as research, education and extension are indistinct. Moreover, each element has a key role in the holistic continuum which makes up this unique program."

The returns are great — far exceeding the investment. In 1987, Sea Grant had an $842 million impact on the national economy — a return triple that of 1981 and more than 20 times the federal investment of $39 million. Not included in this figure are the impacts of better scientific knowledge and better education — important but almost immeasurable.

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

Today, one of those challenges is the zebra mussel. 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 that the collective creativity within Sea Grant can generate.

This publication is testimony to part of that effort, expertise and creativity — an overview of the Great Lakes Sea Grant Network’s progress in combatting zebra mussels to date.
Ohio Sea Grant researcher

David Garton initiated the first of several zebra mussel research projects in late 1988, and outreach programs were underway in all six Great Lakes Sea Grant programs by late 1989. However, the magnitude of the problem demanded a more significant federal response.

The Northeast-Midwest Institute and the Great Lakes Task Force in Congress, led by Senator John Glenn of Ohio, immediately went into action and passed the Nonindigenous Species Control Act in late 1990. A concerned Congress, led by Congressman Carr of Michigan, Congressman Regula of Ohio and Senator Glenn, then appropriated $1.8 million to support Sea Grant's zebra mussel research and outreach programs. Fortunately, funds have been reappropriated every year since. These funds have been distributed competitively among the 29 Sea Grant programs through a national call for research proposals and an extensive peer review process. These federal funds have effectively leveraged significant amounts of state, local and private sector support.

Of the $1.8 million Congress appropriated for zebra mussel activities in the 1991 fiscal year, the National Sea Grant College Program designated nearly $1.3 million for research projects. Following a regional call for research proposals in early 1991, the National Sea Grant College Program received 58 proposals. The proposals were reviewed and ranked by a panel of experts, and 18 were funded.

During the 1992 fiscal year, a $2.9 million special congressional appropriation for zebra mussel projects was divided, with more than $1.8 million designated for research and almost $1 million designated for outreach. Following a national call for research proposals, the National Sea Grant College Program received 77 proposals and funded 13.

Of the $2.8 million appropriated during the 1993 fiscal year, more than $1.7 million was directed for research, allowing the National Sea Grant College Program to fund 12 projects from a total of 55 submitted.

In 1990, the U.S. Great Lakes Nonindigenous Species Coordinating Committee developed a framework for nonindigenous species research with six major areas:

1. Biology/Life History of Nonindigenous Species
2. Ecosystem Effects of Nonindigenous Species
3. Socio-Economic Analysis: Costs and Benefits of Nonindigenous Species
4. Control and Mitigation of Nonindigenous Species
5. Prevention of Introduction of Nonindigenous Species
6. Reducing the Spread of Established Nonindigenous Species
Both the U.S. and Canadian research communities use these major research areas to focus their efforts. The National Sea Grant College Program has endeavored to address all aspects of the zebra mussel problem and supports projects in all six areas.

**Biology/Life History of Nonindigenous Species**

Sea Grant has supported nine projects in this area from six state Sea Grant programs. Literature surveys of European research were conducted to avoid duplication; however, it quickly became apparent that the zebra mussel in the Great Lakes behaves differently than it does in Europe.

Sea Grant researchers found that genetic variability in the zebra mussel is much greater than expected, which has allowed it to adapt quickly to local temperature regimes. Unfortunately, this will facilitate the mussel’s spread, and thermal tolerance studies conducted in northern latitudes may not be directly transferable to southern states.

It was equally disturbing to learn that the veligers could remain suspended for more than 30 days, which is two to three times longer than reported in a number of European studies. This fact, coupled with observations of up to 1 million eggs in mature females, or more than 10 times the number often reported in European literature, and females that can reach maturity in less than 12 months, has made the spread of the mussel more rapid than anticipated.

The metabolic rate and oxygen needs of zebra mussels increase greatly above 30°C, resulting in smaller individuals and slower reproduction. This may be very useful information in our efforts to control and eliminate the mussel.

Genetic research has also demonstrated that the quagga is indeed a second species of zebra mussel.

**Ecosystem Effects of Nonindigenous Species**

In keeping with current resource management efforts to handle aquatic systems and address problems on an ecosystem basis rather than species by species, Sea Grant has invested significantly in efforts to understand the complete impact of the zebra mussel on aquatic ecosystems by supporting 29 projects at four state programs. Results have been astonishing.

Densities of zebra mussels in the western basin of Lake Erie frequently exceed 70,000/m². At water intakes, these densities approach 1,000,000/m². Veliger densities exceed 100,000/m³. Their filtering rate depends on their size and the amount of food available. They remove phytoplankton of the size preferred by Daphnia, and Daphnia have responded with reduced reproduction and survival. Planktonic diatom densities in western Lake Erie from the 1980s to the 1990s have been reduced 85 percent; copepods have also seen major decreases; and some rotifers have all but disappeared. Few algae survive gut passage, and only benthic (bottom dwelling) algae have any likelihood of surviving and escaping from pseudofeces (filtered particles rejected by the mussels as food). This has resulted in up to a four-fold increase in water clarity.

Bacteria are smaller, and bacterial production is reduced 60 to 70 percent in the presence of zebra mussels; but their numbers were not affected.

Zebra mussels use native clams as substrate for colonies, much to the detriment of the native clams that have nearly all been eliminated from western Lake Erie and Lake St. Clair. However, zebra mussel aggregations at the bottom provide great habitat for many benthic macroinvertebrates, with up to 53 taxa reported. These aggregations are dominated by amphipods, turbellaria, gastropods and oligochaetes. Benthic algae and rooted aquatic plants also increase in the presence of zebra mussels.

A significant number of large freshwater drum and yellow perch eat zebra mussels, but they have had no noticeable impact on zebra mussel densities. Because zebra mussels have a body fat content about ten times higher than native clams, they are able to accumulate contaminants at much higher levels. The change in the pattern of contaminant cycling through aquatic systems, caused by zebra mussels, is of great concern, particularly if sport fish are going to use zebra mussels as a significant portion of their food. This has the potential to lead to significant human health risks.

Hard-water, mesotrophic (moderately to highly productive) lakes with rocky substrates are likely to be ideal habitats for the zebra mussel as it spreads. In these situations, the dramatic environmental changes discussed in this section can be anticipated.
Socioeconomic Analyses: Costs and Benefits of Nonindigenous Species

Sea Grant has funded five projects in this area at two state Sea Grant programs. Utilities in both the United States and Canada are spending millions of dollars to clean zebra mussels out of machinery and to prevent further introductions. Private boaters and charter fishing businesses are also experiencing problems with zebra mussels fouling and clogging cooling systems. Fortunately, only two percent of recreational users indicate that they have reduced their use of the lakes because of the zebra mussel invasion.

Control and Mitigation of Nonindigenous Species

Sea Grant has addressed this important issue by supporting 13 research projects at six state Sea Grant programs. A number of chemicals designed to kill and/or prevent the attachment of zebra mussels have been evaluated and found to be safe and effective under a variety of environmental conditions. However, most remain quite expensive and/or require additional regulatory approvals before they can be used. As a result, chlorine remains the most commonly used chemical to kill zebra mussels.

Potassium has been found to be very effective in inhibiting the heart and respiratory activity of the mussels. Sea Grant researchers actually performed EKGs and MRI testing on zebra mussels to obtain this information. Potassium chloride has been found to be the most economical and environmentally compatible form.

Physical removal techniques are being investigated at several programs. A robot has been designed to physically clean the inside of pipes. Ultraviolet light is quite effective on young larvae but loses effectiveness as the mussels grow. Quagga mussels have been found to be more resistant to the ultraviolet light.

Biological controls are also being investigated. A strain of bacteria has been identified that can kill zebra mussels in less than five days.

Sometimes the best way to learn how to kill an organism is to learn how to grow it. As a result, several Sea Grant researchers have been developing techniques to raise zebra mussels in their laboratories. They have found chemicals that artificially induce zebra mussels to spawn. Through these, there may be potential to control zebra mussels by inducing them to spawn at inopportune times. Once the researchers were able to induce the mussels to spawn, they immediately began evaluating chemicals that would inhibit or interfere with spawning.

Researchers are also evaluating narcotizing agents such as carbon dioxide. It is hoped that by first relaxing the mussel with a narcotizing agent, it could be killed with a smaller dose of chlorine or some other chemical. This could reduce the cost and the adverse environmental impacts associated with chlorine.

Prevention of Introduction of Nonindigenous Species

While everyone wishes zebra mussels had never been introduced, the significance of their impact clearly demonstrates the importance of working to prevent further introductions. Consequently, Sea Grant has supported a project to evaluate the safety of ballast water exchanges at sea. This technique deposits freshwater organisms into a salt water environment where they cannot survive, and vice versa. Results indicate that such exchanges are entirely safe for the vessel if wave heights are 10 feet or less. Ballast exchanges when waves are 20-feet high should be avoided.

Reducing the Spread of Established Nonindigenous Species

Reducing the spread of zebra mussels is very important. Sea Grant has attempted to enlist the help of private boaters and anglers by demonstrating how their activities can facilitate the spread. Research demonstrated that veligers were frequently found in all types of water contained in boats, including engine cooling systems, bilges, live wells and bait buckets. Adult mussels were only observed on vegetation entangled on boat trailers; on some days, 30 percent of the boat trailers transported mussels this way.

The following pages briefly summarize 59 Sea Grant zebra mussel research projects in the six areas initiated between 1988 and 1992. This group includes several projects supported with funds from the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service and state Sea Grant program development funds. A list of 12 new research projects—initiated in September 1993 with a special congressional appropriation— begins on page 37. Some of the best university researchers are working with National Sea Grant on zebra mussel concerns. Addresses for the researchers begin on page 65.
Research projects

initiated in 1988-1992 by the National Sea Grant College Program and the Great Lakes Sea Grant Network Programs. Results provided as of May 1993.

Biology/Life History of Nonindigenous Species

Physiology of Zebra Mussels
David W. Garton, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ER-20-PD
Date: 4/1/90 to 12/31/90
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective
- To determine seasonal patterns of metabolism associated with critical life history events, e.g., spawning during the summer.

Results
- In 1990, zebra mussels’ metabolic rate peaked in early July—two weeks before veligers reached peak densities—indicating a link between spawning and metabolic rate.
- Zebra mussels’ oxygen demands increase dramatically above 30°C.

Biomineralization and the Requirement for Strontium During Larval Development of the Zebra Mussel (Dreissena polymorpha)
Scott M. Gallager, Judith E. McDowell and Alan Kuzirian, Woods Hole Oceanographic Institution, and Joseph P. Bidwell, University of Massachusetts
Program: Woods Hole Oceanographic Institution Sea Grant Program
Project Number: R/M-25
Date: 8/1/91 to 7/31/92
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To determine how much strontium and calcium zebra mussel larvae need to mineralize their first shells.
- To pinpoint the period in the life cycle when larvae need these minerals.
- To use electron microscopy to further describe how zebra mussels develop as embryos and larvae.
- To identify a “weak link” in the zebra mussel life cycle.

Genetics of Zebra Mussels: Critical Data for Ecological Studies and Development of Effective Long-Term Control Strategies
J. Ellen Marsden, Illinois Natural History Survey
Program: Illinois-Indiana Sea Grant Program
Project Number: ZM/1
Date: 8/1/91 to 7/31/93
Primary Source of Funds: Pass-through from EPA

Objectives
- To determine whether zebra mussels within the Great Lakes are a genetically uniform population or represent many different subpopulations.
- To examine whether different zebra mussel subpopulations are the result of separate introductions from Europe.
- To determine whether subpopulations respond differently to control techniques and environmental conditions.

In order to accurately predict an ecosystem’s response to an invading species, scientists need to understand the life history and population dynamics of the species. Basic biological research in the areas of life history, population dynamics, physiology and behavior, genetics, parasites and diseases—coupled with review of the existing research literature—may lead to the discovery of ecologically safe, effective and inexpensive control measures and may reveal the invader’s vulnerability to particular alternatives.

Further, research on the ecological and environmental tolerances of nonindigenous species answers important questions about the geographic limits of infestation and which native species and habitats are most likely to be affected by the invader.
Biology/Life History of Nonindigenous Species

Preliminary Results
- There is high genetic variability among Great Lakes zebra mussels.
- A second Dreissena species in the Great Lakes has been identified.
- There is a low level of genetic differentiation among Great Lakes zebra mussel populations.

The Byssal Adhesive of Zebra Mussels, *Dreissena polymorpha*
J. Herbert Waite, University of Delaware
Program: Delaware Sea Grant College Program
Project Number: R/B-26
Date: 9/1/91 to 8/31/94
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To purify the substance that is the precursor of zebra mussels' byssal adhesive.
- To determine the sequence and physical properties of this substance.
- To localize this substance immunochemically.

Preliminary Results
- Several families of DOPA-containing precursor proteins have been purified from zebra mussel byssal threads.
- DOPA content in zebra mussel proteins is lower and more variable than in other marine DOPA proteins.
- DOPA-containing precursor proteins in zebra mussels have no extended sequences in common with other marine mussel glues.

Influences of Temperature and Diet on Physiological Energetics of Growth and Reproduction of *Dreissena polymorpha*
David W. Garton, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ZM-10
Date: 2/1/92 to 1/31/94
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To determine how water temperature and food quantity and quality affect growth and reproduction in zebra mussels.
- To identify environmental factors that limit mussel distribution.
- To identify "weak links" in the zebra mussel life cycle — periods when resistance to environmental stress is low or when reproduction could be reduced.

Preliminary Results
- Zebra mussels are genetically diverse and can adapt to local temperature regimes.
- Thermal tolerances of "northern" mussels may not accurately predict thermal tolerances of "southern" mussels.
- Greatest shell growth occurs with low temperatures and abundant food.
- Body mass is greatest at low temperatures.
- Highest oxygen consumption occurs with high temperatures and abundant food.
- Participation in spawning decreases as temperature increases.
- High temperatures and abundant food retard reproductive effort.
- Temperature — rather than food — appears to be the driving force behind zebra mussel reproduction.
Biology/Life History of Nonindigenous Species

Genetic Variability and Environmental Tolerances of the “Quagga” Mussel: A New Dreisseniid Invader of the Great Lakes
Edward L. Mills, Cornell Biological Field Station, and Bernie May, Cornell University
Program: New York Sea Grant Institute
Project Number: R/CMB-5
Date: 8/1/92 to 5/31/93
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objectives
• To measure the quagga’s genetic variability and its natural hybridization with the zebra mussel.
• To determine the quagga’s tolerance to salinity and heat.

Preliminary Results
• No evidence of hybridization between zebra and quagga mussels has been observed.
• A mussel from the former Soviet Union — previously identified as a zebra — has been shown to be a quagga; this provides a place to start in searching for the quagga’s origins.

Species Identities and Relationships of North American and European Dreissena (Bivalvia: Dreissenidae)
Gary Rosenberg, Academy of Natural Sciences of Philadelphia
Program: New Jersey Marine Sciences Consortium Sea Grant Program
Project Number: R/E-30-ZM
Date: 9/1/92 to 8/31/94
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives
• To confirm that a second Dreissena species is present in North America.
• To evaluate genetic variability in European Dreissena and compare it with North American populations.
• To quantify how many existing Dreissena species occur in Europe.
• To determine whether it’s possible to identify Dreissena species by shell and anatomy alone (as opposed to genetic gel tests).

An Investigation of the Larval Development and Shell Morphology of the Zebra Mussel, Dreissena polymorpha (Pallas)
Gail M. Lima, Illinois Wesleyan University
Program: Illinois-Indiana Sea Grant Program
Project Number: ZM/3
Date: 9/1/92 to 9/1/94
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives
• To determine the maximum time zebra mussel veligers can remain planktonic.
• To determine whether veligers can delay metamorphosis and which environmental factors could influence this.
• To describe larval and post-larval zebra mussel shell morphology.
• To propose control techniques that interfere with larval settlement and metamorphosis.
Ecosystem Effects of Nonindigenous Species

Osmoregulatory Physiology of the Zebra Mussel
Robert L. Preston, Illinois State University
Program: Illinois-Indiana Sea Grant Program
Project Number: ZM/2
Date: 11/1/92 to 10/31/95
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation
Objectives
• To characterize how zebra mussels osmoregulate at the cellular level.
• To test the hypothesis that ion balance is regulated by membrane processes that are potentially sensitive to chemical agents.
• To test specific agents that disrupt osmoregulation in zebra mussels.

Ecosystem Effects of Nonindigenous Species

Interactions Between Newly-Introduced Zebra Mussel, Dreissena polymorpha, and Pelagic Communities
David W. Garton and David A. Culver, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ER-15
Date: 11/15/88 to 8/31/92
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources
Objectives
• To examine whether zebra mussels have diverted a significant amount of energy from the open-water food web to the lake bottom.
• To determine whether zooplankton growth slows as zebra mussel production increases.

Historical and Recent Changes in the Diet of the Alewife in Lake Ontario: Significance and Implications for Ecosystem Change
Edward L. Mills, Cornell Biological Field Station
Program: New York Sea Grant Institute
Project Number: R/FBF-4-PD
Date: 1/1/89 to 12/31/89
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources
Objectives
• To examine the seasonal diet of alewives in Lake Ontario.
• To compare information on dietary changes with data gathered before Bythotrephes cederstroemi colonized the lake.

Results
• In spring 1988, Bythotrephes cederstroemi (spiny water flea) was an important food source for alewives and was the only detectable change in alewife diet since 1972.
• Considerable numbers of Bythotrephes enter Lake Ontario from Lake Erie.
• Bythotrephes spines appear to cause no obvious stomach injury in alewives.
• Any changes in abundance of microzooplankton in Lake Ontario will affect both the alewife community and the salmonine population it supports.
Ecosystem Effects of Nonindigenous Species

The Effects of Zebra Mussels on Pelagic Communities
David A. Culver, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ER-17-PD
Date: 12/1/89 to 6/30/90
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective
• To determine the impact of zebra mussels on the phytoplankton in the western basin of Lake Erie.

Results
• Water clarity and algal abundance changed seasonally in both 1988 and 1989. Spring algal blooms were followed by a clear water phase in early July, followed by a resurgence of algae in August. *Daphnia* was most abundant in late June and declined in mid-July both years. Zebra mussels increased in abundance from 1988 to 1989.
• Grazing estimates suggested that *Daphnia* could explain the decline of phytoplankton during the clear water periods. The resurgence of phytoplankton after *Daphnia* declined both years suggests that zebra mussels were not responsible for the clear water periods, because zebra mussels were still present in August when the resurgence occurred.

Grazing Rates of Zebra Mussels
David A. Culver, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ER-21-PD
Date: 4/1/90 to 12/31/90
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objectives
• To evaluate the grazing rate of zebra mussels as a function of body size to enable estimates of grazing rates in the field from size frequency and density measurements.
• To examine the effects of vertical mixing rates of the western basin of Lake Erie have on the growth rate of zebra mussels suspended at various depths near and above the bottom.

Results
• Grazing rates varied significantly with body size and with added clay particles to simulate the effect of silt with low food quality. Analyses of an extension data set are continuing at this time.
• Zebra mussels in cages near the bottom grew only one-third as fast as those two meters above the bottom. This shows that either existing communities of zebra mussels on the bottom decrease the amounts of algae there relative to further up in the water column, or higher turbulence above the bottom increases the delivery rate of algae to zebra mussels, or both. Clearly, zebra mussels on the lake bottom do not have unlimited access to all algae in the water column.

Concentration of Hydrophobic Carcinogens by Zebra Mussels:
Effects on Aquatic Food Chains
Susan W. Fisher, The Ohio State University, and Paul C. Baumann, U.S. Fish and Wildlife Service National Contaminant Research Center
Program: Ohio Sea Grant College Program
Project Number: R/PS-6-PD
Date: 4/1/90 to 12/31/90
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective
• To make toxicokinetic and physiological measures to examine the movement and importance of contaminants passing through zebra mussels into the greater Great Lakes food web.
Results
- Accumulation rates drop by a factor of two for each 10°C change in temperature.
- Zebra mussels are likely to concentrate contaminants at a level 100 times greater than would be expected in fish.
- Bioconcentration of contaminants in zebra mussels depends on environmental temperature and the contaminant’s affinity for water.

Impact of *Dreissena polymorpha* on the Zooplankton of Western Lake Erie
Alfred M. Beeton, GLERL at NOAA, and John R. Hageman, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ER-25-PD
Date: Regular monitoring as of 4/1/90
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objectives
- To follow changes in zooplankton as the zebra mussel population grows.
- To determine the effects of mussel competition and predation on community structures.

Preliminary Results
- Major decrease in copepod abundance.
- Major population fluctuations for cladocera.
- Almost total disappearance of some rotifers.

The Fate of Phytoplankton Following Processing by the Zebra Mussel
Rex L. Lowe, Bowling Green State University
Program: Ohio Sea Grant College Program
Project Number: R/ER-22-PD
Date: 5/1/90 to 12/31/90
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objectives
- To determine which algal species become zebra mussel feces and pseudofeces.
- To determine the survival of algae following zebra mussel planktivory.
- To identify the implications of zebra mussel planktivory on the food web.

Results
- Few algae that pass through the zebra mussel gut survive.
- Lake-bottom algae are more likely than open-water algae to survive ingestion by zebra mussels, escape from zebra mussel pseudofeces and re-enter the plankton community.

Monitoring the Ecological Impact of Zebra Mussels in the Eastern Basin of Lake Erie
Howard P. Riessen, SUNY College at Buffalo
Program: New York Sea Grant Institute
Project Number: R/FO-1-PD
Date: 5/1/90 to 12/31/90
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective
- To monitor and follow the population dynamics of veligers when zebra mussels first invaded the eastern end of Lake Erie.
Ecosystem Effects of Nonindigenous Species

Results

- In 1989, veligers hit peak densities in September (300 to 3,000 per cubic meter) but were absent from the water column by November.
- In 1990, veligers were absent in May and June, hit peak densities in August (more than 100,000 per cubic meter) and declined rapidly during September.
- During the first year of zebra mussel colonization in this region, veliger densities increased by one to two orders of magnitude.

Trophic Interactions: The Relative Importance of Dreissena and Daphnia Grazing on Phytoplankton Abundance and Water Clarity

Joseph C. Makarewicz, SUNY College at Brockport
Program: New York Sea Grant Institute
Project Number: R/CMB-3-PD
Date: 6/1/90 to 12/31/90
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective

- To test the ability of the pelagic organism Daphnia and the benthic organism, the zebra mussel Dreissena polymorpha to affect water clarity as a result of grazing on phytoplankton.

Results

- Zebra mussels excrete soluble reactive phosphorus (SRP) as they graze on phytoplankton but at much lower levels than when they graze on zooplankton.
- Low rate of phosphorus excretion by zebra mussels suggests that they could be inhibiting phytoplankton growth, thus resulting in greater water clarity.

Epilithic Benthos in the Western Basin of Lake Erie

Jerry H. Hubbschman, Wright State University
Program: Ohio Sea Grant College Program
Project Number: R/ER-23-PD
Date: 4/4/91 to 12/31/91
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective

- To characterize the macroinvertebrate fauna of zebra mussel Dreissena polymorpha beds in western Lake Erie.

Results

- Aggregations of zebra mussels provide excellent habitat for benthic invertebrates.
- Amphipods, turbellaria, gastropods and oligochaetes dominate the assemblage.
- This interstitial community is both large and rich in species. Fifty-three macroinvertebrate taxa have been identified in samples.

Exotic Species Invasions: Population Dynamics and Community Consequences of the Zebra Mussel, (Dreissena polymorpha)

D.K. Padilla and S.L. Dodson, University of Wisconsin-Madison
Program: Wisconsin Sea Grant Institute
Project Number: R/LR-41
Date: 8/1/91 to 7/31/93
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives

- To develop models to predict zebra mussel abundance, distribution, population dynamics and...
Ecosystem Effects of Nonindigenous Species

- Ecological effects in North America.
- To determine which factors are most important in predicting population performance.
- To predict areas likely to be invaded and how zebra mussels might change those ecosystems.

Preliminary Results
- Hard-water, mesotrophic lakes with rocky substrates are likely to be ideal habitat for zebra mussels.
- Zebra mussels are likely to reduce large phytoplankton (blue-green algae).
- Zebra mussels are likely to have small effects on nanoplanckton and herbivorous zooplankton.
- Based on European lakes, there appear to be thresholds in pH and calcium ion concentrations that will determine whether zebra mussels can establish populations in lakes.
- Other lake physical characteristics are not likely to affect their ability to support populations of zebra mussels.

The Impact of Zebra Mussels (Dreissena polymorpha) on Lower Food Web Dynamics in a Large Freshwater Lake
Donald J. Stewart, SUNY College at Stony Brook, E.L. Mills and J.L. Forney, Cornell Biological Field Station, and M.J. Mitchell, SUNY College at Stony Brook
Program: New York Sea Grant Institute
Project Number: R/CE-3
Date: 8/1/91 to 7/31/94
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To test the hypothesis that open-water production of zooplankton will decline in response to colonization by zebra mussels.
- To create a computer model of nutrient-plankton interactions to predict Oneida Lake’s response to invasion by zebra mussels.
- To gauge how zebra mussels might affect nutrients, phytoplankton, zooplankton and larval fish.

Preliminary Results
- Zebra mussel filtration rates depend on mussel size and amount of available food.
- Zebra mussels remove phytoplankton of the size most preferred by Daphnia.
- Daphnia respond to reduced phytoplankton with reduced clutch size and reduced survival.

Influence of Zebra Mussel Invasion on Carbon and Phosphorus Dynamics in Plankton Communities: A Mesocosm Study in Saginaw Bay
Robert T. Heath, Kent State University
Program: Ohio Sea Grant College Program
Project Number: R/ZM-6
Date: 9/1/91 to 8/31/92
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To test the hypothesis that zebra mussels alter carbon and phosphorus dynamics at the base of the food web by grazing selectively on phytoplankton and bacterioplankton.
- To determine whether these effects are related to the trophic state of the community and zebra mussel density.

Preliminary Results
- Mussels prefer to graze on diatoms and small chlorophytes.
- Bacteria are smaller in the presence of zebra mussels, though their numbers do not change significantly.
Ecosystem Effects of Nonindigenous Species

- Release of dissolved organic phosphorus is greatly reduced in the presence of zebra mussels.
- Bacterial productivity is reduced by 60 to 70 percent in the presence of zebra mussels.
- Phosphate uptake in bacteria is greatly reduced in the presence of zebra mussels.
- Oligotrophic, mesotrophic and eutrophic communities all appear to be susceptible to this effect.
- Communities with large portions of large, inedible, blue-green algae seem less affected.

Accumulation and Trophic Transfer of Organic Zenobiotics by the Zebra Mussel, *Dreissena polymorpha*: The Role of Route of Exposure and Lipid Content

Susan W. Fisher, The Ohio State University, and Peter F. Landrum, GLERL at NOAA
Program: Ohio Sea Grant College Program
Project Number: R/ZM-1
Date: 10/1/91 to 9/30/93
Primary Source of Funds: Pass-through from EPA

**Objectives**
- To measure lipid content and production of pseudofeces when zebra mussels are fed two types of algae or sediment.
- To compare the assimilation rates of contaminants into zebra mussels via three types of particulates.
- To use radioactive tracers to measure trophic transfer from pseudofeces to the aquatic invertebrate *Gymnastus*.

**Preliminary Results**
- Mussels exposed to contaminated algae assimilate the contaminant more efficiently than mussels exposed to the same contaminant in sediments.
- Exposure through algae plays a greater role in zebra mussel contamination.

Zebra Mussel: Fish Relations and Their Effects on Nutrient/Energy and Contaminant Dynamics

Konrad Dabrowski, The Ohio State University, and Paul C. Baumann, U.S. Fish and Wildlife Service
National Contaminant Research Center
Program: Ohio Sea Grant College Program
Project Number: R/ZM-4
Date: 10/1/91 to 9/30/94
Primary Source of Funds: Pass-through from EPA

**Objectives**
- To determine if various sizes of freshwater drum and yellow perch exhibit size-selective predation on zebra mussels.
- To determine prey handling times of various sizes of freshwater drum and yellow perch preying on various sizes of zebra mussels.
- To determine if lab-generated predictions of size-selective predation patterns by selected fish species on zebra mussels accurately predict actual predation patterns by fish in the field.
- To determine digestibility of different sizes of mussels as food for various sizes of freshwater drum and yellow perch.
- To determine the metabolic rates of oxygen consumption and ammonia excretion as a function of swimming speed in freshwater drum and yellow perch.
- To determine energy and protein balance in freshwater drum and yellow perch feeding on zebra mussels, as compared to reference diets.
- To estimate ecological significance of freshwater drum and yellow perch preying on zebra mussels in terms of energy flow in Lake Erie.
Ecosystem Effects of Nonindigenous Species

- To document the presence of and determine the concentrations of PCB, dioxin and furan isomers in a wild population of zebra mussels from a contaminated location.
- To determine the ability of drum to bioaccumulate various polychlorinated aromatic isomers by feeding on environmentally contaminated zebra mussels.

Preliminary Results
- Zebra mussels sampled from Ashtabula Harbor did not exhibit extensive contamination; one sample site showed detectable contamination of Chrysene in the larger-sized mussels.
- Stomach and intestinal analyses of drum and perch collected in May 1992 showed that 26.5 percent and 37.3 percent contained zebra mussels, respectively. Drum less than 325 mm and perch less than 175 mm rarely consumed mussels.
- Stomach and intestinal analyses of drum and perch collected in July 1992 showed that 31.3 percent and 15 percent contained zebra mussels, respectively. Drum less than 265 mm and perch less than 200 mm rarely consumed mussels.
- Seasonally, more zebra mussels were consumed in the spring than in the summer.
- The predation on zebra mussels by freshwater drum and yellow perch does not appear to be gape limited.

The Impact of Zebra Mussel Filtering on Pelagic Food Webs
David A. Culver and Robert M. Sykes, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ZN-3
Date: 2/1/92 to 1/31/95

Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To determine how zebra mussel grazing affects open-water communities.
- To gauge how the benthic boundary layer affects the food available to zebra mussels.

Preliminary Results
- Zebra mussels near the lake bottom grow only one-fourth to one-third as much as mussels higher in the water column.
- There is less food available to zebra mussels at greater depths.
- The impact of zebra mussels on open-water communities may depend on the physical structure of the lake bottom and mussel settling depth.

Responses of Macrophytes and Associated Fish Larvae to Zebra Mussels in Saginaw Bay
Thomas G. Coon and Ted Batterson, Michigan State University
Program: Michigan Sea Grant College Program
Project Number: R/ZN-7
Date: 5/1/92 to 4/30/93

Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To document how increased densities of zebra mussels affect water clarity and thus distribution, abundance and species composition of submersed macrophytes.
- To determine whether zebra mussels change densities and growth of yellow perch and common carp larvae.

Preliminary Results
- From 1991 to 1992, macrophytes in Saginaw Bay increased in occurrence and number.
- Species responding to increased water clarity included angiosperms, charophytes and attached chlorophytes.
Ecosystem Effects of Nonindigenous Species

Zebra Mussel’s Directed Trophic Transfer
Susan W. Fisher, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/PS-11-PD
Date: 6/1/92 to 12/31/92
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective
- To test the hypothesis that PCBs are transferred along the food chain from contaminated algae to zebra mussels to gammarids and ultimately to many edible fish species.

Results
- Studies with uncontaminated algae show differential processing and production of pseudofeces as a function of algal species, mussel size and algal concentration.
- Zebra mussels accumulate PCBs and PAHs at levels about ten times higher than those typical of aquatic invertebrates.
- Determinants of bioconcentration in zebra mussels include mussel size and lipid content.
- Contaminated particles are a significant source of PCBs and PAHs for zebra mussels.
- When zebra mussels are exposed to contaminated particles, unassimilated materials pass through to feces and subsequently become a source of contamination for benthic invertebrates.
- Gammarids accumulate 90 to 100 percent of their body burden of PCBs and PAHs through ingestion of contaminated zebra mussel feces.
- Fish eating contaminated zebra mussels versus contaminated gammarids will receive five times the dose of chemical through consumption of gammarids due to food chain magnification.

The Areal and Vertical Distribution of Cladocera glomerata in Western Lake Erie and its Interaction with the Zebra Mussel (Dreissena polymorpha)
Mark E. Monaco, NOAA; Richard C. Lorenz, Columbus (Ohio) Division of Water; and Charles E. Herdendorf, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ER-26-PD
Date: 6/1/92 to 12/31/92
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective
- To determine how zebra mussels have influenced the areal and vertical distribution of Cladophora glomerata in western Lake Erie.

Results
- Biomass of the dominant benthic alga Cladophora glomerata has not increased.
- Water clarity has increased throughout the western basin. Secchi disk depths in 1992 ranged from 0.6 to 4.3 m, compared with 0.7 to 2.6 m for the same sites in the early 1980s.
- Cladophora colonization, which began with lush growth at the splash zone, is inversely related to zebra mussel colonization and begins declining after 1.5 m of depth.
- Based on minimal light requirements, Cladophora is capable of a mean maximum depth of growth to 8.35 m, compared with the mean maximum observed depth of 2.9 m.
- Cladophora colonization is limited by competition with zebra mussels for bedrock habitat at depths greater than 2 m, even when adequate light levels are available for colonization.
- Only trace amounts of Cladophora are found on substrates colonized nearly 100 percent by zebra mussels.
- The blue-green alga Phormidium is present at many of the sampling sites, often colonized directly on zebra mussels and rocks.
Ecosystem Effects of Nonindigenous Species

Impact of *Dreissena polymorpha* on the Plankton Diatoms in Western Lake Erie and Lower Saginaw Bay, Lake Huron

Ruth Holland Beeton, University of Michigan
Program: Michigan Sea Grant College Program
Project Number: R/ZM-3
Date: 8/1/92 to 7/31/94
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

**Objective**
- To evaluate how zebra mussels affect the community structure of diatoms in western Lake Erie and Saginaw Bay.

**Preliminary Results**
- Between the 1980s and 1990s, planktonic diatoms in western Lake Erie declined by more than 85 percent.
- During the same period, water transparency increased by more than 76 percent.
- Concentrations of major nutrients have either remained essentially the same or increased in the waters of Hutchery Bay (near Put-in-Bay, Ohio) since the establishment of *Dreissena polymorpha*.

Influence of Zebra Mussel Invasion on Nutrient Dynamics in Plankton Communities: Field Verification of Mesocosm Findings in Saginaw Bay

Robert T. Heath, Kent State University
Program: Ohio Sea Grant College Program
Project Number: R/ZM-7
Date: 8/1/92 to 7/31/94
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

**Objectives**
- To test the hypothesis that planktonic nutrient dynamics observed in the field will show the same sensitivity in the presence of zebra mussels as seen in lab and mesocosm experiments.
- To confirm that changes in bacterial nutrient dynamics are caused by loss of labile dissolved organic carbon (carbon normally released by algae).

**Preliminary Results**
- Bacterial phosphate uptake in samples taken from oligotrophic sites were consistently more sensitive to zebra mussels than samples taken from eutrophic sites.
- Sensitivity of bacterial phosphate uptake was correlated with the extent to which zebra mussels grazed on phytoplankton at each site. Those sites at which algae were most heavily grazed were those at which bacterial phosphate uptake was most severely affected.
- Algal eutrophic sites that support large populations of zebra mussels develop communities of large-bodied cyanophytes and large colonial chrysophytes, which are not as edible to zebra mussels as diatoms or small-bodied chlorophytes found in oligotrophic sites.
- We tested the hypothesis that zebra mussels affect bacterial activities by depriving them of carbon substrate normally released by algae (i.e., labile dissolved organic compounds, LDOC) by comparing bacterial activities in samples incubated in ambient light intensities with those incubated in low intensity light and in the dark. We found that light deprivation of the community led to similar declines of bacterial activities as experienced by zebra mussel grazing, presumably because of a decrease in available LDOC photosynthate.
Ecosystem Effects of Nonindigenous Species

Remote Sensing Studies of Zebra Mussel Impacts in Saginaw Bay
W. Charles Kerfoot and Ann L. Maclean, Michigan Technological University
Program: Michigan Sea Grant College Program
Project Number: R/ZM-6
Date: 9/1/92 to 8/31/93
Primary Source of Funding: Pass-through from Michigan DNR

Objectives
- To determine whether changes in water quality caused by zebra mussels can be detected, mapped and quantified using remotely sensed images.
- To use Advanced Very High Resolution Radiometer (AVHRR) techniques to monitor changes in water temperature, turbidity and chlorophyll a content.
- To test the hypothesis that the impact of zebra mussels on Saginaw Bay is strongly related to water depth and interactions between inshore and offshore water masses.

Preliminary Results
- Developed automated procedures for generating temperature and reflectance contour maps of Lake Huron, Lake St. Clair and western Lake Erie using satellite data.
- Preliminary maps provide excellent detail of horizontal temperature and reflectance patterns in the study sites.
- Marked thermal gradients of approximately 10°C appear during mid-summer in Saginaw Bay (July 4, 1983 image).
- The maps show that shallower bay waters may be successively closed off from the offshore water masses due to density gradients; under these conditions, the effect of zebra mussel filtering activity may be tracked using satellite data.
- Zebra mussel impacts on water quality may be more difficult to track when flushing occurs (e.g., spring and fall) (September 4, 1987 image).

Direct Experimental Assessment of the Impact of Dreissena polymorpha on Unionid Growth, Mortality and Condition in Lake St. Clair
R. Douglas Hunter, Oakland University
Program: Michigan Sea Grant College Program
Project Number: R/ZM-4
Date: 9/1/92 to 8/31/93
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives
- To provide direct experimental evidence that zebra mussels cause the death of unionids in Lake St. Clair.
- To evaluate whether zebra mussels also cause reduced growth and emaciation in Lake St. Clair unionids.

Preliminary Results
- Massive Dreissena colonization of Lampsilis soliqueoida and Anodonta grandis causes starvation and tissue degrowth, as evidenced by increase in shell: tissue mass ratio.
- In a survey of five species of unionids, those that were colonized by zebra mussels suffered higher mortality rates than those not colonized.
- There were interspecific differences in mortality rates.
- Most unionids will recover if attached zebra mussels are removed.
- Unionids cleaned of zebra mussels had survival rates equal to those of unionids that were uncolonized.
- Species with relatively massive shells had lower percentage of mortality than species with relatively thin and fragile shells.
Ecosystem Effects of Nonindigenous Species

Phosphorus Budget of a Zebra Mussel Population
Joseph C. Makarewicz, SUNY College at Brockport
Program: New York Sea Grant Institute
Project Number: R/CE-4
Date: 9/1/92 to 8/31/94
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives
- To determine a phosphorus budget for a zebra mussel population.
- To compare phosphorus cycling in zebra mussels with downstream transport of phosphorus in the Erie Canal.

The Impact of Zebra Mussels on the Dynamics of Heavy Metals
Peter C. Fraleigh, University of Toledo
Program: Ohio Sea Grant College Program
Project Number: R/ZM-2
Date: 9/1/92 to 8/31/94
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives
- To determine whether zebra mussels increase biodeposition of heavy metals to the lake bottom.
- To test whether zebra mussels increase flux of heavy metals from the water column to the lake bottom.

The Impact of Zebra Mussels on the Benthic Food Web in Saginaw Bay, Lake Huron
Rex L. Lowe, Bowling Green State University
Program: Ohio Sea Grant College Program
Project Number: R/ZM-5
Date: 9/1/92 to 8/31/95
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives
- To determine how increased densities of zebra mussels affect the structure and function of benthic algae communities.
- To test whether zebra mussel feces and pseudofeces increase nutrients available to benthic algae and increase growth.
- To test whether increased light penetration increases growth of benthic algae and leads to changes throughout the food web.

Preliminary Results
- Light availability to benthic algae has increased in Saginaw Bay following the zebra mussel invasion.
- Benthic algal growth in Saginaw Bay has increased following the zebra mussel invasion.
- Benthic algal community structure has shifted following the zebra mussel invasion in Saginaw Bay.
- Benthic algal biomass was not limited by nitrogen or phosphorus in Saginaw Bay following the zebra mussel invasion.

Nutrient Regeneration by Zebra Mussels and its Impact on Phytoplankton
Michael J. Vanni, Miami University
Program: Ohio Sea Grant College Program
Project Number: R/ZM-15
Date: 9/1/92 to 8/31/95
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation
Ecosystem Effects of Nonindigenous Species

Objectives
- To quantify the amount and proportion of nitrogen and phosphorus consumed, assimilated and released by zebra mussels and the fraction available to phytoplankton.
- To determine the effect of nutrient release on phytoplankton nutrition, growth and community structure.
- To create a computer model that predicts the effects of zebra mussel nutrient cycling on the whole ecosystem.

Preliminary Results
- Body and shell C and N content are constant across all size classes (only mussels collected in June analyzed so far).
- Small mussels have more P/mg dry weight in their shells than larger mussels; but less P/mg dry weight in their soft tissue (only mussels collected in June analyzed so far).
- Overall N:P excretion rates are below the Redfield 7:1 molar ratio, and therefore favor blue green algae growth.
- There is a significant effect of month (P<.05) on P excretion but not on N excretion or N:P ratio.
- There is a significant effect of mussel size (P<.05) on P excretion and N:P ratio but not on N excretion.

The Effects of Zebra Mussels on the Invertebrate Communities of Wetlands in Saginaw Bay, Michigan
Thomas M. Burton, Michigan State University
Program: Michigan Sea Grant College Program
Date: 4/1/93 to 3/31/96
Primary Source of Funds: Pass-through from EPA

Objectives
- To determine which sizes and species of the most abundant zooplankton in wetlands are most susceptible to filtration by zebra mussels.
- To observe how zebra mussels affect the invertebrate community in a Scirpus americanus wetland.
- To investigate the dynamics of zebra mussel colonization of the dominant vegetation in a Scirpus americanus wetland.

The Influence of Zebra Mussels on the Recruitment of Saginaw Bay Fishes
David J. Jude, University of Michigan
Program: Michigan Sea Grant College Program
Project Number: R/ZM-5
Date: 9/1/92 to 8/21/95
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives
- To determine which environmental factors are most important in fish year-class strength.
- To test whether zebra mussel and zooplankton abundances affect fish hatching, growth and mortality.
Socio-Economic Analyses: Costs and Benefits of Nonindigenous Species

The Economic Costs of the Zebra Mussel
Leroy J. Hushak, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ME-14-PD
Date: 4/1/90 to 12/31/91
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective
- To survey commercial shippers, ports/harbors, electric power plants, industrial water users, municipal water users, marinas, charter boat firms and private boat owners about costs they’ve incurred as a result of zebra mussels.

Results
- Charter boat firms and private boat owners reported the greatest increased costs.
- Firms with water intakes reported small additional costs, although other evidence suggests that these groups incurred major costs after the survey date.

The Role of Fishing and the Zebra Mussel on the Tourism Industry
Leroy J. Hushak, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ME-12
Date: 9/1/90 to 8/31/92
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objectives
- To survey Ohio licensed drivers about their recreation activities near Lake Erie during 1988, 1989 and 1990.
- To estimate how the zebra mussel changed this participation and affected the tourism economy in northern Ohio.
- To predict how the continued presence of zebra mussels will affect participation in Lake Erie recreation and the tourism economy.

Preliminary Results
- Only 2 percent of Ohioans surveyed said they decreased time spent at Lake Erie because of zebra mussels.
- Of 109 boaters, 14 reported average protective paint costs of $94; four cited additional maintenance costs averaging $171.

The Economic Costs of the Zebra Mussel to Ohio’s North Coast Economy
Leroy J. Hushak, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ZM-13
Socio-Economic Analyses: Costs and Benefits of Nonindigenous Species

Date: 8/1/91 to 7/31/93
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To survey Ohio and Michigan licensed drivers about their current and future recreation activities on Lake Erie and costs incurred as a result of zebra mussels.
- To estimate the economic value and impact of Lake Erie tourism and recreational fishing and how zebra mussels have affected it.

Preliminary Results
- About 25 percent have responded to the survey as of April 1993.

Environmental and Economic Benefits from Zebra Mussel Harvesting Through Contaminant Reduction and Product Development

Joe M. Regenstein, Cornell University, and Susan Goldhor, Center for Applied Regional Studies
Program: New York Sea Grant Institute
Project Number: R/SWM-1
Date: 9/1/91 to 8/31/94
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To determine contaminant levels in Great Lakes zebra mussels.
- To compost and hydrolyze ground zebra mussels.
- To test ultrasound as a way to reduce or destroy contaminants in zebra mussels.
- To evaluate the economic feasibility of different methods of harvesting zebra mussels.
- To evaluate and develop markets for zebra mussel products (compost, liquid fertilizer, liquid protein).

A Policy Framework for Nonindigenous Species in the Great Lakes

Alan J. Randall, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ZM-14
Date: 9/1/92 to 8/31/94
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives
- To develop policy approaches that are appropriate for accidental introductions, purposeful private introductions and purposeful public introductions of exotic species.
- To develop a method to identify the costs and benefits of both accidental and planned introductions of exotics.
- To complete a cost-benefit analysis of an introduction that has already occurred in the Great Lakes.
Control and Mitigation of Nonindigenous Species

Temporary measures may mitigate the effects of invading organisms. But the only truly effective means of control will be identified through long-term research. One example of this approach is the successful control of sea lamprey populations in the Great Lakes. Future success in controlling invading species depends on a research strategy that addresses all physical, chemical and biological requirements of each invading species. Only through understanding each organism's behavior, physiology and genetic and immunological characteristics can scientists devise innovative, effective and selective control techniques. From a base of general biology and life history, researchers can investigate a variety of control measures: engineering (redesigning water intake pipes, etc.), physical (scrapping, filtering, etc.), chemical (antifoulants, biocides, etc.) biological (parasites, predators, etc.), and physicochemical (heat, pH, etc.). These lines of investigation should be parallel and should

Control and Mitigation of Nonindigenous Species

Testing of Mechanical, Molluscicidal, Antiattachment, Antifouling Agents on the Zebra Mussel
Susan W. Fisher, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/PS-8-PD
Date: 4/1/90 to 3/31/91
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective
• To test a variety of different agents for their ability to control zebra mussels.

Results
• Environmentally safe chemicals kill adult mussels in short periods of time at concentrations averaging 150 parts per million.
• These chemicals are effective under a wide variety of environmental conditions.

Control of Zebra Mussels with Lemmatoxins, A Natural Molluscicide from Phytolacca dodecandra
Harold H. Lee, The University of Toledo
Program: Ohio Sea Grant College Program
Project Number: R/PS-7-PD
Date: 12/1/90 to 6/15/91
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective
• To determine the efficacy of Endod, a natural molluscicide from Phytolacca dodecandra, in zebra mussel control.

Results
• Lemmatoxin (Endod) doses of 15 mg/L are lethal to adult mussels, while lower doses prevent mussel adhesion and reduce adhesion and aggravation.
• Endod is recommended for use as a control agent in tandem with other mechanical and chemical means in water intake pipes.

Evaluation of Molluscicides for Zebra Mussel Control
Susan W. Fisher and Jeffrey M. Reutter, The Ohio State University
Program: Ohio Sea Grant College Program
Date: 5/10/91 to 9/30/93
Primary Source of Funds: Pass through from U.S. Fish and Wildlife Service

Objective
• To evaluate a series of candidate molluscicides.

Preliminary Results
• Determined the toxicity of 12 molluscicides to adult zebra mussels.
• Determined the toxicity of five molluscicides to veligers, plantigrade and adult zebra mussels.
Control and Mitigation of Nonindigenous Species

Application of Underwater Robots to Perform Inspection, Cleaning and Maintenance of Intake Pipes
Samuel E. Landsberger, Cornell University

Program: New York Sea Grant Institute
Project Number: R/EMS-4
Date: 7/1/91 to 6/30/93
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objectives
- To develop a prototype robot that will clean and inspect water intake pipes.
- To design and test technology for underwater robots that will perform work in constrained environments.

Preliminary Results
- Scientists have developed a strategy for building a robot that propels itself along a cable within infested intake pipes.
- Scientists have designed a robot that can perform pipe inspections, cleaning and maintenance; work on a prototype has begun.
- The Erie County (N.Y.) Water Authority has installed guide cable in its two pipes to accommodate the new robot.

Effect of Ultraviolet-B Radiation (280-320 nm) on Survivorship of Zebra Mussel (Dreissena polymorpha): A Potential Control Strategy
Linda Chalker-Scott, Howard Riessen and James D. Scott, SUNY College at Buffalo

Program: New York Sea Grant Institute
Project Number: R/EMS-3
Date: 8/1/91 to 7/31/92
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To determine which zebra mussel life stages are sensitive to UV-B radiation.
- To determine minimum dose needed for significant mortality.
- To develop a UV-B prototype for use in water intake pipes and other vulnerable areas.

Results
- Adult mussels survive higher UV-B radiation doses than do larvae.
- UV-B radiation is lethal to adult mussels when it is applied constantly.
- Larvae are killed after relatively short exposure to UV-B radiation; older larvae are less sensitive.

Nonpolluting Control of Biosurface Fouling
Robert E. Baier and Anne E. Meyer, SUNY College at Buffalo

Program: New York Sea Grant Institute
Project Number: R/EMS-2
Date: 8/1/91 to 7/31/93
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To determine how zebra mussel attachment and settling relate to the surface energy of the substrate and other substrate characteristics.
Control and Mitigation of Nonindigenous Species

- To test the hypothesis that the strength of the adhesive bond between zebra mussel and substrate is related to the initial events in the exposure cycle and the substrate’s surface energies.
- To identify coatings that prevent attachment without harming the environment.

Approaches to Zebra Mussel Control Through Intervention in Reproduction

Jeffrey L. Ram and Peter Fong, Wayne State University
Program: Michigan Sea Grant College Program
Project Number: R/ZM-1
Date: 8/1/91 to 7/31/94
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To determine internal and external spawning triggers in male and female zebra mussels.
- To determine the chemical structure of spawning inducers.
- To develop inhibitors to zebra mussel spawning.
- To identify a field site for testing spawning inducers and inhibitors.

Preliminary Results
- Viable gametes can be produced through serotonin-induced spawning.
- Hydrogen peroxide weakly stimulates spawning.
- Several pharmacological agents inhibit serotonin-induced spawning.
- Dopamine inhibits serotonin-induced spawning in zebra mussels, while indomethacin reduces spawning intensity.
- Serotonin produces no significant change in zebra mussel ECGs, but toxic doses of potassium inhibit heart activity in zebra mussels.
- Several agents inhibit zebra mussel fertilization.
- Specific cell-surface sugars may play an important role in fertilization and embryonic development of zebra mussels.

The Use of Potassium in Control of the Zebra Mussel, Dreissena polymorpha Pallas

Susan W. Fisher and Paul C. Stromberg, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ZM-11
Date: 2/1/92 to 1/31/94
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To evaluate potassium salts as molluscicides.
- To determine whether low levels of potassium deter zebra mussel attachment.
- To measure potassium’s toxicity to nontarget animals.

Preliminary Results
- Potassium is highly toxic to adult mussels.
- Potassium chloride (KCl) is the most economical and environmentally compatible form.
- Potassium appears to have no adverse effects on other aquatic animals—even at 10 times the dose used to kill zebra mussels.
- Low levels of potassium prevent zebra mussel larvae from settling onto hard surfaces.
- Pulses of potassium administered every two hours appear to be just as effective as a continuous feed.
- Potassium inhibits both heart and respiratory activity in zebra mussels.
Control and Mitigation of Nonindigenous Species

Developing Mass Culture Techniques for Rearing Larvae of the Zebra Mussel, *Dreissena polymorpha*

David W. Garton, The Ohio State University
Program: Ohio Sea Grant College Program
Project Number: R/ZM-8-PD
Date: 5/1/92 to 12/31/92
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

**Objective**
- To develop mass culture techniques for rearing zebra mussel larvae for application in basic research and applied toxicology.

**Results**
- Veligers survive longer in aquaria with gentle flow systems than in static aquaria.
- Unfed veligers survive about 10 days in culture.
- Fed larvae survive no longer than unfed larvae, although the fed larvae grow and develop more rapidly.
- Egg quality among adult female mussels declines over time.
- Larvae collected from lake water survive longer than lab-spawned larvae and begin to settle.

Carbon Dioxide as a Narcotizing Pre-Treatment for Chemical Control of *Dreissena polymorpha*

William Elzinga, Environmental Science and Engineering, Inc.
Program: Illinois-Indiana Sea Grant Program
Project Number: ZM/4
Date: 9/1/92 to 12/31/93
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

**Objectives**
- To determine the amount of carbon dioxide needed to kill zebra mussels in a closed system and the amount necessary to simply drug the mussels.
- To determine whether using chlorine and carbon dioxide together increases control effectiveness.
- To test how length of application, temperature and mussel size influence the control effectiveness of chlorine and carbon dioxide.

**Preliminary Results**
- Lethal effects have been observed with carbon dioxide at more than 190 mg/l for 24-hour application.
- Narcotizing effects have been observed at lower concentrations (100-150 mg/l) over the same time period.
- Narcotizing effects have been observed within four hours of the initiation of the treatment.

New Approaches to Control of Zebra Mussels by Targeted Microbial Products

Ralph Mitchell, Harvard University
Program: Massachusetts Institute of Technology Sea Grant College Program
Project Number: RT-35
Date: 9/1/92 to 8/31/95
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

**Objectives**
- To isolate bacteria that inhibit attachment or cause disease in zebra mussels.
- To isolate specific substances from these bacteria and evaluate their potential as environmentally safe control measures.

**Preliminary Results**
- Several bacteria that can kill adult mussels in less than five days have been identified.
Prevention of Introduction of Nonindigenous Species

Scientists can predict the spread of an established nonindigenous species (a viable reproducing population) by analyzing the species' environmental requirements and its dispersal mechanisms — vectors that allow it to reach areas where environmental conditions are favorable for growth and reproduction. Most nonindigenous species have been introduced and spread by human activities (ship ballast, boats, pet industry, etc.). However, dispersal mechanisms are often unique to each species and are usually determined after geographic range extensions occur. To predict likely future dispersal mechanisms, scientists couple their knowledge of a species' biology and life history with reports of past modes of dispersal. Once dispersal mechanisms are identified for individual invading species, scholars and policy makers can develop safeguards and international protocols to prevent and/or slow the spread to uninfested areas. Such safeguards and protocols may also prevent the spread of new, not-yet-established, nonindigenous species. Analysis and identification of past and possible future dispersal mechanisms enhances our ability to mitigate the effects of invading species on the ecosystem.

The Use of Acoustic and Hydrodynamic Techniques to Control Zebra Mussel Infestation

Dmitriy M. Donskoy, Stevens Institute of Technology
Program: New Jersey Marine Sciences Consortium Sea Grant Program
Project Number: R/E-29ZM
Date: 9/1/92 to 9/30/95
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
- To test how adults and veligers respond to varying frequencies, intensities and duration of sound and vibration.
- To study ultrasound and hydrodynamic cavitation effects on zebra mussels.
- To develop acoustic and vibrational methods for measuring zebra mussel populations in tanks and pipes.
- To evaluate the feasibility of converting hydrodynamic energy to acoustic energy to enhance the efficiency of the control technique.

Application of Wide-Range Ultraviolet Radiation for Zebra Mussel Control

Linda Chalker-Scott, SUNY College at Buffalo
Program: New York Sea Grant Institute
Project Number: R/EMS-6
Date: 9/1/92-8/31/94
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives
- To determine the minimum level of ultraviolet exposure necessary to prevent larval settling and the minimum chronic level necessary to kill existing populations.
- To gauge the effects of ultraviolet light on veliger behavior.
- To develop a prototype instrument that will deliver ultraviolet radiation in restricted locations.

Preliminary Results
- Adult mussels demonstrate a limited ability to move away from UV exposure.
- While wide-range UV will eventually kill off adult populations, the killing time is so long as to be of doubtful use as a control mechanism for existing populations (using our existing UV source).
- Higher intensity UV sources show more promise in killing adults.
- Quagga mussels appear to be more resistant than zebra mussels.
- Planktonic larvae show a negative directional response to UV radiation and are killed rapidly (~2 hrs.), even under our existing UV source.

Prevention of Introduction of Nonindigenous Species

Ship Operational & Safety Aspects of Ballast Water Exchange at Sea

John B. Woodward, Michael G. Parsons & Armin W. Troesch, University of Michigan
Program: Michigan Sea Grant College Program
Project Number: R/ZM-2
Date: 8/1/91 to 7/31/92
Reducing the Spread of Established Nonindigenous Species

Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
• To analyze how hull bending stresses change during at-sea ballast water exchanges.
• To describe the consequences of ballast exchange during bad weather.
• To determine whether slowing or rerouting may result from ballast exchange in bad weather.
• To make ballast exchange recommendations to the U.S. Coast Guard.

Preliminary Results
• Ballast water exchange is not likely to affect metacentric height — a measure of ship stability.
• Ballast water exchange during storms that produce a significant wave height of 10 feet appears to be safe — it creates bending and shear values still within American Bureau of Shipping safety guidelines.
• Ballast water exchange during storms that produce a significant wave height of 20 feet can create hull slamming and should be avoided.

Reducing the Spread of Established Nonindigenous Species

The Significance of Spreading Vectors in the Zebra Mussel Invasion: Experimental and Observational Studies on Dispersal Mechanisms of Dreissena polymorpha

James T. Carlton, Williams College
Program: Connecticut Sea Grant Program
Project Number: R/ES-5
Date: 7/1/91 to 6/30/93

Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives
• To quantify the role of sport boats, commercial craft and sport fishing in dispersing zebra mussels in the Great Lakes basin.
• To conduct experiments to test how vessels and sport fishing affect zebra mussel dispersal.
• To conduct preliminary investigations on natural dispersal vectors, especially aquatic birds.

Preliminary Results
• More than 50 percent of boaters using Great Lakes waters in eastern Michigan also use their boats in inland waters.
• Transit times between Great Lakes and inland waters averaged five days but were occasionally as short as a day.
• Veligers were frequently found in all types of water contained in boats, including engine cooling systems, bilges, live wells and bait buckets.
• Adult mussels were found only on vegetation entangled on boat trailers; however, on some days, 30 percent of the boat trailers transported mussels in this way.
• Based on reported destinations, larger inland lakes are predicted to be invaded first.
Reducing the Spread of Established Nonindigenous Species

Prediction and Early Detection of Zebra Mussel Invasions of the Inland Waters of Michigan
Ladd E. Johnson and James T. Carlton, Maritime Studies Program
Program: Michigan Sea Grant College Program
Project Number: R/ZM-8
Date: 2/8/93 to 10/31/93
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objectives
• To determine the likely rate, direction and pattern of the spread of zebra mussels to Michigan’s inland waters.
• To test the hypothesis that recreational boat traffic between the Great Lakes and inland waters is responsible for initial invasions.
• To detect the early stages of zebra mussel invasion of Michigan’s inland lakes.
Newly funded research projects

initiated in 1993 by the National Sea Grant College Program

Biology/Life History of Nonindigenous Species
Swimming and Settlement Behavior in the Quagga Mussel
Victor S. Kennedy, University of Maryland
Program: Maryland Sea Grant College Program
Project Number: NA
Date: 1/1/94 to 12/31/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives
- To observe the behavior of the quagga mussel to determine possible options for preventing fouling at industrial water delivery systems.
- To refine protocols for culturing and rearing quagga mussel larvae.
- To study how gravity, temperature, salinity and dissolved oxygen content affect quagga swimming behavior.
- To determine how light and substrate orientation affect settling behavior in quagga pediveligers.

Assessing the Spatial and Temporal Distribution of Zebra Mussel Larvae in Saginaw Bay, Michigan, Using the Video Plankton Recorder
Scott M. Gallager and Cabell S. Davis, Woods Hole Oceanographic Institution
Program: Massachusetts Sea Grant College Program
Project Number: R/B-119-PT
Date: NA
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives
- To modify the Video Plankton Recorder for use on a small vessel in shallow, turbid water for survey and experimental work in the Great Lakes.
- To determine the temporal and spatial distribution and abundance of zebra mussel larvae in Saginaw Bay, relative to the physical dynamics of the water column.
- To evaluate the extent of diel vertical migration of mussel larvae and its potential importance as a transport mechanism.

Species Identification of Early Life History Stages of Dreissenid Mussels and Other Co-occurring Bivalves in Freshwater and Oligohaline Habitats
Richard A. Lutz and Brad S. Baldwin, Rutgers University
Program: New Jersey Marine Sciences Consortium Sea Grant Program
Project Number: R/E-45ZM
Date: 7/1/93 to 6/30/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives
- To develop a practical way to identify larval and postlarval stages of Dreissena polymorpha, D. bugensis (quagga mussel), Mytilopsis leucophaca (dark false mussel) and other co-occurring bivalve species and freshwater and oligohaline habitats by using SEM and other routine optical microscopic examination of shell and hinge form and structure.
- To develop routine methods for rearing zebra and quagga mussel larvae through to post-larval stages.
- To determine whether shell morphological features used for identification purposes are altered by environmental conditions or differ with respect to the geographic location of parental source populations.
Newly funded research projects

**Genetics of the Zebra and Quagga Mussels: A Comparative Analysis of Mitochondrial DNA Sequence Data**
Carol A. Stepień, Case Western Reserve University
Program: Ohio Sea Grant College Program
Project Number: R/ZM-9
Date: 9/1/93 to 8/31/96
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

**Objectives**
- To determine genetic differences between zebra and quagga mussels and develop rapid screening methods for assessing the relative abundance and genetic variability of both veligers and newly settled mussels.
- To determine whether there are additional cryptic species in this North American nonindigenous complex.
- To test whether there are differences in both overall genetic variation and base substitution frequencies in both species of mussels from the “Old” and “New” Worlds.
- To pinpoint the original European source of mussel parental stocks.
- To determine whether different mussel genetic strains and/or subpopulations exist in North America and, if so, which are most successful in various habitats and on various invasive fronts.

**Preliminary Result**
- The first DNA sequence data for dreissenid mussels has recently been obtained.

---

**Ecosystems Effects of Nonindigenous Species**

**Zebra Mussel and Sediment Interactions: Is There an Effect on Nitrogen and Phosphorus Regeneration Ratios?**
James B. Cotner, Texas A & M University
Program: Texas A & M University Sea Grant College Program
Project Number: R/ES-60
Date: 9/1/93 to 8/31/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

**Objectives**
- To determine whether zebra mussels change the dissolved nitrogen/phosphorus supply ratio in areas of Lake St. Clair where they are abundant.
- To test the hypothesis that mussels directly affect microbial sediment oxygen demand by increasing the flux rate of reduced carbon and other nutrients to the sediments.
- To test the hypothesis that increased benthic microbial activity results in lower nitrogen/phosphorus ratios.

---

**Foodchain Contamination of Edible Fish Through Zebra Mussel Directed Trophic Transfer**
Susan W. Fisher, The Ohio State University, and Peter F. Landrum, GLERL at NOAA
Program: Ohio Sea Grant College Program
Project Number: R/ZM-21
Date: 9/1/93 to 3/31/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

**Objectives**
- To quantify the amount of trophic transfer at each level of an aquatic food chain.
- To assess how biological variables affect trophic transfer.
- To determine how the nature of the chemical being transferred affects each step of trophic transfer.
Newly funded research projects

**Remote Sensing Studies of Zebra Mussel Impacts in Saginaw Bay**
W. Charles Kerfoot and Ann Maclean, Michigan Technological University
- Program: Michigan Sea Grant College Program
- Project Number: R/ZM-9
- Date: 9/1/93 to 8/31/96
- Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation
  - **Objectives**
    - To determine whether changes in water quality caused by zebra mussels can be detected, mapped and quantified using remotely sensed images.
    - To determine whether computer-assisted image and analysis procedures that use spectral information can be used to quantify spatial and temporal changes in water quality variables.
    - To map and model spatial and temporal changes in water quality, caused either directly or indirectly by zebra mussels in Saginaw Bay.

**Shifts in Southwestern Lake Michigan Benthic Food Web Dynamics Since the Invasion of the Zebra Mussels**
Nancy C. Tuchman, Loyola University of Chicago
- Program: Illinois-Indiana Sea Grant Program
- Project Number: NA
- Date: 8/1/93 through 7/31/95
- Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation
  - **Objectives**
    - To determine how the 1992 zebra mussel invasion of the rock reef in southwestern Lake Michigan will affect the dynamics of the benthic food web.
    - To compare pre-1992 data on benthic algal, macroinvertebrate and crayfish composition and crayfish diet, abundance and size class distribution with post-1992 data.
    - To determine the relative contribution of the benthic and the limnetic littoral communities on total littoral zone primary production.
  - **Preliminary Results**
    - Light penetration to the lake-bottom community has increased significantly since the 1992 zebra mussel invasion.
    - The benthic algal community has become dominated by green filamentous algae since the 1992 zebra mussel invasion.

**Socio-Economic Analyses: Costs & Benefits of Nonindigenous Species**
Present and Expected Economic Costs of Zebra Mussel Damages to Water Users with Great Lakes Water Intakes
Leroy J. Hushak, The Ohio State University
- Program: Ohio Sea Grant College Program
- Project Number: R/ZM-12
- Date: 9/1/93 to 8/31/95
- Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation
  - **Objectives**
    - To survey industries with Great Lakes water intakes about the annual costs associated with zebra mussels (damage, maintenance, control, full or partial plant shut-down, plant design modifications, research costs).
    - To survey public organizations and researchers about annual spending on zebra mussel control research.
    - To survey researchers at public and private institutions about the feasibility of zebra mussel control research resulting in annual cost reductions for industry.
    - To estimate the expected annual rate of return of investment in zebra mussel control research to industries with Great Lakes water intakes.
Newly funded research projects

Control and Mitigation of Nonindigenous Species

The Role of Continuous Introductions in Establishing Zebra Mussel Colonies in Areas Where Environmental Factors May Be Limiting

Mary Balcer, University of Wisconsin
Program: Wisconsin Sea Grant Institute
Project Number: R/LR-47
Date: 7/1/93 to 6/30/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives
- To determine whether zebra mussels can survive, grow and reproduce under the pH, calcium and water temperature conditions of Duluth-Superior harbor in western Lake Superior.
- To estimate how many zebra mussel veligers and juveniles are introduced yearly to Duluth-Superior harbor from ballast water discharge and boat hull transport.
- To explore how continuous introductions help mussel populations reach the numbers necessary for self-sustaining population growth.

Preliminary Result
- Wisconsin Sea Grant’s Zebra Mussel Watch program has documented the presence of zebra mussels in Duluth-Superior harbor but has recorded only low densities of mussel veligers and juveniles.

Chlorine Minimization and Boundary Layer Injection for Control of Zebra Mussel Fouling in Hudson River Water Intakes

Vincent Guida, Lehigh University
Program: New Jersey Marine Sciences Consortium Sea Grant Program
Project Number: R/E-44ZM
Date: 7/1/93 to 6/30/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives
- To assess both the environmental impact and the economic viability of using staged boundary layer injection technology to place chlorine only along intake walls, where fouling occurs.
- To determine the optimal level of continuous chlorine necessary to control zebra mussel settlement in a Hudson River water intake.
- To test the degree of control, chloride consumption and chlorine discharge associated with boundary layer chlorination.

Control of Zebra Mussel Veligers in Water Treatment Plants by Chemical Coagulants

John E. Van Benschoten and Joseph F. Atkinson, SUNY College at Buffalo
Program: New York Sea Grant Institute
Project Number: NA
Date: 8/1/93 through 7/31/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives
- To characterize how coagulants affect veliger behavior.
- To characterize the particle stability characteristics of both veliger and non-veliger particulates.
- To identify how adding coagulants at water intakes affects solid-liquid separation processes.
- To measure particle aggregation/disaggregation characteristics of veligers at varying coagulant doses and turbulence levels.
- To develop a model predicting how coagulant additions would affect different water intakes.
Sea Grant outreach

The six Great Lakes Sea Grant programs working as a unified team are the primary source of Great Lakes information for the general public and water users. The extension component of these programs includes more than 30 agents and specialists who cover the U.S. Great Lakes shoreline. These extension professionals are the primary liaisons with the public. They translate scientific discoveries and technological developments and transfer them to waters users, ensuring that society receives the maximum benefit from research efforts. Also, through their interactions with the public and businesses and industries that use the lakes, these agents identify critical research needs and issues for their programs. This guarantees that Sea Grant research remains focused on the real issues affecting society and that the research results obtained represent practical, “real world” solutions to problems.

Each Great Lakes Sea Grant program began education and public information efforts on zebra mussels in 1989. However, the zebra mussel population explosion in Lake Erie in 1989 — in one year densities reached over 30,000 per square meter — and the associated clogging of everything from large electric power plant cooling systems to engines in small private boats created a near-panic in the Great Lakes community. Sea Grant’s agents and communication specialists put all their energy into providing the most current zebra mussel information possible. This information took many forms: videos, news releases, fact sheets, conferences, seminars, network television spots, newsletters, displays and one-on-one sessions. By mid-1990, Ohio Sea Grant agents and researchers alone had conducted more than 200 seminars and conferences on zebra mussels.

The six programs in the Great Lakes Sea Grant Network carefully coordinated their efforts to prevent duplication and to provide accurate information to as many people as possible. In this brief report, it is impossible to describe all programs and activities undertaken. Instead, we have described 13 efforts that illustrate the breadth and scope of Sea Grant’s zebra mussel outreach efforts. These are outlined briefly below and in greater detail in the pages that follow.

▼ The programs have produced many important fact sheets and videos. However, more than 300,000 copies of two fact sheets produced by Ohio Sea Grant were printed by Brunswick Marine and have been distributed widely by Sea Grant programs and 100 other agencies.

▼ New York Sea Grant, in response to many information requests from surrounding states, has conducted more than 125 one- or two-day regional training sessions since 1990, primarily in New England and the mid-Atlantic states. This would not have been possible without strong support from U.S. Fish and Wildlife Service as the co-sponsor of the program.

▼ In 1990, Ohio Sea Grant hosted the first zebra mussel research conference to enhance communication among interested scientists and to provide a forum for recent research results. This conference has become a very important annual event. As of the 1993 conference, it is now hosted by a Sea Grant program or a Canadian sponsor.

▼ In 1990, New York Sea Grant, with a great deal of private sector support, created the Zebra Mussel Information Clearinghouse — part library and part public information office. With its “800” number and its newsletter, this office provides one-stop shopping for anyone interested in the most current research information on zebra mussels.

▼ In 1991, Michigan Sea Grant instituted an annual conference on zebra mussels for municipal and industrial water users. This provides a forum for gathering and sharing information on problems and solutions about zebra mussels and water intakes.

▼ To slow the spread of the mussel and to document the spread as it occurs, the public needs to know how to identify mussels and report them when observed. To address this need, Wisconsin Sea Grant developed a color, wallet-sized identification card for zebra mussels. Since 1990, more than one million cards have been produced, including a version in French for the Ontario Ministry of Natural Resources.
Photographs and slides of exotic species are in great demand for educational purposes. To meet this need, Michigan Sea Grant created the Nonindigenous Species Graphics Library in 1991. Since then, they have distributed more than 1,200 photographs, slides and illustrations of exotic species.

Illinois-Indiana Sea Grant has developed an exceptional education program, using 130 Illinois high schools and almost 10,000 students to monitor river systems throughout the state for zebra mussels. The results are reported to Illinois Natural History Survey.

Recognizing that the nation’s science writers at the largest newspapers can reach more people than our programs can reach with seminars and fact sheets, Ohio Sea Grant coordinated a special zebra mussel information session at the 1992 conference of the Scientists’ Institute for Public Information, co-sponsored by the Society for Environmental Journalists in Toronto. Major newspapers, public television stations and network affiliates were present.

Sea Grant’s development of educational displays is exemplified by Minnesota Sea Grant’s Exotic Aquatic of the Great Lakes Region display at the Bell Museum of Natural History. This comprehensive interactive display was created by the Bell Museum, with Sea Grant as science advisor, and funding from the state. Three copies are available for travel.

In an effort to provide concrete information to Wisconsin industries facing a possible zebra mussel infestation, Wisconsin Sea Grant developed its Zebra Mussel Watch program in 1990. With assistance from municipalities, power plants, industries and four Wisconsin colleges and universities, this project monitors zebra mussel populations and reports the results in the periodic newsletter Zebra Mussel Update.

Surveys of user needs are a regular component of Sea Grant activities. Illinois-Indiana’s 33-question survey on the information needs of municipal and industrial water users is a good example of Sea Grant’s efforts to address real issues and provide real world solutions.

Transferring the knowledge gained in the Great Lakes region has been a major effort of Sea Grant. Minnesota Sea Grant’s conference for upper-Mississippi water users in 1992 is a good example. With support from a dozen agencies from Arkansas to Wisconsin, the two-day conference with 250 participants was successful in letting the users know what to expect and how to deal with the problem when it arrives.
Just the facts

WAT ARE ZEBRA MUSSELS?

How did they get here? What will they do to Lake Erie? And what will they do to my boat?

It was summer 1989 — just a year after the first zebra mussel was discovered in Lake Erie — and such questions were pouring in to Ohio Sea Grant.

"People called and wanted us to tell them everything we knew about zebra mussels," says Maran Hilgendorf, Ohio Sea Grant communicator. "We were glad to do it, but it meant hours on the phone for the extension agents."

"We were also receiving many requests for speakers," she says. "We wanted to find some way to provide a service without taxing the same people again and again."

So Hilgendorf and her colleagues posed a question: Wasn't there a more efficient way to meet public demand for zebra mussel information?

Today, the answer is clearly "yes." Ohio Sea Grant's solution is two informative fact sheets and a video called Too Much Mussel.

Together, the three pieces form a package. One fact sheet details the invasion and its implications — for both the Great Lakes ecosystem and the economy. The other tells boaters how to keep zebra mussels off their boats and out of inland waters. And the five-minute video provides pictures to accompany the words — striking visual evidence of the zebra mussel's impact on Lake Erie.

Best of all, the information pieces are meeting a need, both within and outside the Great Lakes. Hilgendorf reports that Ohio Sea Grant has distributed more than 300,000 general zebra mussel fact sheets and 30,000 of the boaters’ version since 1989. In 1992 alone, she says, Ohio Sea Grant handled more than 800 requests for the fact sheets from people in 43 states. She also notes that prominent television programs — including PBS's "Scientific American Frontiers" and TNN's "Fishing with Roland Martin" — have incorporated Sea Grant's zebra mussel video footage into their shows.

Hilgendorf says the information pieces began when Ohio extension agent Fred Snyder wrote the first version of a zebra mussel fact sheet in late 1989. Ohio Sea Grant printed and distributed the first copies — to an overwhelming response. Ultimately, the demand for copies became so great that Hilgendorf made a plea: could anyone help Sea
Grant print zebra mussel fact sheets?

Brunswick Marine responded.

To date, the company has printed 250,000 of the 300,000 general zebra mussel fact sheets in circulation and thousands of copies of three other publications — a gift worth about $25,000, Hilgendorf says.

"Brunswick’s generosity allowed us to better serve our audience, but also helped clear the way for other zebra mussel projects — including the fact sheet for boaters (written by extension agent Dave Kelch) and the video (produced by Ohio State University Extension),” Hilgendorf says.

Today, Hilgendorf is pleased about the benefits of the zebra mussel information pieces — for Ohio and the entire Great Lakes region.

“We’ve raised public awareness about zebra mussels. And we’ve filled an information need for other states in the region and many inland states,” she says. “But probably the best outcome is that people have become more knowledgeable about the value of Lake Erie. Seeing this threat to it makes them appreciate the value Lake Erie has for them.”

Don Tharke looks over a copy of the report that was printed at Mercury Marine (photo from PROFILE magazine, Brunswick Corporation’s employee magazine.)
Mussel busters

he old joke on tours of Europe is that if it’s Tuesday, it must be Brussels. Apparently the pace on these tours is so frenetic that the only way to know where you are is to ask what day it is.

Let it be known that travelers on whirlwind tours of Europe have nothing on Chuck O’Neill. He may be in Baltimore instead of Brussels, but the schedule is just as crazy. He’s up and down the East Coast in North Carolina one week, in Connecticut the next. He’s on a plane to Philadelphia, to Nashville, to New Orleans. From Lake Champlain to Chesapeake Bay, his fame is growing. He’s fast becoming one of the country’s favorite traveling mussel busters.

It’s a tough job. O’Neill, an extension specialist with New York Sea Grant, has a serious charge: to bring the people in the five major river basins outside New York state up to speed about zebra mussels. To accomplish this, he and fellow agent Dave MacNeill travel far and wide. They cover Lakes Erie, Ontario and Champlain, as well as the Connecticut, Susquehanna, Delaware and Allegheny rivers and the eastern portion of the Mississippi River basin. They also conducted a workshop in Tulsa for those in Arkansas, Oklahoma, Texas and Kansas to cover the western portion of the Mississippi and the Arkansas rivers. There, at the states’ request, they teach diverse audiences about zebra mussels—everyone from Sea Grant staff to natural resources workers to representatives from industrial and municipal plants.

“Dave tells them about the critter, and I tell them what the critter can do and how to control it,” O’Neill says.

O’Neill and MacNeill started conducting these one- to two-day regional training sessions in 1990. The format is simple, but effective. They devote the first day to basic questions about zebra mussels: what are they? What can they do? Will they get into my river? They also present control options. “everything from keeping mussels off a boat to keeping them out of a nuclear power plant,” O’Neill says.

If the session continues for a second day, O’Neill and MacNeill teach the group such things as how to tell the difference between zebra and quagga mussels and how to test for zebra mussels in rivers and lakes—basic topics in identification and monitoring. They cram as much information as they can into the time available and even bring in other expert speakers.

“It really is a ‘know your enemy’ type of approach,” O’Neill says.

He estimates that he and MacNeill did 125 sessions that ranged from a few hours long to the full two-day workshops in 1990 and 1991, reaching 5,000 people in the mid-Atlantic states and northeast.

It’s this kind of impact that’s so essential in winning the battle against zebra mussels, O’Neill says. In fact, it was the need for more zebra mussel information in the mid-Atlantic and northeast that got the project started in the first place.

“We didn’t see all the water users—the small-town industries, the engineers from bigger industries—making it to the major conferences,” he says. “And we didn’t see people

New York Sea Grant Extension Specialist Dave MacNeill examines a vial of zebra mussels. (photo by Scott Weston)
New York Sea Grant has recently entered an agreement with the USDA Extension Service to provide "teach the teacher" training for inland state Cooperative Extension Services to "pass the baton" from Sea Grant to Extension as the mussel moves further inland.

But O'Neill doesn't take full credit for the idea. The National Sea Grant office also recognized the need and encouraged New York Sea Grant to pursue it, he says.

"They wanted us to provide information that wasn't getting to people from within their own areas."

For New York Sea Grant, the question was how to get regional training sessions going. The answer lay with the U.S. Fish and Wildlife Service. O'Neill and MacNeill proposed the project, and the Fish and Wildlife Service signed on as a co-sponsor, agreeing to make presentations at the sessions and to pay for outside speakers and any printed materials.

"This is a unique, strong collaboration," O'Neill says. "It's important that we're doing these sessions with the Fish and Wildlife people, even though we're not from the same parent agency."

Today, O'Neill reports that the training sessions are working out well for all involved.

"We're working very closely with the mid-Atlantic and New England Sea Grant networks and we're bringing them up to speed fast," he says.

Fast indeed. In March, O'Neill trained members of the mid-Atlantic network; in April of 1992, he trained New Hampshire/Maine Sea Grant and Louisiana Sea Grant. He's confident that because they've learned from the Great Lakes' experience, they'll know what to do about zebra mussels when the time comes.

"They won't have the headache of having to figure out what to do. They can just act."

Nancy Balcom, extension educator in fisheries and aquaculture with Connecticut Sea Grant, agrees.

"The sessions are great," she says. "In terms of time and value, many of our participants said it was the best workshop they'd ever been to. It bumps you up the learning curve real fast."

O'Neill sees New York Sea Grant benefiting, too.

"We're reaching an audience that didn't know Sea Grant existed, forging a lot of good linkages," he says. "Media and federal agencies are getting to know us better. They're starting to realize that Sea Grant has so much good information to give them."
Musseling in on research

About the same time each year, it happens: the invasion of the zebra mussel people. Their experiments and projects temporarily tucked away, scientists, graduate students, business executives and resource managers from California to Connecticut converge by the hundreds for an intensive week of zebra musseling—everything from the ins and outs of spawning to zapping the bothersome bivalves with ultraviolet light. The occasion? The annual International Zebra Mussel Research Conference—sponsored, in part, by the Great Lakes Sea Grant Network.

For those interested in zebra mussels—both researchers trying to understand them and industries trying to get rid of them—it's the major event of the year.

"The conference is the main network for getting results of zebra mussel research," says Indiana University-Kokomo biologist Dave Garton. "It's very valuable."

And it's growing. The first conference, hosted in December 1990 by Ohio Sea Grant, drew an audience of nearly 200 from 20 states and Canada and included 34 presentations on zebra mussel biology, ecology and control by nearly 90 authors. Audience members included prominent scientists from Canadian and American universities, as well as a member of the Ohio legislature and a writer from Time magazine.

The second conference, hosted in November 1991 by New York Sea Grant, drew an audience of 361 from 29 states, the District of Columbia and Canada and included 70 presentations by nearly 150 authors.

For Ohio Sea Grant extension agent Fred Snyder, who helped organize the first conference, these numbers prove what many suspected all along: that zebra mussel research warrants its own forum.

He says Ohio Sea Grant initiated the first conference to ensure that there would be such a gathering.

"There was no forum for researchers to exchange their findings about zebra mussels," he says. "It was a big problem."

Snyder says it was no easy job solving this problem. It took some...
furious fact-finding to pull it off.

"We had to find out who was doing zebra mussel research, who had findings to present and who would be interested in that information," he says. "We had a lot of ground to cover in a few months."

But Snyder is quick to credit his colleagues within the Great Lakes Sea Grant Network with coming to his aid.

Through the cooperation of the communications network, he says, the conference was promoted to many major media outlets, resulting in coverage on NBC News and the Today show.

But more importantly, Snyder says, the first zebra mussel conference showed the necessity of good information flow among scientists and served as a model for subsequent conferences.

Today, the conferences highlight Sea Grant's position in the scientific world, identifying it as a major player in zebra mussel research.

"Our credibility and visibility have increased," he says. "And it's likely that the conferences have inspired more and better proposals for zebra mussel research."

But beyond the benefits for Sea Grant, Snyder believes the conferences ultimately make for better science—and better problem-solving.

"Through the zebra mussel research conferences, scientists interact with each other and can potentially collaborate and cooperate in a way they wouldn't have done otherwise," he says.

Dave Garton agrees.

"One of the real benefits of the conferences is definitely collaboration," he says. "Another is the rapid dissemination of knowledge about zebra mussels. The conference fits in that gap between when a project is completed and when the results appear in print."

"Also, it's useful in that we university scientists can meet with our counterparts from industry and government agencies," Garton says. "From my point of view, I get a lot of interaction I normally wouldn't have on my campus."

Fortunately, all these benefits will continue. In 1994 and beyond, Sea Grant will join with Canadian conference organizers to offer one conference each year. The fourth International Zebra Mussel Research Conference is scheduled for March 7-11, 1994, hosted by the University of Wisconsin Sea Grant Institute.

Garton is looking forward to it.

"It will be my chance to get the latest information about the state of zebra mussel research," he says. ▲
It's a typical day at the Zebra Mussel Information Clearinghouse. Dr. Dan Molloy is visiting from the New York State Museum at Albany, wading through a hefty stack of journal articles, scanning papers for that elusive something from someone else's research that might help him with his own. Administrative assistant Jeanine Munn is taking requests for inter-library loans and journal article copies on the 1-800 line. And director Chuck O'Neill is reviewing submissions for the upcoming issue of *Dreissena polymorpha Information Review*, the clearinghouse's research-oriented newsletter.

This is the hybrid known as the Zebra Mussel Information Clearinghouse — part library, part public information office. For its part, the library features a collection of 1,400 zebra mussel research papers from peer-reviewed journals, including nearly 400 in Cyrillic. And for its part, the bimonthly *Dreissena polymorpha Information Review* is the only place in the Great Lakes to find preliminary zebra mussel research findings. It has 500 subscribers in 40 states, four Canadian provinces, The Netherlands and Hong Kong.

If it seems that the clearinghouse leads a bit of a double life, it's no wonder — even its office is cut in two. The site is the old library at SUNY-Brockport, the biggest and oldest building on campus. Half is in its original state, complete with stacked shelves and crowded reading tables. The other half has been converted to offices bustling with publishing and information operations, telephones ringing, printers whirring.

Fortunately, the Zebra Mussel Information Clearinghouse and its small corps of employees see plenty of activity on both sides, says director Chuck O'Neill. Since it began in 1990, the clearinghouse has tripled the number of research papers in its collection and has distributed 14,000 copies of *Dreissena polymorpha Information Review*. Further, in 1991, it handled nearly 900 information requests from people in 37 states and four Canadian provinces; in 1992, the clearinghouse served 1,000 people from 40 states and five provinces.

People who use the clearinghouse are "folks of all stripes," O'Neill says. The largest user groups are consulting engineers, researchers and government employees, followed closely by industrial employees. There's a lot of diversity, even within categories.

"We work with everyone, from the guy who's got a cottage on Lake Erie and is concerned about zebra mussels to officials with EPA, the U.S. Army Corps of Engineers, Eastman Kodak and Xerox," says O'Neill who characterizes the clearinghouse as a liaison.

"We act as a broker, putting researchers in touch with each other, putting industry and utility researchers in touch with a basic theoretical scientist," he says. "We also try to help smaller operations gain experi-
tise. We put the consulting engineer who just designed a power plant in touch with the engineer for a power plant that pumps just six hours a day."

According to O'Neill, there was a real need for the clearinghouse, even before it began. Researchers were frustrated by how little they knew about zebra mussels and how difficult it was to find good, current information.

"They could only find a few things easily, and those were written in 1954 and didn't say much," O'Neill says.

Seeing a potential need that Sea Grant could fill, New York Sea Grant approached the Empire State Electric Energy Research Corporation and asked its scientists whether their zebra mussel research information was adequate. They gave a resounding no.

"They said they had a pressing need for more information, and that if we wanted to start a technical library, they'd help bankroll it," O'Neill says.

Sea Grant accepted. Additional grants from Eastman Kodak, the Monroe County Water Authority, the Great Lakes Sea Grant Network and New York Sea Grant helped the zebra mussel clearinghouse become a reality.

Today, the benefits of the clearinghouse are clear.

"There's a lot of collaboration going on between researchers and engineers. I don't think that happens unless there's a clearinghouse," O'Neill says.

The U.S. Fish and Wildlife Service, for example, has used clearinghouse information on zebra mussel sightings to develop its own computerized geographic information system map of zebra mussel sightings.

The New York State Museum's Dan Molloy, for one, is enthusiastic in his praise for the clearinghouse.

"I can't speak well enough of it," he says. "It's extraordinary in how it pulls all the zebra mussel literature together. It's personally saved me an inordinate amount of research time and has speeded up general communication about zebra mussels."

O'Neill emphasizes that the clearinghouse benefits people outside New York as well.

"We're putting researchers in touch with each other, but it's more than that," he says. "Our providing this service means that each Sea Grant program can use the money it's receiving on things that are important to the people of the state. They don't have to spend a major chunk reinventing the wheel."

O'Neill relishes the role New York Sea Grant plays in providing a service for the region. He's even taking steps to improve it. Currently, O'Neill and company are creating an electronic form of the ever-expanding zebra mussel research bibliography. It is now available to U.S. and Canadian electric utilities on EPRI Net and they hope to have it available to Internet users early in 1994. They're also creating a master list of all zebra mussel research that's been funded by Sea Grant, the government or private sources. And O'Neill has a scientist formerly associated with the Ukrainian Academy of Sciences translating a Cyrillic bibliography into English.

People who use the clearinghouse are "forks of all stripes," O'Neill says.

The largest user groups are consulting engineers, researchers and government employees, followed closely by industrial employees.

For O'Neill, it's all part of running a good clearinghouse.

"Scientific research without an outlet to user audiences is research only partially appreciated," he says.
Zebra mussels & the bottom line

Each January since 1991, Warren Isaacson has taken out an insurance policy. It has no deductible, no terms, no promise of compensation. But for Isaacson, water department superintendent for the city of Escanaba, Mich., it's a keeper. His insurance policy is a presentation about minuscule microbes that could someday become tiny zebra mussel assassins. It's an update on government regulations on molluscicides; it's a helpful chat with colleagues over drinks. It's Michigan Sea Grant's zebra mussel conference for municipal and industrial water users.

No conference can completely ensure against zebra mussel infestation. But for Isaacson and about 200 others annually, the conference does ensure that they have the latest information on key issues.

The format is straightforward. Scientists, resource managers and government officials come from around the country to speak to an audience of water managers from both private industry and city facilities. The crowd includes such big names as Detroit Edison, Morton Salt Co., Michigan Department of Natural Resources and Exxon. They all gather at the Kellogg Center on the Michigan State University campus for two days of give and take, discussing new findings in zebra mussel biology, monitoring and control techniques and regulatory implications. Some participants are already facing zebra mussel infestation; others, like Isaacson, are there to prepare for it.

The speakers include experts from within Sea Grant, but also prominent researchers from other organizations, says Chuck Pistis, Michigan Sea Grant extension agent. Renata Claudi from Ontario Hydro, Wayne Weiner from Maryland Sea Grant and Dan Molloy from the New York State Museum are just a few who have been featured since the meetings began in 1991.

Pistis says the conference is simply a local, more convenient variation on the standard professional meeting. The need for a conference with a local spin occurred to him, he says, after he came back from a zebra mussel conference in Rochester, N.Y. He knew the big conferences were valuable, but also knew that local Michigan water users didn't have the time or the money to get there. Responding to what he saw as an "educational need," he and fellow Sea Grant agent Steve Stewart proposed a zebra mussel conference for Michigan. The first one was held in January 1991.

That meeting was well-received, as were the next two, Pistis says. Participants rated the 1992 and 1993 conferences a 3.35 on a scale of 1-4, 1 meaning poor and 4 meaning excellent.

Pistis says the biggest reason for the high marks is that the conferences save people money.

"At the conferences, peers talk to each other about what they're doing. If one has a proven track record in dealing with a certain problem, just sharing that with the other saves money," he says.

Isaacson echoes that sentiment.

"The value of these conferences is that we all stay up-to-date. As a result, we don't spend money on something that's not worthwhile."

Beyond the dollars saved, Pistis also sees intangible benefits for the entire region. Sea Grant included.

The conferences serve almost as mixers, ways of introducing participants to Sea Grant people and services from all the Great Lakes states.

Pistis says the result is an enhanced image of Sea Grant and more healthy dialogue about zebra mussels.

"Because of these conferences, the people in Michigan and the region involved with zebra mussels talk to each other a lot more," he says. "There's great value in that."
May I see some I.D., please?

They’re entrenched in the Great Lakes. They’re spreading into the mid-Atlantic region. Soon they may be in California.

If you guessed zebra mussels, you’re right—kind of. These fast-spreaders are Wisconsin Sea Grant’s zebra mussel information cards. They’re 4½ by 3½-inch flier-type cards small enough to fit in a wallet. Though tiny, they’re full of information. On the outside, two-color photographs show the mollusk’s tell-tale markings: the brownish-yellow striped pattern and D-shaped shell. Inside, readers learn about the multi-billion-dollar threat zebra mussels pose, how to identify them and how to report sightings.

Best of all, these cards have spread even faster than the mussels themselves. Wisconsin Sea Grant communicator Stephen Wittman reports that nearly one million cards have been printed since the project began in 1990. In 1992 alone, Wisconsin Sea Grant produced more than 580,000 cards, including more than 110,000 for other Sea Grant programs in the Great Lakes (customized for each state) and almost 8,000 for the Nashville office of the U.S. Army Corps of Engineers.

Wisconsin Sea Grant provides these cards to any group that’s interested, at cost. Most card carriers reside in the Great Lakes region, but Wittman reports that he’s also filled sizable orders for programs in the Mid-Atlantic Sea Grant Network, the Lake Champlain Basin Program and the Tennessee Shell Company, the nation’s leading exporter of commercially harvested freshwater mussels. Wisconsin Sea Grant has even produced a version in Canadian French for the Ontario Ministry of Natural Resources.

According to Wittman, the cards sprang from a need for fundamental public awareness about zebra mussels—both how to identify them and why it is important to do so. The idea took root after Wisconsin Sea Grant graphic designer Christine Kohler saw a Lyme tick identification card produced by the Wisconsin Department of Natural Resources and asked “why not zebra mussels?”

Four years and thousands of copies later, the cards are a clear success. Wisconsin Sea Grant has printed more cards than almost all previous publications combined, and total distribution is among the largest of all Sea Grant zebra mussel publications. Also, Wittman continues to receive dozens of inquiries about the card from industries and government agencies as far away as California, Arkansas and Connecticut.

“We’re pleased the cards have turned out to be so popular,” Wittman says.

---

**Zebra Mussel Alert**

The bivalve-like zebra mussel poses a multi-billion-dollar threat to industrial and public drinking water supplies and may become a costly nuisance to shippers, boaters, commercial fishermen, anglers and beachgoers as well—far more costly in human terms than all previous Great Lakes invaders combined.

Public assistance in reporting zebra mussel sightings at new locations is essential to help prevent its spread to our inland lakes and rivers.

- Zebra mussels look like small clams with a yellowish and/or brownish D-shaped shell, usually with alternating dark and light bands of color (thus the name “zebra”).
- They can grow up to two inches long, but most are under an inch long. Zebra mussels usually grow in clusters containing numerous individuals (see photo) and are generally found in shallows (0 to 30 feet deep), algae-rich water.
- Zebra mussels are the ONLY freshwater mollusk that firmly attaches itself to solid objects, including rocks, boat hulls, etc.

Write the date and precise location where the mussel was found, take the mussel with you (preferably if possible) and (in rubbing alcohol if dry case) DON’T throw it in the water, and IMMEDIATELY contact the nearest Ohio Sea Grant Navy Service field office in Elyria, Pataskala or Port Clinton, or phone (614) 292-8949.

---

University of Wisconsin Sea Grant Institute
Look inside boxes at Michigan Sea Grant and you’ll find zebra mussels, ruffe, spiny water fleas, sea lamprey, shoots of Eurasian water milfoil, stalks of purple loosestrife, tube-nosed goby and alewives.

There’s no genetic tinkering going on here, and it’s not an aquatic exotic species convention. These inhabitants are photographs, slides and illustrations, some of the members of Great Lakes Sea Grant Network’s Nonindigenous Species Graphics Library.

According to Carol Allaire, a Michigan Sea Grant writer and editor who helped develop the collection, Michigan Sea Grant has distributed more than 1,200 photographs, slides and illustrations of exotic species since the graphics library began in 1991. Because most people who call the library want camera-ready graphics of the zebra mussel, the collection is zebra mussel-heavy. It includes more than 100 shots of zebra mussels enrusting everything from an unsuspecting crayfish to a Lake Michigan shipwreck.

Most requests come from government agencies, industries and other Sea Grant programs, Allaire says. The U.S. Army Corps of Engineers, for example, has used slides in staff training presentations, and a Cleveland-based BP Oil executive has used slides and photos in presentations at corporate headquarters in London.

Though they’re not the largest user group, prominent museums and media organizations also use the service. Library graphics have appeared at the Kohl Children’s Museum in Wilmette, Ill., the Bell Museum of Natural History at the University of Minnesota and in Science and National Fisherman magazines.

Requesters can borrow the graphics from Michigan Sea Grant and return them after a two-week lending period or can purchase copies for a nominal fee. To get the word out about the library, Michigan Sea Grant distributes library catalogs and color promotional brochures at various conferences and meetings.

For Allaire, the creation of the graphics library was an example of Sea Grant at its best. She says the Great Lakes Sea Grant Network saw the spread of zebra mussels and the accompanying media stories and presentations about it, anticipated a need and began filling it.

“We just asked ourselves how we could best meet this need and began doing it.”

For Roland Humborg, an environmental resources specialist with the U.S. Army Corps of Engineers, this decision came just in time.

“Before I heard about the graphics library, I couldn’t find any source of...
It's early May, and Leslie Kilvery and Michelle Smith from Janet Franklin's 10th-grade biology class are on a barge that's permanently anchored at the Central Illinois Power System facility on the Illinois River. Notebooks and sampling jars in hand, they look like two typical, if young, field scientists. Tension builds as they reel in about four feet of rope and pull up a curious-looking contraption— a series of four successively larger layers of plastic plates attached to a steel cable. They huddle to inspect the plates. The evidence is clear. One girl smiles; the other groans. They've discovered zebra mussels.

Franklin's students from Meredosia-Chambersburg High School in Meredosia, Ill., are some of the youngest soldiers in the battle against zebra mussels. They're part of the Illinois Rivers Project, an effort that involves 130 Illinois high schools and almost 10,000 students in gathering data on the Mississippi, Illinois and other major rivers and lakes in the state.

Though the project has been around for three years, the zebra mussel monitoring component is a new addition. Credit, in part, belongs to Illinois-Indiana Sea Grant research coordinator Glenn Stout for suggesting the idea and to Illinois-Indiana Sea Grant for providing financial support.

According to Cindy Bidlack, project coordinator for the Illinois Rivers Project, the zebra mussel monitoring effort is pretty straightforward. School groups set monitoring devices out in late March. Then over the course of the next eight months, they visit the sites every two weeks. When zebra mussels are found, students notify Bidlack or Doug Blodgett, associate biologist with Illinois Natural History Survey's long-term resource monitoring program. Some students also send preserved mussel samples to Blodgett. The cycle ends in November, as weather conditions dictate.

The project is young, but Bidlack emphasizes that it has produced some significant results for both scientists and students. Ten schools, including Meredosia-Chambersburg, reported mussel sightings to Illinois Natural History Survey in 1992. In addition, Illinois schools have embraced the project, she says, and have worked it into student life in many different ways. At some schools, the entire first-year class goes monitoring for zebra mussels; at others, only upper-level biology students participate. Franklin's students at Meredosia-Chambersburg, for example, try to culture the little mollusks in aquaria and ultimately hope to capture the zebra mussel's entire life history on videotape.
In Bidlack’s view, this project is providing a real service. Government agencies facing stiff cutbacks need help where they can get it, “people to act as their eyes.”

At the same time, says Bidlack, students need to gain awareness about water quality and all the other environmental issues that they will be voting on as adults.

Franklin, too, is enthusiastic.

“It’s good for students to realize that things they learn in school have a bearing on the real world. It’s been a very good experience for them.”

It was a vision of these kinds of benefits that led Stout to suggest the project. The idea hit him while he was attending the second International Zebra Mussel Research Conference in Rochester, N.Y., he says. Talks he heard there confirmed his evaluation that zebra mussels would spread down the Illinois River from Chicago to St. Louis. He knew high schools in the area were already doing water quality sampling. Why couldn’t they keep an eye on zebra mussels, too?

Stout admits he was excited about the prospect.

“I called the Illinois Rivers Project from Rochester,” he says. “I couldn’t wait.”

Things moved pretty quickly after that. Materials to build the monitoring devices were distributed—two sets per school—at the Rivers Project’s student meeting in March. Doug Blodgett came to the weekend meeting to train the teachers attending how to use the devices correctly. The schools took it from there.

Today, Stout and Bidlack see many of their hopes for the project coming true. It’s been favorably received at meetings and symposia from Sweden to Japan and was recently included in a feature story in National Geographic. Students continue to gather helpful information for Illinois Natural History Survey.

“They fill in the holes that can’t be attended to by staff,” Blodgett says.

And student interest remains high. At last year’s student meeting of the Illinois Rivers Project, Janet Franklin’s two 10th-graders presented a short videotape about potential infestation sites within the Central Illinois Power System facility. The response was very positive, Franklin says.

The next step is to increase zebra mussel monitoring efforts throughout the region. Indiana is next. Bidlack reports that a fledgling effort, Water Watchers of Indiana, is currently underway. Illinois-Indiana Sea Grant plans to provide financial support.

“We’ve seen it work before,” Stout says. “It’s just a good investment.” ▲

Glenbrook South teacher Jim Shefard and student Tara Aylton with zebra mussel monitoring device.
Getting the scoop

“New invaders menace Lakes”
“Tiny foreign clams loom large in Lake Erie’s future”

“Uninvited guests crash Lake Erie parties”

It was 1991 — three years after such headlines heralded the zebra mussel invasion of the Great Lakes. For Maran Brainard Hilgendorf, Ohio Sea Grant communicator, it was a crucial time. Zebra mussel research was beginning to yield results, with many findings disproving early concerns. What was the best way to let the public know?

For Ohio Sea Grant, an information session for science journalists proved to be the key.

The format was simple, but effective. The Scientists’ Institute for Public Information (SIPI) and the Society for Environmental Journalists provided the writers — prominent science journalists attending a workshop on Great Lakes environmental reporting. Ohio Sea Grant provided the zebra mussel know-how — Ohio Sea Grant director Jeff Reutter, researcher David Garten and Ontario Hydro scientist Renata Claudi.

Together, the two groups met in Toronto in mid-April 1992, exchanging questions and answers for a couple hours on a Sunday morning. The discussion was broad, including such topics as Canadian and American zebra mussel regulations, ongoing research and the invasion’s effects on the Great Lakes ecosystem and economy.

Major newspapers — such as the Minneapolis Star-Tribune and The Buffalo News — public television stations and network affiliates were represented at the session.

This was just what Hilgendorf was hoping for.

“There was just so much new information about zebra mussels coming out. We needed a vehicle to distribute new research findings to established science reporters,” she says.

Hilgendorf says the science writers’ session became reality only after about two years of planning. She proposed the project to the Great Lakes Sea Grant Network and the National Sea Grant office in 1990. Then in August, funding for the session secured, Hilgendorf started considering people to lead it.

In the end, Reutter, Garten and Claudi seemed the best choices.

“Those three made the most sense,” Hilgendorf says. “Under Jeff Reutter, Ohio Sea Grant was leading the nation in zebra mussel research. Dave Garten was the zebra mussel expert. And Renata Claudi brought the perspective of being a scientist with the largest business that uses Great Lakes water.”

Ultimately, the hard work it took to plan the session was worth it, Hilgendorf says.

“In just about two hours, journalists were able to get a greater understanding of the zebra mussel issue and were also able to ask questions about infestations in their specific regions,” she says.

Dean Rebuffoni, who attended the session from the Minneapolis Star-Tribune, agrees.

“The zebra mussel session was extremely informative,” he says. “It was useful not only to members of the media in the Great Lakes region, but also to the scientists. We found out we really can speak the same language. I left with a notebook full of contacts and ideas. I’d love to do another one,” he says.

Hilgendorf adds that the Sea Grant programs in the Great Lakes region also benefited from the session.

“We were able to get more coverage of an important issue,” she says, pointing to stories that appeared in the South Bend Tribune and Minneapolis Star-Tribune.

“And we were able to establish relationships with good science reporters — relationships we can build on in the future.”

“It was a very successful and very productive effort,” Hilgendorf says. ▲
An exotic exhibit

"Who's feeding the lamprey from Great Lakes fisheries?" asks a boldly lettered sign above a display panel at the University of Minnesota's Bell Museum of Natural History. A pretty obvious clue is the sea lamprey hanging from the panel, its suction cup-like mouth affixed to an unfortunate fish.

Fortunately for museum visitors, this lamprey is no blood-sucker; it's a puppet, and its prey is a photograph. Along with a trophy stuffed carp and dozens of paintings, photographs, cartoons and diagrams, it's part of the Bell Museum's new exhibit titled "Exotic Aquatics of the Great Lakes Region."

The display, which opened to the public in July 1992, is the result of cooperation among the Minnesota legislature, the Bell Museum, the Science Museum of Minnesota, the Minnesota Department of Natural Resources, several other state agencies and two zoos. And Minnesota Sea Grant.

Four museum staff worked full time for a year to create it, says Don Luce, the Bell Museum's curator of exhibits. The finished product is a series of 12 panels on different exotics topics.

The form may sound familiar, but this is no ordinary display. "Exotic Aquatics" includes sliding panels that kids can move back and forth to show a lake scene, both before and after exotics. It has a magnetic map of the Great Lakes region, complete with little boats and cartoon characters that kids can move around to show how exotics spread. And it even has a giant marsh ecosystem jigsaw puzzle with two different solutions: a complex one with cattail at the base of the food chain and a simpler one that can be solved with purple loosestrife.

All these bells and whistles belie a single, simple goal—to teach, says Minnesota Sea Grant writer Mike McLean. The main thrust of the display is to teach people that introductions and infestations of exotic species don't happen merely by chance or accident—that they happen and succeed partly because of environmental neglect, he says.

"One of the reasons exotics are here is because the natural environment has been perturbed. If you take a plow and dig up a field, weeds take advantage of that open space. There's really no difference between a weed and an exotic that takes advantage in a lake."

For McLean, the display was just what Minnesota needed to get its environmental groups working toward a common goal.

"One after another, an exotic would become a problem, the different groups would try to deal with it, and they'd come up with the same advice," he says. "The idea was to put together a comprehensive exhibit to educate people about the interrelationships between these problems."
Thanks to a $500,000 grant from the Legislative Commission on Minnesota Resources, money made available from lottery ticket proceeds, the idea came to life. Or at least still-life. Minnesota Sea Grant’s involvement first came when it joined the consortium of environmental groups that proposed the display to the legislature. Later, Minnesota Sea Grant served as an adviser for the display’s creators at the Bell Museum, providing expertise for the display panels on zebra mussels, sea lamprey, exotic species movement and control options.

Planning the exhibit was a pleasant experience and beneficial for Minnesota Sea Grant, McLean says.

“It really was a very good cooperative effort. Minnesota’s a pretty small state, and the consortium was a pretty small group. Most people knew each other, and working relationships became stronger.”

Ultimately, three copies of the display will be available to travel—one that can be wall-mounted and two that can be displayed free-standing.

“It’s geared for easy setup and easy maintenance,” McLean says. The display is booked at the Bell Museum, the Science Museum of Minnesota, state parks and visitors centers until July 1993. After that, it will be available for loan throughout the Great Lakes region. McLean says that some Great Lakes Sea Grant programs have proposed to cover transport costs to bring the display to their states but that final decisions on this are still pending.

There are high hopes riding on this display among all the consortium members, McLean says. The official goal is that one million Minnesotans will see and learn from it.

For McLean, this seems likely.

“This display will be beneficial because students will be able to take a basic biological problem out of the textbook and see its application to principles in the real world,” he says. “As for adults, it will help them understand that the problems at their dock may be related to the way they’ve treated their lakeshore, that these problems aren’t always caused by some far-off shipper.” McLean doesn’t see these lessons as limited to Minnesota.

“This display will benefit all the Great Lakes states simply because there’s a lot of common information,” he says. ▲
On the lookout

After three years, it's become something of a ritual: Every week from late June through November. John Babiniec, a water intake specialist with Wisconsin Electric Power Co. in Milwaukee, pumps 1,000 liters of unfiltered Lake Michigan water through a 55-gallon steel drum. But this is no ordinary drum; inside is a funnel-shaped mesh net with a tiny bucket attached at the tip. The water through the drum, Babiniec rinses the net, retrieves the bucket and carefully pours its contents into a sample bottle. Later, with the help of a stereo-microscope with a polarized lens, he'll see the fruits of his labor: zebra mussel veligers swimming around in the water intake sample, wriggling around under the microscope, plain as day.

This is Wisconsin Sea Grant's zebra mussel watch in action. Begun in spring 1990, it's a sampling and analysis project that involves 16 municipal water intake facilities, 11 power plants, five industries and four Wisconsin colleges and universities, all with the goal of determining how many zebra mussel veligers and young adults are present in Wisconsin's Great Lakes waters.

It's a big job. To tackle it, Wisconsin Sea Grant divides it into categories—harbors and water intakes.

Four Sea Grant researchers and their students handle Wisconsin's 10 major harbors. They sample at 28 different sites every two weeks, using a mesh net to snag veligers and plexiglass pyramids to collect young adults.

At the same time, industrial and municipal technicians sample at their own water intakes, recording data about zebra mussel quantity, size and density, much the way the scientists do. The end result of both efforts is a mass of helpful information about where zebra mussels are, how fast they're growing and reproducing, and how dense the colonies really are. Wisconsin Sea Grant compiles this information and gets it out to the people who need it, both in person and through the periodic newsletter Zebra Mussel Update.

Al Miller, project director and assistant director for advisory services with Wisconsin Sea Grant, says the project began because Wisconsin industries facing zebra mussel infestation needed sound information about what was actually happening in Lake Michigan and Lake Superior, not merely newspaper stories and unconfirmed reports.

"Businesses don't make decisions based on newspaper stories," he says. "They weren't going to spend $300,000 on control measures until there was more scientific information about what was really happening with zebra mussels."

According to Miller, the Wisconsin Department of Natural Resources also was hesitant to begin taking steps to control zebra mussels prematurely.

"They didn't want to put a lot of chlorine into the lakes if it wasn't necessary," he says.

Dave Michaud, senior scientist in Wisconsin Electric Power Co.'s environmental department, says there was also a tremendous need in industry for information about how to conduct a systematic zebra mussel watch program.

"In 1990, not many companies had biologists on staff who were even trained in identifying zebra mussels," he says. "No one really knew what they were looking for."

Recognizing these needs, Wisconsin Sea Grant responded. Miller and colleague Cliff Kraft, zebra mussel watch coordinator, identified the Wisconsin harbors
and nearshore areas most likely to be exposed to zebra mussels, got a list of water users in those areas and got to work contacting them. The response was positive.

“We talked to various industries, and they said they’d like to have us analyze samples in their plants,” Miller says.

In working with these industries, Wisconsin Sea Grant soon shifted out of active sampling and into an advising role. Seeing that the water intake technicians were already doing many water quality tests, Miller and Kraft decided that the best use of Sea Grant’s time would be to teach the technicians how to identify veligers and adults. More than 200 trained technicians later, Wisconsin Sea Grant is now nearly out of the intake sampling and analysis business; the technicians have taken over.

Kraft says he’s pleased with the way intake technicians have responded and that he has full confidence in their ability.

“Anybody who’s doing water quality tests in a plant is certainly able to identify juvenile and adult zebra mussels,” he says.

Miller is pleased with the positive response the zebra mussel watch has received among Wisconsin industries, offering recent grants from Wisconsin industries totaling over $40,000 as an example.

“Without a doubt, the feedback has been very positive,” he says. “The water user community is very pleased with what they’re getting, and they’re very willing to provide financial support to see that it continue.”

Proof of this comes from Michaud.

“When we were asked to help fund the program this year, it was no big deal,” he says. “Sea Grant has been very helpful in providing us with baseline data that we’re confident with and doing it relatively quickly. They’ve saved us money by producing some pretty amazing results for a tiny number of dollars. I don’t think a private firm could have done it.”

But Miller emphasizes that the rewards aren’t all financial.

“Probably the most positive thing to come out of this project is that it has opened the door between Sea Grant and industry in the state,” he says. “Our previous relationships with industry were not that strong. Now that we’re into the zebra mussel issue, communications have opened and we’re now talking about other issues.”

For Miller, the Great Lakes region also benefits from the zebra mussel watch.

“Sea Grant has taken on new life because of the zebra mussel effort. One program’s accomplishment enhances Sea Grant’s image in the whole region,” he says. “It carries over.”

Researchers have found that mussels will attach to almost all solid surfaces, natural or man made. This multi-material sampler was placed in the western basin of Lake Erie in May of 1989. (Photo provided by the Ontario Ministry of Natural Resources)
HOW MANY CUY AND BUSINESS
water users along lower
Lake Michigan have seen
zebra mussels? Where? What are
they doing about them? Do water
users know enough about combatting
the pesky mollusks?

Robin Goettel wanted answers
— answers that weren’t readily avail-
able.

“We didn’t know what the area
water users were doing about zebra
mussels, and we didn’t know if
they were getting the information
they needed,” says Goettel,
communications coordinator for the
Illinois-Indiana Sea Grant Program.

So Goettel, Illinois-Indiana Ma-
rine Advisory Service leader Joe
O’Leary, former communications
assistant Kimberly Meenen and
University of Illinois decision data
specialist Gail Snowdon set out to
remedy the situation.

The remedy was a 33-question
“information needs” survey. The
Illinois-Indiana Sea Grant team be-
gan work in June 1991, determining
topics, writing questions, selecting
a random sample. Five months later
the survey was ready and was
mailed to 29 municipal and indus-
trial water users in Illinois and Indi-
ania’s lakeshore counties. According
to Goettel, most of the organizations
surveyed were medium-sized munic-
ipal water treatment plants, but the
group also included Chicago Water
Works, Commonwealth Edison and
the Great Lakes Naval Station.

The goal of the survey was two-
fold: to gather data on the ever-in-
creasing spread of zebra mussels and
to act as a sort of report card—a
gauge of how well Illinois-Indiana
Sea Grant was meeting the area’s
information needs.

Thanks to a 93 percent response
rate, Goettel and her colleagues got
the data they wanted. Survey results
showed that 74 percent of municip-
al and industrial water users have
seen zebra mussels at their plants in
Lake Michigan and that 80 percent
of these sightings are the result of
industry-run monitoring programs.
The results further showed that 50
percent of respondents treat the wa-
ter as a means of controlling zebra
mussels, mainly with chlorine.

“These findings were very help-
ful because they allowed us to get a
better handle on the scope of the in-
festation in lower Lake Michigan,”
Goettel says.

She says that data about the
area’s information needs also were
valuable. Survey results showed
that respondents prefer to get their
information about zebra mussels
from workshops and newsletters,
and that 73 percent think their in-
formation needs are being met.

According to Goettel, informa-
tion like this was just what Sea
Grant needed.

“Many of our efforts were rein-
forced and verified, but we also
learned about areas we should em-
phasize more to most effectively
educate the water users,” she says.

As one example, Goettel notes
that several respondents asked for
more information about ways to
control zebra mussels and how
much these methods cost. As a result, Illinois-Indiana Sea Grant included journal articles and a list of publications about zebra mussel control with the summary of results it sent to each respondent. Future follow-up plans include a slide show about control methods that will be available throughout the Great Lakes region.

Goettel says the slide show, to be written by prominent zebra mussel scientist Ellen Marsden of the Illinois Natural History Survey, will become a feature of future industry workshops. The emphasis will be on teaching industry leaders how to choose the most appropriate, environmentally friendly and least expensive control technologies from among the 50 available. Goettel says Marsden also hopes to show industry leaders how to implement their chosen methods.

Goettel says she hopes the slide show will help people both within and beyond the bounds of the Hoosier and Illini states deal more effectively with zebra mussels.

“Our goal is always to ask the questions that need to be asked and then get information out to those who need it,” she says.
Mussels and the Mississippi

They were coming — no doubt about it. It was early winter 1992 and zebra mussels were already in the Illinois River. It was just a matter of time before they made it to the Mississippi.

Fortunately, Minnesota Sea Grant was ready with the age-old defense — information. If the spread into the Mississippi couldn't be prevented, it could at least be understood in time. The race was on.

It was close, but thanks to the Upper Mississippi River Basin Association, Minnesota Sea Grant and more than a dozen other agencies from Arkansas to Wisconsin, the upper Mississippi water users got the head start they needed in the race against zebra mussels — an introduction to them from the people who know them best — the Great Lakes water users. In early April 1992, the two camps, 250 strong, converged in suburban Minneapolis for a conference. What followed were two days of straight talk about what zebra mussels are, how much damage they can do and what can be done about them. (For the record, zebra mussels were discovered in the Mississippi just two months later.)
“It was a very practical, down-to-earth conference,” says Mike McLean, a writer with Minnesota Sea Grant who helped organize it.

Scientists, resource managers and utility operators came from all over the Great Lakes region to bring their upper Mississippi counterparts up to speed on the pesky mollusks. Presentations spanned broad territory, covering the tiniest aspect of the mussel’s anatomy, its monumental effects on the power industry and everything in between. Dave Garton and Fred Snyder from Ohio Sea Grant, Doug Blodgett from Illinois Natural History Survey, Pam Thiel from the U.S. Fish and Wildlife Service and Jack Mattice from the Electric Power Research Institute were just a few of the featured speakers. Holly Stoerker, chairwoman of the Upper Mississippi River Basin Association, gave the keynote address.

McLean says that for most of the upper Mississippi water users, the conference came just in time.

“There was a fair amount of anxiety in the river basin about what the zebra mussels would do, but not many people knew what they were going to do about them,” he says.

Sensing this anxiety and knowing that the threat of invasion was imminent, the Upper Mississippi River Basin Association decided in January to push up the date of its planned zebra mussel conference from early fall to early spring. Minnesota Sea Grant and the other co-sponsors spent the next few months furiously planning.

It took a lot of hard work, but the conference was very well-received, McLean says. Ken Mueller, senior biologist at Northern States Power Company’s Prairie Island Nuclear Power Generating Plant, who attended the conference speaks of tangible benefits.

“It was an extremely valuable experience for Northern States Power,” he says. “As a result of the conference, we upgraded monitoring considerably and started more of an educational effort within the company.”

McLean also speaks of other tangible benefits—for Sea Grant. He points to several hundred orders for Sea Grant zebra mussel publications that came in as a result of the conference.

“Our co-sponsorship allowed people to identify Sea Grant as a primary source of information for the region on zebra mussels,” he says.

McLean hopes that this event is just the first of many Minnesota Sea Grant projects in the Mississippi River basin.

“Our emphasis has always been the Great Lakes,” he says. “But through this, we learned an awful lot about people Sea Grant hadn’t traditionally served. We hope we can get this audience interested in other Sea Grant issues.”
Researchers

This list includes only the first researcher listed on every project. For a complete list of researchers, see the project description. Students are not included.

Robert E. Baier
SUNY College at Buffalo
Department of Biomatertials
110 Parker Hall
3435 Main Street
Buffalo, NY 14214
716/829-2231, FAX 716/835-4872

Mary D. Balcer
University of Wisconsin
Department of Biology/Lake Superior Research Institute
145 McCaskill Hall
1800 Grand Avenue
Superior, WI 54880
715/394-8242, FAX 715/394-8454

Alfred M. Bexton
National Oceanic and Atmospheric Administration (NOAA)
Great Lakes Environmental Research Laboratory (GLERL)
2005 Commonwealth Blvd.
Ann Arbor, MI 48105-2999
313/668-2244, FAX 313/741-2055
E-mail: ABexton@GLERL.NOAA.GOV

Ruth Holland Bexton
University of Michigan
Department of Atmospheric, Oceanic and Space Studies
Space Research Building
Hayward Boulevard
Ann Arbor, MI 48109
313/769-3348, FAX 313/764-4585

Thomas M. Burton
Michigan State University
Department of Zoology
203 Natural Sciences
East Lansing, MI 48824
517/353-4475, FAX 517/336-2789

James T. Carlson
Maritime Studies Program
Williams College-Mystic Seaport
50 Greenmanville Avenue
Mystic, CT 06355
203/572-5359, FAX 203/572-5329

Linda Chalker-Scott
SUNY College at Buffalo
Department of Biology
1300 Elmwood Avenue
Buffalo, NY 14222
716/878-5418, FAX 716/878-4009
E-mail: Chalkerel@SUNY.BUFFALO

Thomas G. Coon
Michigan State University
Fisheries & Wildlife
13 Natural Resources Building
East Lansing, MI 48824
517/353-3373, FAX 517/336-1699
E-mail: CooTG@MSU.BITNET

James B. Cotner
Texas A & M University
Department of Wildlife and Fisheries Sciences
210 Nagle Hall
College Station, TX 77843-2258
409/845-0169, FAX 409/845-4096
E-mail: BL4788@TAMXMI.TAMU.EDU

David A. Culver
The Ohio State University
Department of Zoology
117 B & Z Building
1735 Neil Avenue
Columbus, OH 43210
614/292-6995, FAX 614/292-2030
E-mail: dculver@magnus.acs.ohio-state.edu

Konrad Dabrowski
The Ohio State University
School of Natural Resources
210 Kittman Hall, 2021 Coffey Road
Columbus, OH 43210
614/292-4555, FAX 614/292-7432
E-mail: Dabrowski.1@OSU.EDU

Dimitri M. Donskoy
Stevens Institute of Technology
Davidson Laboratory
Castle Point Station
Hoboken, NJ 07030
201/216-5316, FAX 201/216-8214
E-mail: AN_Donskoy@VAXC.Stevens-Tech.EDU

William Elzinga
Environmental Science and Engineering, Inc.
11665 Lilburn Park Road
St. Louis, MO 63146
314/567-4600, FAX 314/567-5030

Susan W. Fisher
The Ohio State University
Department of Entomology
103 B & Z Building
1735 Neil Avenue
Columbus, OH 43210
614/292-2133, FAX 614/292-2180

Peter C. Fralick
University of Toledo
Biology Department
2851 West Bancroft
Toledo, OH 43606
419/537-2125, FAX 419/537-7737

Scott M. Gallager
Woods Hole Oceanographic Institution
Biology Department
Woods Hole, MA 02543
508/457-2000, ext. 2783
E-mail: SGallager@WHOI.EDU

David W. Gerston
Indiana University at Kokomo
Department of Biological and Physical Sciences
2300 South Washington Street
Kokomo, IN 46904
317/455-9444, FAX 317/455-9444
E-mail: DGerston@Indiana.EDU
(Previously with the Department of Zoology at The Ohio State University.)

Vincent G. Guida
Lehigh University
Laboratory of Environmental Science
526 Bradhead Avenue
Bethlehem, PA 18015
215/758-4412

Robert T. Heath
Kent State University
Department of Biological Sciences
Cunningham Hall
Kent, OH 44242-0001
216/672-7828, FAX 216/672-3713
E-mail: R.T.Heath@KENTVM.KENT.EDU

Jerry H. Hulbichman
Wright State University
Department of Biological Sciences
Dayton, OH 45435
513/873-2257, FAX 513/873-3301
(Retired as of May 1993.)

R. Douglas Hunter
Oakland University
Department of Biological Sciences
Rochester, MI 48309-4401
313/370-3552, FAX 313/370-4280

NOTE: Electronic mail addresses are provided for the researchers who have a mailbox on an electronic mail system. Most mailboxes are on the Internet. If you can't get through, try changing the case of the letters in the address.
Researchers

Lynn J. Hushak
The Ohio State University
Department of Agricultural Economics and Rural Sociology
232 Agricultural Administration
2120 Fyffe Road
Columbus, OH 43210
614/292-3548, FAX 614/292-4749
E-mail: Hushak.1@osu.edu

Ladd E. Johnson
University of California
Department of Biological Sciences
Santa Barbara, CA 93106
305/685-4278
(For projects in this report, he was a visiting scientist at NOAA's Great Lakes Environmental Research Laboratory (GLERL), from Williams College—Mystic Seaport.)

David J. Jude
University of Michigan
Center for Great Lakes and Aquatic Sciences
2200 Bonisteel Boulevard
Ann Arbor, MI 48109-2099
313/763-3183, FAX 313/747-2748
E-mail: David.Jude@umich.cc.bitnet

Victor S. Kennedy
University of Maryland
Horn Point Environmental Laboratory
PO Box 775
2020 Horn Point Road
Cambridge, MD 21613
410/228-8200, FAX 410/476-5490

W. Charles Kerfoot
Michigan Technological University
Department of Biological Sciences
Houghton, MI 49931
906/487-2025, FAX 906/487-3167
E-mail: WKerfoot.MTUS5.CTS.MTU.EDU

Samuel E. Landsberger
Cornell University
Department of Mechanical and Aerospace Engineering
150 Upson Hall
Ithaca, NY 14853
607/255-5545, FAX 607/255-1222
E-mail: SELX@cornell.A.Cornell.EDU

Harold H. Lee
The University of Toledo
Department of Biology
2801 West Bancroft Street
Toledo, OH 43606
419/537-2123, FAX 419/537-7737

Gail M. Lima
Illinois Wesleyan University
Department of Biology
Bloomington, IL 61702-2900
309/556-3307, FAX 309/556-3411
E-mail: LimaG@vmd.csq.uiuc.edu

Rex L. Lowe
Bowling Green State University
Department of Biology
Bowling Green, OH 43403
419/372-8562, FAX 419/372-2024
E-mail: Lowe@opie.bgsu.edu

Richard A. Lutz
Rutgers University
Institute of Marine and Coastal Sciences
New Brunswick, NJ 08905
908/932-8959 ext 200, FAX 908/932-6557

Joseph C. Makarewicz
SUNY College at Brockport
Department of Biological Sciences
Brockport, NY 14420
716/395-5747, FAX 716/395-2416
E-mail: JCM@BROCK1P

J. Ellen Marsden
Illinois Natural History Survey
Lake Michigan Biological Station
Box 634
Zion, IL 60099
708/872-8677, FAX 708/872-8677 (call first)

Edward L. Mills
Cornell Biological Field Station
Department of Natural Resources
900 Shackleton Point Road
Bridgeport, NY 13030-9750
315/633-9243, FAX 315/633-2358

Ralph Mitchell
Harvard University
Division of Applied Sciences
Pierce Hall
Cambridge, MA 02138
617/495-4180, FAX 617/496-1471

Mark F. Monaco
National Oceanic and Atmospheric Administration (NOAA)
Strategic Environmental Assessments Division
SSMC-4, 9th Floor
1305 East-West Highway
Silver Spring, MD 20910
301/713-3000, FAX 301/713-4384
E-mail: M.Monaco (on OMNET)

D.K. Padilla
University of Wisconsin-Madison
Department of Zoology
356 Birge Hall
430 Lincoln Drive
Madison, WI 53706
608/262-6506, FAX 608/262-9080
E-mail: Padilla@MACC.WISC.EDU
Researchers

Robert L. Preston
Illinois State University
Department of Biological Sciences
Normal, IL 61761
309/438-7933, FAX 309/438-7933
E-mail: RLPresto@RS6000.CMP.ILSTU.EDU

Jeffrey L. Rani
Wayne State University
Department of Physiology
540 East Canfield
Gordon H. Scott Hall
Detroit, MI 48201
313/577-1520, FAX 313/577-5494

Atam J. Randhaw
The Ohio State University
Department of Agricultural Economics
and Rural Sociology
333 Agricultural Administration
2120 Fyffe Road
Columbus, OH 43210
614/292-6423, FAX 614/292-0078

Joe M. Regenstein
Cornell University
Department of Food Science
Stevenson Hall
Ithaca, NY 14853-7201
607/255-2109, FAX 607/257-2871
E-mail: JMR9@Cornell.EDU

Howard P. Rissien
SUNY College at Buffalo
Department of Biology
1300 Elmwood Avenue
Buffalo, NY 14222
716/878-6409, FAX 716/878-4009
E-mail: RissienHP@SUNYBUFFALO

Gary Rosenberg
Academy of Natural Sciences of Philadelphia
Department of Malacology
1900 Benjamin Franklin Parkway
Philadelphia, PA 19103-1195
215/299-1033, FAX 215/299-1170

Donald J. Stewart
SUNY College of Environmental Science
and Forestry
103 Illich Hall
1 Forestry Drive
Syracuse, NY 13210
315/470-6924, FAX 315/470-6934
E-mail: DJStewart@SUNY.MITNET

Nancy C. Tuchman
Loyola University of Chicago
Department of Biology
Dunham Hall
6525 North Sheridan Road
Chicago, IL 60626
312/508-3289, FAX 312/508-3646
E-mail: L08NCT@lucee.edu

summer address:
University of Michigan Biological Station
Pellston, MI 49769
616/539-8404
E-mail: NANCY_C_TUCHMAN@UMCCUMICH.EDU

John E. Van Benschoten
SUNY College at Buffalo
Department of Civil Engineering
Buffalo, NY 14260
716/645-2409

Michael J. Vanni
Miami University
Department of Zoology
Oxford, OH 45056
513/529-3192, FAX 513/529-6900
E-mail: MVANNI@MIAVU.UCS.MUOHIO.EDU

J. Herbert Waite
University of Delaware
College of Marine Studies
700 Pilottown Road
Lewes, DE 19958-1298
302/645-4257, FAX 302/645-4007

John B. Woodward
University of Michigan
Department of Naval Architecture and
Marine Engineering
2600 Draper Road
Ann Arbor, MI 48109-2145
313/764-8269, FAX 313/936-8820
E-mail: John-Woodward@UB.CC.UUMICH.EDU
Sea Grant offices

Alaska Sea Grant
University of Alaska
304 Eielson Building
Fairbanks, AK 99775-5040
907/474-7086

California Sea Grant
University of California—San Diego
9500 Gilman Drive
La Jolla, CA 92030
619/534-4440

University of Southern California Sea Grant
Hancock Institute for Marine Studies
University Park
Los Angeles, CA 90089-1231
213/740-1961

Connecticut Sea Grant
University of Connecticut
1084 Shennecossett Road
Groton, CT 06340
203/445-3457

Delaware Sea Grant
University of Delaware
Robinson Hall, Room 111
Newark, DE 19716
302/831-2841

Florida Sea Grant
University of Florida
Building 803
Gainesville, FL 32611
904/392-5870

Georgia Sea Grant
University of Georgia
Ecology Building
Athens, GA 30602
706/542-7671

Hawaii Sea Grant
University of Hawaii
1000 Pope Road, Room 223
Honolulu, HI 96822
808/956-7031

Illinois-Indiana Sea Grant
Room 104, Huff Hall
1206 South Fourth Street
Champaign, IL 61820
217/333-1824

Louisiana Sea Grant
Louisiana State University
128 Wetland Resources
Baton Rouge, LA 70803-7507
504/388-6710

Maine-New Hampshire Sea Grant
University of Maine
14 Coburn Hall
Orono, ME 04469-0114
207/581-1436

Maryland Sea Grant
University of Maryland
1012 Skinner Hall
College Park, MD 20742
301/405-6371

MIT Sea Grant
Massachusetts Institute of Technology
Building E38, Room 300
77 Massachusetts Avenue
Cambridge, MA 02139
617/253-7041

WHOI Sea Grant
Woods Hole Oceanographic Institution
CRL 209
Woods Hole, MA 02543
508/548-1400, ext. 2665

Michigan Sea Grant
University of Michigan
4113 I.S.T. Building
2200 Bonisteel Boulevard
Ann Arbor, MI 48109-2099
313/764-1138

Minnesota Sea Grant
University of Minnesota
Room 302
1518 Cleveland Avenue, North
St. Paul, MN 55108
612/625-9288

Mississippi-Alabama Sea Grant Consortium
P.O. Box 7000
703 East Beach Drive
Ocean Springs, MS 39564-7000
601/875-9341

Maine-New Hampshire Sea Grant
University of New Hampshire
Kingman Farm
Durham, NH 03824
603/749-1565

New Jersey Sea Grant
NJ Marine Sciences Consortium
Building No. 22
Pt. Hancock, NJ 07732
908/772-1300

New York Sea Grant Institute
Nassau Hall
Stone Brook, NY 11794-5000
516/632-6905

North Carolina Sea Grant
North Carolina State University
Box 8605
Raleigh, NC 27695-8605
919/515-2454

Ohio Sea Grant
Ohio State University
1541 Research Center
1314 Kinnear Road
Columbus, OH 43212
614/292-8949

Oregon Sea Grant
Oregon State University
Administrative Services
Building A320
Corvallis, OR 97331-2131
503/737-3396

Puerto Rico Sea Grant
University of Puerto Rico
Department of Marine Science
P.O. Box 5000
Mayaguez, PR 00681-5000
809/832-3855

Rhode Island Sea Grant
University of Rhode Island
Narragansett Bay Campus
Narragansett, RI 02882-1197
401/792-6800

South Carolina Sea Grant Consortium
287 Meeting Street
Charleston, SC 29401
803/727-2078

Texas Sea Grant
Texas A&M University
1716 Briarcrest Drive, Suite 702
Bryan, TX 77802
409/845-3854

Virginia Sea Grant
Virginia Graduate Marine Science Consortium
Madison House
170 Rugby Road
Charlottesville, VA 22903
804/924-5965

Washington Sea Grant
University of Washington
HG-30
3716 Brooklyn Avenue, N.E.
Seattle, WA 98105-6716
206/543-6600

Wisconsin Sea Grant
University of Wisconsin—Madison
1800 University Avenue
Madison, WI 53705
608/262-0905

National Sea Grant
NOAA, Sea Grant, R/01
SSMC-1
1335 East-West Highway
Silver Spring, MD 20910-3226
301/713-2431

National Sea Grant Depository
Pell Library, URI
Bay Campus
Narragansett, RI 02882-1197
401/792-6539

68
Resource list

This list includes material that is distributed by the six Sea Grant programs in the Great Lakes Sea Grant Network as of December 1993. Many of the other Sea Grant programs are producing material about the zebra mussel, too. For example, Rhode Island (401/792-6842), Virginia (804/924-5965) and North Carolina (919/515-2452) Sea Grant programs all currently have material available. Other U.S., state and Canadian agencies also have material available.

To order any item in this resource list, complete and mail the order form for the program distributing the material. Free items are for single copies only unless specified otherwise. For prices on bulk orders, contact the program that is distributing the material. Please prepay all orders.

Resources on zebra mussels

The first three publications provide information on how this species was introduced into the Great Lakes, areas colonized in the lakes, what methods of eradication exist, provides tips on what you can do to slow the mussel’s spread, and the impact zebra mussels will have on industry, recreation and the Great Lakes ecosystems.


Mid-Atlantic zebra mussel Fact sheet. Reprinted January 1994. Barbara Doll. 6 pp. Explores the possible routes of entry the zebra mussel might take and examines the environmental characteristics that would make this area a hospitable host and could include the expansive estuaries and freshwater rivers and lakes. Free. To order, write N.C. Sea Grant, Box 8605, N.C. State University, Raleigh, NC 27695-8605.

Zebra mussel: An unwelcome visitor. 1993 Karin A. Tammi. 2 pp. Describes the biology, impact and history of zebra mussels in the United States along with identification information and help to help Islanders to prevent their introduction into the state. $5.00 To order, write R.I. Sea Grant Information Office, URI Bay Campus, Narragansett, RI 02882. 401/792-6842.

Zebra mussels in Virginia’s future. March 1993. 2 pp. Includes the zebra mussel’s physical requirements and a list of its potential range in Virginia’s waters. Free. To order, write Virginia Institute Marine Science, Gloucester Point, VA 23062.

• Boaters—Slow the spread of zebra mussels and protect your boat, too. 1993. David O. Kelch. 2 pp. OHSU-FS-054. Free for any size order. OH
• Identification of juvenile Dreissena polymorpha and Mytilopsis leucophneutus. 1992. David B. MacNeil. 3-fold brochure includes diagrams, glossary and references for the zebra mussel and dark false mussel. NYSG-I-92-001. Free NY
• Zebra mussel information needs survey for municipal and industrial water users—Summary report. 1992. Robin Goettel and Gail Snowden. 8 pp. A survey of 29 southern Lake Michigan municipal and industrial water users provided findings on what types of zebra mussel information were most needed and in what form the information could best be delivered. Free. IL-IN
• Control of zebra mussels in residential water systems. 1993. Charles R. O’Neill, Jr. 8 pp. $1.00 NY
• Zebra mussels may clog irrigation systems. 1993. 2 pp. MICHU-SG-93-701. Free. MI
#1: Case studies of constructed filter bed intakes. A description of 10 such systems in the western Great Lakes that range from one to 100 years old. Included is information on operational experience and who to contact (plant operators and design engineers) for further information, plus commentary from marine contractors and design engineers. 16 pp.
#2: Infiltration intakes for very large water supplies: Feasible? A review of four 20-year-old papers that considered design feasibility as a means of protecting larval organisms from entrainment in power plant and water diversion project intakes. 11 pp.
#3: Zebra mussel (Dreissena polymorpha) distribution: Reported size, depth and temperature variables. A summary of relevant data about zebra mussels intended for project design engineers. 7 pp.
#4: Using filtration and induced infiltration intakes to exclude organisms from water supply systems. A literature review plus an overview of slow sand filtration and infiltration systems. 13 pp.
• Don’t let these invaders hijack your boat! is a 17"x22" humorous cartoon poster telling boaters what to do to slow the spread of zebra mussels. Perfect for fishing/bait shops. Pub X6. Free. MN
• Don’t pick up hitchhikers! Stop the zebra mussel is a 3 pp. flyer and 11"x17" poster. One or two copies of the flyer and poster are free. NY
Resources

Zebra mussel watch identification card. Christine Kohler and Stephen Wittman. Wallet-sized cards have a color picture of the zebra mussel with text describing their appearance and what to do if you find a mussel. Free; 20 cards for $1.00. Available from each program. Order customized cards from Wisconsin, WI

Zebra mussel distribution map from the latest issue of Dreissena polymorpha information review. Free, NY

Zebra mussel distribution in Michigan. Free, MI

Zebra mussels: From spawning to settlement. January 1994. 20-minute video shot through a microscope shows mussels spawning naturally and induced. Voice-over provides details. $15.00. OH

Zebra mussels. 1993. Produced by New York Sea Grant and PBS-affiliate WLIIW, Long Island as 30-minute show. $12.00. NY

Protecting your boat from zebra mussels. Revised 1993. This 15 minute video gives pointers on how to prevent damage to your recreational boat and tips on preventing the spread of the mussel to inland waters. $10.00, NY

Too much mussel. January 1991. This 5.5 minute video (VHS format) provides an overview of the impact of zebra mussels to Lake Erie. $15.00. OH

Zebra mussel features. Collection of 90 second feature stories produced by Outreach Communications TV at Michigan State University. Contact Carol Swinehart at MSU 517/353-9723. $10.00.

Nonindigenous Species Graphics Library contains slides, photographs and illustrations of zebra mussels and other aquatic nuisance species. Also includes a videotape resource list. Contact Michigan Sea Grant at 313/764-1138 for more information.

Resources on other species


The Ruffe invasion, Gymnocephalus cernuus. 1993. Mike McLean. Describes the aggressive, perch-like fish found in Lake Superior. This invader was first identified in the St. Louis River in 1987. It is now the most numerous forage fish in the estuary and its range is expanding. PUB X7. Free, MN


Don’t let exotics ride with you. 1992. A simple card explaining four major exotics that threaten our lakes and rivers and what boaters and anglers can do to prevent their spread. 2 pp. Free for any quantity. Available from each program. OH

Scientific publications on zebra mussels


**Resources**


- "International zebra mussel research conference (1991) proceedings sponsored by the Great Lakes Sea Grant Network and hosted by New York Sea Grant. 352 pp. $8.00. NY


**Scientific publications on other species**


- "Genetics and ecology of an invading species: Bythotrephes cederstroemi in western Lake Erie, 1991. David J. Berg, 164 pp. TD-030. On loan from the Sea Grant Depository, Pell Library Building/Bay Campus, University of Rhode Island, Narragansett, Rhode Island 02882. (All items listed in this publication can be borrowed from the Depository.)


Resources

Newsletters
• *Dreissena polymorpha* information review. Summaries of research, meetings, legislation and sightings of the zebra mussel for the interested professional. Bimonthly. $60.00 annual subscription rate includes other benefits. Contact Zebra Mussel Clearinghouse at 800/285-2285.
• *Zebra mussel update* reports on the status of the zebra mussel invasion in the region, zebra mussel-related research, upcoming conferences, new publications, etc. Written by Clifford Kraft. Published irregularly; Free. WI

The following Sea Grant program newsletters cover Great Lakes issues, education, environment, economic development, fisheries and aquaculture activities in each state. Conferences, publications and journal articles may also be listed. Contact your closest Sea Grant program for a subscription. Some programs also produce additional topic-specific newsletters.

- *Twine Line*, issued bimonthly by Ohio. $4.50 a year. Each issue includes a zebra mussel update.

To order material from the Great Lakes Sea Grant Network

**IL-IN**
Illinois-Indiana Sea Grant Program
University of Illinois
65 Mumford Hall
1301 W. Gregory Dr.
Urbana, IL 61801-3068
217/333-9448

**MI**
Michigan Sea Grant College Program
University of Michigan
2200 Bonisteel Blvd.
Ann Arbor, MI 48109-2099
313/764-1138

**MN**
Minnesota Sea Grant College Program
University of Minnesota
1518 Cleveland Ave., N.
Suite 302
St. Paul, MN 55108-6001
612/625-9790

**NY**
New York Sea Grant Institute
SUNY College at Oswego
Sweitzer Hall
Oswego, NY 13126-3599
315/341-3042
800/285-2285

**OH**
Ohio Sea Grant College Program
The Ohio State University
1314 Kinnear Rd.
Columbus, OH 43212-1194
614/292-8949

**WI**
Sea Grant Institute
University of Wisconsin-Madison
1800 University Ave.
Madison, WI 53705-4094
608/263-3259
Invasion of an Exotic Species: Stop the Zebra Mussel!

Activities and Resources For Grades 8 - 12

Virginia Sea Grant Marine Advisory Program
Invasion of an Exotic Species: Stop the Zebra Mussel!

Activities and Resources
For Grades 8 - 12

By
Vicki P. Clark
Thomas J. Miller

Virginia Sea Grant Marine Advisory Program
School of Marine Science
Virginia Institute of Marine Science
The College of William and Mary
Gloucester Point, Virginia 23062

VIMS Educational Series No. 41
VSG 94-03

This work is a result of research sponsored by NOAA Office of Sea Grant,
U.S. Department of Commerce, under federal Grant No. NA 90AA-D-
SG045 to the Virginia Graduate Marine Science Consortium and the
Virginia Sea Grant College Program. The U.S. Government is authorized to
produce and distribute reprints for governmental purposes notwithstanding
any copyright notation that may appear hereon.
Invasion of an Exotic Species:
Stop the Zebra Mussel!

Activities and Resources
For Grades 8 - 12

Thousands of exotic plants, animals, and microbes have been introduced into the United States. Some of these organisms were intentionally imported for use in agriculture, the pet industry, and fish and wildlife management. Others accidentally found their way to the United States in ships’ ballast water, in packing materials, or as hitchhikers on other plants and animals. Many exotic species, such as soybeans and wheat, have been beneficial. Others, such as the Japanese beetle and kudzu, have had a negative impact. In addition, plant and animal species from the Americas have been exported to other parts of the world, with similar effects. Many exotic species displace native plants and animals, alter ecosystems, cause disease, and interfere with human activities in industry, agriculture, and recreation.

The zebra mussel is an exotic freshwater mollusk from Europe which was accidentally introduced into the United States in the Great Lakes area in 1985 or 1986. The mussel larvae were most likely transported in the ballast water of a ship and released into Lake St. Clair. The mussels reproduce rapidly in suitable habitats and have created serious environmental and economic problems in many parts of the country. Zebra mussels are spreading toward the mid-Atlantic states. Where and how will they be most likely to invade Virginia? How can the zebra mussel invasion be controlled?

The activities and resources presented in this packet will guide students in a study of the zebra mussel and the possibilities of its invasion of Virginia. Actual scientific research data are introduced as a critical part of group problem-solving activities. Students are challenged to use the scientific data and other information to design action plans to help prevent the introduction and spread of zebra mussels into the state. Additional follow-up activities extend the study of zebra mussels and encourage the investigation of the impact of other exotic plants and animals.
Acknowledgments

The information used to develop the data cards in the activity “Where Will the Zebra Mussel Invade?” was obtained from personal communications with Patrick Baker, a graduate student at the Virginia Institute of Marine Science, and from the following research reports:


Supplementary materials:

North Carolina Sea Grant
Ohio Sea Grant
Virginia Sea Grant
Virginia Department of Game and Inland Fisheries
Zebra Mussel Information Clearinghouse, New York Sea Grant

Editorial Review:

Bland Crowder
Jan Hodges
Lee Larkin
Carol Rideout

Design and Layout: Susan Stein

Zebra mussel art work: Carol Allaire, Michigan Sea Grant

Printing: Sylvia Motley
Activity Instructions

Where Will the Zebra Mussel Invade?

Objective

Students will work in small groups to communicate and analyze scientific data on zebra mussels and water quality. Using this information, each group will predict the likelihood of zebra mussels becoming introduced and established in various aquatic sites in Virginia.

Student Preparation

Students should have a basic understanding of pH, temperature, and calcium content as measurable characteristics of the water in aquatic habitats. They should understand that “parts per thousand” and “parts per million” refer to the concentration of chemical substances present in a body of water.

Time Needed

1 class period (45 - 50 minutes)

Materials Needed (for each group of 4 - 6 students)

From the “Student Activities” section:

- Zebra Mussel Biology
- Zebra Mussel Critical Habitat Needs
- Zebra Mussel Impacts
- Zebra Mussel Study Site Data Cards (one set of 6 data cards per group)
- Zebra Mussel Study Site Report

Optional: Virginia highway map (one per group)

Teacher Preparation

1. Read the information in the “Student Activities” section and the supplementary reference materials provided in the packet to familiarize yourself with zebra mussels and their impact.

2. Duplicate the Zebra Mussel Study Site Data Card sheets. (You will need one set of 6 cards for each student group.) Cut the data cards apart and put each set of six in a separate envelope, or paper clip them together. (If the cards become mixed up, the small number at the bottom of each card will help you put the sets back together.)
3. For each group, duplicate one copy of the other four pages ("Zebra Mussel Biology," "Zebra Mussel Critical Habitat Needs," "Zebra Mussel Impacts," and "Zebra Mussel Study Site Report"). If you wish, give the "Biology" sheet to each student to read before class. You may want to make overhead transparencies of the "Critical Habitat Needs" and "Impacts" sheets and display them for reference during the activity.

4. If students are not already familiar with the concept of exotic species, decide how you will relate the zebra mussel issue to other concepts that they have studied, such as animal adaptation, species competition, impact of human activities on ecosystems, etc.

Conducting the Activity

1. Divide the class into groups of four to six students each. Assign roles within the groups as follows:

   **Materials Manager:** Obtains activity materials from teacher, distributes them to group, and returns all materials to teacher in good order after activity is finished.

   **Recorder:** Keeps written notes on group discussions and observations. Records group responses to questions on activity worksheets. Reads written information back to rest of group for their approval.

   **Reporter:** Gives verbal report to the class summarizing the group’s conclusions, using the activity worksheets and other notes from the Recorder.

   **Research Technician(s):** Provide(s) additional information to the group during the problem-solving activities by consulting supplementary handouts and reference materials.

2. Introduce students to the information from the "Zebra Mussel Impacts," "Zebra Mussel Biology," and "Critical Habitat Needs" sheets. You may lead a class discussion, or each small group may read and discuss the information and review it with the teacher and the rest of the class. Explain that they will be working in groups to analyze scientific information in order to predict whether or not various places in Virginia are suitable habitat for zebra mussels.

3. Give each Materials Manager a set of Zebra Mussel Study Site data cards and a copy of the Zebra Mussel Study Site Report form. The Materials Manager should distribute the data cards one at a time to all group members (some students may get more than one card if groups have fewer than six students). In turn, the students read aloud the information on their data cards to the other group members. The Recorder reads the Study Site Report form to the group.

4. Based on this information, each group develops a prediction about the likelihood that its study site will be affected by zebra mussels. The questions on the
Study Site Report form will guide their discussion. The Recorder writes the predictions and supporting information on this form.

5. Once all groups have completed their report forms, each group's Reporter shares the results with the rest of the class. To facilitate discussion as the class compares the sites, the Recorders can post on a chart or the chalkboard the predictions for their sites, along with water quality data and other important facts.

6. If you plan to follow this activity with "Developing a Zebra Mussel Action Plan," have the Recorders keep their Site Report forms to use as reference.

Summary and Evaluation

1. Based on the information known about each study site, did each group make a reasonable prediction about the zebra mussel's introduction and establishment? (See chart below for scientists' predictions.) If students disagree, remember that all of the facts are not yet known, and that there is some room for debate.

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Chances for Introduction</th>
<th>Chances for Establishment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. James River</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>2. Potomac River</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>3. Smith Mountain Lake</td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>4. Rappahannock River</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td>5. Kerr Reservoir and Lake</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Gaston and Parunkey Rivers</td>
<td>moderate</td>
<td>low</td>
</tr>
<tr>
<td>7. Lake Anna</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>8. Claytor Lake</td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>9. South Holston Lake</td>
<td>high</td>
<td>high</td>
</tr>
</tbody>
</table>

2. Rank the study sites from "lowest risk" to "highest risk" for the successful establishment of a zebra mussel population. Which site is closest to your school?

3. Overall, what human activity might be most likely to contribute to the introduction of zebra mussels in Virginia?

4. Locate the study sites on a Virginia highway map. How could the location and geography of each study site contribute to the introduction of zebra mussels? Once the zebra mussel becomes established, how far away from each study site do you think the mussel could spread?

5. At which study site might zebra mussels have the most serious economic impact?
Activity Instructions

Developing a Zebra Mussel Action Plan

Objective

Students work in small groups to design and communicate action plans to help prevent the introduction and spread of zebra mussels in areas which are at risk.

Time Needed

2 class periods or more, depending on number of groups (students may need additional time outside of class to prepare group presentations)

Materials Needed

- Zebra Mussel Action Plan Outline (in “Student Activities” section)
- Zebra Mussel Study Site Reports (the same forms which were completed by the groups in the previous activity)
- Supplementary zebra mussel publications included in this packet (See “Resources” section for list of titles. You may duplicate these so that each group has a copy, or groups can share materials.)
- Posterboard, markers, and other art materials
- Optional: Additional zebra mussel articles (See “Resources” for bibliography)

Student Preparation

Students should have already completed the “Where Will the Zebra Mussel Invade?” activity and be divided into small groups.

Teacher Preparation

1. Read the “Zebra Mussel Action Plan Outline” for information on how the activity is done.

2. For each group, duplicate one copy of the “Zebra Mussel Action Plan Outline” and the supplementary publications. These publications contain background information the students will need to develop their action plans.

3. Divide students into small groups and assign roles, as in the previous activity. Groups may remain the same, or students may rotate into another group. NOTE: You may decide to have the class develop action plans only for those study sites which are at a high or moderate risk. If so, students from “low-risk” groups can be moved into “high-risk” groups.
Conducting the Activity


2. Briefly introduce the activity, and give students the timeline for the completion of their plans and for their class presentations (5-10 minutes each). Encourage the groups to use charts, posters, and any other creative methods to make their presentations effective.

3. On the day set aside for presentations, assign a timekeeper to help keep the activity on schedule. Each group should allow time for questions and comments from the rest of the class when its presentation is finished.

Summary and Evaluation

1. Have a small group of students serve as an evaluation team, and let them choose which plans are the most creative, comprehensive, practical, effective, etc. Alternatively, have the entire class discuss and evaluate the merits and shortcomings of each plan.

2. How do the groups’ action plans compare to the efforts which Virginia and other states are making to control the zebra mussel? Students may want to contact zebra mussel specialists to get their reactions to the student plans. (See “Resources” for contact people.)
Publications Included In This Packet


Ohio Sea Grant College Program. A Great Lakes Sea Grant resource list on zebra mussels and other nonindigenous species. 1993. Ohio Sea Grant College Program, OHSU-FS-052.


Selected Bibliography

For more information on zebra mussels and other exotic species, check local libraries for the following publications:


Additional curriculum materials may be ordered from the following sources:

“Alien Invaders: A Case Study on Zebra Mussels”
(curriculum unit with student activities)
The Rivers Project
Southern Illinois University
Box 2222
Edwardsville, IL 62026

“Saving America’s Pearly Mussels”
(video, script, and poster)
Virginia Tech Extension Distribution Center
112 Landsdowne St.
Blacksburg, VA 24061-0512
Mid-Atlantic Contacts for
Zebra Mussel Information

Delaware
Tracey Bryant
Delaware Sea Grant Program
University of Delaware
Marine Communications Office
263 East Main Street
Newark, DE 19716-3530
(302) 831-8185

Jim Falk
Delaware Sea Grant Program
Marine Advisory Services
700 Pilottown Road
Lewes, DE 19958-1298
(302) 645-4997

Maryland
Dan Terlizzi
Sea Grant Extension Service
NOAA Chesapeake Bay Office
410 Severn Avenue, Suite 107A
Annapolis, MD 21403
(410) 280-1871

New Jersey
Eleanor Bochenek
New Jersey Sea Grant
Rutgers Cooperative Extension
1623 Whitesville Road
Toms River, NJ 08755
(908) 349-1152

New York
Charles O'Neil, Jr.
Zebra Mussel Information Clearinghouse
New York Sea Grant Extension
250 Hartwell Hall
SUNY College at Brockport
Brockport, NY 14420-2928
(800) 285-2285

North Carolina
Barbara Doll
North Carolina Sea Grant
Box 8208
North Carolina State University
Raleigh, NC 27695
(919) 515-7802

Virginia
William DuPaul
Vicki Clark
Virginia Sea Grant Marine Advisory
Program
Virginia Institute of Marine Science
P.O. Box 1346
Gloucester Point, VA 23062
(804) 642-7169

Virginia Department of Game and
Inland Fisheries
Fisheries Division
P.O. Box 11104
Richmond, VA 23230-1104
(804) 367-1000

Louis A. Helfrich
Department of Fisheries and Wildlife
Sciences
Virginia Polytechnic Institute and State
University
Blacksburg, Virginia 24060
(703) 231-5059
Other Zebra Mussel Contacts

Ohio Sea Grant College Program
The Ohio State University
1314 Kinnear Road
Columbus, OH 43212
(614) 292-8949

Michigan Sea Grant College Program
Zebra Mussel Information Office
University of Michigan
20200 Bonisteel Blvd.
Ann Arbor, MI 48109
(313) 764-1138

Minnesota Sea Grant
Zebra Mussel Information Center
208 Washburn Hall
University of Minnesota
Duluth, MN 55812
(218) 726-8712

Tennessee Valley Authority
1101 Market Street
Chattanooga, TN 37402
(800) 538-2526
Master copies of student activity pages included in this section are as follows:

- Zebra Mussel Biology
- Zebra Mussel Critical Habitat Needs
- Zebra Mussel Impacts
- Zebra Mussel Site Report
- Zebra Mussel Action Plan Outline
- Zebra Mussel Study Site Data Cards (9 pages)
- Follow-Up Ideas

NOTE TO TEACHERS AND STUDENTS:
It is against Virginia state law to import live zebra mussels or any other non-indigenous (exotic) species into the state. No activity in this curriculum involves the use of live zebra mussels. Due to the danger of accidental introduction and the strict laboratory controls required for their use, live exotic species are not recommended for student research.
Zebra Mussel Biology

The zebra mussel is a freshwater bivalve mollusk, originally found in Europe in the Caspian, Aral, and Black seas. Adult zebra mussels range from 0.5 to 3.5 cm long. The zebra mussel's scientific name is *Dreissena polymorpha*. The name *polymorpha* refers to the many individual variations in the color and pattern of the shell. Most zebra mussels have striped shells, but some are solid black or brown.

Zebra mussels feed on plankton, including algae, bacteria, larval animals, and other tiny particles of organic matter suspended in the water. The mussel pumps water into its body through a siphon tube and filters out the food. The water is pumped out through a second siphon. An adult zebra mussel filters an average of one liter of water each day.

Although they are freshwater animals, zebra mussels can survive in slightly brackish water (0.5 parts per thousand). Some adult zebra mussels have survived for several days in water with salinities as high as 12 parts per thousand under controlled laboratory conditions.

Zebra mussels grow and reproduce best in water which is 12 to 26°C with a calcium content of at least 20 parts per thousand. The calcium is important for the growth and maintenance of the shell.

Zebra mussels are either male or female. Mature females can produce 30,000 eggs each year. Some females have produced as many as one million eggs per year. Spawning occurs when water temperatures warm to 12 to 23°C. If the water temperature remains suitable, spawning may occur several times during the season.

A fertilized zebra mussel egg becomes a microscopic, planktonic larva. The larval mussel spends two to three weeks swimming about, feeding on phytoplankton. During this stage, downstream currents can easily transport the larval zebra mussel from one body of water to another.

About two to three weeks after hatching, the larva begins to settle to the bottom. To survive, it must settle on a hard surface. Almost anything will do, including rocks, pier pilings, boats, concrete, or another animal’s shell. It attaches to the surface with strong fibers called byssal threads. Zebra mussels frequently grow in large colonies, with hundreds of individuals attached to an object and to each other.

Zebra mussels can crawl from place to place by secreting temporary byssal threads which the mussels attach and detach as they move along.
Zebra Mussel Critical Habitat Needs

- **water temperature**: 6 - 28°C  
  (spawn at 12 - 23°C;  
  die above 30°C)

- **pH**: 7.4 - 9.4

- **salinity**: less than 5 parts per thousand (ppt)

- **calcium (from CaCO₃)**: greater than 20 parts per million (ppm)

- **substrate**: need firm surface for attachment

*NOTE: Larval forms are more sensitive than adults, especially to cold water temperatures.*
Zebra Mussel Impacts

Zebra mussels can reproduce in large numbers in suitable habitats. Although individual zebra mussels are small, they attach to each other to form large colonies which grow on almost any solid underwater material. These colonies can grow to contain as many as 100,000 mussels per square meter!

Large populations of zebra mussels in many parts of the United States can cause serious problems, such as the following:

- Clog intake pipes in water treatment plants, power generating plants, and industrial facilities, reducing water flow and causing occasional shutdowns

- Attach to pier pilings, navigational buoys and markers, and docks, interfering with navigation and increasing corrosion

- Grow on boat hulls and inside engine systems, decreasing fuel efficiency and damaging engines

- Attach to shells of native freshwater mussels, weakening or killing them by interfering with the mussels' ability to open or close their shells, as well as competing for food

- Filter large amounts of phytoplankton from the water, reducing food available for other filter-feeding organisms and many fish
Zebra Mussel Site Report

Location of zebra mussel study site:

Names of study team members:

1. The chance that zebra mussels will be introduced to this site is (circle one):

   low  moderate  high

   What specific facts and information about zebra mussels and about the study site led you to this conclusion?

2. If zebra mussels are introduced, the chance that they will survive and successfully reproduce in this site is (circle one):

   low  moderate  high

   What specific facts and information about zebra mussels and about the study site led you to this conclusion?

3. List three specific actions which your group feels people should take to prevent the introduction of zebra mussels into this site.
Zebra Mussel Action Plan Outline

Names of team members:

Location of zebra mussel study site:

Chance that zebra mussels will become introduced at this site (see your “Zebra Mussel Site Report” form):

- low
- moderate
- high

Chance that zebra mussels will survive and successfully reproduce in this site:

- low
- moderate
- high

Your team is responsible for developing an action plan which will help reduce the chances that zebra mussels will be introduced in your study site. As a team, discuss the following questions (be sure to have your team’s recorder take notes during the discussion):

What groups of people (your “target audience”) will need to know about zebra mussels?

What will each group of people need to do to help keep zebra mussels out of the area?

How will you communicate this information to each group in your target audience?

How will you pay for developing and conducting your activities?

What can you do to find out if your action plan is successful?

Use your answers to these questions to develop your action plan. Prepare a 5 - 10 minute presentation to give to the rest of the class which describes what your group wants to do. Include a written summary of the plan as well as charts, posters, or other items which will help explain your ideas.
Follow-Up Ideas

Classroom Activities

1. Work with your group to design a method to remove zebra mussels from one of the following areas:

   Small lake used for swimming, fishing, and boating

   Water treatment facility which provides water for an entire community, including homes, schools, businesses, hospitals, and industries

   Stream which supports a population of a freshwater mussel which is important to the local economy (its shells are exported to Japan for use in the cultured pearl industry)

Consult the supplementary materials in this packet for information on zebra mussel control. As you design your control method, consider the following:

Some control methods which kill zebra mussels may also be harmful to native freshwater mussels, fish, aquatic plants, and other organisms. How will you make sure your method will not be harmful to other organisms in the area?

What will you do with the zebra mussels that you destroy?

If drinking water supplies are affected, how will you avoid contaminating the water with chemicals and with dead zebra mussels?

Describe your control method in writing, or present a report to the class. You may want to draw diagrams and pictures or build a model to show how your control method will work.

2. Design a poster which educates recreational boaters, fishermen, and other users of lakes and streams about the zebra mussel problem. In addition, develop a bumper sticker or T-shirt design using the zebra mussel theme.

3. Produce a public service announcement for television which informs people about the zebra mussel problem. Videotape or present the announcement live to the rest of the class.

4. Write a short play or skit with a zebra mussel as the main character.

5. If you have access to a computer and a telecommunication network, contact students who live in an area where zebra mussels have become established (see range map in “The Zebra Mussel: An Unwelcome North American Invader”). Find out what people in their community are doing about the problem. If you cannot use a computer to communicate, write letters.
Field Activities

1. Visit your local water treatment facility or electric power plant to find out how the operators keep the water intake areas free of debris, animals, plants, etc. It is usually possible to schedule a tour for a group if you call in advance.

2. Take a walk around your school, a local park, or your yard. List the plants and animals which were introduced from another part of the United States or another country. A horticulture teacher, science teacher, botanist, or garden club member might be able to help you with the survey.

3. Call a local greenhouse or plant nursery and ask if your class can schedule a visit to learn about the types of plants which are grown and sold there. How many of these are native plants? What different parts of the world have provided us with some of our most common house and garden plants? What are the advantages and disadvantages of cultivating native vs. exotic plants?

4. Many exotic animals have been intentionally brought into the United States. These animals may have been imported for pets, for hunting, or for control of other species. Contact state and federal wildlife and agriculture departments for information on regulations which control the importation of exotic animals into your state. Local pet stores should also be able to explain how they are required to follow regulations concerning the sale of exotic species.

5. Many plants which originated in the Americas, including corn, tomatoes, and “Irish” potatoes, have been introduced to Europe and Africa. What impacts have these exotic species had on the economies and ecosystems of these areas?

6. Get involved in a water quality monitoring project to learn how to measure mineral content, pH, temperature, and other water conditions. Many communities have organized groups which monitor water quality in specific sites. Contact the following organizations for information on citizen water quality monitoring:

   Jay West
   Save Our Streams (SOS)
   Izaak Walton League of America
   1401 Wilson Blvd., Level B
   Arlington, VA 22209
   (703) 528-1818

   Kathleen Ellett, Monitoring Director
   Alliance for the Chesapeake Bay, Inc.
   6600 York Road, Suite 100
   Baltimore, MD 21212
   (410) 377-6270

   Global Rivers Environmental Education
   Network (GREEN)
   721 East Huron
   Ann Arbor, MI 48104
   (313) 761-8142
The land area which drains into the James River has many large lakes and reservoirs with heavy recreational use. There are over 90 public boat ramps in the area, mostly on lakes.

Large ships traveling from freshwater ports in Europe frequently dock at the deepwater port in Richmond. There is also heavy barge and boat traffic between the James River and other tributaries of the Chesapeake Bay.

Each year, professional bass fishing tournaments are held near Richmond on the tidal freshwater portions of the James. Most of these fishing boats are brought to the tournaments on trailers. The boats may have been in lakes and rivers throughout the country only a day or two earlier.

The water monitoring site closest to Richmond is near Cartersville. The pH of the James River at this site in August is 8.1. The calcium content of the river near Cartersville is about 22 ppm.

In areas where the mussels thrive, adult zebra mussels frequently attach to boats and trailers. These mussels can live out of water for two to three days under certain environmental conditions.

Free-swimming zebra mussel larvae can survive for several days or even weeks in the ballast water of ships. Under some conditions, they can also survive for days in water contained in bait buckets, live wells, boat trailer frames, and other enclosed areas in boats and ships.
Large vessels travel regularly into the Potomac River from the Great Lakes area. For example, according to officials at one dock terminal, cargo ships from Quebec City on the St. Lawrence River arrive in Alexandria six or seven times a year.

The pH of the Potomac River near Alexandria is 8.1 - 8.4 from May to September. Calcium content of the Potomac River near Alexandria is 32 - 40 ppm.

Many zebra mussels live in the St. Lawrence River near Quebec City in Canada.

Free-swimming zebra mussel larvae can survive for several days or even weeks in the ballast water of ships. Under some conditions, they can also survive for days in water contained in bait buckets, live wells, boat trailer frames, and other enclosed areas in boats and ships.

Alexandria is the largest port in the freshwater portion of the Potomac River. No one knows the volume of ballast water dumped by ships in the port at Alexandria. Commercial and recreational traffic into the Potomac estuary from neighboring estuaries is very high.

The Potomac is the Virginia estuary which is closest to the Susquehanna River. Zebra mussels are living in the Susquehanna River in the vicinity of Johnson City, NY.
Smith Mountain Lake is a large reservoir on the headwaters of the Roanoke River near the city of Roanoke.

The pH of Smith Mountain Lake in the summer ranges from 7.6 to 9.1.

Smith Mountain Lake is heavily used for recreational boating and fishing. There are 17 public boat ramps and a very popular state park located on the lake.

The calcium level of Smith Mountain Lake is about 15 - 17 ppm.

A large professional bass tournament is held annually on Smith Mountain Lake. Participants travel from all over the country to compete, and bring their own boats on trailers.

In areas where the mussels thrive, adult zebra mussels frequently attach to boats and trailers. These mussels can live out of the water for two to three days under certain environmental conditions.
Along the Rappahannock there are several reservoirs which are used for recreational boating and fishing. There are 11 public boat ramps in the freshwater portion of the river.

Near Fredericksburg, the Rappahannock River has a pH of 7.8 (measured in August).

Boat traffic into the Rappahannock from other estuaries is low to moderate. Residential development surrounds several large, private reservoirs in the Rappahannock drainage area.

Calcium levels of the Rappahannock in August have been measured at 5.2 ppm.

Free-swimming zebra mussel larvae can survive for several days or even weeks in the ballast water of ships. Under certain conditions, they can also survive for days in water contained in bait buckets, live wells, boat trailer frames, and other enclosed areas in boats and ships.

Currents moving downstream from one body of water to another can easily transport larval zebra mussels.
Kerr Reservoir and Lake Gaston are on the Roanoke River. Both lakes are heavily used for recreational boating and fishing.

Water chemistry varies from place to place in both Lake Gaston and Kerr Reservoir. Scientists have recorded pH readings of 6.9 - 9.3 in parts of both lakes.

Currents moving downstream from one body of water to another can easily transport larval zebra mussels.

Scientists have measured calcium levels in Lake Gaston at 24 - 44 ppm. Data on calcium levels in Kerr Reservoir are not yet available.

Several public-access reservoirs with a total of 80 public boat ramps are located upstream from both lakes.

In areas where the mussels thrive, adult zebra mussels frequently attach to boats and trailers. These mussels can live out of the water for two to three days under certain environmental conditions.
The Mattaponi and Pamunkey rivers flow together at West Point to form the York River. The York River has a salinity of about 5 ppt at West Point.

Free-swimming zebra mussel larvae can survive for several days or even weeks in the ballast water of ships. Under some conditions, they can also survive for days in water contained in bait buckets, live wells, boat trailer frames, and other enclosed areas in boats and ships.

Large barges and ships travel up and down the York River to and from a large paper mill in West Point. The barges travel between West Point and the Eastern Shore of Virginia. The ships travel from a number of ports in northern Europe, Canada, and South America.

At the Beulahville monitoring site northeast of Mangohick, scientists measured the pH of the Mattaponi in July at 6.9. Calcium content was 3.7 ppm.

The Mattaponi River has several freshwater reservoirs upstream from West Point. These reservoirs are used for boating and fishing. Lake Anna, a large freshwater reservoir in the Pamunkey River drainage, is also a popular boating and fishing site.

In June at the Hanover monitoring site, scientists recorded pH readings for the Pamunkey at 6.9. Calcium content was 9 ppm.
Lake Anna, the largest reservoir in the Pamunkey River drainage, is a very popular site for recreational fishing and boating. There are nine public access boat ramps on the lake.

Larval zebra mussels can easily be transported by currents moving downstream from one body of water to another.

The pH of Lake Anna measures 7.9 in some branches of the lake during the summer, but most of the lake has a pH of slightly less than 7.0.

There is a nuclear power plant located on Lake Anna which requires large amounts of water for its operation.

The greatest calcium content measured in Lake Anna waters is 6.0 ppm.

In areas where the mussels thrive, adult zebra mussels frequently attach to boats and trailers. These mussels can live out of the water for two to three days under certain environmental conditions.
Zebra Mussel Study Site No. 8
Claytor Lake

Claytor Lake has heavy recreational use. There are eight public boat ramps on the lake, and eight more are located on the New River upstream.

Zebra Mussel Study Site No. 8
Claytor Lake

The calcium level in Claytor Lake is usually low, around 9.0 to 10.0 ppm. However, in some years, the calcium has been measured at 30.0 ppm.

Zebra Mussel Study Site No. 8
Claytor Lake

Claytor Lake hosts numerous fishing tournaments. Participants travel with their boats to Claytor Lake from many areas outside of Virginia.

Zebra Mussel Study Site No. 8
Claytor Lake

Claytor Lake was built as a reservoir to provide water for a hydroelectric power plant.

Zebra Mussel Study Site No. 8
Claytor Lake

The pH of surface waters in Claytor Lake in June ranges from 7.3 to 9.3.

Zebra Mussel Study Site No. 8
Claytor Lake

In areas where the mussels thrive, adult zebra mussels frequently attach to boats and trailers. These mussels can live out of the water for two to three days under certain environmental conditions.
South Holston Lake is located near Abingdon on the South Fork of the Holston River. The Holston is a tributary of the Tennessee River.

The pH of South Holston Lake has been measured at 6.9 to 8.6 in June and July.

South Holston Lake is only a few hundred miles from other lakes in the Tennessee River system. Zebra mussels are living and successfully reproducing in the Tennessee River.

Calcium levels in South Holston Lake range from 18 to 30 ppm.

There are 16 public boat ramps on South Holston Lake and two more upstream on Hungry Mother Lake.

In areas where mussels thrive, adult zebra mussels frequently attach to boats and trailers. These mussels can live out of the water for two to three days under certain environmental conditions.
CRITERIA FOR PREDICTING ZEBRA MUSSEL INVASIONS IN THE MID-ATLANTIC REGION

BY

 PATRICK BAKER
 SHIRLEY BAKER
 ROGER MANN

SCHOOL OF MARINE SCIENCE
VIRGINIA INSTITUTE OF MARINE SCIENCE
COLLEGE OF WILLIAM AND MARY
GLOUCESTER POINT, VIRGINIA 23062
This document was published by
Virginia Sea Grant's Marine Advisory Program,
School of Marine Science,
Virginia Institute of Marine Science,
College of William & Mary,
Gloucester Point, Virginia 23062.

Authors: Patrick Baker, Shirley Baker, Roger Mann
Editor and Designer: Susan C. Waters
Typography: Ruth Hershner

Virginia Sea Grant Marine Resource Advisory No. 50
Virginia Sea Grant Advisory No. VSG-93-03
Virginia Institute of Marine Science Contribution No. 1821
INTRODUCTION

The following document is from the proceedings of a 1993 zebra mussel workshop, conducted in Baltimore, Maryland. At the workshop forecasts were presented concerning the future of zebra mussels, Dreissena polymorpha, in the mid-Atlantic states.

What is the probability that zebra mussels will invade specific bodies of water within a given state? If they do invade, will they become economic and ecological pests as they have in portions of the Great Lakes? These and similar questions are addressed, with the expectation that management strategies can be developed to delay, mitigate, or possibly even prevent zebra mussel invasions, in some areas.

The probability of invasion is related to the frequency with which a specific body of water is inoculated with zebra mussels and their ability to survive in that body of water. The variety of dispersal mechanisms, and the frequency and relative importance of each potential inoculation affect the overall chance that a reproducing population of zebra mussels will become established in a lake or estuary.

Prior experience with zebra mussel invasions in Europe and other parts of North America indicates that, at least initially, population growth is not limited by predators, parasites, or other biological factors. Certain abiotic parameters, however, seem to limit zebra mussel populations in Europe. For these reasons, the criteria for predicting zebra mussel invasion success in the mid-Atlantic region are primarily physical environmental parameters, and especially aspects of water chemistry. The degree to which a particular body of water conforms to the known optimum physiological requirements for zebra mussels is here termed its susceptibility. The second part of this document is a review of the physiological requirements used to predict susceptibility. For an example of similar predictions for other regions, see Neary and Leach (1992).

A second species of Dreissena, with at present only the common designation "quagga mussel" (its taxonomic identity is uncertain), has been found in parts of the Great Lakes and New York inland waters (May and Marsden, 1992). At present, nothing is known about the dispersal or physiological requirements of the quagga mussel, other than that it lives with Dreissena polymorpha, and dominates some deep-water populations (Marsden, 1993). Throughout this chapter, Dreissena is used to indicate both the zebra mussel and the quagga mussel.

I. INVASION RISK

DISPERAL MECHANISMS OF ZEBRA MUSSELS

Invasion risk is here defined as the probability, relative to other bodies of water, that zebra mussels will be inoculated to a specific body of water in sufficient numbers to establish a viable population. As will be explained, risk is related to the numbers of zebra mussels inoculated, and the conditions of inoculation, which are in turn related to the mechanisms of inoculation.

Terminology for biological invasions merits a brief discussion. An invasion is the successful (reproductive) establishment of a species in an area in which it had historically been absent. The vector for invasion can be either human-mediated or natural. When an invasion is known to be human-mediated, it can be termed an introduction. Thus, Dreissena was introduced to Lake St. Clair, in Michigan, and from there they invaded (by natural dispersal) Lake Erie and Lake Ontario. The actual event that leads to an introduction, such as the release of ballast water containing larvae, is termed inoculation, and the process by which the new species becomes a self-maintaining population is termed establishment. Thus, inoculation and establishment are events within an introduction, which is itself a specific form of invasion. These usages come from no single source, and alternate terms are used elsewhere, but the above are generally consistent with modern literature on aquatic biological invasions.
Population Establishment

One of the most difficult aspects of predicting biological invasions is forecasting when (how soon) an invasion will occur. Dreissena invaded the Great Lakes some time shortly prior to 1988 (Hebert et al., 1989), but the mechanisms responsible for invasion, ballast water (Carlton, 1993), has existed for decades before Dreissena became established. Similarly, the rate and direction of dispersal by both natural and human-mediated means from the Great Lakes has often defied prediction. For example, Dreissena has been present in an upper portion of the Susquehanna River, in New York, since at least 1991 (Lange and Cap, 1992), but to date has not appeared in downstream portions. This absence does not mean that zebra mussels will not invade downstream, only that we cannot predict closely when they will.

We do have limited understanding of how some inoculations may be favored over others. Dreissena reproduces sexually, releasing male and female gametes into the water. Prior research on other aquatic organisms (Pennington, 1985; Lasker and Stewart, 1992) show that gamete viability decreases dramatically with dilution, so that low-density populations of benthic invertebrates have much lower reproductive success than high-density populations. Not only does this mean that the initial inoculation of Dreissena must result in animals in sufficient proximity to spawn successfully, but also that there must be enough offspring produced so that they, too, can reproduce successfully. Larvae disperse in the plankton and face high mortality; those that survive to settlement are widely scattered, and only those that settle near others can reproduce. Thus, the greater the founding population, the greater the chance of subsequent establishment, and the more quickly the population will attain high levels. Dispersal mechanisms which deliver many individuals to the same location are the most likely to spread invasions (Johnson and Carlton, 1993).

There are two practical aspects to the above observation, and its corollary, that not every inoculation will result in invasion. First, it is cost-effective for management agencies to concentrate first on major invasion vectors, rather than trying to prevent every possible mechanism for invasion. Second, when obtaining public cooperation in limiting Dreissena invasion, it is important to make individuals believe that their own reasonable efforts can make a difference in Dreissena invasion. This latter aspect has been discussed by Johnson and Carlton (1993).

Natural Dispersal

Larval Dispersal

Dreissena is unusual among freshwater bivalves in that it has planktonic larvae and postlarvae (Griffiths et al., 1991; McMahon, 1991). Postlarvae drift passively with currents by means of long byssal threads (Martel, 1992). Larvae swim by means of the velum, a ciliated organ, but most bivalve larvae have swimming rates of less than 1 mm s⁻¹ (Mann and Wolf, 1983; Jonsson et al., 1991; Mann et al., 1991), and therefore cannot swim against most currents. Juveniles and adults can crawl actively but not rapidly, and it is extremely improbable that a juvenile or adult could crawl upstream against a current as far in its lifetime as it would be carried downstream as a larva (planktonic period of about 12 days: Neumann et al., 1993) or postlarva. Dreissena, therefore, is ecologically adapted more for lakes (no net currents) or estuaries (bidirectional currents), than for rivers (unidirectional current) (Neumann et al., 1993). Rivers which have attached oxbow lakes, fluviallogical locks, or other calm backwaters, could probably support significant populations of Dreissena (e.g. Bryukov et al., 1968). The native range of Dreissena is estuaries in southern Russia, Ukraine, and Kazakhstan, and the largest populations outside of the native range, in Europe and North America, have been in lakes, estuaries, and other calm waters (Shetman, 1968; Wolff, 1969; Sta czykowska, 1977; Griffiths et al., 1991).

High densities of Dreissena in non-estuarine rivers can be maintained only by a continual input of individuals from upstream lakes or backwaters. Thus, streams without such areas cannot be successfully invaded by Dreissena. Unfortunately, most major North American rivers, including those along the eastern coastline of the U.S.A., have upstream reservoirs that could support Dreissena populations, given the correct water quality parameters. High densities of Dreissena can be attained in rivers downstream of lakes (e.g. Piesik, 1983; Neumann et al., 1993). There is no data on the effect of reservoir size or flushing rates on downstream Dreissena population densities, so for now, all freshwater downstream of a lake capable of supporting Dreissena populations must be considered at risk from invasion.

Dreissena are limited in their ability to tolerate salt water, but most major estuaries in North America have large freshwater tidal portions. Even in years of low freshwater input, significant portions of most estuaries remain fresh. Dreissena larvae and postlarvae could be retained within the estuary by the same mechanisms used by oyster larvae (Seliger et al., 1982; Mann, 1988). A native species closely related to Dreissena, the false mussel Mytilopsis leucophaca, is already present in oligohaline and freshwater portions of estuaries from New York to Texas (Abbott, 1974). Water chemistry of these estuaries, in terms of pH and calcium, is often nearly ideal for Dreissena, and many must be considered at risk from Dreissena invasion. Furthermore, any freshwater portions of an estuary will eventually be invaded if there are Dreissena populations established in upstream lakes or reservoirs. The St. Lawrence River in Quebec and the Hudson River in New York are two North American examples of invaded freshwater estuaries (New York Sea Grant, 1992).

Adult and Juvenile Dispersal

Adults and juveniles of Dreissena can crawl by alternately attaching and releasing byssal threads. Based on crawling rates of juvenile marine mussels, Mytilus spp. (these authors,
unpubl. data), Dreissenia individuals can probably move several meters per day. A very short stream between a Dreissenia-infested reservoir and an upstream, non-infested reservoir, would probably not be a barrier against invasion by crawling individuals. Two examples of this situation include a series of ponds in a typical golf course, and the network of ponds, canals, and ditches in many coastal cities in the mid-Atlantic region. Dreissenia individuals probably cannot circumnavigate a waterfall or spillway, however, nor can they prevent a rapidly flowing stream more than several hundred meters in sufficient numbers to establish a new population in an upstream reservoir.

Adult and juvenile Dreissenia attach to a variety of substrates with sturdy byssal threads. A number of natural mechanisms (amphibious animals) have been proposed that could transfer byssally-attached adults or juveniles between very close but separate bodies of water. These mechanisms have been reviewed by Carlton (1993), and an example includes aggregations attached to the carapaces of turtles, which often migrate between nearby bodies of water. Certain species of turtle may become important in dispersing Dreissenia within regions with many small lakes, or in coastal regions with many small estuaries isolated from each other by high-salinity barriers, but only low, narrow terrestrial barriers. This last condition is typical of the coastal plain from New Jersey to Texas. In the mid-Atlantic region, the eastern musk turtle (Sternotherus odoratus), a common species living in a variety of bodies of water, is noted for having heavy algal fouling (McCauley, 1945; Martoff et al., 1980), and the much larger snapping turtle (Chelydra serpentina) can also be heavily fouled (J. Brown, Virginia Inst. Marine Science, pers. comm.).

Waterfowl have been suggested by a variety of authors as potential vectors of transport, and Carlton (1993) reviews evidence both for and against this as a mechanism of invasion. Birds could transport Dreissenia many kilometers by a variety of means, although the actual numbers transported by any one bird would be small relative to the numbers that could be transported by almost any human-mediated process. The role of large flocks of migratory birds in dispersing Dreissenia is worth investigating, however.

It should be noted that so far the spread of Dreissenia in North America across natural barriers can be attributed to human actions alone. Thus while amphibious animals may be mechanisms of invasion, most emphasis should be placed on controlling human-mediated dispersal mechanisms.

HUMAN-MEDIATED DISPERAL MECHANISMS

OVERLAND TRANSPORT

Overland transport of Dreissenia associated with recreational vessels, or the trailers that transport them, has received much attention, and is thought to be the primary mechanism whereby inland lakes separated from other navigable waters will be invaded. Baltimore County, Maryland, has restricted the use of recreational vessels in several municipal reservoirs in response to this threat. McMahon and Payne (1992) have shown that Dreissenia can survive several days out of water even at high temperatures, and dispersal by overland transport is known to have occurred (Carlton, 1993). Public education has focused on the potential for Dreissenia attached to vessel hulls to be moved between lakes, but it has recently been noted that under certain circumstances more Dreissenia will probably be transported on strands of aquatic macrophytes that become entangled in boat trailers (Carlton, unpubl. data).

Known or suspected invasions that have occurred as a result of overland transport have been fewer, so far, than have been expected. The reason may be that, normally, few individuals are introduced by a single inoculation. Several overland invasions have occurred, however, including the invasion of the upper Susquehanna drainage in New York state (Lange and Cap, 1992), and either vessel hulls or their trailers are the most probable vector.

Juveniles or adults, not larvae, will be transported overland by the above mechanisms. To be introduced to the new location, the Dreissenia must detach from the vessel or trailer. Juveniles are more likely to move than adults (Eckroat et al., 1993). If the Dreissenia are attached to macrophytes associated with the boat trailer, it is simply necessary for the plant to detach in the new body of water. Furthermore, a piece of drifting plant with attached Dreissenia could drift rapidly down a river until it reached a lake, where a population could be established, whereas adult Dreissenia entering individually into a river would be less likely to reach a downstream lake or successfully establish a population.

BALLAST WATER, BILGES, BAIT WELLS

It is believed that the introduction of Dreissenia into the North American Great Lakes was accomplished by the release of ballast water, containing larvae or postlarvae, from the holds of ore carriers from Europe. Evidence for this route has been well documented (see Carlton, 1993, for review). Guidelines to prevent further introductions of exotic species by ballast water into the Great Lakes have been set up, but compliance is not thought to be 100% (J. Carlton, pers. comm.), and probably a single inoculation under optimal conditions is sufficient to permit invasion. Furthermore, ballast into other North American freshwater ports remains undocumented. For example, Richmond, Virginia, a freshwater estuarine port, is regularly visited by container ships from Antwerp, Belgium, and other European ports (Mechan Overseas Terminal, Inc., 1991). Alexandria, Virginia, another freshwater port, is visited six to seven times annually by ships from Quebec City, Quebec, in the St. Lawrence River, where Dreissenia is established (Robinson Terminal Warehouse Corp., Alexandria, VA, pers. comm.). The amount of ballast water exchanged, and the nature of the exchange, is undocumented and unregu-
lated, but represents a potential vector for the introduction of Dreissena into Virginia. Port logs, sometimes available upon request, will not doubt reveal many further points of potential introduction, and it may be chance that the Great Lakes were invaded by Dreissena before another North American body of water.

Bait wells, bilge water, shipments of live fish or bait, and many other means of transporting water between bodies of water may harbor larvae or postlarvae for several days, although to date no specific examples of this occurring in North America are known. This means of transport is reviewed at length by Carlton (1993).

VEssel TRANSPORT BETWEEN ESTUARIES

Once established in Lake St. Clair and Lake Erie in 1989, Dreissena was subsequently identified at many isolated points elsewhere in the Great Lakes and in the Erie Canal, New York. The vector of dispersal in these cases was thought to be vessel hulls with byssally-attached adults or juveniles (Griffiths et al., 1991). Since vessels can move upstream or across salinity barriers relatively rapidly, they are a major mechanism for expanding the range of Dreissena. Postlarvae and juveniles attached to the hull of a recently moved vessel can detach at a new mooring, and accumulate on nearby stationary substrate. Alternately, adults attached to the hull can spawn at a new location. The relative importance of these two phenomena depends on the number of postlarvae or juveniles transferred in the first case, or the number of adults and the amount of time spent at the new mooring in the second case. The resettlement of postlarvae and juveniles from vessel hulls as a means of dispersal is likely to be favored during the reproductive season, by vessels with relatively clean hulls that do not spend extended periods at any particular mooring. Even a high density of microscopic Dreissena postlarva and juveniles would be unnoticed by persons visually inspecting vessel hulls in an attempt to prevent the spread of Dreissena. On the other hand, some vessels, especially barges, spend weeks or months at any particular mooring, giving fouling organisms attached to their hulls multiple opportunities to spawn. In such cases, vessels with large fouling populations of adult Dreissena would be favored as a method for introducing this species.

Barges in particular represent a major vector for Dreissena dispersal. They have large hull areas for colonization from the source population, they are infrequently cleaned, and they often have long residence periods at any particular mooring. Once moved, barges may be moored for months or even years, giving any fouling organisms many opportunities to reproduce. In addition, freshwater regions are attractive to many vessel owners for long-term moorage, because of the relative lack (prior to Dreissena) of fouling organisms. The hulls of other vessels that travel between estuaries are generally smaller and cleaner than barge hulls, but the possibility of introduction via these cannot be ruled out. Even a small, possibly unnoticed portion of a hull could harbor tens of thousands of adult, juvenile, and postlarval Dreissena.

Given the ability of Dreissena to tolerate moderately saline waters for at least a short period, vessel traffic represents a major intracoastal vector for the spread of Dreissena between estuaries. Dreissena is present in both the Hudson and Susquehanna Rivers (New York Sea Grant, 1992), and could potentially spread from those sites to most other estuaries with barge traffic between New York and Florida. At present no records on commercial or recreational traffic between freshwater estuarine ports in North America have been compiled. The length of time that Dreissena can tolerate full seawater, perhaps by completely closing their valves, is unknown, but they have been shown to be able to survive several days out of water, attached to pleasure craft hulls, under certain circumstances (McMahon and Payne, 1992), and can survive several days without oxygen (Mikheev, 1968).

Introduction of Dreissena to a body of water via the hull of a vessel does not automatically ensure establishment. Establishment is favored by high survival of Dreissena during the passage overland or through high salinity, by large numbers (e.g. millions) of individuals, by favorable water conditions for growth and reproduction in the host estuary; and by long moorage of the fouled vessel.

INTENTIONAL INTRODUCTION

The possibility of deliberate, misguided introductions of Dreissena must be seriously considered. Dreissena populations are believed to be responsible for a dramatic increase in water clarity in Lake Erie (Wright and Mackie, 1990; Greenberg et al., 1992; Madsen and Sprules, 1992; Leach, 1993), and would probably do the same for any small lake to which they were successfully introduced. Water clarity, while of uncertain ecological advantage, is enormously attractive aesthetically, and the impact of Dreissena on water clarity in Lake Erie has been well-publicized (e.g. Di Vincenzo, Newport News Daily Press, Dec. 5, 1991; Walker, 1991; Cohen, 1992; Sisson, 1993). Other reasons to intentionally introduce Dreissena could be a desire to increase biodiversity, provide food for other organisms, or to provide a new bait source. If Dreissena are used as bait, there is also a risk of recreational fishermen dumping left-over bait into a pond or lake. Many previous introductions of freshwater mollusks are believed to have been carried out by private landowners, intentionally or through carelessness (Carlton, 1993), and Dreissena are exceptionally easy to collect and transport. Because Dreissena larvae disperse, a small lake that retains and concentrates successive generations may be at much at risk from a single introduction as a large lake.
II. Susceptibility To Invasion

Physiological Requirements of Zebra Mussels

This section reviews published data on the physiological requirements of *Dreissena* with respect to water quality and chemistry. Four common aspects appear critical to the persistence and reproduction of *Dreissena* populations: temperature, salinity, alkalinity (pH), and calcium content. Table 1 summarizes this information for adults and larvae.

**Temperature**

Stanczykowska (1977) stated that adult *Dreissena* began growth at 11-12°C in European lakes, similar to a value of 10-12°C reported by Mackie (1991) for *Dreissena* in the Great Lakes. Bij de Vaate (1989), however, reported that growth of *Dreissena* in the Netherlands occurred at temperatures as low as 6°C, and in a review of European lakes with *Dreissena*, Strayer (1991) reported that the largest populations were in lakes with a mean annual temperature of only 6-9°C, inferring that temperatures exceeded 6-9°C only half of the year. Borcherding (1991), who reported gametic growth at temperatures as low as 2-4°C, suggested that reported differences could be due in part to food quality and quantity for different populations. Differences may also reflect methods of measuring or defining growth.

Schneider (1992) predicted that growth rate is strongly affected by temperature, with slower growth rates at low temperatures. The minimum temperature tolerance for survival appears to be just above freezing (Strayer, 1991).

**Salinity**

Mackie and Kilgour (1992) reported an LC₅₀ of 7.6 salinity at 96 hours for unacclimated adult *Dreissena*, at 19°C. Over a period of 42 days, *Dreissena* which had been slowly acclimated had only 15% mortality at 8.0 salinity at 4°C or 10°C. Barber (1992), however, reported 100% mortality within 52 days of adult *Dreissena* in water slowly raised from 0 to 2.7°C at 15°C. Wolff (1969) cites an unpublished source stating that *Dreissena* could survive salinities as high as 12.2, although the circumstances of exposure were not given. In the Delta region of the Netherlands, adult *Dreissena* tolerate continental salinity of 4 in ponds, but were not found in estuaries with mean salinities above 0.6, in which salinity fluctuated with tides (Wolff, 1969). Wolff (1969) concluded that the higher mean salinities could be tolerated only if there were not tidally-driven fluctuations.

The apparent difference in reported salinity tolerance in *Dreissena*, between Mackie and Kilgour (1992) and Barber (1992) (above), may reflect a strong interaction of salinity and temperature (with higher tolerance at lower temperatures), or it may reflect physiological differences in the experimental animals. Hebert *et al.* (1989), and Garton and Haag (1991), reported high genetic variability, for an introduced species, among *Dreissena* in the Great Lakes and this may be reflected in variation in physiological tolerances.

---

**Table 1. Physiological Requirements of Zebra Mussels: Summary**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Temperature</th>
<th>Salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult Survival</td>
<td>0.33°C</td>
<td>0-12 ppt</td>
</tr>
<tr>
<td>Adult Growth</td>
<td>6-9°C</td>
<td>0.6 ppt</td>
</tr>
<tr>
<td>Larval Growth</td>
<td>12-24°C</td>
<td>Oppt-7</td>
</tr>
<tr>
<td></td>
<td>(17-18°C)</td>
<td></td>
</tr>
</tbody>
</table>

Gametogenesis in *Dreissena* has been reported at temperatures as low as 2-4°C in the presence of good food quality (Borcherding, 1991), and spawning is known to occur at 12°C (Sprung, 1987; Bij de Vaate, 1999; Borcherding, 1991) and at 22-29°C (Haag and Garton, 1992). Sprung (1987) reported a loss of sperm motility in *Dreissena* at 26°C, and zygote failure above 34°C. This last evidence indirectly supports predictions by Strayer (1991) that populations of *Dreissena* will be heat-limited in the southernmost regions of North America. Haag and Garton (1992), however, reported that *Dreissena* in Lake Erie, spawned during a period of water temperatures above 26°C; the maximum temperature at this time was 30°C. Temperatures as high as 30°C, therefore, may not inhibit reproduction. Strayer (1991), in a review of climatological conditions in Europe, reported that the highest mean monthly temperature tolerated by *Dreissena* was 26.4°C. Optimum larval rearing temperatures in the laboratory were reported to be about 17-18°C by Sprung (1987).

In temperate regions, with seasonal temperature fluctuations, the maximum temperature that permits *Dreissena* reproduction is less important than the temperature tolerance of adults, since there will always be optimal temperature windows at some point of the year for spawning. *Dreissena* tolerates extended periods of temperatures in excess of 25°C, so the majority of the United States and southern Canada are within the temperature tolerance of this species.
When plotting potential spread of *Drissena* in North America, it is safest to assume that they can tolerate salinities of at least 12.2 for a few days. This would be significant for *Drissena* fouling slow-moving vessels, such as barges, that are periodically moved between freshwater portions of estuaries. For example, a barge fouled by *Drissena* in the Susquehanna River in Pennsylvania or Maryland, could probably be towed to a new anchorage (and a new watershed) in Philadelphia, Pennsylvania, or Alexandria, Virginia, without submitting the *Drissena* to lethal osmotic stress. On the other hand, only areas with salinity below 1 are likely to maintain high *Drissena* densities. Walton (1993) found *Drissena* in salinities as high as 6 in the Hudson river, but high densities (>1000 m-3) were maintained only at a site that never exceeded 3 salinity, and was often fresh.

The salinity tolerances of *Drissena* spawning adults, eggs, veliger larvae, or planktonic postlarvae, have not been reported. Mann et al. (1991), however, in a review of physiological tolerances of oysters of the genus *Crassostrea*, reported that the ranges of salinity tolerances for spawning adults or for larvae were equal to or less than those for adult survival.

**PH, CALCIUM, OTHER IONS**

pH in North American fresh waters varies depending on rainfall acidity and bedrock composition. Adult *Drissena* have a heavy periostracum covering all but the oldest, thickest portion of the shell (pers. obs.). The periostracum in freshwater mollusks is thought to aid in prevention of shell dissolution (McMahon, 1991), and *Drissena* may thus be able to survive periods of relative acidity. The minimum pH tolerance of adult *Drissena* appears to be 7.0, the point at which shell dissolution exceeds calcium uptake (Vinogradov et al., 1993), but Ramcharan et al. (1992), in a literature survey of European lakes, reported that significant populations of *Drissena* persisted only above a mean pH of 7.5.

Larval development in *Drissena* appears to be tightly regulated by pH. Sprung (1987) reported *Drissena* egg survival between only pH 7.4 and 9.4, and optimal survival between pH 8.4 to 8.5, at temperatures of 18-20°C. Even if these values vary among *Drissena* populations, or with rearing conditions, it appears that at least during the reproductive season, *Drissena* requires slightly alkaline water.

Calcium, a major component of mollusk shells, appears to be limiting in some cases. Ca²⁺ (from CaCO₃) is expressed either as "hardness" (milliequivalents, or meq), or as mg per liter. European lakes with large populations of *Drissena* have hardness levels of about 1.75 to 3.16 meq (Strayer, 1991), or a minimum of about 34.5 mg Ca²⁺ l⁻¹, a mean of about 45-52 mg Ca²⁺ l⁻¹, and a maximum of 76 mg Ca²⁺ l⁻¹ (Ramcharan et al., 1992). These values should not be considered limits, but only the range for which large populations of *Drissena* have been recorded in Europe. Actual requirements for adult *Drissena* have not been determined in the laboratory. Sprung (1987) reported minimum embryo survival at 12 mg Ca²⁺ l⁻¹, and optimum survival at levels of 40 mg Ca²⁺ l⁻¹ (2.0 meq) and above. Larvae grew relatively well at calcium levels of 106 mg l⁻¹, the maximum level tested.

Other salts, including MgSO₄, NaCl, KHCO₃, NaHCO₃, and MgCl₂, do not appear limiting to *Drissena* embryos (Sprung, 1987). Potassium (KCl) is lethal at levels of about 100 ppm (LC₅₀ for 24 hours) (Fisher and Stromberg, 1992), but concentrations rarely approach this level in natural waters. Ramcharan et al. (1992), in a review of European lakes, reported that the mean phosphate (PO₄) level of lakes with stable populations of *Drissena* is about 0.12 mg l⁻¹, with a maximum level of 0.18 mg l⁻¹ and a minimum of 0.05 mg l⁻¹, although *Drissena* have been reported in lakes with no measurable free phosphate. Phosphorus and nitrogen may have indirect roles on *Drissena* population growth rates, since they are critical nutrients for freshwater phytoplankton, and thus affect abundance of phytoplankton, the primary food source for *Drissena*. Ammonia (NH₃) is lethal at a level of about 2 mg l⁻¹ (Nichols, 1993), but this level is lethal to many other aquatic organisms as well.

**OXYGEN**

Sprung (1987), with limited data, concluded that *Drissena* larvae survived for short periods at oxygen levels as low as 20% of saturation, at 18°C. This oxygen level in natural systems is considered to be a hypoxic condition, and aquatic systems with oxygen levels of 20%, for significant periods have problems far worse than zebra mussel infestations. During periods of highest pollution in the 1970s, hypoxia eradicated *Drissena* from much of the Rhine River in Germany (Neumann et al., 1993). Survival of adults in hypoxia is unknown, but juvenile oysters have been shown to be significantly more tolerant of hypoxia than larvae (Wildow et al., 1989), so adult and juvenile *Drissena* are probably more tolerant of hypoxia than are larvae. Under anoxic conditions, 100% mortality of *Drissena* occurs in about 6 days at 17-18°C, and 3 days at 23-24°C (Mikhee, 1968). McMahon and Alexander (1991) concluded that *Drissena* are poorly adapted for survival at low oxygen levels in warm water (25°C), which indirectly supports Strayer's (1991) predictions of a warm-water limitation to *Drissena* invasion. In general, however, only severely stressed aquatic systems would have oxygen levels low enough to inhibit *Drissena* invasions.
Acknowledgements. This work is a result of research sponsored by NOAA Office of Sea Grant, U. S. Department of Commerce, under federal Grant No. NA 90AA-D-SC045 to the Virginia Graduate Marine Science Consortium and the Virginia Sea Grant College Program. The U. S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon. The authors wish to thank James Carlton, of Williams College, and Gene Burreton, Robert Diaz, Elizabeth Keane, and Rochelle Seitz, of the Virginia Institute of Marine Science, for their useful comments on this manuscript.

REFERENCES


Schneider, D.W. 1992. A bioenergetics model of zebra mussel,

*Mareis Biology* 71:57-72.


*Soundings: Trade Only* January 1993: p 44.

Spring, M. 1987. Ecological requirements of developing Dreissena

Stanczykowska, A. 1977. Ecology of Dreissena polymorpha (Pall.)

Suyker, D. L. 1991. Projected distribution of the zebra mussel,
48:1389-1395.

Vinogradov, G.A., N.F. Smirnova, V.A. Sokolov, and A.A.
Bruzinsky. 1993. Influence of chemical composition of the
water on the mollusk *Dreissena polymorpha*. 283-293. In
Nalepa, T.F. and D.W. Schloesser (eds.). *Zebra Mussels:
Biology, Impact, and Control*. Lewis Publishers, Ann Arbor, MI.


Walton, W.C. 1993. The invasion of the Hudson River estuary by
the zebra mussel *Dreissena polymorpha*, and its subsequent
range overlap with the dark false mussel, *Mytilopsis*
Sciences, Rutgers Univ., New Brunswick, N.J.)

Widdows, J., R.I.E. Newell, and R. Mann. 1989. Effects of hypoxia,
and anoxia on survival of oyster larvae (*Crassostrea virginica*,

Wolff, W.J. 1960. The Mollusca of the estuarine region of the
rivers Rhine, Meuse and Scheldt in relation to the hydrography of the area. II. The Dreissenidae. *Basteria* 33:53-105.

and B.O.D. from activated sewage sludge and its
biodeposition by the zebra mussel, *Dreissena polymorpha*
POTENTIAL RANGE OF THE ZEBRA MUSSEL, *Dreissena polymorpha*, IN AND NEAR VIRGINIA

BY
PATRICK BAKER
SHIRLEY BAKER
ROGER MANN

SCHOOL OF MARINE SCIENCE
VIRGINIA INSTITUTE OF MARINE SCIENCE
COLLEGE OF WILLIAM AND MARY
GLOUCESTER POINT, VIRGINIA 23062
This document was published by Virginia Sea Grant's Marine Advisory Program, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia 23062.

Authors: Patrick Baker, Shirley Baker, Roger Mann
Editor and Designer: Susan C. Waters
Typography: Ruth Hershner

Virginia Sea Grant Marine Resource Advisory No. 51
Virginia Sea Grant Advisory No. VSG-93-04
Virginia Institute of Marine Science Contribution No. 1822
INTRODUCTION

The following document is from the proceedings of a 1993 zebra mussel workshop, conducted in Baltimore, Maryland. At the workshop, forecasts were presented concerning the future of zebra mussels, Dreissena polymorpha, in the mid-Atlantic states.

This publication is devoted to predictions of the probability of invasion by the zebra mussel, Dreissena polymorpha (and the quagga mussel, Dreissena sp.) to specific bodies of water in Virginia. Probability of invasion is divided into risk and susceptibility. Risk refers to the chance, relative to other sites, that a body of water will be inoculated with Dreissena, in sufficient number to establish a population. Inoculation can occur by natural dispersal, but in the mid-Atlantic region is most likely to occur through accidental introduction by humans, especially via boat traffic. Susceptibility of a body of water refers to the probability, based on known physiological requirements, that Dreissena could survive and reproduce. In this publication predictions are made, concerning both risk and susceptibility, for several bodies of water in Virginia.

Original Dreissena populations are native to freshwater or brackish portions of estuaries, with bidirectional water flow, in eastern Europe and central Asia (Staczykowska, 1977), and most subsequent invasions have occurred in lakes and freshwater portions of estuaries (Shivegman, 1968; Wolff, 1969; Staczykowska, 1977; Griffiths et al., 1991). Freshwater portions of estuaries, and natural and artificial reservoirs in the mid-Atlantic region of the United States (here defined as drainages east of the Appalachian Mountains between New York and South Carolina) are therefore at risk from invasion by Dreissena, given correct water quality parameters. Dreissena populations cannot be maintained at high levels in freshwater rivers without an upstream reservoir or lake, because it has planktonic larvae and postlarval stages. This topic is discussed at greater length in Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region, a Virginia Sea Grant Publication, which can be obtained from the Virginia Institute of Marine Science.

TEMPERATURE-LIMITED SYSTEMS

None of the systems in the mid-Atlantic region fall below the minimum temperature requirements for Dreissena reproduction (refer to Criteria for Predicting

A zebra mussel is a small, striped mollusk capable of raising havoc. (Although the mollusk can grow up to two inches, it is usually much smaller — fingernail size.) Zebra mussels have cost millions of dollars in the Great Lakes region where they rapidly colonized water-intake pipes, boats, docks, piers, and other structures. Dreissena polymorpha was inadvertently delivered to U.S. waters around 1986 through the discharge of European shipping ballast water.

Zebra Mussel Invasions in the Mid-Atlantic Region), but most estuaries and lowland reservoirs in South Carolina and Georgia have summer temperatures that may exceed Dreissena tolerances, based on reported European limits (Strayer, 1991), and reported physiological limits of zygotes and adults (Sprung, 1987; McMahon and Alexander, 1991). Reported European temperature limits for Dreissena may be based on geography as much as temperature, however, since the Mediterranean Sea acts as a southern barrier. The movement of Dreissena down the Mississippi River, tracked recently as far as Vicksburg, Mississippi (New York Sea Grant, 1993), should be closely monitored as a natural test of temperature tolerance of this species in North America.

ESTUARIES

 Virtually all estuaries with permanent freshwater inputs in the mid-Atlantic region have tidal freshwater portions, and are potentially susceptible to invasion by Dreissena. Examples of major estuaries (more than 1000 ha. of open, permanently fresh water) between New York and North Carolina include the Hudson River; the Delaware River; the Susquehanna, Potomac, Rappahannock, Mattapom, Pamunkey, and James Rivers in the Chesapeake Bay; Currituck and Albemarle Sounds, and Pamlico, Pungo and Neuse Rivers in North Carolina (Coupe and Webb, 1984; U.S. Army Corps of Engineers, 1984; NOAA, 1985).

Estuaries can be invaded by Dreissena in several ways, all discussed at length in Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region. Briefly, they can be invaded overland, usually with recreational
vessels, either directly to the freshwater estuarine portion, or to a lake, from where, if they become established, they will subsequently invade all downstream waters. Alternately, estuaries can be invaded from the seaward direction, with vessels traveling from other estuaries. Ballast water containing *Dreissena* larvae is a well-known vector, but under some circumstances, *Dreissena* may also be introduced as adults on the hulls of vessels, if the time spent in high-salinity water is not long. This is often possible, as discussed below.

Natural terrestrial and high-salinity barriers between major estuaries and smaller estuaries have been partially eliminated by canals of the Intracoastal Waterway, and may facilitate *Dreissena* transfer between basins. For example, the Chesapeake-Delaware canal, between oolgohaline portions of those respective estuaries, is at times of high freshwater runoff, fresh or nearly fresh at both ends (U.S. Army Corps of Engineers, 1985; NOAA, 1985; Mellor, 1986), and thus represents a route for natural invasion by *Dreissena* of the Delaware estuary from the Susquehanna drainage, where it is found at present (Lange and Cap, 1992; New York Sea Grant, 1999). Two canals, the Dismal Swamp Canal and the Chesapeake and Albemarle Canal, connect the Elizabeth River estuary in southern Chesapeake Bay, Virginia, to freshwater portions of the Albemarle and Currituck Sounds in North Carolina so that freshwater portions of the two formerly separate estuaries are now a single body of water. The Alligator River and Pungo River Canal connect tidal fresh waters of Albemarle and Pamlico Sounds, respectively, in North Carolina. Similar examples can be found elsewhere along the Intracoastal Waterway. Even if there are high salinity regions that act as barriers to natural range expansion by *Dreissena*, barge and other boat traffic carrying *Dreissena* along these canals could pass relatively quickly through high salinity areas and *Dreissena* can tolerate at least several days of relatively high salinity.

*Dreissena* has already invaded the Hudson River estuary (Walton, 1993), and appears poised to invade the Susquehanna River estuary (Lange and Cap, 1992; New York Sea Grant, 1993). These estuaries will serve as models of the sorts of biological and economic impacts to expect in other mid-Atlantic estuaries. In addition, they will serve as reservoirs of *Dreissena* to invade adjacent estuaries, particularly on the hulls of vessels travelling between estuaries, as discussed in *Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region*.

Some, but not all, of Virginia's freshwater estuarine regions are at risk of, or susceptible to, invasion and establishment by *Dreissena*. The risk of inoculation varies between estuaries, according to the level of boat traffic and other human factors. Susceptibility of establishment, on the other hand, varies according to water chemistry, independently of human use. In the following discussion for each estuary, values for pH and calcium are the maximum reported monthly averages for summer (May to September), based on existing water chemistry data.

**POCOMOKE RIVER**

The Pocomoke River is at low risk of inoculation, and is not susceptible to establishment of *Dreissena*. Like other estuaries on the Delmarva Peninsula, it has relatively low freshwater inflow, and no major upstream reservoirs for *Dreissena* to invade. There is little commercial vessel traffic into the estuary, although the channel is maintained to Snow Hill, Maryland, and there is a marina near Snow Hill. Opportunities for inoculation, therefore, are relatively limited, relative to other Chesapeake Bay estuaries.

Water chemistry data for February 1991, near the upstream tidal limit at Snow Hill showed low pH (6.1) and calcium content (4.3 ppm) (Jones et al., 1991). If *Dreissena* were to invade this estuary, they probably would not attain high population levels.

**POTOMAC RIVER**

The Potomac River is at high risk of inoculation, and highly susceptible to establishment of *Dreissena*. The tidal freshwater portion of the Potomac estuary stretches from Washington, D.C., to Quantico, Virginia in most years. There are few lakes adjoining the Potomac River estuary; therefore, the invasion of the Potomac River drainage by *Dreissena* carried by recreational vessels transported from an adjoining drainage is less likely to occur than in some other systems. The Virginia portion of the Potomac/ Shenandoah drainage, for example, has only about 40 public boat ramps (most of which are on rivers) compared to more than twice that number for some other Virginia drainages of similar size (DeLorme Mapping Co., 1989). Resource managers have fewer major lakes to monitor in a program to prevent the introduction of *Dreissena*. Invasion could occur via intentional, misguided introduction to a farm pond or other small impoundment, however. This possibility can be prevented only through education of landowners and users.

Inoculation of the Potomac by *Dreissena* could also occur from the seaward direction, via ballast water of the hulls of incoming vessels. Ballast water containing *Dreissena* larvae or postlarvae is a distinct risk to the Potomac estuary. Bulk cargo ships from Quebec City, Quebec, arrive in Alexandria, Virginia, 6-7 times annually (Robinson Terminal Warehouse Corp., Alexandria, VA, pers. comm.). Alexandria is the largest port in the freshwater portion of the Potomac; Quebec City is on a population of the St. Lawrence River that has established populations of *Dreissena* (New York Sea Grant, 1993). The amount of ballast water exchanged, and the nature of the exchange, are unknown. Commercial and
recreational traffic into the Potomac estuary from adjoining estuaries is very high, and the Potomac is the closest Virginia estuary to the Susquehanna River, where *Dreissena* is already present.

Water chemistry data indicate that both pH (8.1-8.4, May to September at Washington, D.C.) and calcium content (32-40 ppm) (Prugh *et al.*, 1992) are suitable for *Dreissena* reproduction. If *Dreissena* becomes established in the Potomac estuary, all indications are that it would rapidly attain pest proportions. This region has already experienced invasion by the asiatlic clam, *Corbicula fluminea*, which has attained high abundance (Phelps, 1991).

**RAPPAHANNOCK RIVER**

Risk of inoculation to, and susceptibility of, the Rappahannock River to *Dreissena* invasion, are moderate. The tidal freshwater portion of the Rappahannock estuary extends upstream from Fredericksburg, Virginia, to somewhere between Port Royal and Tappahannock, depending on freshwater inflow levels. Invasion of the Rappahannock could occur from upstream, where there are several reservoirs of moderate size, if they were invaded. There are 11 public boat ramps in the freshwater portion of the Rappahannock drainage (DeLorme Mapping Co., 1989), and there are also several large, privately maintained reservoirs, such as Lake of the Woods, which is surrounded by a housing development. Inoculation could also occur from the seaward direction, via fouling on the hulls of vessels moved from nearby estuaries already invaded by *Dreissena*, but both commercial and recreational movement from other estuaries to the Rappahannock is low to moderate.

The lower Rappahannock River has relatively low pH (7.8 in August, at Fredericksburg) and very low calcium (5.2 ppm) (Prugh *et al.*, 1992). Based on these data, even if *Dreissena* becomes established here, it is not predicted to have high reproductive success most years, and is unlikely to maintain pest proportions.

**PIANKATANK RIVER**

The tidal freshwater portion of the Piankatank River is at relatively low risk of inoculation, and is not susceptible to establishment of *Dreissena*. The Piankatank, and its adjoining freshwater tidal portion, Dragon Swamp, is the largest of a number of small estuaries on the west side of Chesapeake Bay for which the drainage basins rise entirely within the coastal plain region. There are no large upstream reservoirs, and no commercial traffic into freshwater tidal portions, so the only likely mechanisms of *Dreissena* inoculation would be via private introductions to upstream farm ponds, or via the hulls of small pleasure vessels from other estuaries. The Piankatank has low pH (6.5 in July at Mascot) and low calcium (13 ppm) (Prugh *et al.*, 1992), so *Dreissena* would be unlikely to survive or reproduce.

Data for other small Virginia estuaries are limited, and while some (e.g. the Pocomoke, discussed above) are known to be acidic, pH and calcium of small-to medium-sized impoundments upstream on these varies dramatically within the same drainage (Virginia Department of Game and Inland Fisheries, unpubl. data). No small estuary, therefore, should be considered safe from *Dreissena* invasion until water quality has been measured and determined to be unsuitable for *Dreissena* growth and reproduction.

**MATTAPONI AND PAMUNKEY RIVERS**

The Mattaponi and Pamunkey Rivers, which unite at West Point, Virginia, to form the York River estuary, are both at moderate risk of inoculation by *Dreissena*, and are moderately susceptible to establishment of this species. The York River is rarely fresh or oligohaline, even at West Point (NOAA, 1985), so freshwater portions of the Mattaponi and Pamunkey are normally distinct from each other. Small tributaries of the two subestuaries are very close to each other, though, and could be host to brief overland transport by animals such as turtles (see *Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region*).

Inoculation of either estuary by *Dreissena* could occur from upstream reservoirs which had been previously invaded overland. The Mattaponi River has several upstream reservoirs of moderate size and recreational use, such as Ni River Reservoir, and Caroline Reservoir, and in the Pamunkey drainage the relatively large Lake Anna (discussed separately in this chapter in the section on lakes). There are about 12 and 15 public boat ramps in the Mattaponi and Pamunkey drainages, respectively (DeLorme Mapping Co., 1989). Inoculation of the estuaries could also occur via *Dreissena* attached to hulls of vessels incoming from other, already invaded estuaries, but probability of invasion by this method is low, due to the relatively limited traffic, compared to other major estuaries. Barges with wood chips travel between the upper York River and other estuaries, but the major moorage site, in the lower Pamunkey, is rarely fresh, and the salinity regime probably is suboptimal for reproduction of *Dreissena*.

Both rivers are slightly acidic and have low calcium, and are thus only marginal for *Dreissena* growth and reproduction. Near Beulaville, pH of the Mattaponi in July is about 6.9, while calcium content is only about 3.7 ppm. Near Hanover, pH of the Pamunkey in June is about 6.9, with a calcium content of about 9 ppm (Prugh *et al.*, 1999). Even if *Dreissena* becomes established, it is unlikely that they would attain pest proportions in either estuary.
JAMES RIVER

The James River is at high risk of inoculation by *Dreissena*, and is highly susceptible to subsequent establishment of large populations. The freshwater tidal portion of the James River extends downstream from Richmond to Jamestown, and includes large portions of the Chickahominy and Appomattox Rivers, with over 8000 ha of open freshwater. The James River drainage has many large reservoirs with heavy recreational use (high risk of inoculation), and some of these reservoirs could support *Dreissena* populations. Examples include Briery Creek Reservoir, Lake Chesdin, Swift Creek Reservoir, Lake Moomaw, and Little Creek Reservoir. (Lake Chesdin, the largest of these, is discussed separately under the section on lakes.) The danger of introduction via vessel hulls or trailers increases with the amount of recreational use, and the James River drainage has over 90 public boat ramps, mostly on lakes (DeLorme Mapping Co., 1989). In addition, there are annual professional bass fishing tournaments on the tidal freshwater portions of the James and Chickahominy Rivers, with many vessels trailerd in from other states, where they may have been in *Dreissena*-infested waters only a day or two previously.

The risk of inoculation from the seaward direction is also high, via both ballast water and the hulls of incoming vessels. Large vessels containing varying amounts of ballast water regularly visit the Port of Richmond from freshwater European ports (Meehan Overseas Terminal, Inc., 1991), some of which have large *Dreissena* populations. Whether freshwater ballast containing *Dreissena* larvae is acquired in Europe and released, undiluted by seawater, in Richmond, is unknown, but it appears probable. Barge and other vessel traffic between industrialized areas of the James River and other estuaries in Chesapeake Bay is heavy. There is also heavy recreational traffic from other estuaries.

Conditions for *Dreissena* reproduction are favorable throughout much of the estuary, and two other non-native bivalves, *Corbicula fluminea* and *Rangia cuneata*, have already successfully invaded freshwater and oligohaline portions of this estuary (Diaz, 1977, 1989). The native bivalves *Mysilopis leucophaeata* (a close relative to *Dreissena*), *Sphaerioides transversus*, and *Pisidium caesareum* are also common in oligohaline and freshwater portions of the James River (Diaz, 1977). Near Carterville, pH in August is 8.1, and calcium content is about 22 ppm (Prugh et al., 1992), both within the minimum requirements for *Dreissena* reproduction.

ELIZABETH RIVER AND ALBEMARLE SOUND

Tidal freshwaters of southeast Virginia, including the Elizabeth River and parts of the Albemarle Sound system, are at risk of inoculation by *Dreissena*, and some regions within this area are susceptible to establishment of the species. The Elizabeth, Nansemond, and Lynnhaven Rivers in southeast Virginia, Currituck Sound and the Pasquotank River in North Carolina (Albemarle Sound), and many lesser bodies of water, form an extremely complex estuarine and freshwater system, because of the Intracoastal Waterway and many lesser canals. The northernmost portion of Currituck Sound is Back Bay, in Virginia; other connected bodies of water include Lake Drummond (Dismal Swamp), Lafayette River (Norfolk), Rudee Inlet (Virginia Beach), and various small lakes in the cities of Virginia Beach, Chesapeake, Norfolk, and Suffolk. The freshwater portions of the Elizabeth, Nansemond, and Lynnhaven Rivers are relatively small, but the Chesapeake and Albemarle Canal, the Dismal Swamp Canal, and lesser waterways are usually fresh, and all of Currituck Sound and most of Albemarle Sound are oligohaline or fresh water, depending on freshwater inflow (NOAA, 1985). All of these bodies of water are intimately connected by a network of canals or ditches (refer to United States Geological Survey topographical maps), so if *Dreissena* becomes established in any part of this system it could eventually spread to all others.

Inoculation of the above region by *Dreissena* is most likely to occur via the heavy recreational and commercial traffic incoming from other estuaries. There are few freshwater lakes in Virginia Beach with boat ramps, so the risk of inoculation by *Dreissena* on the hulls of recreational vessels trailerd from other systems is low. Conversely, there are thousands of small recreational vessels which use creeks, canals, and oligohaline portions of the many small substuaries in this area, and there is heavy barge traffic along the Chesapeake and Albemarle Canal, part of the Intracoastal Waterway. *Dreissena* need become established only in one of the other Chesapeake estuaries and, sooner or later it will appear in Virginia Beach or the City of Chesapeake waterways, fouling organisms on small vessel hulls.

The Chesapeake and Albemarle Canal is potentially important in aiding dispersal of *Dreissena*. Even if the canal does not serve as a reservoir for *Dreissena* recruits, it will serve as a temporary relief of osmotic stress to *Dreissena* that are fouling vessels traveling along the Intracoastal Waterway. This could prolong the survival of *Dreissena* on vessels otherwise traveling in relatively high-salinity areas.

Some regions within southeast Virginia are susceptible to establishment of *Dreissena*; others are not. Back Bay, the northernmost extension of Currituck Sound, is normally fresh, but in some years, salinity can increase to as high as 10 for extended periods, although small tributary estuaries remain fresh (Norman and Southwick, 1991). The only bivalve which presently persists in Back Bay is the non-native oligohaline clam, *Rangia cuneata* (Lane and Dauer, 1991). Alkalinity and
calcium levels for Back Bay are marginal for Dreissena reproduction (mean pH 7.7, calcium content of 10-20 ppm) (Sincock et al., 1969), but the presence of Rangia suggests that other species of bivalves, such as Dreissena, could survive there. Once established, Dreissena would survive high-salinity periods by persisting in freshwater tributaries.

The Dismal Swamp and the Dismal Swamp Canal, in contrast to Back Bay, have very low pH (maximum 6.7 in July) and calcium (7.2 ppm) (Lichter and Marshall, 1979), probably much too low for the reproduction or even extended survival of Dreissena. The Dismal Swamp Canal therefore is unlikely to be invaded by, or serve as, a route for natural dispersal of Dreissena, but it remains a ready passage for dispersal by fouling on the hulls of vessels passing between the Elizabeth River, in the Chesapeake Bay system, and the Pasquotank River, in the Albemarle/Pamlico Sound system.

Urban development in southeast Virginia has lead to the creation of many small lakes, most of which are connected by ditches or pipes to other waterways. Water quality and chemistry are unknown for most of these, but it is probable that at least some will have ideal conditions for Dreissena. For example, Smith and Whitehurst Lakes, in the Little Creek drainage adjacent to the Norfolk International Airport, are both modally alkaline with sufficient calcium for Dreissena reproduction (Virginia Department of Game and Inland Fisheries, unpubl. data). If Dreissena is introduced, therefore, the probability that it could become established in some part of the system is high.

Table 1 summarizes the information for estuaries discussed above. The relative chance of inoculation, or "Risk," is given as "high," "moderate," or "low," based on factors discussed above. Using available water chemistry data and published data on Dreissena physiological requirements, the relative threat of establishment of large populations of Dreissena following inoculation, or "susceptibility," is also given as "high," "moderate," or "low." "High" predicts that if Dreissena becomes established, it will rapidly attain high population levels, and stay at those levels at least until the ecological community adjusts to the invasion. "Moderate" predicts that if Dreissena becomes established, it will reproduce successfully only during certain, favorable periods, and will attain pest proportions only occasionally. "Low" indicates that Dreissena is unlikely to be able to reproduce successfully.

### LAKES AND RESERVOIRS

All major rivers and many small rivers in the mid-Atlantic region have large artificial impoundments. It is unlikely that Dreissena could become established in a river system by a single inoculation into the river itself, but once they become established in a reservoir, they would then spread to downstream reservoirs and freshwater portions of estuaries. Only unfavorable water quality, such as low pH and low calcium concentrations, would then limit Dreissena population levels.

Water chemistry data were available for some Virginia lakes, discussed in alphabetical order hereafter, except where two or more adjacent reservoirs are discussed together. Water chemistry data, especially calcium levels, are incomplete for most lakes, and while risks have been assessed based on known data, it is possible that the known data are not representative of common conditions. The role of water chemistry in Dreissena survival and reproduction are discussed in Criteria for Predicting Zebra Mussel Infections in the Mid-Atlantic Region.

### CLAYTOR LAKE

The risk of inoculation by Dreissena to Claytor Lake, is high, relative to other lakes, but its susceptibility to the establishment...
ment of large populations is only moderate. Claytor Lake is a multi-purpose reservoir (recreation, hydropower) on the New River (Kanawha River), a tributary of the Ohio River. It receives heavy recreational use, with eight improved public boat ramps, as well as eight more on the New River upstream (DeLorme Mapping Co., 1989). There are thus many opportunities for accidental inoculation of Dreissena via the hulls of small recreational vessels. Fields Dam impounds the New River upstream of Claytor Lake, but the reservoir is probably too small and locations are too high for Dreissena. Although Dreissena is already present in other portions of the Ohio River basin (New York Sea Grant, 1993), the probability of its dispersing naturally upstream to Claytor Lake is low, relative to the risk posed by human-influenced invasion. Surface waters are normally quite alkaline (7.3-8.3 in June), but calcium is generally low (9-10 ppm). In some years, however, calcium levels can attain 30 ppm (Virginia State Water Control Board, unpublished data), so the question of Dreissena success in Lake Claytor, should it be introduced, would depend on the varying water chemistry.

**FLANAGAN RESERVOIR**

John W. Flanagan Reservoir is at high risk of inoculation by Dreissena, but its susceptibility to establishment of large populations is only moderate. Flanagan Reservoir is on the Pound River, a tributary of the Ohio River via the Big Sandy River. The reservoir has three improved public access boat ramps; there are two more just upstream on tributaries, and three more are on North Fork Pound River Lake, also upstream (DeLorme Mapping Co., 1989). There are thus many opportunities for inoculation via the hulls of small recreational vessels. Although Dreissena is present in other portions of the Ohio River basin (New York Sea Grant, 1993), the probability of its dispersing naturally upstream to Flanagan Reservoir is low, relative to the risk posed by human-mediated invasion. The surface waters are alkaline (pH 7.6-8.9 in June), with low to moderate levels of calcium (9-29 ppm) (Virginia State Water Control Board, unpublished data). Dreissena would survive, if released into Flanagan Reservoir, but in some years reproducibility may be calcium-limited.

**HARWOOD MILLS RESERVOIR**

Harwood Mills Reservoir is one of many small multi-use (fishing, municipal water storage) reservoirs in urbanized southeast Virginia. The risk of inoculation by Dreissena is low, but the lake is highly susceptible to establishment of this species, should it become introduced. Harwood Mills, on the headwaters of the Poquoson River, in Newport News, has a single public boat ramp, limited to craft without internal-combustion engines. This reduces but does not eliminate the possibility of Dreissena inoculation via the hulls of recreational vessels. Like the majority of small municipal reservoirs in southeast Virginia, it is modally alkaline (pH 8.1 in June), with moderate levels of calcium (25 ppm) (Virginia Dept. Game and Inland Fisheries, unpublished data). These conditions are favorable for Dreissena reproduction.

Of ten similar small reservoirs in that area surveyed by Virginia Department of Game and Inland Fisheries, six have water chemistry that would support high populations of Dreissena, three have chemistry that would support at least moderate populations, and only one (Kilby Reservoir) has water chemistry that would be unlikely to support Dreissena populations.

**KERR RESERVOIR AND LAKE GASTON**

John H. Kerr Reservoir, and Lake Gaston; just downstream, are at high risk of inoculation by Dreissena, and at least portions of both lakes are highly susceptible to establishment of large populations of this species. Both reservoirs are large multi-use (recreation, hydropower) impoundments on the Roanoke River, astride the Virginia/North Carolina Reservoir. Just below Lake Gaston in North Carolina is the Roanoke Rapids Dam and Reservoir, and the Roanoke ends in Albemarle Sound, North Carolina, which has an extensive freshwater portion. Kerr Reservoir and Lake Gaston are heavily used by recreational boaters and fishermen, with a total of about 50 public boat ramps. In addition, both are downstream of a variety of public-access reservoirs, including Philpott Reservoir, Banister Lake, Smith Mountain Lake, and Leesville Lake in Virginia, and Hyco Lake, Mayo Reservoir, and After Bay Reservoir in North Carolina, with over 60 public access boat ramps (Alexandria Drafting Co., 1981; DeLorme Mapping Co., 1989). Water chemistry in both Kerr Reservoir and Lake Gaston varies between stations, and on the basis of this McMahons (1992) considered the susceptibility of Lake Gaston to be relatively low. Both lakes, however, have semi-enclosed branches in which water chemistry may differ, and in both lakes there are modally alkaline regions (pH 6.9-9.3). Calcium levels for Kerr Reservoir were unavailable, but calcium content of the alkaline stations in Lake Gaston are about 34-44 ppm (Virginia State Water Control Board, unpublished data), and because of the proximity of the two lakes, it is safest to assume that Kerr Reservoir, more complex even than Lake Gaston, also has regions of modally high calcium.

**LAKE ANNA**

Lake Anna is at high risk of inoculation by Dreissena, but its susceptibility to subsequent establishment of this species is low. It is on the North Anna River, a tributary
of the Pamunkey, and is the largest reservoir in the Pamunkey River drainage. Lake Anna is used heavily by recreational boaters and fishermen, and is the water source for the North Anna Nuclear Power Plant. Downstream is the freshwater tidal portion of the Pamunkey River. There are 9 improved public access boat ramps on Lake Anna. Upstream of Lake Anna are Lake Orange, with one public boat ramp, and Lake Louisa, which is surrounded by a housing development (DeLorme Mapping Co., 1989). McMahon (1992) considers Lake Anna to be highly susceptible to the establishment of large Dreissena populations, but based on unpublished water chemistry data provided by Virginia Power (Innsbrook Technical Center, Glen Allen, VA), this seems unlikely. Although pH often rises as high as 7.9 in some branches of Lake Anna during the summer, most of the lake is modally acidic, and even where waters are alkaline, the calcium content remains too low (maximum about 6.0 ppm) for Dreissena reproduction.

**Lake Chesdin.**

Lake Chesdin is at relatively high risk of inoculation by Dreissena, but its susceptibility to establishment of this species is low. On the Appomattox River (a tributary of the James), it has several public-access boat ramps, and receives heavy recreational use from the nearby Richmond area. It has a water chemistry unsuited for Dreissena; however, the pH is variable (6.4-8.7), but modally acidic in summer; shallow water, and calcium levels are very low (about 7.1 ppm). The Smith Mountain Lake is also the site of a large, annual professional bass fishing tournament. The pH of both lakes is generally high (7.5-8.7) and calcium levels are about 15-17 ppm (Virginia State Water Control Board, unpubl. data). These conditions permit reproduction of Dreissena, although in some years calcium content may limit population levels. Downstream of these lakes are John H. Kerr Reservoir and Lake Gaston.

**Lake Moomaw**

Lake Moomaw is a rarity in Virginia; a large reservoir at relatively low risk of inoculation by Dreissena. If Dreissena were introduced, however, Lake Moomaw is moderately susceptible to establishment of a large population. It is on the Jackson River, in the headwaters of the James River, within a state wildlife management area, where recreational use is limited. DeLorme Mapping Co. (1989) shows no public-access boat ramps on or upstream of Lake Moomaw. The pH is modally alkaline (7.5-8.4) in shallow water in summer, with calcium levels of about 15-17 ppm (Virginia State Water Control Board, unpubl. data); marginal conditions for Dreissena reproduction.

**Leesville Reservoir**

(See Smith Mountain Lake)

**Philpott Reservoir**

Philpott Reservoir is at relatively high risk of Dreissena inoculation, but its susceptibility to establishment of this species is low. It is on the Smith River, a tributary of the Roanoke River via the Dan River, and has 11 improved, public access boat ramps. The water is modally alkaline (pH 7.2-8.4), but available calcium data indicates very low levels (4.5 ppm) (Virginia State Water Control Board, unpubl. data), which would inhibit Dreissena reproduction. If it does become established, however, it will spread to Kerr Reservoir and Lake Gaston, downstream, which have more benign water chemistry.

**Smith Mountain Lake and Leesville Lake**

Smith Mountain Lake is a large reservoir on the headwaters of the Roanoke River, and Leesville Lake is directly below it. Both are at high risk from inoculation by Dreissena, although the susceptibility of both lakes to establishment of large populations is only moderate. There are only two improved public access boat ramps into Leesville Lake, but there are more than 17 into Smith Mountain Lake, upstream. Smith Mountain Lake is also the site of a large, annual professional bass fishing tournament. The pH of both lakes is normally high (7.5-8.4), but calcium levels are about 15-17 ppm (Virginia State Water Control Board, unpubl. data). These conditions permit reproduction of Dreissena, although in some years calcium content may limit population levels. Downstream of these lakes are John H. Kerr Reservoir and Lake Gaston.

**South Holston Lake**

South Holston Lake is at relatively high risk of inoculation by Dreissena, and its susceptibility to subsequent establishment of large populations of this species is also high. South Holston Lake is a large multipurpose reservoir (recreation, hydropower) on the South Fork Holston River, a tributary of the Tennessee River. It is in southwest Virginia, and the majority of the lake is within Tennessee. The lake is within a few hours' drive of other lakes in the Tennessee River system containing Dreissena (New York Sea Grant, 1993). There are 16 public access boat ramps on the lake, and two more upstream on the smaller Hungry Mother Lake. The pH of South Holston Lake is relatively stable and modally alkaline (6.9-8.6 in June and July), with moderately high levels of calcium (18-30 ppm), based upon data collected largely in the 1970s (Tennessee Valley Authority unpubl. data). These conditions are favorable for Dreissena growth and reproduction, and once introduced, it would rapidly attain pest proportions.
Western Branch Reservoir, Lake Meade

Western Branch Reservoir, Lake Meade, and some adjacent reservoirs are at moderate risk of inoculation by Dreissena, and highly susceptible to establishment of large populations of this species. Western Branch Reservoir is the largest of seven impoundments in the Nansemond River drainage, in southeast Virginia. It is on the Western Branch Nansemond River, while Lake Meade is the largest of four impoundments on the Eastern Branch Nansemond River, but the drainages of these are very close to each other. Other lakes include Lake Prince and Lake Burnt Mills, upstream of Western Branch Reservoir, and Lake Cohoon, Lake Kilby, and Spaetes Run Lake, upstream of Lake Meade. Western Branch Reservoir has two public boat ramps on or upstream of it, and Lake Meade has four. All lakes are used heavily for recreational fishing, but the majority of the users are local (Virginia Dept. Game & Inland Fisheries, pers. comm.). Water chemistry data shows moderately alkaline water (pH 8.2 at 2 m depth, June) with moderate levels of calcium (20-25 ppm) in all of these lakes except Lake Cohoon and Lake Kilby (no data is available for Spaetes Run Lake). Lakes Cohoon and Kilby are often acidic, and their levels of susceptibility are thus moderate or low. (Virginia Dept. Game and Inland Fisheries, unpubl. data.) In the remaining four lakes, conditions are favorable for Dreissena reproduction. Once invasion occurred in any of those four lakes, Dreissena would reach high population levels. Natural dispersal, perhaps by adults attached to turtles or other amphibious organisms, could then spread Dreissena to the other impoundments in the Nansemond drainage.

Table 2 summarizes the information for reservoirs discussed above. The definitions for "risk" and "susceptibility" are the same as for Table 1.


### Table 2. Predicted Invasion Success in Virginia Lakes and Reservoirs

<table>
<thead>
<tr>
<th>Lake</th>
<th>Drainage</th>
<th>Recreational Vessel Use</th>
<th>Other Uses</th>
<th>Risk</th>
<th>Susceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clary Lake</td>
<td>Ohio</td>
<td>high</td>
<td>hydroelectric power</td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>Flannagan Res.</td>
<td>Ohio</td>
<td>high</td>
<td></td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>Harwood Mills Res. (Newport News)</td>
<td>Poquoson</td>
<td>moderate</td>
<td>municipal water</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>Kerr Reservoir</td>
<td>Roanoke</td>
<td>high</td>
<td>hydroelectric power</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Lake Anna</td>
<td>Pamunkey</td>
<td>high</td>
<td>nuclear power plant</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Lake Chesdin</td>
<td>James</td>
<td>high</td>
<td></td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Lake Gaston</td>
<td>Roanoke</td>
<td>high</td>
<td>hydroelectric power</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Lake Meade</td>
<td>Nansemond</td>
<td>high</td>
<td></td>
<td>moderate</td>
<td>high</td>
</tr>
<tr>
<td>Lake Moomaw</td>
<td>James</td>
<td>low</td>
<td>wildlife mgmt. area</td>
<td>low</td>
<td>moderate</td>
</tr>
<tr>
<td>Leesville Lake</td>
<td>Roanoke</td>
<td>moderate</td>
<td></td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>Philpott Res.</td>
<td>Roanoke</td>
<td>high</td>
<td></td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Smith Mtn. Lake</td>
<td>Roanoke</td>
<td>high</td>
<td></td>
<td>high</td>
<td>moderate</td>
</tr>
<tr>
<td>S. Holston Lake</td>
<td>Tenesse</td>
<td>high</td>
<td>hydroelectric power</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>W. Branch Res.</td>
<td>Nansemond</td>
<td>moderate</td>
<td>municipal water</td>
<td>moderate</td>
<td>high</td>
</tr>
</tbody>
</table>

Reservoirs are listed alphabetically. Invasion Risk refers to the relative chance that Dreissena will be introduced, and Susceptibility refers to the relative chance that Dreissena will attain high population levels. See also text for explanation of terms.


Acknowledgements. This work is a result of research sponsored by NOAA Office of Sea Grant, U. S. Department of Commerce, under federal Grant No. NA 90AA-D-SC945 to the Virginia Graduate Marine Science Consortium and the Virginia Sea Grant College Program. The U. S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon. The authors—Patrick Baker, Shirley Baker, and Roger Mann—wish to acknowledge the cooperation of the Virginia Institute of Marine Science Marine Advisory Program, the Virginia Department of Game and Inland Fisheries, the Virginia State Water Control Board, the Virginia Power Company, and the Tennessee Valley Authority.

Virginia Sea Grant
Marine Advisory Program
Virginia Institute of Marine Science
Gloucester Point, Virginia 23062
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-ATLANTIC 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 barnacelike 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
Continued from page 1

in power plant and industrial water systems. The mussels 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 can 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.

Zebras 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. Zebras 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 unionoids have been found covered with mussel growths. Many unionoids 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 mussels. Young, first-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 larva 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 sub-
strates 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/l).

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

**DISPERAL**

Three natural and 20 human-related dispersal 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 stockers, 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 mussels’ 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 tolerances.

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 infected 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/Pamlico estuarine system by several man-made canals, including the Intracoastal Waterway. These connections make all drainage 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 northwestern Maryland, south into northern Virginia and

Continued on page 5
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 transported to mid-Atlantic drainages from river networks, including the Mississippi and Tennessee, through the sale of fish for bait and for stocking aquaculture 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 an 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 sightings 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 can reveal how it is developing and expanding. Sampling should occur at intervals that span the entire spawning season. Any
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.

For more information, contact the Sea Grant expert in your state:

Delaware
Jim Falk 302/645-4235
New Jersey
Eleanor Bochenek 908/349-1152
New York
Chuck O’Neill 716/395-2638

References

Alderman, John. 1993. Freshwater Mussels in Swift Creek Subbasin Biological Inventory. Funded by the N.C. Recreation and Natural Heritage Trust Fund.

Baker, Patrick K. A graduate student at the School of Marine Science, Virginia Institute of Marine Science, Baker researched and provided much of the information on environmental parameters.


Rice, James A. Personal correspondence on Nov. 20, 1992. Zoology Department, N.C. State University, Raleigh, N.C.


Acknowledgments

This fact sheet was compiled with the assistance of Sea Grant staff in the mid-Atlantic states: Roger Mann, Virginia; Daniel Terlizzi, Maryland; Jim Falk, Delaware; Eleanor Bochenek, New Jersey; Dave MacNeil and Chuck O’Neill, New York.

N.C. Sea Grant
Box 8605
North Carolina State University
Raleigh, North Carolina 27695

ADDRESS CORRECTION REQUESTED
INTRODUCTION

The zebra mussel, *Dreissena polymorpha*, is an alien species introduced to the Great Lakes in the 1980s, via ballast water from Europe. It has since invaded all of the Great Lakes, and the Hudson, Ohio, and Mississippi Rivers. The zebra mussel is also in the upper Susquehanna River, and is expected to appear in other mid-Atlantic drainages. As a consequence of their ability to heavily foul submerged surfaces, zebra mussel populations have had severe ecological and economic impacts in areas in which they have become established.

This report summarizes the physiological requirements, dispersal mechanisms, and potential range in Virginia, of zebra mussels. Critical physiological parameters are temperature, salinity, pH, and calcium. Dispersal mechanisms discussed include both natural and human-mediated vectors. Water quality and vectors of introduction are used to predict whether zebra mussels are likely to become established in specific bodies of water in and near Virginia.

REQUIREMENTS

Optimum temperatures for growth and reproduction of zebra mussels are between 12 and 26°C, so temperatures in the mid-Atlantic region are unlikely to be limiting. While zebra mussels are found primarily in freshwater, they can persist in slightly brackish water (0.5%o), and tolerate salinities of up to 12%o for a few days. Zebra mussels can survive short periods of acidity, but require relatively alkaline water (above pH 7.5) to reproduce. Calcium, required for shell growth, may be limiting in some bodies of water.

DISPERAL

Zebra mussel adults and juveniles can crawl short distances, but the primary means of natural dispersal is by planktonic larvae and postlarvae. Zebra mussels are more likely to become initially established in lakes or estuaries, than in rivers where the dispersing forms would be swept away. Zebra mussels may reach high densities in rivers, however, if there are lakes or reservoirs upstream which have reproducing populations. Once zebra mussels are established in a lake, all lakes and estuaries downstream are subject to invasion by drifting larvae. Most mid-Atlantic estuaries have large freshwater portions, many with nearly ideal water chemistry, in which zebra mussels can become established.

Zebra mussels can be introduced to bodies of water by several human-mediated means. Larvae and postlarvae may be transported long distances in the ballast water of commercial ships, and it was by this means that they were introduced to the Great Lakes. The hulls of commercial vessels also represent a means of transport. Adults and juveniles attach to the hulls of vessels which may subsequently move upstream or across salinity barriers. At the new location, the zebra mussels can detach and reattach to a nearby substrate, or adults may reproduce and release larvae at the new location. Barges are an important example of this, because they remain in one place for long periods of time and are infrequently cleaned of fouling organisms, but any vessel could serve as a vector. Zebra mussels can survive several days out of water and can be introduced via the hulls of recreational craft trailered between watersheds. Alternately, larvae or postlarvae could inadvertently be transported in the bilge or bait wells of recreational vessels. The possibility also exists that zebra mussels may be deliberately introduced by landowners to increase water clarity of ponds or lakes.

POTENTIAL RANGE: ESTUARIES

**POTOMAC RIVER**

The freshwater portion of the Potomac estuary stretches from Washington, to near Quantico, Virginia. Zebra mussels are most likely to be introduced to the Potomac River by vessels traveling from nearby estuaries or the Great Lakes, either attached to hulls or in ballast water. Water quality in the Potomac is suitable for zebra mussel reproduction. The risk of invasion is high and, once established, zebra mussels would rapidly attain pest proportions.

**RAPPAHANNOCK RIVER**

The tidal freshwater portion of the Rappahannock estuary extends from Fredericksburg to near Tappahannock. Invasion of the Rappahannock could occur from upstream reservoirs, or vessels from other estuaries could bring in zebra mussels attached to their hulls. Water quality is not conducive to reproductive success of zebra mussels. Invasion risk and establishment potential are moderate for the Rappahannock.
PIEKATANKRIVER

The Pikatatank and the adjoining freshwater tidal portion, Dragon Swamp, have no major upstream reservoirs, and limited vessel traffic. The water has low pH and calcium, and is unlikely to support zebra mussels. Risk of invasion and establishment is low compared to other estuaries.

MATTAPONI AND PAMUNKEY RIVERS

The Mattaponi and Pamunkey Rivers unite at West Point to form the York River estuary; however, the freshwater portions remain separate. The Mattaponi River has several upstream reservoirs which are at risk of introduction via recreational vessels. Traffic from other estuaries is moderate. Water chemistry is unlikely to support large populations of zebra mussels. Risk of introduction is moderate but reproductive success would be low.

JAMES RIVER

The freshwater tidal portion of the James River extends from Richmond to Jamestown, Virginia, and includes portions of the Chickahominy and Appomattox Rivers. The James River drainage has many large reservoirs with heavy recreational use. Zebra mussels may be introduced to these lakes via trailered pleasure craft. The James River is industrialized and traffic from other estuaries is heavy. Large vessels carrying ballast water visit the Port of Richmond from freshwater European ports. Conditions favorable for zebra mussel reproduction are found throughout the estuary, and zebra mussels will attain pest populations if introduced. Risk of invasion and establishment is high for the James River.

ELIZABETH RIVER/ALBEMARLE SOUND

The South Branch Elizabeth River in Chesapeake, Virginia, is Albemarle Sound in North Carolina via the Chesapeake and Albemarle Canal and the Dismal Swamp Canal. Back Bay, in Virginia, is the northernmost portion of Albemarle Sound, and is usually fresh. These bodies of water are interconnected by an intricate network of canals and ditches. If zebra mussels become established in any part of the system, they will spread to all other portions that have adequate water chemistry. They are most likely to be introduced to the system by the heavy vessel traffic from other estuaries. Water chemistry is sufficient for zebra mussels throughout much of the system although populations in Back Bay would be limited in some years by salinity, and the Dismal Swamp Canal is too acidic for zebra mussel survival. In general, however, invasion risk and establishment potential are high for these bodies of water.

POTENTIAL RANGE: LAKES

CLAYTOR LAKE

Claytor Lake is a multi-purpose reservoir on the New River (Kanawha River), a tributary of the Ohio. Recreational use is heavy and zebra mussels are likely to be introduced via recreational vessels. Risk of invasion is high but water chemistry varies, making establishment potential moderate.

FLANAGAN RESERVOIR

John W. Flannagan Reservoir is on the Pound River, a tributary of the Ohio via the Big Sandy River. Opportunities for introduction by the hulls of small recreational vessels are high. The water is alkaline but calcium varies; zebra mussels will survive but reproduction may be calcium-limited in some years.

KERR RESERVOIR AND LAKE GASTON

John H. Kerr Reservoir and Lake Gaston, just downstream, are large multi-use impoundments on the Roanoke River, which ends in the Albemarle Sound. The lakes are heavily used by recreational boaters and fishermen and are downstream of a variety of public-access reservoirs. Kerr Reservoir and Lake Gaston are, therefore, at higher risk of invasion by zebra mussels via recreational vessels than any other lakes in Virginia. Water chemistry is optimal for reproduction in portions of both lakes and, once introduced, zebra mussels will rapidly become established.

LAKE ANNA

Lake Anna, on the North Anna River, is the largest reservoir in the Pamunkey River drainage. Recreational boaters use Lake Anna as well as two other lakes upstream, thus, opportunities for introduction are high. Water chemistry is not favorable for zebra mussels, however, the chance that they will become established is low.

LAKE CHESDIN

Lake Chesdin, on the Appomattox River, receives heavy recreational use but water chemistry is unsuited for zebra mussels. Therefore, risk of invasion is high but establishment potential is low.
Safe use of zebra mussels in classroom and laboratories

by Thomas G. Comn, Department of Fisheries and Wildlife
Michigan State University
13 Natural Resources Building
East Lansing, MI 48824

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 opening problems and provides basic information needed to better manage the Great Lakes for both present and future generations.

Sea Grant is a program in the National Oceanic and Atmospheric Administration (NOAA), Department of Commerce

Produced by Michigan and Ohio Sea Grant programs as a joint project for the Great Lakes Sea Grant Network. It is available from Michigan Sea Grant at MICH-UG-93-703 and Ohio Sea Grant at OHSU-FS-059. (Michigan Sea Grant project R/M-7, AC-1, AFT-4, grant N09AA-D-30583, Ohio Sea Grant project M/P-2, grant N09AA-D-50496.)

Zebra mussels (Dreissena polymorpha) were accidentally introduced into North American waters in the mid-1980s. Since that time, they have spread throughout the Great Lakes region and into the Mississippi River basin. They have attained considerable notoriety because they are extremely prolific and move into new regions fairly quickly, but most importantly because they clog water intakes and plumbing systems and foul boat hulls, docks and other submerged surfaces.

Several fact sheets on the biology and control of zebra mussels are available from Sea Grant offices. See the references at the end of this fact sheet or contact the nearest Sea Grant office for more information.

Some of the features that make zebra mussels a nuisance also make them interesting for use in the classroom. Adult mussels can be kept alive easily in a simple aquarium system for at least several days, and they readily exhibit interesting facets of animal behavior, physiology and ecology.

However, zebra mussels are not native to North American waters and they can be a costly nuisance. Because of this, it is important to use extreme caution when using them for class instruction. It is imperative that classroom use not result in the release of live mussels—either adults or larvae—into lakes, streams or plumbing systems, either by accident or by intent.

To understand the basis for control measures, it is important to understand a few aspects of zebra mussel biology, specifically, their means of transport and their tolerance of adverse conditions. Adult zebra mussels attach themselves to hard substrates such as rocks, other mussels, logs, boat hulls and the inner walls of pipes with secreted fibers called byssal threads. It is when these attached mussels accumulate (up to hundreds of thousands per m²) that they become a nuisance to industries, municipal watersuppliers, powerplants and other water users. Adult mussels can survive being detached from their substrate, and they can crawl along the substrate to find new attachment sites. In fact, adult mussels will readily detach themselves from a substrate, crawl to another substrate and reattach.

The primary means of dispersal for zebra mussels is not the movement of adult mussels, however. Rather, zebra mussels spread as their planktonic larvae are carried by water currents into previously mussel-free habitats. Though this passive transport can only occur downstream in rivers, it assures broad dispersal of mussels within a lake basin.

However, zebra mussels can and do move upstream and against lake currents—with human help. For example, larvae can be carried in the bilge water of boats (including pleasure craft) traveling upstream or being transported over land to upstream waters. Adult mussels attached to boat hulls, trailers, anchors or ropes can also be transported upstream by boat travel. Adult mussels, in particular, can survive out of water for days simply by closing their valves and slowing their metabolic processes.

These “opportunistic” characteristics make it imperative that people take precautions to prevent the spread of zebra mussels into waters where they could not go without our assistance. For example, zebra mussels have effectively surrounded lower Michigan by colonizing Lakes Erie, St. Clair, Huron and Michigan. However, they have only been found in a few inland water bodies. These invasions occurred when boats from the Great Lakes were transported to these inland lakes.

Even in areas where zebra mussels are established, it is important to use them with caution in the laboratory. For example, a flow-through aquarium that drains into a sink or floor drain could introduce mussels into plumbing and eventually clog the plumbing and require expensive repairs.

We recommend several preventative measures for teachers and students to follow to ensure against introducing zebra mussels into plumbing or inland waters.

First, know the current status of zebra mussels in your area. You can get this information by calling your state’s Sea Grant office or natural resources
agency or the zebra mussel hotline operated by New York Sea Grant.

Are zebra mussels present in the lakes or streams around your school? If mussels are not present in your area’s surface waters, then you should not transport them to your lab or classroom from infested areas. Transportation across state lines is generally illegal and many states forbid transporting them anywhere within the state. If there are no mussels in your area, do not use them in your class but go to a site that is already infested to study them. In other words, confine your use of zebra mussels to field trips to areas where they are already present.

Do not bring live mussels, water that was in contact with zebra mussels or items that have been in contact with water that contained zebra mussels back to your classroom. The water may contain microscopic larvae, and items with hard surfaces may have tiny post-larval mussels attached. To avoid the risk of introducing zebra mussels to the interior waters of Michigan, Michigan State University researchers have conducted their research with live mussels at F.T. Stone Laboratory, Ohio State University’s biological field station on Lake Erie.

Second, if you do use zebra mussels, water or items that have been in contact with zebra mussels in your classroom, quarantine them from contact with your plumbing system and the surface waters in your area. In other words, keep the mussels and water in closed systems.

Third, treat any items that have been in the water with mussels (such as gravel, rocks, filters, siphon tubes, plants, etc.) with 10% solution of household chlorine bleach before using them again. This will kill any attached larvae, juvenile or adult mussels. Also, be sure to treat any water that has come into contact with mussels before disposing of it. The preferred treatment is a bleach solution (1 part full-strength bleach to 9 parts water, minimum 30 minute exposure). Alternatives include exposure to hot water $\geq 40^\circ$C ($104^\circ$F) or hot salt water ($\geq 3$ parts per thousand) for at least 15 minutes or freeze samples at $-18^\circ$C ($0^\circ$F) for a minimum of 24 hours.

We recommend using a water-proof bin or tub to soak all items that came into contact with zebra mussels or zebra mussel water and a separate container for discarded zebra mussel water. Keep these containers away from sink and floor drains so that untreated spillage does not escape down the drain. At the end of each day, treat both containers with chlorine bleach or hot water as prescribed above. This will kill any remaining larvae, juvenile or adult mussels. Overnight exposure is more than long enough to kill remaining mussels, as long as concentrations are appropriate. You may want to place several live adult mussels into the treatment water to verify that your treatment is adequate to kill zebra mussels.

Fourth, dispose of any treated water very carefully. Do not pour chlorinated water or salt water directly into a lake or stream—this is toxic to resident organisms. You may likely pour the treated water down your drain, but use caution. Large volumes of chlorinated water may cause problems for your wastewater treatment facility. Check with the facility’s operators to see if they have any special concerns or suggestions.

Fifth, know where your drain goes. Some floor drains go directly to a storm sewer or open body of water. It’s best to avoid these. Passing the treated water through a wastewater treatment plant further ensures that no mussels survive your treatment efforts.

The only other appropriate way to dispose of treated water is to pour it over very porous (sandy) soil—far from a surface water body or storm sewer.

Zebra mussels and other exotic organisms can be effective teaching tools for a variety of biological topics. However, careless use of any exotic species will likely result in an undesired, costly lesson—both in terms of potential repairs and in terms of adverse ecological effects on your local aquatic ecosystems. To avoid this, use any exotic species with caution and take all necessary precautions to prevent release of live exotics into aquatic or terrestrial ecosystems!

For information about Sea Grant’s work on zebra mussels, contact the Great Lakes program nearest you. If you are interested in another area of the country, ask for the phone number of any of the 23 coastal Sea Grant programs.

**Illinois-Indiana Sea Grant Program**
University of Illinois, 65 Mumford Hall, 1301 West Gregory Drive, Urbana, IL 61801, 217/333-9448

**Michigan Sea Grant College Program**
4113 IST Building, 2200 Bonisteel Boulevard, Ann Arbor, MI 48109-2099, 313/764-1138

**Minnesota Sea Grant College Program**
1518 Cleveland Avenue North, Suite 302, St. Paul, MN 55108, 512/625-6781

**New York Sea Grant Institute**
Hartwell Hall, SUNY College at Brockport, Brockport, NY 14420-2928, 716/395-2638 or 800/285-2285

**Ohio Sea Grant College Program**
The Ohio State University, 1314 Kinnear Road, Columbus, OH 43212-1194, 614/292-8949

**Wisconsin Sea Grant Institute**
ES 105, UW-Green Bay, Green Bay, WI 54311-7001, 414/465-2795
Zebra mussels (Dreissena polymorpha) were first discovered in Lake St. Clair in 1988. Within one year, they had colonized the surfaces of nearly every firm object in western Lake Erie. As of December 1993, zebra mussels have been found in all of the Great Lakes and in waterways in 18 states and two provinces. Major river systems that now have zebra mussels include the St. Lawrence Seaway and the Hudson, Illinois, Mississippi, Ohio, Arkansas, and Tennessee Rivers.

Zebra mussels also have been reported in several inland lakes, including Lake Wawasee in Indiana; Hargus Lake and White Star Quarry in Ohio; Kentucky Lake and Dale Hollow Reservoir in Kentucky; at least 10 lakes in Michigan; and Balsam, Rice, and Big Bald Lakes in Ontario.

In 1991, a second species of Dreissena was discovered in North America but was only recently identified. Quagga mussels (Dreissena bugensis) have been found in the St. Lawrence Seaway, Lake Ontario, Lake Erie, and Saginaw Bay in Lake Huron.

It is not clear when, how far and into which waterways the zebra and quagga mussels spread. The zebra mussel has spread faster and farther than expected. Its southward spread will likely be limited because of average summer water temperatures above 81 F (27 C). The northward spread might be limited by soils deficient in calcium or by summer water temperatures below 54 F (12 C).

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

The invasion

Dreissena polymorpha and Dreissena bugensis are native to an area in Russia near the Caspian Sea. Canals built during the late 1700s allowed the mussels to spread throughout eastern Europe. During the early 1800s, canals were built across the rest of Europe, which made bulk shipping much easier but also allowed rapid expansion of the zebra mussel's range. By the 1830s, the mussels had covered much of the continent and had invaded Britain.

The introduction of zebra mussels into the Great Lakes appears to have occurred in 1985 or 1986, when one or more transoceanic ships discharged ballast water into Lake St. Clair. The freshwater ballast, picked up in a European port, may have contained zebra mussel larvae and possibly juveniles. Adult mussels may have been carried in a sheltered, moist environment, such as a sediment-encrusted anchor chain. The faster speed of today's ships provides exotic species a better chance of surviving the trip across the Atlantic. Being a temperate, freshwater species, the zebra mussels found the plankton-rich Lakes St. Clair and Erie to their liking.

Zebra and quagga mussels

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

Eggs are fertilized outside the mussel's body and within a few days develop into free-swimming larvae called veligers. Veligers swim by using their hair-like cilia for 3 to 4 weeks, drifting with the currents. If they don't settle onto firm objects in that time, they die; and the vast majority actually suffer this fate. It is estimated that only 1 to 3 percent survive to adulthood. Those that find a hard surface quickly attach and transform into the typical, double-shelled mussel shape; they are then considered to be juveniles.

Mussels become adults when they reach sexual maturity, usually within a year. They grow rapidly, nearly an inch in their first year, adding another 1/2 to 1 inch their second year.

European studies report mussels may live 4 to 6 years. Three years seems to be the maximum life span in Lake Erie, but there is insufficient data to know what to expect in other North American bodies of water.

Zebra mussels generate a tuft of fibers known as a byssus, or byssal threads, from a gland in the foot. The
bysseus protrudes through the two halves of the shell. These threads attach to hard surfaces with an adhesive secretion that anchors the mussels in place. Small juveniles can actually break away from their attachments and generate new, buoyant threads that allow them to drift again in the currents and find a new surface. Zebra mussels can colonize any firm surface that is not toxic: rock, metal, wood, vinyl, glass, rubber, fiberglass, paper, plants, other mussels—the surface need only be firm. Beds of mussels in some areas of Lake Erie now contain more than 30,000—and sometimes up to 70,000—mussels per square meter.

Zebra mussel colonies show little regard for light intensity; hydrostatic pressure (depth); or even temperature, when it is within a normal environmental range. The life stage most sensitive to low temperature is the veliger stage, and juveniles are more sensitive than adults. All life stages are sensitive to low levels of dissolved oxygen, particularly as temperature increases. Colonies grow rapidly wherever oxygen and particulate food are available and water currents are not too swift (generally less than 6 feet per second). Thus, colonies are rare in wave-washed zones, except for sheltered nooks and crevices. In most European lakes, the greatest densities of adult mussels occur at depths ranging from 6 to 45 feet.

Zebra mussels can also colonize soft, muddy bottoms when hard objects deposited in or on the mud—such as pieces of native mussel shells—serve as a substrate (base) for settling veligers. As a few mussels begin to grow, they in turn serve as substrate for additional colonization, forming what is known as a drive. Quagga mussels can live directly on a muddy or sandy bottom and appear more tolerant of low temperatures and extreme depths than zebra mussels.

**Biological and ecological concerns**

Zebra mussels disrupt the aquatic food chain. Literature reviews suggest that they eat mostly algae in the 15–40 micrometer size range. Each adult mussel, however, is capable of filtering 1 or more liters of water each day. They remove nearly all particulate matter, including phytoplankton and some small forms of zooplankton, including their own veligers. Instead of passing any undesired particulate matter back into the water, mussels bind it with mucous into loose pellets called pseudofeces that are ejected and accumulate among the shells in the colony.

By removing significant amounts of phytoplankton from the water, zebra mussels remove the food source for microscopic zooplankton, which in turn are food for larval and juvenile fishes and other plankton-feeding forage fish. These forage fish support sport and commercial fisheries. This competition for phytoplankton, the base of the food chain, could have a long-term negative impact on Great Lakes fisheries. Observations of the effects of zebra mussel filtration upon the food base for fish communities are still inconclusive.

Most rocky areas in Lake Erie are almost completely covered with mussels several inches deep. In laboratory observation, the accumulation of pseudofeces in these beds creates a foul environment. As waste particles decompose, oxygen is used up, and the pH becomes very acidic. Biologists were initially concerned that such poor environmental conditions could potentially hinder normal egg development of reef-spawning fish (walleye, white bass, and smallmouth bass). However, large hatches of walleye documented in Lake Erie in 1990, 1991, and 1993 suggest that flushing water currents are sufficient to prevent environmental deterioration.

Zebra mussels readily encrust native North American mussels (family...
In Lakes St. Clair and Erie, heavy fouling by zebra mussels has severely reduced populations of native mussels. Some native mussel species are more tolerant to fouling than others, but even for these resistant species, zebra mussel encrustation leads to reduced energy reserves and vulnerability to other environmental stressors, such as extreme water temperatures, lack of food, or parasites and disease. As zebra mussels spread, biologists are concerned that populations of native mussels will decline, and perhaps some of the rarer species may be completely eliminated.

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

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

Industrial, commercial, and recreational concerns

The zebra mussel’s proclivity for hard surfaces located at moderate depths has made water intake structures, such as those used for power and municipal water treatment plants, susceptible to colonization. Since 1989, some plants located in areas of extensive zebra mussel colonization have reported significant reductions in pumping capabilities and occasional shutdowns.

Investigations of zebra mussel control on intake structures have included prechlorination, preheating, electrical shock, and sonic vibrations. Current control methods include prechlorination, ozone, potassium permanganate injection, and sand bed filtration. Prechlorination has been the most common treatment used to date, because it is already approved for use by the Environmental Protection Agency; but it also raises concerns about the toxicity of chlorinated compounds to other aquatic organisms.

Zebra mussels are very sensitive to high temperatures. Some thermal electric plants currently are experimenting with the diversion of waste heat into intake structures to kill zebra mussels or prevent settlement.

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

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

Zebra mussel control

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

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

In North America, the species most likely to prey on relatively deep beds of zebra mussels are scap, canvassbacks, and old squaws. But populations of these species are quite low; in fact, canvassbacks are so rare that they are protected. In the Great Lakes, diving ducks are migrating visitors, pausing only to feed during north- and southward migrations. However, Canadian researchers have documented increasing numbers of migrating ducks around Pt. Pelee in western Lake Erie, and these ducks were observed to be feeding heartily on zebra mussels. In southern Lake Michigan, zebra mussels encrusting an underwater power plant intake attracted flocks of lesser scaup. Unfortunately, some were pulled into the intake pipe and drowned. The stomachs of these dead scaup were full of zebra mussels. Mallard ducks also are frequently observed foraging on zebra mussels on shoreline rocks and shallow structures. In addition, freshwater drum, or sheepshead, are known to feed substantially on zebra mussels; and yellow perch have been observed feeding on juveniles, particularly when they are detached and drifting.

One novel approach to controlling zebra mussel populations is by disrupting the reproductive process. Zebra mussel eggs are fertilized externally; therefore, males and females must release their gametes (sperm and eggs) simultaneously. After release, zebra mussel sperm remain viable for only a short time—perhaps only a few minutes. Disrupting the synchronization of spawning by males and females may effectively reduce the numbers of fertilized eggs. Researchers are currently studying the environmental cues and physiological pathways that coordinate zebra mussel spawning activity.

Spread to inland waters

Zebra mussels can spread to other inland waters either as veligers transported in water or as adults attached to boat hulls, engines, aquatic weeds, or other surfaces. Veligers are small—about the size of the period at the end of this sentence—and may be able to survive in any residual water source.

Adult mussels are very hardy and can survive out of water for extended periods depending upon temperature, humidity, wind, and sunlight. Maximum out-of-water survival time in ideal conditions is about 10 days for adults and 3 days for newly-settled juveniles.
Based on a survey of boat users in Michigan, Dr. Ladd Johnson recommends the following to prevent further spread of zebra mussels:

- Remove any visible vegetation from items that were in the water, including the boat, trailer, and all equipment.
- Flush engine cooling system, live wells, and bilge with tap water. If possible, use hot water.
- Do not re-use bait if exposed to infested waters.
- Dry boat and other equipment for at least 48 hours before using in uninfested waters.
- Examine boat exterior for mussels if it has been docked in infested waters; if mussels are found or exterior is heavily fouled by algae, either clean fouled surfaces or leave boat out of the water for at least 5 days before entering uninfested waters.

Be advised that these recommendations are still being studied by researchers and resource managers.

Tests show that mussels will die if they are exposed to water hotter than 110°F (43°C) for more than 15 minutes or to freezing temperatures (0°F or -18°C) for more than 24 hours.

In earlier versions of this publication, chlorine disinfection was suggested but is no longer recommended since chlorine is toxic to other organisms and may also damage boat equipment. Salt water mixtures are also not recommended.

Velligers may be transported easily in water used in live bait containers. Minnows or crayfish used in lakes containing zebra mussels should be transferred to well water or aged chlorinated tap water before carrying them to other bodies of water.

Waterfowl and other wildlife may transport zebra mussels, carrying veligers and/or adults in wet fur or feathers.

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

Theoretically, zebra mussel populations should peak a few years after initial infestation and then decline, depending upon predation and upon each water body's carrying capacity. There is little doubt that the zebra mussel's impact will be felt by everyone who uses our nation's inland waters.

---

1 For more information on this issue, request a copy of Ohio Sea Grant’s fact sheet titled Zebra mussel migration in inland lakes and reservoirs: A guide for lake managers (OHSU-FS-058).

2 For more information on this issue, request a copy of Ohio Sea Grant’s fact sheet titled Slow the spread of zebra mussels and protect your boat and other equipment, too (OHSU-FS-054).

---

### Zebra mussels and Quagga mussels

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

<table>
<thead>
<tr>
<th>ZEBRA MUSSELS</th>
<th>QUAGGA MUSSELS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shell</strong></td>
<td>Triangular shape</td>
</tr>
<tr>
<td></td>
<td>Obvious ridge between side and bottom</td>
</tr>
<tr>
<td></td>
<td>Sides merge with bottom</td>
</tr>
<tr>
<td></td>
<td>Byssal (ventral) side flat</td>
</tr>
<tr>
<td><strong>Color</strong></td>
<td>Variable colors and patterns</td>
</tr>
<tr>
<td></td>
<td>Usually dark</td>
</tr>
<tr>
<td><strong>Byssal</strong></td>
<td>Large groove in middle of flat side; allows tight hold on rocks</td>
</tr>
<tr>
<td><strong>Depth in Lake</strong></td>
<td>3 to 98 feet (1-30 m)</td>
</tr>
<tr>
<td></td>
<td>Maximum 33 feet (10 m); rare below 50 feet (15 m.)</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>32 to 86 F (0 to 30 C)</td>
</tr>
<tr>
<td><strong>Tolerance</strong></td>
<td>54 to 68 F (12 to 20 C) preferred</td>
</tr>
<tr>
<td><strong>Reproductive Temperature</strong></td>
<td>Young present at 57 to 68 F (14 to 20 C)</td>
</tr>
<tr>
<td><strong>Growth</strong></td>
<td>Up to 1 inch (25 mm)/year</td>
</tr>
</tbody>
</table>

Provided by Ontario Ministry of Natural Resources, with an update by Dr. Robert Heath of Kent State University.
Slow the spread of zebra mussels and protect your boat and motor, too

Zebra mussels (Dreissena polymorpha) have spread throughout the Great Lakes and in waterways in 18 states and two provinces since they were accidentally introduced into Lakes Erie and St. Clair in the 1980s. In 1991, a second species, quagga mussels (Dreissena bugensis), was discovered. Quagga mussels are similar to zebra mussels, but they survive in deeper, colder waters. They have been found in the St. Lawrence Seaway, Lake Ontario, Lake Erie and Saginaw Bay in Lake Huron.

The zebra mussels’ range will continue to expand naturally as flowing water carries their young—veligers—downstream. Commercial and recreational vessels and equipment also can spread zebra mussels when they move from infested waters to uninfested waters. Adult mussels may attach to hard surfaces, and veligers may be transported in water. Veligers are small—about the size of the period at the end of this sentence—and may be able to survive in any residual water. Zebra mussels spawn when the water temperature is between 57 and 68°F (14 to 20°C). Young quagga mussels have been observed in water as cool as 46°F (8°C).

Some inland lakes have already been colonized by zebra mussels because of man’s activities. For example, White Star Quarry, a 15-acre, 90-foot-deep Ohio lake, is not connected to any other waterway and is not used by boaters. It is, however, used by divers and anglers; and now it, too, is colonized by zebra mussels.

Nearly anything that has been in a zebra and quagga mussel-infested waters may have the mussels on them. This list of potential carriers includes:

- plants and animals
- any water
- snorkeling and scuba gear
- fishing gear and bait buckets
- scientific equipment
- boats, trailers and related equipment

Placing these items in uninfested waters without precautions may lead to an accidental introduction of these pesky mussels. The guidance provided in this publication is not guaranteed to remove or kill all the mussels; but it should vastly reduce the number being transported away from infested sites, and thus greatly reduce the probability of accidental further spread.

There are currently several states with laws that prohibit intentional introduction of non-native species such as the zebra mussel. Other states prohibit the possession of some plants and animals, and still other states have laws pending. Researchers must follow protocols approved by an interagency committee to impede the spread of mussels to uninfested waters.

How to slow the spread

The first step in prevention of spread is to develop an attitude of concern. Second, accept the fact that your activities are a potential means of transportation, and that adherence to the recommendations in this publication and to those of your state natural resources agency.

An interagency Great Lakes task force recommends the actions (listed below) be taken after using a boat or other equipment in zebra mussel-infested waters. Be advised that these recommendations are still being studied by researchers and resource managers; therefore, the recommendations may change.

Actions

- Remove any visible vegetation from items that were in the water, including boat, propeller, trailer and all equipment. (Zebra mussels readily attach to aquatic vegetation.)

- Flush engine cooling system, live wells and bilge with hot water. If hot water is not available, use tap water.

- Rinse any other areas that got wet, such as water collected in trailer frames, safety light compartments, boat’s deck and the lower portion of motor cooling systems. (Water hotter than 110°F will kill veligers, and 140°F will kill adults. If hot water is not available, it is still important to rinse your boat and equipment. Do not use salt and chlorine water mixtures as both mixtures are very toxic to other organisms and may also damage boat equipment. Therefore, neither is recommended now for use outdoors.)

- Always air dry boat and other equipment for five days before using in uninfested waters. If boat and equipment are completely dry for two days, it may be safe to use in uninfested waters.

- Examine boat exterior for mussels if it has been docked in infested waters; if mussels are found or exterior is heavily fouled by algae, either clean fouled surfaces or leave boat out of the water for at least five days before entering uninfested waters.

- If your gear feels gritty, then tiny microscopic mussels may be attached. Any mussels scraped off should be bagged and discarded in the trash.

- Do not re-use bait if exposed to infested waters.
How to protect your boat and motor
The longer a boat remains in zebra mussel-infested waters, the more apt it is to be fouled by zebra mussels. Therefore, boats that are docked or moored are more likely to be fouled by mussels than boats that are launched and retrieved in a single day.

Usage
The most expensive type of destruction to your boat is probably motor damage. Veligers can cause this harm when they are taken into the cooling system, where they can attach, grow and block intake screens, internal passages, hoses, seacocks and strainers.

The best prevention against such damage is to use your boat. Try to run your boat twice a week at high speed for 10 to 15 minutes. The mussels can’t attach when the water velocity exceeds 1.5 meters a second (about 3.5 mph or about 3 knots) and may be washed off at speeds exceeding two meters a second (about 4.5 mph or 4 knots). The high-speed running will also help flush any attached young mussels from inside the motor systems, and the heat generated past the waterpump will kill any veligers that may have been drawn into the system.

For outdrives and inboard units, run the engine at operation temperature for one-half hour each week. Watch temperature gauges and record readings for each use; any increase in readings over the previous use warrants disassembly and inspection of the cooling system. Consider installing a high temperature alarm.

After returning to the dock, flush any veligers out of the lower unit’s intake by running tap water through the system. (Never use a chlorine mixture in the engine cooling system.) Do this by having a hose fitting installed on the intake system or investigating current commercial “engine boot” systems that contain lower unit water and that recirculate the heated water through the engine. This flushing practice, however, won’t prevent veligers from entering the intake screens while your boat is at the dock.

Mussels can also accumulate around propeller shafts and can cause increased wear and possible damage to drive shafts or shaft seals. Reduce the amount of time in the water by tipping the drive units up and out of water when at dock.

During pre-season maintenance, and frequently thereafter, inspect cooling systems, intake screens, lower unit steering and hydraulic controls, propellers and propeller shaft seals. Frequently inspect the rubber boot that surrounds the I/O unit at the hull, because mussel shells can tear the boot, resulting in water entering the hull. Check water pump impeller for damage from shell fragments if adults are found near the intake systems. At the end of the season, follow the pre-season guidelines and disassemble everything, including the parts between the seacock and the engine.

Antifoulant products
Maintain a good quality antifoulant paint on the hull and other accessories because such paint releases toxins. Most marine algae, slime growths and mussels—including zebra and quagga mussels—are sensitive to these chemicals and will not attach to them. Several types of antifoulant paints exist, including copper-based, tributyltin (TBT)-based, copolymer, vinyl/epoxy binder, resin binder and hard- and soft-film types.

Copper-based paints are used on fiberglass and wooden hulls and accessories (trim tabs, etc.). They are usually viable for one or two seasons. A primer may be necessary on some surfaces, and the old coating must be removed first. A primer coat is absolutely necessary before applying to aluminum, because the aluminum and copper react with each other (electrolytic action) and cause corrosion. (Most lower motor units are aluminum.)

Tributyltin (TBT)-based antifoulants are restricted by law because they are extremely toxic. Early forms of TBT antifoulant paints leached biocides into the water and contaminated and killed non-target organisms. In 1988, a federal law restricted the use of TBT as an antifoulant.

Some states have approved use of newer “slow-release” TBT paints (bulk brush-on) for application only on the hulls of aluminum boats and vessels exceeding 82 feet in length. This treatment can last two to three seasons when properly applied. The person applying the paint is required to obtain a pesticide applicator’s license, generally available through your state’s agriculture agency, to purchase and apply this antifoulant. Some states and provinces, including Michigan and Ontario, have banned the use of TBT paints altogether. Check applicability and legality of use of these paints with the product’s manufacturer, boat dealer or regulatory agency. Where legal, a TBT-based spray for use on outboards, I/O sterndrives, propellers and internal passages is available for over the counter purchase.3

Copolymer coatings are best for high-speed boats because they are thinner and smoother than the others. They are also recommended for trailered or rack storage boats because they only react when immersed in water. Other coatings oxidize when exposed to air for as little as one week and become useless.

Vinyls, epoxies and resin coatings allow biocides to leach to the surface.

Soft-film types result in a soft residue remaining after the biocide is leached out and are well suited for boats that remain in the water.

Hard-film types can be sanded to restore effectiveness.

Consult your manufacturer or boat dealer to determine the type best suited for your hull and accessories. Applying paints to some accessories may cause a loss in performance. Apply spray inside passages as far as possible. Some units require an annual breakdown for lubrication of the drive shaft; this is an excellent opportunity to spray deep inside otherwise hidden water passages.

Never apply a new antifoulant over an existing coating of another type. Remove old paint and read container labels for compatibility.

Remember, it may take only a few viable adult zebra mussels or a minnow bucket containing microscopic veligers to start a new colony. Do your part to prevent the spread while protecting your boat and equipment, too!

---

1For more information about zebra and quagga mussels, request Ohio Sea Grant’s fact sheet Zebra mussels in North America: The invasion and its implications (OHSU-FS-045).

2For more information on this subject, request Ohio Sea Grant’s fact sheets Zebra mussel migration to inland lakes and reservoirs: A guide for lake managers (OHSU-FS-058) or Safe use of zebra mussels in classroom and laboratories (OHSU-FS-059).

3A 1990 Ohio Sea Grant study revealed a loss of effectiveness of TBT-based spray coatings used on accessories after 9 to 12 weeks in the water.
Zebra mussel migration to inland lakes and reservoirs: A guide for lake managers

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 (Ca²⁺) concentrations above 12 mg/L, alkalinity above 50 mg CaCO₃/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 Ca²⁺ concentrations above 30 mg/L, alkalinity of 86 mg CaCO₃/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/m² 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 Ca²⁺ 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 Ca²⁺/L and an alkalinity of 4.7 mg CaCO₃/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°C but 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...
sels 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 infor-
Aquatic nuisance species and Sea Grant

Kelly Kerstner, 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 Pontic-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 prolific 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, going 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.
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

Range of the zebra mussel in North America
as of August/September 1993
© Copyright 1993, New York Sea Grant

THE ZEBRA MUSSEL (DREISSENA POLYMORPHA): AN UNWELCOME NORTH AMERICAN INVADER

Charles R. O'Neill, Jr.
New York Sea Grant Extension Specialist

David B. MacNeill
New York Sea Grant Extension Specialist

INTRODUCTION

A new invader of North American fresh surface waters, Dreissena polymorpha (Pallas), commonly known as the "zebra mussel," has the potential to biofoul 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 surface waters.

ORIGIN OF THE ZEBRA MUSSEL IN THE GREAT LAKES

The zebra mussel, Dreissena polymorpha, 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.

Although the actual pathway of the mussel's introduction into 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. Although adult mussels are capable of attaching to ships' hulls, 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.

The zebra mussel was first discovered in the Great Lakes Basin in Lake St. Clair in June 1988. Judging from shell size, it was theorized that the mussels were introduced into the lake sometime in 1986. 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 per square meter were reported in the western basin of Lake Erie in the summer of 1989 by the Ontario Ministry of Natural Resources. By the end of 1989, specimens had been found in water treatment and Industrial water systems In The Detroit River below Lake St. Clair, on beaches and in water treatment and industrial facilities along most of the north and south shores of Lake Erie. Adult mussels were first reported in Lake Ontario in Port Weller at the mouth of the Welland Canal in November 1989 and on a navigation buoy four miles off the Niagara Bar in December 1989.

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; Ceyuga and Seneca Lakes (in New York's Finger Lakes); the headwaters of the 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.

Biologists believe that 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. This prediction seems to be borne out by sightings in the Illinois, Susquehanna, Mississippi, Tennessee, and Hudson Rivers. (See map for...
the zebra mussel's range in North America.)

Such dispersal will likely be greatly enhanced by interlake transport of veligers (larvae) in ship ballast and adult and juvenile mussels attached to ship and recreational boat hulls. The discovery of zebra mussels in Duluth Harbor (Lake Superior) may be evidence of such transport. There is concern that the range expansion of the zebra mussel will be further facilitated by 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.

**BIOLOGY OF THE ZEBRA MUSSEL**

Zebra mussels are small (5 cm and smaller) bivalve mollusks (relatives of clams and oysters) with elongated shells typically marked by alternating light and dark bands (Fig. 1). As its scientific name *polymorpha* implies, the species shows considerable genetic and morphological plasticity, particularly in its marking and coloration patterns. Specimens with few markings, with a 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* (Smirnova 1990). Early Soviet studies described at least five species (Andrussov, 1898).

![Figure 1](photo.png)

**Figure 1.** The origin of the name *polymorpha* can readily be seen in the variations in the light and dark banded markings on Zebra mussels.

Zebra mussels secrete durable elastic strands, called byssal fibers, by which they can securely attach to nearly any surface, forming barnacle-like encrustations (Fig. 2). 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 (serious impacts in Europe since the late 1800s).

Zebra mussels will colonize lakeshores and riverbanks where they attach to rock or gravel substrates, forming broad reef-like mats (Fig. 3). In some European lakes, colony densities exceeding 100,000 per square meter have been reported with 15 cm deep shell accumulations from dead mussels on the lake bottom within two years.

![Figure 2](photo2.png)

**Figure 2.** Zebra mussels can attach to nearly any surface. This car, retrieved from the bottom of Erieau Harbor, Ontario, had mussels growing on every surface including sheet metal, tires, fiberglass, glass, even cloth seats.

The mussels are generally found within 2 to 7 meters of the water surface but may colonize to depths up to 50 meters (Walz, 1978). 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 per 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 ppt (parts per thousand) total salinity in estuarine locales. European reports indicate occasional sightings of zebra mussels in total salinities exceeding 12 ppt (Bentem, Jutting, 1943).

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 (parts per million). 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 per second or rapid water level fluctuations. Zebra mussels can withstand dessication for two to three days, depending upon atmospheric humidity.

Figure 3 Zebra mussels attached to rock or gravel substrates can reach colony densities greater than 100,000 per square meter with shell accumulations reaching 15 cm or more on the lake bottom.

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. 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 female mussels can produce 30,000 to 40,000 eggs per year, as the water temperatures reach 12°C (54°F). At least one European study has indicated that a 30 mm female can produce, on average, up to 1 million eggs per year. Precocious young-of-the-year mussels as small as 3 mm may produce as many as 6,000 eggs per year (Walz, 1976). 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.

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, elevated 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 (sex products) in the water.

In Europe, fertilized eggs are 40 to 70 microns long and become planktonic larvae (veligers) in 2 to 3 days when water temperatures reach 14° to 16°C (57° to 61°F). In Lake Erie 11°C (52°F) is the norm, with the Ontario Ministry of Natural Resources reporting veligers in water as cold as 5.0°C (46°F). Veligers are capable of active swimming for 1 to 2 weeks, and are also transported by water currents, enabling them to disperse considerable distances from their parent colonies. Nocturnal vertical migrations of veligers have been reported in European lakes.

Within 3 weeks of hatching, the young mussels reach the "settling stage," where they can attach to bedrock, cobble, bottom debris or such manmade objects as boat hulls, breakwaters and water intake cribs. At this life-cycle phase, the settling larvae can experience mortalities exceeding 99%, primarily from hypoxia, temperature shock, and failure to locate a suitable attachment substrate (which could result in larvae sinking into bottom sediments or into deeper, colder water with lower productivity).

During the first year of life, young mussels are capable of active crawling along the substrate at speeds over 3.8 cm per hour until they find a suitable location to attach with small, temporary byssal fibers. With age, the mussels develop extensive 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.

The lifespan 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 systems.

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 oscil-
tions. However, in Sweden the population of zebra mussels has not yet crashed 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 regimes.

USE OF THE ZEBRA MUSSEL AS FOOD:
NATURAL PREDATION

Although larval and adult zebra mussels (which offer a high nutritional value to predators) are regularly consumed in Europe by several species of fish, the overall impact upon mussel populations is believed to be insignificant in many instances. Veliger and post-veliger larvae are also preyed upon by young fish and zooplankton, but to what extent this predation contributes to mussel mortality is unknown, although some researchers estimate this loss can reach five percent (Pielak, 1974). In some European lakes, crayfish predation on mussels 1 to 5 mm long is considerable, with adult crayfish (90 mm) consuming over 100 mussels per day (about 6,000 mussels per summer). Crayfish, however, are believed to be ineffective predators in deeper lakes due to cooler water temperatures. Some studies indicate that over 90% of the diet of the roach, a Eurasian fish species, is composed of zebra mussels. In the Great Lakes, the role of coarse fish species such as carp, eels and sheepshead may become increasingly important as a biological control agent; sheepshead are already reportedly feeding extensively upon zebra mussels in inshore areas of Lake Erie.

In Europe, studies indicate that waterfowl predation rates on zebra mussel populations are variable, ranging from insignificant to as high as 32% during the summer months and greater than 90% during the winter in some lakes. In the littoral zone (water depths of 0 to 5 meters) waterfowl are considered to be the prime controller of zebra mussels. For example, Lake IJssel, in the Netherlands, supports a large population of diving ducks feeding on zebra mussels.

The value of zebra mussels as a human food source is doubtful. It appears that they may not be a viable human food because of their small size, a strong byssal attachment which would make them difficult to harvest, and a possible tendency to serve as a parasite vector (transmitter) to humans. Furthermore, the mussel’s filter feeding process may cause bioaccumulation of toxic contaminants, making the mussels unfit for human consumption.

BIOLOGICAL IMPACTS

Using siphons and a ciliated gill system, zebra mussels filter small particles such as phytoplankton (microscopic plants and many forms of algae), small zooplankton (microscopic animals) such as rotifers, and detritus (bits of organic debris) out of water drawn into the mussel’s mantle cavity. Laboratory studies indicate that the mussels can efficiently filter food particles down to 0.7 microns, but preferentially select those particles between 15 to 40 microns as food. Rotifiers as large as 450 microns can be retained and eaten. 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.

Filtration rates (volume of water filtered per unit of time) 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 1 liter of water per day. Filtration rates up to 2 liters per day under optimal conditions have been observed. European studies indicate that the filtration ability of the mussels can dramatically increase lake water clarity. Since the introduction of zebra mussels into the western basin of Lake Erie, Canadian researchers have observed a two- to three-fold increase in water clarity and a significant reduction in chlorophyll a content (chlorophyll a analysis provides an index of the open water food chain production available for the aquatic plants and animals in a waterbody). The extent that changes in the lake’s clarity and productivity can be attributed directly to zebra mussel filtration activity is unknown. It is suspected that the zebra mussel has played a role. Lake Erie has also experienced an effective phosphate abatement program, which may be responsible in part for these observed trends in increased water clarity and decreased chlorophyll a content.

Since phytoplankton and detritus are major food sources for pelagic (open water) lake and riverine food webs respectively, fisheries-related impacts could result from zebra mussel filtration activity. 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 species and larval fish of all species preying on smaller zooplankton could face reduced survival as mussel populations expand, suggesting other potential food web impacts. In addition, extensive deposition of mussel pseudofeces on
the lake bottom could favor the proliferation of benthic (bottom-dwelling) fish and invertebrate species, especially in littoral areas. The changes in water transparency and the selective survival of benthic algae in mussel pseudofeces could favor a shift towards increased importance of primary production of benthic algae in the Great Lakes.

Because zebra mussels settle on rock cobbles as an attachment substrate, there is concern that extensive colonization of shoal areas could impair reproduction of species of fish (such as walleye and lake trout) which spawn only on rocky-bottomed areas. Some biologists are concerned that decomposing mussel pseudofeces could reduce water quality in and around fish egg masses on shoals, reducing egg survival. Data collected by the Ohio Department of Natural Resources in 1990-91, however, indicated good year classes of walleyes produced from mussel-encrusted shoals in western Lake Erie. Apparently, mussels were scoured from some spawning areas by ice prior to 1990 walleye spawning. Wave action also helped by sweeping shoal areas clear of mussel pseudofeces. Continued monitoring of spawning areas is necessary to quantify any future mussel impacts. Furthermore, increased water clarity may reduce the ability of larval fish to avoid predation. This also makes zooplankton more visible to fish predators.

In general, freshwater mollusks are important vectors of parasites (digenetic trematodes) in waterfowl, fish, wildlife, and, occasionally humans (in tropical areas). The typical life cycle of digenetic trematodes involves the development of the parasite within the bodies of mollusks, which serve as intermediate hosts. 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 colonizes rapidly throughout North America. Zebra mussels themselves show little effects from parasites.

Native mussel populations may be adversely impacted by competition for food and space by the sheer numbers of zebra mussel colonies reported in areas of the Great Lakes. There are already early signs that native unionid clam populations in Lake St. Clair are disappearing rapidly coincident with zebra mussel colonization. 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 damage to the shell edges.

**THE ZEBRA MUSSEL AS A BIOFOULER IN RAW WATER SUPPLIES**

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. Water intake structures (intake crib, trash racks, pipelines and tunnels) serve as excellent habitat for mussel colonization. The continuous flow of water into intakes carries with it a continuous source of food and oxygen to the mussels and carries away wastes, while the structures themselves protect the mussels from predation and ice scour. This makes water intakes ideal mussel habitat.

The zebra mussel is capable of attaching to firm substrates at water flow velocities below 2.5 meters per second on horizontal surfaces or 2.0 meters per second on vertical surfaces. Researchers in the Netherlands have reported that flows of 1.0 to 1.5 meters per second are sufficient to preclude settling under some conditions (Jenner, 1989). The presence of zebra mussels in a raw water main is usually first detected by the discharge of shells into the facility's raw well or forebay, possibly accompanied by a noticeable decrease in head, as the mussels line the pipeline or tunnel, eliminating the laminar flow along the walls of the conduit. In some cases, layers up to 0.3 meters or more in thickness are formed in intake mains.

Once in a drinking water treatment facility, zebra mussels may 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. The main impacts associated with colonization are: loss of intake head, obstruction of valves, putrefactive decay of highly proteinaceous mussel flesh, obnoxious methane gas production, and increased electrocorrosion of steel and cast iron pipelines.

A similar fouling problem can occur in power plants and industrial water systems which use an infested waterbody as their raw water supply. Condenser and heat exchanger tubing can become clogged, leading to loss of heat exchange efficiency and overheating. Service water (fire protection, bearing lubrication/cooling, 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 deliver sufficient fire fighting water.
The rate of overgrowth of zebra mussels from intake cribs and trash racks to internal distribution systems is dependent upon chemical and physical characteristics of the raw water supply, flow velocity within the system, the three-dimensional position of the surface of the overgrowth, and the surface structure of the substrate. One Great Lakes utility has reported mussel densities as high as 750,000 per square meter in its intake canal.

**IMPARTS ON NAVIGATION AND RECREATIONAL BOATING**

Zebra mussels can impact commercial navigation and recreational boating. As with any organism capable of attaching to hulls, zebra mussels 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 clog the cooling system, leading to overheating and possible damage to the engine. If shells are drawn into the engine, abrasion of cooling system parts, especially impellers, could result.

Commercial and recreational navigation can also be impacted if marker buoys sink under the weight of mussel encrustations on the submerged portions of the navigation aids. There is 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 slowing corrosion as a result of the mussels’ waste excretions. On floating dock systems, each square meter of adult mussels on the bottom and sides of floats can add as much as 20 to 30 pounds. Dock systems that are left in the water year-round could be destabilized or sunk by mussel colonization. Bubbler or flow developer systems which are used to prevent ice damage to dock systems could be colonized, decreasing the systems’ ice minimization effectiveness.

**IMPARTS ON RECREATION**

Recreational use of beaches in infested areas may be impaired by colonization of cobble in shallow nearshore areas by the mussels and by littering of beaches by shells washed up from submerged colonies by storm waves. Bathers on some Great Lakes beaches are reportedly adopting the use of beach/bathing footgear to prevent cuts from zebra mussel shells. Obnoxious smells from the decomposition of mussels also detract from the enjoyment of shoreline recreational activities.

**PHYSICAL AND MECHANICAL CONTROL ALTERNATIVES**

The European and Soviet experiences indicate 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 unhindered through the pipeline. Control can be continuous or periodic with the time schedule for elimination based upon the mussel’s growth rate for the specific waterbody and the minimum openings in the pipeline through which dead or living specimens can pass.

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 is 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 of traveling and stationary screens and the size of the mesh.

The common traveling screen mesh used in water supply systems is 9 to 13 mm. The effectiveness of screens can be increased by reducing the mesh size (some newer power plants use traveling screens with openings as small as 1 mm). This method is effective in excluding only those mussels which originate upstream of the screens or filters. Mussel colonization downstream of the screens (as a result of the passage of veligers through the screens) is not impacted. Additional service water strainers can exclude adult and juvenile mussels that were not excluded by the initial screening. Centrifugal separation debris filters or backflushable bag filters can be used to exclude most sizes of zebra mussels but may result in a loss of head in distribution lines.

Unfortunately, veligers pass easily through both screens and service water strainers and perhaps filters, as well, and need to be eliminated in some other manner before they have an opportunity to settle and colonize within the distribution system. The possibility does exist to use microstraining fabrics or filters with an aperture of 60-70 microns or smaller to keep veligers out of very sensitive portions of distribution systems. However, this is not practical on systems requiring large amounts or high velocities of water.

A different approach is filtration of intake water at the source, before the water enters the pipeline. This can be accomplished through the use of several different forms of buried intakes or sand filters. These types of filters are suitable for low flow requirements, up to a maximum of about 25,000-30,000 gallons per
minute. These types of intake filters are either drilled vertically and laterally into a good sand and gravel aquifer near a lake or river (Ranney wells); consist of porous intake pipes laid in trenches excavated into the bed of a lake or river and backfilled with a graded sand and gravel media (infiltration galleries); or are comprised of a flowing water source entering a surface trench or basin filled with a graded sand/gravel media with the pumping conduit either beneath the trench/basin, in the center, or at the outflow end (surface sand filter). Some modified form of sand filtration may also be suitable for use in single family homes or cottages using raw lake or stream water.

Since zebra mussels do not attach in high velocity current areas, another control method is to maintain intake and distribution system flows exceeding the rates stated earlier in this paper. This may not be possible in existing facilities due to pipe and pump size, pipeline configuration, or other factors, but should be taken into consideration in the design of new facilities in infested areas. Anything that causes either a significant drop in flow velocity or an eddying effect (such as changes in pipe diameter, short radius bends, square wall intersections in pumping wells, etc.) which would allow for increased mussel settlement and subsequent colonization, should be avoided. Also, rough pipe walls caused by scale, pitting, or poor welds should be corrected, as these areas create turbulence which allows the mussels an improved chance of reaching conduit walls through the laminar layer and increasing rates of attachment.

Physically scraping mussels from water systems (removal) is also a viable method of control. The desirability and effectiveness of scraping depends upon the design and operational characteristics of the impacted system. 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 (or non-dive personnel, in the case of dewatered systems) can remove the accumulated mussels. This alternative is, however, very expensive in terms of labor and lost production.

In smaller pipes or in pipelines where the configuration does not allow for direct access by workers, scraping may be accomplished by "pigging." The effectiveness of this method depends upon the design of the system and the intensity of the infestation. Pigging is not effective in systems with sharp, short radius bends in the pipeline or where the infestation is so great that the large amount of dislodged mussels might obstruct the progress of the pig or cannot be effectively removed from the conduit. Pigging can be designed into new systems constructed in infested areas.

Attachment of zebra mussels on open surfaces (i.e., trash racks and gates) may be discouraged through the use of electrically charged surfaces using industrial-frequency currents. Care should be taken to ensure that humans cannot come in contact with the charged surfaces. Potential impact on fish, ducks and other animals should also be considered.

It may be possible to control veliger settling in pipelines by the use of electrostatic filters placed in a pipeline cross section. In this case, exposure time depends upon water flow rates. Soviet research indicates that veliger death can be achieved by exposure to high voltage for 0.1 second. For such short exposures, 225 to 250 volts per centimeter would be needed for specimens with open shell valves or 300 to 400 volts per centimeter for those with closed valves (Morton, 1969), making this alternative impractical for most situations. At higher temperatures and voltages, specimens die proportionately more quickly. It should be noted that preliminary testing in the U.S. indicates that even greater charges may be required to ensure 100% mortality.

A "last resort" mechanical control for extreme situations is the removal and replacement of clogged tubing.

**AVOIDANCE CONTROL ALTERNATIVES**

For facilities that place marker buoys to locate intake cribs, it would be advisable to keep the buoy anchors well away from the intake structures to prevent veligers from settling on the anchor cable and spreading down the cable to the cribs. Periodic scraping of the bottoms of buoys is advised to avoid possible sinking under the weight of attached mussels.

The use of acoustic vibrations (>20kHz) is also being researched as an avoidance methodology. Preliminary data indicate that certain frequencies and intensities may be effective in "deactivating" veligers, that is, rendering them unable to attach to available substrates. Ultraviolet B radiation may also prove to have some effectiveness at killing veligers entering low flow conduits.

**OXYGEN DEPRIVATION CONTROL**

Since zebra mussels "breathe" oxygen as they draw water over their gills, oxygen deprivation, accomplished by hermetically 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 to three days exposure to anaerobic water at 23°C to 24°C (73.5°F to 75°F) will result in 100% mortality (Mikheev, 1968; see Table 1). Oxygen can be eliminated from a sealed conduit using sodium metabisulfite with cobalt chloride as a catalyst. Hydrogen sulfide gas may be added to increase the effectiveness of the treatment.

A relationship also exists between mussel size and susceptibility to oxygen deprivation. Small specimens die first because smaller mussels consume more oxygen than larger ones (Table 2). Unfortunately, however, since zebra mussels can survive several days of anaerobic conditions, any pipeline treated in this manner must be capable of being shut down and sealed for a number of days, a major drawback for most applications. It should be noted that many European water systems are designed with dual intakes, often quite short, to enable one to be shut down for cleaning while the other carries on the business of the facility.

When eliminating zebra mussels through oxygen deprivation, it should be noted that mussels in closed vessels die more rapidly when dead specimens are already present. There are several explanations for this: the appearance of disintegration products in water, extensive development of bacterial flora, and the rapid uptake of any remaining oxygen for oxidation (decomposition) and bacterial respiration.

### THERMAL CONTROL

Experience in Europe and the Soviet Union indicates that one of the most efficient, environmentally sound and cost effective methods of controlling zebra mussel encrustations is the systematic, periodic flushing of water systems with heated water. Water temperatures must exceed 37°C (98.6°F) for approximately 1 hour to ensure 100% mortality for mussels acclimated to 10°C (50°F) water temperatures (Ontario Hydro, 1990). Water temperatures in excess of 55°C (131°F) will result in rapid death of the most mussels of the widest size (life stage) range. In this temperature range, mussels tend to die with their shells slightly opened, promoting exposure and degeneration of byssal threads, followed by detachment of many specimens from the substrate (the smallest mussels, <7.0 mm, detach first). Lower temperatures, or thermal shocking applied to mussels acclimated to warmer water temperatures, will take longer periods of time to achieve 100% mortality (Figure 4). Mussels which remain attached must be mechanically scraped from the attachment areas or may be allowed to decompose. Treatments at temperatures greater than 60°C (140°F) result in immediate 100% mortality. However, many mussels may die with closed shells and may remain attached for several days.

When utilizing thermal control, it is often necessary to treat as many as three or more times annually to remove adults and to target the more vulnerable

| CRITERIA STUDIED | \begin{tabular}{|c|c|c|c|c|c|}
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td>Day 1</td>
</tr>
<tr>
<td>------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>17-18</td>
<td>7.5</td>
</tr>
<tr>
<td>20-21</td>
<td>9.6</td>
</tr>
<tr>
<td>23-24</td>
<td>7.1</td>
</tr>
<tr>
<td>D.O. (mg/l)</td>
<td>D.O. (mg/l)</td>
</tr>
<tr>
<td>% Dead</td>
<td>% Dead</td>
</tr>
</tbody>
</table>

### Table 1
Zebra mussel mortality rates at differing water temperatures and dissolved oxygen concentrations (Mikheev, 1968).

<table>
<thead>
<tr>
<th>Length (mm)</th>
<th>% Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0-4.9</td>
<td>100</td>
</tr>
<tr>
<td>5.0-9.9</td>
<td>61</td>
</tr>
<tr>
<td>10.0-14.9</td>
<td>34</td>
</tr>
<tr>
<td>15.0-19.9</td>
<td>2</td>
</tr>
<tr>
<td>20.0-24.9</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table 2
Relationship of zebra mussel size and mortality under anaerobic conditions for 37 hours at 22°C (Mikheev, 1968).
Chemical control strategies may be applied once per year at the end of the mussel spawning season (to kill all mussels of all ages which have been allowed to grow in a system since the end of the last spawning season); periodically throughout the spawning season (allowing some colonization but killing the mussels before densities get too great for efficient operation of the system; this allows less colonization than seasonal treatment); frequent intermittent treatment with relatively high concentrations of chemical (generally once or twice per day to purge the system of recently settled post-veligers, preventing growth to the more troublesome adult stage); and continuously with lower concentrations of chemical throughout the spawning season to prevent all settlement and colonization within the system.

Commercially available molluscsicides lend themselves more to 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 (mainly bacterial growth in rotting mussel flesh and taste and/or odor problems), 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

<table>
<thead>
<tr>
<th>ION</th>
<th>mg/l</th>
<th>% MORTALITY</th>
<th>TEST CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SILVER</td>
<td>2.5</td>
<td>40.0</td>
<td>20°C, 24 hour</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>71.5</td>
<td>20°C, 24 hour</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>100</td>
<td>20°C, 24 hour</td>
</tr>
<tr>
<td>MERCURY</td>
<td>5.0</td>
<td>57.2</td>
<td>20°C, 24 hour</td>
</tr>
<tr>
<td>ZINC*</td>
<td>5.0</td>
<td>4.8</td>
<td>20°C, 24 hour</td>
</tr>
<tr>
<td>COPPER</td>
<td>4.0</td>
<td>100</td>
<td>10°C, 20 hour</td>
</tr>
<tr>
<td>COPPER</td>
<td>3.9</td>
<td>8.0</td>
<td>20°C, 24 hour</td>
</tr>
<tr>
<td>COPPER</td>
<td>3.8</td>
<td>93.0</td>
<td>20°C - 22°C, 20 hr</td>
</tr>
</tbody>
</table>

Table 3 The effects of metal ions on zebra mussels. *Surviving mussels filter water but do not attach to substrate. 1 Static water test. 2 Flowing water test. (Dudnikov and Mitchev, 1968)
response due to incomplete hermetic sealing of their shells. While discharge of many of these metals into the natural environment (receiving waters) would not be permissible under state and federal regulations, some metallic ions might be applicable for use in closed water systems. Another factor which could limit use of metallic ions as a zebra mussel control measure is the potential corrosion of metal system components.

The use of copper sulfate has been shown in Soviet experiments to be an effective zebra mussel control. However, at temperatures below 22.5°C (72.5°F), lethal doses of copper sulfate are so high (e.g., 300 mg/l at 17.5°C for 5 hours results in 60% mortality [Lukhin, 1988]) as to be impractical, considering corrosion of metal pipes caused by the copper. At temperatures above 27.5°C (81.5°F), lethal concentrations decrease to more practical values (e.g., 11.0 mg/l at 27.5°C for 5 hours yields 88% mortality), perhaps making water pre-heating combined with copper sulfate a feasible control alternative in some situations.

Treatment at the point of raw water intake or within the system with various oxidizing chemicals has been proven in Europe, the Soviet Union, Canada, and the United States to be effective in controlling zebra mussels. Concentrations in the range of 0.25 mg/l to 1.0 mg/l total residual chlorine (TRC) for 2 to 3 weeks has been found to be effective in killing 95%-100% of zebra mussels (Jenner, 1989; see Table 4). Continuous treatment at concentrations of 0.25 mg/l to 0.5 mg/l during that period of the year when veligers and post-veligers are present in source waters has been shown to be effective in preventing settlement and growth of mussels in water treatment facility intakes. Chlorine treatment is more effective at warmer water temperatures than cold.

In power generation and industrial settings, continuous chlorination is feasible only for limited portions of water systems that are highly vulnerable to infestation and/or are part of safety-related systems. This is not a problem in water treatment facilities where oxidizing chemicals are commonly used during most, if not all, of the year for taste and odor control as well as disinfection purposes.

There is concern for negative effects of chlorine on nontarget species in discharge receiving waters. Therefore, dechlorination at the point of discharge is usually required.

There is also the risk that too high concentrations of chlorine may result in harm to the biological character of slow sand filters, thereby requiring dechlorination prior to filtration. In addition, an excessive rate of mussel killing can result in the putrefactive decay of the highly proteinaceous mussels, production of obnoxious or dangerous methane gas, and concentrated deposition of detached shells with a subsequent blockage of conduits when pipelines containing significant infestations are "shock treated."

| TABLE 4 Mortality rate of zebra mussels in laboratory experiments at varying chlorine concentrations. |
| The lines represent linear correlations. Experiments were run at water temperatures of 12°-15°C. |
| x = 1.0 mg/l Total Residual Chlorine (TRC); 3 experiments in duplicate; r = 0.972 |
| o = 0.5 mg/l Total Residual Chlorine (TRC); 2 experiments in duplicate; r = 0.988 |
| ▲ = 0.25 mg/l Total Residual Chlorine (TRC); 2 experiments in duplicate; r = 0.958 |
Chlorination of organic-rich water at the intake end of pipes may cause the formation of trihalomethanes (THMs), suspected carcinogens, and may therefore not be practical for public water treatment facilities which already have THM production problems. In these situations, other oxidizing compounds (e.g., chlorine dioxide, ozone, potassium permanganate, hydrogen peroxide) may be alternatives to chlorine.

Molluscicides may also be effective in industrial and power plant applications. These are usually short-term applications used periodically throughout the year, similar to periodic thermal treatments.

Before using any chemical treatment method, readers are advised to check with local environmental regulatory agencies to determine legality of use for their situation.

COATINGS

Organometallic antifouling 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 ablate off the substrate into the surrounding waters. Many such compounds are currently banned for most uses in the Great Lakes. Since these coatings do ablate into the water, they are unsuitable for use in potable water systems. Other coatings, such as copper paints or epoxies or zinc galvanizing may be useful in minimizing zebra mussel attachment and growth without environmental consequences as great as those caused by TBTO. Silicone-based coatings may also prove to be effective.

SUMMARY AND CONCLUSIONS

The zebra mussel, Dreissena polymorpha, is now well established throughout the Great Lakes and their connecting channels, as well as in numerous inland river systems in North America. There is no way to eliminate the mollusk in these water bodies without harming other life forms, so we must assume that the mussel is here to stay and that it will eventually be found throughout most inland water bodies throughout North America. The task now is to control its impacts on ecosystems and water uses.

The control methods cited above will give readers an introduction to the mussel and its control. Note that new control alternatives will most likely be developed as a result of the invasion of the zebra mussel into the Great Lakes. Readers should augment this fact sheet by referring to research reports available from Sea Grant, federal, state and provincial environmental management/regulatory agencies, and researchers.

REFERENCES


ACKNOWLEDGEMENTS

The authors thank Joe Leach, Ontario Ministry of Natural Resources; Dr. Gerry Mackie, University of Guelph; Dr. Bob Malouf, N.Y. Sea Grant Institute; Don Schloesser, U.S. Fish & Wildlife Service; and Rick Turnbull, Ontario Ministry of Environment for their review and comments on this factsheet.


Copies of this publication are available from:

New York Sea Grant
Hartwell Hall
SUNY College at Brockport
Brockport, NY 14420-2928
(716) 395-2638

New York Sea Grant Extension is a state and federal program designed to help people solve coastal problems along New York’s Great Lakes, St. Lawrence, Niagara, and Lower Hudson Rivers, the New York City waterfront, Long Island Sound, and the State’s Atlantic Ocean coast. It is administered through the State University of New York and Cornell University. Sea Grant funds research projects and conducts educational programs on issues ranging from off-shore mining and erosion control to commercial fisheries, coastal tourism, and aquaculture.

This publication is issued to further Cooperative Extension work mandated by acts of Congress. It was produced by the New York Sea Grant Extension with the cooperation of the U.S. Department of Agriculture, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Cornell Cooperative Extension, New York State College of Agriculture and Life Sciences, New York State College of Human Ecology, and New York State College of Veterinary Medicine, at Cornell University, and the State University of New York. New York Sea Grant Extension offers equal employment and program opportunities.
North American Range of the Zebra Mussel
as of 13 December 1993


1. Hog's Back Lock, Rideau River, Ottawa, ONT
2. Bruce's Rapid Locks, Rideau River, ONT
3. Lower Rideau Lake, ONT
4. Ojibway Lake, ONT
5. Big Rideau Lake, ONT
6. Owen Sound Harbour, ONT
7. Collingwood Harbour, ONT
8. Mississagi Strait, ONT
10. Haugton Lake, Michigan
11. Casa Lake, Walled Lake, Michigan
12. Bellefonte Lake, Michigan
13. Lake Paw Paw, Michigan
A Great Lakes Sea Grant resource list on zebra mussels and other nonindigenous species

This list includes material that is distributed by the six Sea Grant programs in the Great Lakes Sea Grant Network as of December 1993. Many of the other Sea Grant programs are producing material about the zebra mussel, too. For example, Rhode Island (401/792-6842), Virginia (804/924-5965) and North Carolina (919/515-2452) Sea Grant programs all currently have material available. Other U.S., state and Canadian agencies also have material available.

To order any item in this resource list, complete and mail the order form for the program distributing the material. Free items are for single copies only unless specified otherwise. For prices on bulk orders, contact the program that is distributing the material. Please prepare all orders.

Resources on zebra mussels

The first three publications provide information on how this species was introduced into the Great Lakes, areas colonized in the lakes, what methods of eradication exist, provides tips on what you can do to slow the mussel’s spread, and the impact zebra mussels will have on industry, recreation and the Great Lakes ecosystems.


Zebra mussels: A 1992 Great Lakes overview. 1992. Avery Klauber. 8 pp. Free; multiple copies are $0.10 each. NY


Boaters—Slow the spread of zebra mussels and protect your boat, too. 1993. David O. Kelch. 2 pp. OHSU-FS-054. Free for any size order. OH


Zebra mussel information needs survey for municipal and industrial water users—Summary report. 1992. Robin Goettel and Gail Snowdon. 8 pp. A survey of 29 southern Lake Michigan municipal and industrial water users provided findings on what types of zebra mussel information were most needed and in what form the information could best be delivered. Free. IL-IN

Control of zebra mussels in residential water systems. 1993. Charles R. O’Neill, Jr. 8 pp. $1.00 NY


#1: Case studies of constructed filter bed intakes. A description of 10 such systems in the western Great Lakes that range from one to 100 years old. Included is information on operational experience and whom to contact (plant operators and design engineers) for further information, plus commentary from marine contractors and design engineers. 16 pp.

#2: Infiltration intakes for very large water supplies: Feasible? A review of four 20-year-old papers that considered design feasibility as a means of protecting larval organisms from entrainment in power plant and water diversion project intakes. 11 pp.

#3: Zebra mussel (Dreissena polymorpha) distribution: Reported size, depth and temperature variables. A summary of relevant data about zebra mussels intended for project design engineers. 7 pp.

#4: Using filtration and induced filtration intakes to exclude organisms from water supply systems. A literature review plus an overview of slow sand filtration and infiltration systems. 13 pp.

Mid-Atlantic zebra mussel fact sheet. Reprinted January 1994. Barbara Doll. 6 pp. Explains the possible routes of entry the zebra mussel might take and examines the environmental characteristics that would make this area a hospitable host, including the expansive estuaries and freshwater rivers and lakes. Free. To order, write N.C. Sea Grant, Box 8605, N.C. State University, Raleigh, NC 27695-8605.

Zebra mussel: An unwelcome visitor. 1993 Karin A. Tammi. 2 pp. Describes the biology, impact and history of zebra mussels in the United States along with identification information and help to Rhode Islanders to prevent their introduction into the state. $0.50 To order, write R.I. Sea Grant Information Office, URI Bay Campus, Narragansett, RI 02882, 401/792-6842.

Zebra mussels in Virginia’s future. March 1993. 2 pp. Includes the zebra mussel’s physical requirements and a list of its potential range in Virginia’s waters. Free. To order, write Virginia Institute of Marine Science, Gloucester Point, VA 23062.


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 supports 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. Sea Grant is a program in the National Oceanic and Atmospheric Administration (NOAA), Department of Commerce. This list was compiled by Ohio Sea Grant Communications (Projects MP-2 and AZM-1, grant NA90AA-D-SC456.) as OHSU-FS-052. December 1993.

Printed compliments of Mercury Marine, A Brunswick Company

Don't let these invaders hijack your boat! is a 17"x22" humorous cartoon poster telling boaters what to do to slow the spread of zebra mussels. Perfect for fishing/bait shops. Pub X6. Free. MN

Don't pick up hitchhikers! Stop the zebra mussel is a 3 pp. flyer and 11"x17" poster. One or two copies of the flyer and poster are free. NY

Zebra mussel watch identification card. Christine Kohler and Stephen Wittman. Wallet-sized cards have a color picture of the zebra mussel with text describing their appearance and what to do if you find a mussel. Free; 20 cards for $1.00. Available from each program. Order customized cards from Wisconsin. WI

Zebra mussel distribution map from the latest issue of *Dreissena polymorpha* information review. Free. NY

Zebra mussel distribution in Michigan. Free. MI

Zebra mussels: From spawning to settlement. January 1994. 20-minute video shot through a microscope shows mussels spawning naturally and induced. Voice-over provides details. $15.00. OH

Zebra mussels. 1993. Produced by New York Sea Grant and PBS-affiliate WLIW, Long Island as 30-minute show. $12.00. NY

Protecting your boat from zebra mussels. Revised 1993. This 15 minute video gives pointers on how to prevent damage to your recreational boat and tips on preventing the spread of the mussel to inland waters. $10.00. NY

Too much mussel. January 1991. This 5.5 minute video (VHS format) provides an overview of the impact of zebra mussels to Lake Erie. $15.00. OH

Zebra mussel features. Collection of 90 second feature stories produced by Outreach Communications TV at Michigan State University. Contact Carol Swinchart at MSU 517/353-9723. $10.00.

NonIndigenous Species Graphics Library contains slides, photographs and illustrations of zebra mussels and other aquatic nuisance species. Also includes a videotape resource list. Contact Michigan Sea Grant at 313/764-1138 for more information.

---

**Resources on other species**


The Ruffe Invasion, *Gymnocephalus cernuus*. 1993. Mike McLean. Describes the aggressive, perch-like fish found in Lake Superior. This invader was first identified in the St. Louis River in 1987. It is now the most numerous forage fish in the estuary and its range is expanding. PUB X7. Free. MN


Don't let exotic fish ride with you. 1992. A simple card explaining four major exotics that threaten our lakes and rivers and what boaters and anglers can do to prevent their spread. 2 pp. Free for any quantity. Available from each program.


---

**Scientific publications on zebra mussels**


"Synchronous spawning in a recently established population of the zebra mussel, Dreissena polymorpha, in western Lake Erie, USA" by Wendell R. Haag and David W. Garton reprinted from Hydrobiologica 234:103-119, 1992. OHSU-RS-151. Free. OH

International zebra mussel research conference (1991) proceedings sponsored by the Great Lakes Sea Grant Network and hosted by New York Sea Grant. 52 pp. $8.00. NY


The white perch and its interaction with yellow perch in Lake Erie. 1989. Donna L. Parrish. 137 pp. TD-021. $15.50. OH

Newsletters

Dreissena polymorpha information review. Summaries of research, meetings, legislation and sitings of the zebra mussel for the interested professional. Bimonthly. $60.00 annual subscription rate includes other benefits. Contact Zebra Mussel Clearinghouse at 800/22-2825.

Zebra mussel update reports on the status of the zebra mussel invasion in the region, zebra mussel-related research, upcoming conferences, new publication, etc. Written by Clifford Krafy. Published irregularly; Free. WI

For more information...

**Michigan/Indiana Sea Grant Program**
University of Illinois
63 Murdock Hall
1301 W. Gregory Dr.
Urbana, IL 61801-3068
217/533-9448

**Michigan Sea Grant College Program**
University of Michigan
2200 Bonisteel Blvd.
Ann Arbor, MI 48109-2099
313/764-1135

**Minnesota Sea Grant College Program**
University of Minnesota
1518 Cleveland Ave., N.
Suite 302
St. Paul, MN 55108-6001
612/625-5790

**New York Sea Grant Institute**
SUNY College at Oswego
Swetman Hall
Oswego, NY 13126-3599
315/341-3042
0800/228-2825

**Ohio Sea Grant College Program**
The Ohio State University
1314 Kinnear Rd.
Columbus, OH 43212-1194
614/292-8494

**Sea Grant Institute**
University of Wisconsin-Madison
1800 University Ave.
Madison, WI 53705-0949
608/263-3259
# IL-IN Publications

<table>
<thead>
<tr>
<th>Publication #</th>
<th>Title</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Make checks payable to
University of Illinois

| Send to | TOTAL |

---

# MI Publications

<table>
<thead>
<tr>
<th>Publication #</th>
<th>Title</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Make checks payable to
Michigan Sea Grant

| Send to | TOTAL |

---

# MN Publications

<table>
<thead>
<tr>
<th>Publication #</th>
<th>Title</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Make checks payable to
University of Minnesota

| Send to | TOTAL |

---

# NY Publications

<table>
<thead>
<tr>
<th>Publication #</th>
<th>Title</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Make checks payable to the
New York Sea Grant Institute

| Send to | TOTAL |

---

# OH Publications

<table>
<thead>
<tr>
<th>Publication #</th>
<th>Title</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Make checks payable to
The Ohio State University

| Send to | TOTAL |

---

# WI Publications

<table>
<thead>
<tr>
<th>Publication #</th>
<th>Title</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Make checks payable to
UW Sea Grant Institute

| Send to | TOTAL |

---
Invasion Of An Exotic Species: Stop The Zebra Mussel!

Activities And Resources For Grades 8 - 12

Virginia Sea Grant
Marine Advisory Program

New Jersey Sea Grant
Education And Outreach Program of the New Jersey Marine Sciences Consortium
INVASION OF AN EXOTIC SPECIES: STOP THE ZEBRA MUSSEL!

NEW JERSEY CURRICULUM SUPPLEMENT

NEW JERSEY SEA GRANT EDUCATION AND OUTREACH PROGRAM
of the
New Jersey Marine Sciences Consortium
Building 22 Fort Hancock
Sandy Hook, New Jersey 07732
(908) 872-1300
INVASION OF AN EXOTIC SPECIES: STOP THE ZEBRA MUSSEL!

NEW JERSEY CURRICULUM SUPPLEMENT

ABSTRACT

The Virginia Sea Grant Marine Advisory Program has developed the INVASION OF AN EXOTIC SPECIES: STOP THE ZEBRA MUSSEL! curriculum package in order to introduce students to the problems associated with the introduction and spread of zebra mussels in Virginia waterbodies. The activities and resources in that packet guide students in a study of the zebra mussel and the possibilities and resultant impact of its invasion. Students use actual scientific data to identify which Virginia waterbodies will be introduced or infested with zebra mussels. Further activities provide students with the opportunity to create action plans to prevent the spread of zebra mussel within each waterbody, and follow-up activities for both the field and classroom provide a number of possibilities to investigate the impact of zebra mussels on other animals and plants as well as structures located within these waterbodies.

The New Jersey Zebra Mussel Curriculum Supplement, developed by the New Jersey Sea Grant Education and Outreach Program, is intended for use with the Virginia Sea Grant Marine Advisory Program INVASION OF AN EXOTIC SPECIES: STOP THE ZEBRA MUSSEL! curriculum package. It is designed to provide New Jersey students with the opportunity to identify the susceptibility of New Jersey waterbodies to the introduction and invasion of zebra mussels using actual water quality data collected throughout the state. Additional literature on zebra mussel life history, physiology and spread through waterbodies in North America has been included in order to provide background information for teachers and students.
INVASION OF AN EXOTIC SPECIES: STOP THE ZEBRA MUSSEL!

NEW JERSEY CURRICULUM SUPPLEMENT

CONTENTS

Abstract

A Field Guide to Aquatic Exotic Plants and Animals - Identification Brochure

Invasion of an Exotic Species: Stop the Zebra Mussel! - New Jersey Study Activity Set

Invasion of an Exotic Species: Stop the Zebra Mussel! - Annotated Bibliography

Showing Our Mussel - The Great Lakes Sea Grant Network Report on Zebra Mussel Research and Outreach

Zebra Mussel Environmental Tolerances - Data Sheet - New York Sea Grant Institute

Mussel Menace - Fact Sheet - New Jersey Sea Grant Marine Advisory Service


Zebra Mussel Watch - Identification Card - Mid-Atlantic Sea Grant Network
INVASION OF AN EXOTIC SPECIES: STOP THE ZEBRA MUSSEL!

NEW JERSEY CURRICULUM SUPPLEMENT

ACKNOWLEDGEMENTS

These materials were prepared by the staff of the New Jersey Sea Grant Education and Outreach Program including John Tiedemann, Director, New Jersey Sea Grant Education and Outreach Program, Kerry Lynch, Marine Specialist, Claire Antonucci, Education Program Coordinator and Liel Holmdag, Outreach Program Coordinator.

The New Jersey Zebra Mussel Curriculum Supplement was adapted for use in New Jersey from the accompanying INVASION OF AN EXOTIC SPECIES: STOP THE ZEBRA MUSSEL! authored by Vicki Clark and Thomas Miller, Virginia Sea Grant Marine Advisory Program.

Information contained in the curriculum supplement was reviewed by Eleanor Bochenek, Marine Extension Agent with the New Jersey Sea Grant Marine Advisory Service and Vicki Clark, Marine Educator with the Virginia Sea Grant Marine Advisory Program.

The New Jersey Sea Grant Education and Outreach Program is a program of the New Jersey Marine Sciences Consortium (NJMSC). NJMSC is a private, non-profit organization comprised of member colleges, universities and private groups interested in marine affairs. The New Jersey Sea Grant Education and Outreach Program supports the education goals of the Consortium by planning and conducting a wide range of pre-college, college, teacher and public education programs.

The activities of the New Jersey Sea Grant Education and Outreach Program are the result of funding, in part, by NOAA, Office of Sea Grant, Department of Commerce, under Grant No. NA 36-RG0505, (Project No. A/S-6ZM). The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies. The U.S. Government is authorized to produce and distribute reprints for governmental purpose notwithstanding any copyright notation that may appear hereon. New Jersey Sea Grant Publication Number NJSG-95-307.
# INVASION OF AN EXOTIC SPECIES: STOP THE ZEBRA MUSSEL!

**NEW JERSEY CURRICULUM SUPPLEMENT**

**ZEBRA MUSSEL STUDY SITE - WATER QUALITY INFORMATION**

<table>
<thead>
<tr>
<th>Location</th>
<th>Temp. (C)</th>
<th>Salinity (ppt)</th>
<th>pH</th>
<th>Calcium CaCO3</th>
<th>Introduce</th>
<th>Survive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delaware River at Montague</td>
<td>14.75</td>
<td>0</td>
<td>7.15</td>
<td>9.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hackensack River at New Milford</td>
<td>16.5</td>
<td>0</td>
<td>7.25</td>
<td>29.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wallkill River at Hamburg</td>
<td>14.25</td>
<td>0</td>
<td>7.25</td>
<td>41.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delaware River at Riegelsville</td>
<td>17.5</td>
<td>0</td>
<td>7.9</td>
<td>17.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raritan River at North Branch</td>
<td>15</td>
<td>0</td>
<td>8.1</td>
<td>19.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kettle Creek at Route 70</td>
<td>16.1</td>
<td>0</td>
<td>5.54</td>
<td>1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barnegat Bay at Mantoloking Bridge</td>
<td>18</td>
<td>19</td>
<td>7.86</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Egg Harbor River at Folsom</td>
<td>14.65</td>
<td>0</td>
<td>6.65</td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maurice River at Millville</td>
<td>15.3</td>
<td>0</td>
<td>6.86</td>
<td>5.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cape May Harbor</td>
<td>17</td>
<td>30</td>
<td>8.0</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 1: Delaware River at Montague</td>
<td>Zebra Mussel Study Site 1: Delaware River at Montague</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------------------------------------</td>
<td>------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>The salinity measurement at the monitoring station is 0 ppt and the calcium measurement is 9.25 ppm.</strong></td>
<td><strong>The Delaware River flows from New York State along the western border of New Jersey.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Zebra mussel veligers are carried by water currents which in turn infest new waters.</strong></td>
<td><strong>The average annual water temperature is 14.75°C with a pH reading of 7.15.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Delaware River is widely used by recreational boaters and anglers. The monitoring station is included in the Delaware Gap National Recreational Area which is frequently used by trailered boats.</strong></td>
<td><strong>Boaters who use trailers to utilize several waterbodies must be informed that boat equipment and parts may transport both adult zebra mussels and veligers to new waterbodies where they may colonize.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 2: Hackensack River at New Milford</td>
<td>Zebra Mussel Study Site 2: Hackensack River at New Milford</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
<td>----------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Hackensack River originates in New York State and flows south to Newark Bay.</td>
<td>Large ships traveling from freshwater ports in Europe frequently dock at the Port of Newark, located south of the Hackensack River.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra mussels have been found in the Hudson River in New York.</td>
<td>The Hackensack River, heavily used for both commercial and recreational boating, has nine public boat ramps south of New Milford.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At the monitoring site in New Milford, the average salinity of the river is 0 ppt.</td>
<td>On average, the calcium level along the river in New Milford is 29.45 ppm, water temperature is 14.75°C, salinity is at 0 ppt and pH is 7.15.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 3: Wallkill River at Hamburg</td>
<td>Zebra Mussel Study Site 3: Wallkill River at Hamburg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------</td>
<td>---------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The average yearly salinity of the monitoring station at Hamburg is 0 ppt and the average water temperature is 14.25°C.</td>
<td>Below the Franklin Pond outlet the river can experience severely reduced flow during the summer months, resulting in high stream temperatures.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 3: Wallkill River at Hamburg</td>
<td>Zebra Mussel Study Site 3: Wallkill River at Hamburg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Wallkill River drains from New Jersey into New York and has a 203 square mile watershed in New Jersey, which is predominantly rural.</td>
<td>Currents moving within a single body of water can transport zebra mussel veligers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 3: Wallkill River at Hamburg</td>
<td>Zebra Mussel Study Site 3: Wallkill River at Hamburg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The average calcium level at the monitoring site is 41.34 ppm with an average pH measurement of 7.25.</td>
<td>Small boats are trailered within the watershed of the river.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 4: Delaware River at Riegelsville</td>
<td>Zebra Mussel Study Site 4: Delaware River at Riegelsville</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
<td>----------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Delaware River is heavily used for recreational and commercial boating.</td>
<td>On average, the calcium level measured at the monitoring station is 17.2 ppm., water temperature is 17.5°C, the pH reading is 7.9 and the salinity level is 0 ppt.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 4: Delaware River at Riegelsville</td>
<td>Zebra Mussel Study Site 4: Delaware River at Riegelsville</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The total drainage area of this part of the river is 200 square miles with a total of 75 stream miles.</td>
<td>Larval zebra mussels can easily be transported by currents moving downstream between waterbodies.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 4: Delaware River at Riegelsville</td>
<td>Zebra Mussel Study Site 4: Delaware River at Riegelsville</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adult zebra mussels frequently attach to boat hulls and trailers. These mussels can live up to four days out of water under certain environmental conditions.</td>
<td>Fertilized eggs develop into free swimming larval veligers that remain suspended in currents for three to four weeks before they settle and attach to hard substrates.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 5: Raritan River at North Branch</td>
<td>Zebra Mussel Study Site 5: Raritan River at North Branch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>--------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreational fishing for trout and smallmouth bass is very popular in many of the streams of this 190 square mile watershed.</td>
<td>The average annual water temperature is 15°C.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>--------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 5: Raritan River at North Branch</td>
<td>Zebra Mussel Study Site 5: Raritan River at North Branch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The mouth of the Raritan River flows into Raritan Bay and New York Harbor which is heavily used for shipping.</td>
<td>On average, salinity at the monitoring station is 0 ppt, pH is 8.1 and the calcium level is measured at 19.4 ppm.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>--------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 5: Raritan River at North Branch</td>
<td>Zebra Mussel Study Site 5: Raritan River at North Branch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large ships use ports within New York Harbor for loading and unloading cargo.</td>
<td>Free swimming zebra mussel larvae can survive for several weeks in the ballast water of ships.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 6: Kettle Creek at Route 70</td>
<td>Zebra Mussel Study Site 6: Kettle Creek at Route 70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra mussel veligers can easily be transported from downstream by current movement within a waterbody.</td>
<td>Several public access boat ramps are located at the mouth of Kettle Creek where recreational boating is heavy during summer months.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 6: Kettle Creek at Route 70</td>
<td>Zebra Mussel Study Site 6: Kettle Creek at Route 70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small trailered boats are used upstream for recreational fishing.</td>
<td>On average, annual water temperature is 16.1°C, salinity is 0 ppt, the pH is 5.54 and the calcium is measured at 1.6 ppm.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 6: Kettle Creek at Route 70</td>
<td>Zebra Mussel Study Site 6: Kettle Creek at Route 70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In areas where the mussels thrive, adult zebra mussels frequently attach to boats and trailers. These mussels can live out of water for two to three days under certain environmental conditions.</td>
<td>Free swimming larvae can survive for several days in water contained in bait buckets, live wells, boat trailer frames and other enclosed boat areas.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Zebra Mussel Study Site 7:</strong> Barnegat Bay at Mantoloking</td>
<td><strong>Zebra Mussel Study Site 7:</strong> Barnegat Bay at Mantoloking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
<td>----------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The average annual temperature is 18°C.</td>
<td>There are five (5) public boat ramps within a two mile radius of the monitoring site.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Zebra Mussel Study Site 7:</strong> Barnegat Bay at Mantoloking</td>
<td><strong>Zebra Mussel Study Site 7:</strong> Barnegat Bay at Mantoloking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The bay is used for recreational boating especially during summer months.</td>
<td>The monitoring site located at the Mantoloking Bridge has an annual average salinity of 19 ppt and a pH level of 7.86.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Zebra Mussel Study Site 7:</strong> Barnegat Bay at Mantoloking</td>
<td><strong>Zebra Mussel Study Site 7:</strong> Barnegat Bay at Mantoloking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barnegat Bay is an estuary fed by the Metedeconk, Toms and Forked Rivers as well as the Oyster, Cedar and Kettle Creeks.</td>
<td>The nuclear power plant located on Oyster Creek is dependent on water from Oyster Creek and Barnegat Bay for its operation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 8: Great Egg Harbor River at Folsom</td>
<td>Zebra Mussel Study Site 8: Great Egg Harbor River at Folsom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
<td>----------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>There are five (5) public boat ramps south of Folsom on the Great Egg Harbor River.</td>
<td>The average annual temperature at the monitoring station is 14.56°C and the average salinity is 0 ppm.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 8: Great Egg Harbor River at Folsom</td>
<td>Zebra Mussel Study Site 8: Great Egg Harbor River at Folsom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Great Egg Harbor River feeds Great Egg Harbor, an estuarine environment used widely by recreational boaters and anglers.</td>
<td>Boats trailered between waterbodies within several days speeds the spread of zebra mussels due to the time period which adult zebra mussels can live out of water attached to boats.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 8: Great Egg Harbor River at Folsom</td>
<td>Zebra Mussel Study Site 8: Great Egg Harbor River at Folsom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The average pH level at Folsom is 6.65, and the average calcium level is 3.6 ppm.</td>
<td>It is recommended to dispose of live bait and water from bait buckets prior to leaving each waterbody since veligers can survive in bait buckets and the enclosed engine parts of boats for several days.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 9: Maurice River at Millville</td>
<td>Zebra Mussel Study Site 9: Maurice River at Millville</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
<td>-----------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The average temperature of the water in the Maurice River at the Millville monitoring station is 15.3°C and the average salinity level is 0 ppt.</td>
<td>There are eight (8) public access boat ramps south of Millville on the Maurice River.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
<td>-----------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 9: Maurice River at Millville</td>
<td>Zebra Mussel Study Site 9: Maurice River at Millville</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The average calcium level of the river at Millville is 5.4 ppm, and the average salinity level is 0 ppt.</td>
<td>The Maurice has a drainage area of 386 square miles and travels for 50 miles into Delaware Bay, a waterbody heavily used for shipping.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
<td>-----------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 9: Maurice River at Millville</td>
<td>Zebra Mussel Study Site 9: Maurice River at Millville</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The river is widely used for recreational boating and fishing.</td>
<td>Zebra mussel veligers can travel between waterbodies in currents.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 10: Cape May Harbor</td>
<td>Zebra Mussel Study Site 10: Cape May Harbor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>-------------------------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The annual average pH is measured at 8.0.</td>
<td>There are five (5) public access boat ramps located within the harbor.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 10: Cape May Harbor</td>
<td>Zebra Mussel Study Site 10: Cape May Harbor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On the average, the water temperature at Cape May Harbor is 17°C and the salinity level is 30 ppt.</td>
<td>Cape May Harbor is fed from several tributaries including; Schellenger, Cedar, Ford, and Skunk Creeks, the Upper, Middle and Lower Thorofares and the Cape May Canal.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zebra Mussel Study Site 10: Cape May Harbor</td>
<td>Zebra Mussel Study Site 10: Cape May Harbor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cape May Harbor is used by recreational boaters and anglers.</td>
<td>Transient boaters should be aware that because zebra mussels can survive for several days in live bait wells and enclosed engine compartments they should take precautions prior to entering a new waterbody.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
INVASION OF AN EXOTIC SPECIES: STOP THE ZEBRA MUSSEL!

ANNOTATED BIBLIOGRAPHY

NEW JERSEY SEA GRANT EDUCATION AND OUTREACH PROGRAM
of the
New Jersey Marine Sciences Consortium
Building 22 Fort Hancock
Sandy Hook, New Jersey 07732
INVASION OF AN EXOTIC SPECIES: STOP THE ZEBRA MUSSEL!

ANNOTATED BIBLIOGRAPHY


This publication covers the introduction and dispersal mechanisms, physiological requirements and likelihood of invasion of the zebra mussel. Temperature, salinity, pH and oxygen are discussed in detail as the environmental parameters measured to predict zebra mussel introduction and infestation in Virginia waters.


This publication discusses the probability of zebra mussel infestation in specific waterbodies located in Virginia. Risk and susceptibility of zebra mussel infestation are used to determine whether zebra mussels could be introduced and, if introduced, whether they could attain high populations within specific waterbodies.


This fact sheet provides a synopsis of the physiological requirements of the zebra mussel and their dispersal and potential range in specific Virginia waterbodies.


This article discusses the possibilities of commercial value for zebra mussels which, if feasible, would reduce the costs of preventing the spread of the mussel. Examples discussed include whether the glue used by the mussel to attach itself to hard substrates could be a possible product.

This educational packet provides activities and resources designed to educate students in grades 8 - 12 about the zebra mussel as an exotic species. Students are given water quality parameters to determine the possibility of a zebra mussel invasion in several Virginia waterbodies.


This text book outlines the anatomy, monitoring techniques, common places of infestation and types of mitigation treatments of the zebra mussel. Case histories are also included.

Delaware River Basin Commission. (undated). Attention Boaters: Have You Seen this Mussel? West Trenton, N.J.

This fact sheet identifies the problems and potential damage of zebra mussel infestation as well as directions for the prevention of their spread by boaters.

Garton, D. and W. Haag. 1993. Seasonal Reproductive Cycle and Settlement Patterns of *Dreissena polymorpha* in Western Lake Erie. Ohio Sea Grant College Program. Publication No. OSHU-RS-159. Columbus, OH.

This publication is a review of data related to the reproduction of the zebra mussel during the summers of 1989-1990. Zebra mussel larvae measurements taken between June and October during those two years are used to determine environmental factors found during peak larvae abundances.

Great Lakes Sea Grant Network. Exotics: Don't Let them Ride With You! Minnesota Sea Grant Program. St. Paul, MN.

This illustrated fact sheet identifies and describes exotic species and the damage that they have caused or could cause, to an aquatic environment upon introduction.


Identification criteria and control methods for the zebra mussel are explained in this booklet. Agencies to call if zebra mussels are found are listed.

This list describes resources available from all members of the Great Lakes Sea Grant Network, including posters, videos, maps, ID cards and newsletters.


This booklet provides an overview of various Great Lakes Sea Grant Network activities related to zebra mussels and other nonindigenous species. The response, control, prevention and ecological impacts of the zebra mussel are reviewed as well as their impact on commerce and industry. Other nonindigenous nuisance species and outreach activities related to these species are also highlighted.


Research on zebra mussel reproductive patterns conducted in order to determine the peak periods of spawning is described in this publication. The influence of warm weather months, especially late August, have proved to be the periods of abundant veliger populations.


This publication reviews precautionary actions taken by Green Bay Water Utility, located on Lake Michigan, to prevent zebra mussels from invading the water intake system, including the installation of chlorine control systems that may kill the larval and adult forms of this mollusk.


Included in this handout are detailed guidelines designed to prevent the spread of zebra mussel veligers. SCUBA equipment, water transport, boat hulls and all boat engine parts are discussed as possible sources of infestation. Preventive boat maintenance is described in detail.

The life history of the zebra mussel is reviewed in this booklet. A sampling program is outlined and a chart of Pennsylvania waterbodies with a temperature and pH range within zebra mussel tolerance are included.


This color photo card provides a key to the identification of the zebra mussel and lists the agencies to contact if a zebra mussel is identified.


This publication reports recent sightings of the zebra mussel or its larvae. Current zebra mussel topics such as new sightings and chlorination techniques to prevent infestation are also covered.


This publication provides guidance on detection of the zebra mussel based on the premise that early identification of the zebra mussel may not come from complicated or expensive monitoring equipment, but from educated water users able to detect the zebra mussel in its earliest stages.


This resource package, includes background information, slides and a video, that provide an introduction to the methods of teaching students about zebra mussels. The package may also be used by water user groups and youth groups such as scouts and fishing clubs.


This paper reviews and discusses methods of testing for zebra mussel larvae. Included is a description of the bridal veil sampling method which has proven to be more effective than other tests due to increased amount of surface settling area.

This brochure identifies the differences between the zebra mussel and the dark false mussel. Included in the comparison are salinity tolerance differences, shell features, and internal and external body parts of both species.


Various non-indigenous species are highlighted in this article in terms of future destruction, possible causes of accidental introduction and intentional introduction. Benefits and consequences of these species are discussed.


This article emphasizes current studies about zebra mussels and efforts to control the spread of zebra mussels. State Sea Grant programs and projects are discussed. Publications, including videos, are listed.


This 15 minute video is intended for use in conjunction with the Mussel Menace! Zebra Mussels and You, educational package.


This brochure describes the life history of the zebra mussel and the damage it causes due to its infestation. Specific areas within Maryland are discussed as potential zebra mussel sites and precautionary methods to prevent infestation are outlined.


The proceedings of a 1993 conference held March 10-12, 1993 in Baltimore. Maryland review each of the Mid-Atlantic Sea Grant programs plans to study, monitor and control the invasion of zebra mussels in their state waterbodies. Included are the plans for New York, New Jersey, Delaware, Maryland, Virginia, and North Carolina.
Mid-Atlantic Sea Grant Network. Mid-Atlantic Zebra Mussel Fact Sheet. University of North Carolina Sea Grant College Program. Raleigh, NC.

This booklet presents an introduction to the problems and potential effects of the zebra mussel in North America. Topics included encompass biology, reproduction, dispersal, and control measures of the Mid-Atlantic region.


This booklet discusses the introduction of the zebra mussels to North America and assesses the threat of possible invasion into other adjacent waterbodies. A list of related Mid-Atlantic Sea Grant publications is provided.


This book covers topics such as the ecology and life history of the zebra mussel, its morphology, physiology, and the effects of its introduction in U.S. waters. Methods of monitoring and controlling the nonindigenous species are described in detail.

New York Sea Grant. Don't Pick Up Hitchhikers! New York Sea Grant. Stop the Zebra Mussel!. New York Sea Grant. Brockport, NY.

This brochure provides a brief overview of the zebra mussel and methods of preventing their spread.


This brochure provides an overview of zebra mussel spread and infestation in the U.S. Precautionary methods to prevent their introduction into North Carolina waterbodies are also outlined.


This article outlines the introduction of zebra mussels into U.S. waters and the methods employed to prevent infestation. Methods to monitor waters for zebra mussels and funding sources to support those monitoring efforts are described.

This booklet reviews the research and outreach projects of the Great Lakes Sea Grant Network related to zebra mussels.

Ohio Sea Grant. 1994. Publications Available on Zebra Mussels. Ohio Sea Grant College Program. Columbus, OH.

This fact sheet provides a list of free zebra mussel publications and materials available for distribution from Ohio Sea Grant.


Zebra mussel environmental tolerances including salinity, calcium, pH, water temperature, turbidity, dissolved oxygen and water velocity are used as parameters in determining the potential for colonization.


This fact sheet outlines the introduction of the zebra mussel into U.S. waters. Its origin, biology and identification are detailed as well as its impact on the surrounding environment. Other topics such as biofouling and zebra mussel control methods are covered.


This paper reports on the results of a study that was conducted to predict the occurrence and density of the zebra mussel as to the limnological features of different lakes. The effects of limnological features of a specific lake on the spread of the zebra mussel are described.


This report includes an article outlining a zebra mussel monitoring program being conducted on behalf of the Pennsylvania Department of Environmental Resources and the Delaware River Basin by the Delaware River Basin Commission. The monitoring process and reproduction of the zebra mussel are described.

This textbook provides a series of papers and case studies in which the translocating of aquatic plants and animals are analyzed. The book is divided into two sections: Risk & Impacts, and Risk Reduction & Safety.


This publication provides the results of a study conducted in order to determine the growth rate and food consumption of the zebra mussel based on varying rates of food availability and optimum water temperature.


This handout presents an overview of the history, reproductive cycle, and ecological concerns related to the zebra mussel. Industrial, commercial and recreational concerns related to the zebra mussel are addressed including recreational boating, swimming beaches and marine structures.


An introduction to the life history and biology of the zebra mussel and the impact of their eminent spread on New England are included in this fact sheet. Damage due to zebra mussel infestation and precautions to prevent infestations are also discussed.

Virginia Sea Grant. Mid-Atlantic Zebra Mussel Outreach Plan. Tideline. Virginia Graduate Marine Science Consortium. Charlottesville, VA.

This article defines exotic species and uses zebra mussel as an example of how non-indigenous species can invade an environment. A description of how individual Sea Grant programs act as the communication link between researchers and water resource users in order to provide education programs to slow the spread of the zebra mussel is provided.

This newsletter discusses the economic consequences, control methods and inevitable spread of the zebra mussel. A detailed checklist of preventive zebra mussel spread action is given as well as funding sources and people to contact for more information.
The zebra mussel (*Dreissena polymorpha*) is a small freshwater shellfish native to Europe that attains a maximum length of one to two inches. This D-shaped bivalve has alternating light and dark bands on its shell and usually grows in clusters containing thousands of individuals that attach to hard substrates by small threads called byssal threads, in shallow surface waters (6-30 feet deep). The non-native zebra mussel was accidently introduced into the Great Lakes region in 1986, by bilge water released from European transoceanic ships. They have since spread throughout the Great Lakes and into the Hudson, Susquehanna, Ohio, Illinois, Tennessee and Mississippi river systems as well as many isolated lakes.

Zebra mussels have an enormous capacity to reproduce which enables them to spread to other water bodies at alarming rates. Females can produce more than 30,000 eggs per season. Fertilized eggs develop into free swimming larval veligers that remain suspended in currents for three to four weeks. They then settle and attach to hard surfaces and mature within a year. Adult mussels can withstand drying for several days with their shells closed.

The zebra mussel has already caused a monumental amount of economic damage by fouling power plant, industrial and public drinking water intake pipes, damaging boat hulls, engine cooling systems, docks, navigation buoys, and littering beaches.

Zebra mussels do not have natural predators in the United States and as a result, their exploding populations are disrupting natural food chains and threatening native fish and mussel populations. These mussels compete with resident fish and native mussels for planktonic food. Threatened and endangered native freshwater bivalves are at risk because they cannot compete with zebra mussels for available food and space.

Zebra mussels are dispersed naturally by birds, turtles, and currents and by human activity. It’s estimated they will find their way into New Jersey waters within the next few years. But it’s better to take precautions now. It’s suggested that water users, particularly recreational boaters, follow recommended preventative practices to help slow the spread of the mussels.
1. Before transporting your boat to a new water body, thoroughly inspect the boat's hull, outdrive, trolling and trim plates, prop guards, transducers, trailers, anchor, anchor rope and all other parts which may have been exposed to the infested waters. Any surfaces which feel grainy may have small zebra mussels attached. These mussels should be scraped off and discarded into a garbage container.

2. Drain all water from your boat's bilge, motor well and live well and empty your bait buckets. Do not transport leftover bait to other waters.

3. Flush hulls, outdrives, live wells, trailer frames, bait buckets and all other parts which may get wet, using hot water (140 F or hotter). Pressurized steam cleaners which are environmentally favorable can also be used or high pressure (250 psi or greater) hot water power washers are also effective and require less time.

4. Boats and trailers should be dried in the sun for at least two to four days before transporting to other waters.

5. If you do not follow the above precautions, allow your boat and trailer to dry for a minimum of two weeks before entering another water body.

Contact New Jersey Sea Grant at 908/872-1300 for a free Zebra Mussel Watch card. It provides a close-up of the mussel and other zebra mussel facts. If you think you've spotted one, note the location and approximate quantity of mussels sighted. If possible, save a few in alcohol and call Dr. Eleanor Bochenek of the New Jersey Sea Grant Marine Advisory Service at 908/349-1152.

Written by Dr. Eleanor Bochenek and Mary Kreiss. Edited by Kim Kosko. Layout and design by Kim Kosko.
# Zebra Mussel Environmental Tolerances

Variables vs. Colonization Potential

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>HIGH</th>
<th>MODERATE</th>
<th>LOW</th>
<th>VERY LOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity (ppt)</td>
<td>0 - 1</td>
<td>1 - 4</td>
<td>4 - 10</td>
<td>10 - 35</td>
</tr>
<tr>
<td>Calcium (ppm)</td>
<td>25 - 125</td>
<td>20 - 25</td>
<td>12 - 20</td>
<td>&lt;12</td>
</tr>
<tr>
<td>pH</td>
<td>7.4 - 8.5</td>
<td>7.0 - 7.4</td>
<td>6.5 - 7.0</td>
<td>&lt;6.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.5 - 9.0</td>
<td></td>
<td>&gt;9.0</td>
</tr>
<tr>
<td>Water Temp. (°C)</td>
<td>17 - 25°C</td>
<td>25 - 27°C</td>
<td>15 - 17°C</td>
<td>&lt;15°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt;27°C</td>
</tr>
<tr>
<td>Turbidity (cm secchi disk)</td>
<td>40 - 200</td>
<td>20 - 30</td>
<td>10 - 20</td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>200 - 250</td>
<td>&gt;250</td>
</tr>
<tr>
<td>Dissolved Oxygen (ppm)</td>
<td>8 - 10</td>
<td>6 - 8</td>
<td>4 - 6</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Water Velocity (ft./sec.)</td>
<td>1.6 - 2.3</td>
<td>0.3 - 1.6</td>
<td>3.3 - 6.6</td>
<td>&gt;6.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.3 - 3.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Charles R. O'Neill, New York Sea Grant
A Field Guide to Aquatic Exotic Plants and Animals
Exotic Introductions

“Exotic” species — organisms introduced into habitats where they are not native — are severe world-wide agents of habitat alteration and degradation. A major cause of biological diversity loss throughout the world, they are considered “biological pollutants.”

Introducing species accidentally or intentionally, from one habitat into another, is risky business. Freed from the predators, parasites, pathogens, and competitors that have kept their numbers in check, species introduced into new habitats often overrun their new home and crowd out native species. In the presence of enough food and a favorable environment, their numbers will explode. Once established, exotics rarely can be eliminated.

Most species introductions are the work of humans. Some introductions, such as carp and purple loosestrife, are intentional and do unexpected damage. But many exotic introductions are accidental. The species are carried in on animals, vehicles, ships, commercial goods, produce, and even clothing. Some exotic introductions are ecologically harmless and some are beneficial. But other exotic introductions are harmful to recreation and ecosystems. They have even caused the extinction of native species — especially those of confined habitats such as islands and aquatic ecosystems.

The recent development of fast ocean freighters has greatly increased the risk of new exotics in the Great Lakes region. Ships take on ballast water in Europe for stability during the ocean crossing. This water is pumped out when the ships pick up their loads in Great Lakes ports. Because the ships make the crossing so much faster now, and harbors are often less polluted, more exotic species are likely to survive the journey and thrive in the new waters.

Many of the plants and animals described in this guide arrived in the Great Lakes this way. But they are now being spread throughout the continent’s interior in and on boats and other recreational watercraft and equipment. This guide is designed to help water recreationalists recognize these exotics and help stop their further spread.

Midwest Aquatic Exotics

Common carp (Cyprinus carpio) are domesticated ancestors of a wild form native to the Caspian Sea region and east Asia. Carp degrade shallow lakes by causing excessive turbidity which can lead to declines in waterfowl and important native fish species.

Sea lamprey (Petromyzon marinus) are predacious, eel-like fish native to the coastal regions of both sides of the Atlantic Ocean. They entered the Great Lakes through the Welland Canal about 1921. They contributed greatly to the decline of whitefish and lake trout in the Great Lakes.

Rusty crayfish (Orconectes rusticus) are native to streams in the Ohio, Kentucky, and Tennessee region. Spread by anglers who use them as bait, rusty crayfish are prolific and can severely reduce lake and stream vegetation, depriving native fish and their prey of cover and food. They also reduce native crayfish populations.

White perch (Morone americana) are native to Atlantic coastal regions and invaded the Great Lakes through the Erie and Welland canals. Prolific competitors of native fish species, white perch are believed to have the potential to cause declines of Great Lakes walleye populations.

Flowering rush (Butomus umbellatus) is a perennial plant from Europe and Asia that was introduced in the Midwest as an ornamental plant. It grows in shallow areas of lakes as an emergent, and as a submerged form in water up to 10 feet deep. Its dense stands crowd out native species like bulrush. The emergent form has pink, umbellate-shaped flowers, and is 3 feet tall with triangular-shaped stems.

Curly-leaf pondweed (Potamogeton crispus) is an exotic plant that forms surface mats that interfere with aquatic recreation. The plant usually drops to the lake bottom by early July. Curly-leaf pondweed was the most severe nuisance aquatic plant in the Midwest until Eurasian watermilfoil appeared. It was accidentally introduced along with the common carp. It has been here so long, that most people are not aware it is an exotic.
Zebra mussels are small, fingernail-sized mussels native to the Caspian Sea region of Asia. They were discovered in Lake St. Clair near Detroit in 1988. Tolerant of a wide range of environmental conditions, zebra mussels have now spread to parts of all the Great Lakes and the Mississippi River and are showing up in inland lakes. Zebra mussels clog water-intake systems of power plants and water treatment facilities, and the cooling systems of boat engines. They have severely reduced, and may eliminate native mussel species.

Female zebra mussels can produce as many as 1 million eggs per year. These develop into microscopic, free-swimming larvae (called veligers) that quickly begin to form shells. At about three weeks, the sand grain-sized larvae start to settle and attach to any firm surface using “byssal threads”. They will cover rock, gravel, metal, rubber, wood, crayfish, native mussels, and each other.

Zebra mussels filter plankton from the surrounding water. Each mussel can filter about one quart of lake water per day. However, not all of what they remove is eaten. What they don’t eat is combined with mucus as “pseudofeces” and discharged onto the lake bottom where it accumulates. This material may benefit bottom feeders while reducing the plankton food chain for upper water species.

Diving ducks and the freshwater drum eat zebra mussels, but will not significantly control them.

**Likely means of spread:** Microscopic larvae may be carried in livewells or bilge water. Adults can attach to boats or boating equipment that sit in the water.

---

**Ruffe**

_**Gymnocephalus cernuus**_

The ruffe is a small European member of the perch family that is native to central and eastern Europe. It was introduced to Duluth harbor, probably in tanker ballast water, around 1985, and is spreading to other rivers and bays around Lake Superior.

In Europe, the ruffe is a pest species in newly invaded areas. In a Scottish lake it displaced the native perch population, and in lakes in Russia, it has significantly reduced whitefish populations.

In the St. Louis River near Duluth, populations of yellow perch, emerald shiners, and other forage fish caught in survey trawls have declined dramatically as numbers of ruffe have increased.

The ruffe’s ability to displace other species in newly invaded areas is due to: (1) its high reproductive rate, (2) its feeding efficiency across a wide range of environmental conditions, and (3) characteristics that may discourage would-be predators such as walleye and pike.

Ruffe grow rapidly and can reproduce in their first year. In the St. Louis River, females can lay between 45,000 and 90,000 eggs a year. Ruffe are primarily bottom feeders, preferring dark environments where they can hide from predators. Ruffe rarely grow bigger than 5 inches, although the sharp spines on their gill covers, dorsal and anal fins make them difficult for larger fish to eat.

**Likely means of spread:** Ruffe could be accidentally transported in livewells, bilge water, bait buckets, and in the ballast water of Great Lakes freighters.
Eurasian watermilfoil typically has 12 to 21 pairs of teatlets. The native northern watermilfoil with which it is often confused, usually has 5 to 9 pairs.

On a line, spiny water fleas look like bristly globs of jelly with black spots.

Spiny Water Flea

Bythotrephes cedraster

The spiny water flea, or “B.C.,” is not an insect at all, but a tiny (less than half an inch long) crustacean with a long, sharp, barbed tail spine. A native of Great Britain and northern Europe east to the Caspian Sea, the animal was first found in Lake Huron in 1984 — probably imported in the ballast water of a trans-oceanic freighter. Since then, populations have exploded and the animal can now be found throughout the Great Lakes and in some inland lakes.

No one is really sure what affect spiny water fleas will have on the ecosystems of the Great Lakes region. But resource managers are worried, because the animals may compete directly with young perch and other small fish for food, such as Daphnia zooplankton.

Spiny water fleas also reproduce rapidly. During warm summer conditions each female can produce up to 10 offspring every two weeks. As temperatures drop in the fall, eggs are produced that can lie dormant all winter.

High numbers would not pose a problem if spiny water fleas were heavily consumed by predators. But its sharp spine makes it extremely hard for small fish to eat, leaving only some large fish to feed on them. As a result, spiny water flea populations remain high while populations of plankton, which they eat, have declined.

Likely means of spread: Spiny water flea eggs and adults may wind up unseen in bilge water, bait buckets, and livewells. Also, fishing lines and downriggers will often be coated with both eggs and adults.

Eurasian watermilfoil

Myriophyllum spicatum

Eurasian watermilfoil was accidently introduced to North America from Europe. Spread westward into inland lakes primarily by boats and also by waterbirds, it reached midwestern states between the 1950s and 1980s.

In nutrient-rich lakes it can form thick underwater stands of tangled stems and vast mats of vegetation at the water’s surface. In shallow areas the plant can interfere with water recreation such as boating, fishing, and swimming. The plant’s floating canopy can also crowd out important native water plants.

A key factor in the plant’s success is its ability to reproduce through stem fragmentation and underground runners. A single segment of stem and leaves can take root and form a new colony. Fragments clinging to boats and trailers can spread the plant from lake to lake. The mechanical clearing of weed beds for beaches, docks, and landings creates thousands of new stem fragments. Removing native vegetation creates perfect habitat for invading Eurasian watermilfoil.

Eurasian watermilfoil has difficulty becoming established in lakes with healthy populations of native plants. In some lakes the plant appears to coexist with native flora and has little impact on fish and other aquatic animals.

Likely means of spread: Milfoil may become entangled in boat propellers, and may wrap around other external parts of the boat. Stems can become lodged among any watercraft apparatus or sports equipment that moves through the water, including boat trailers.
Purple loosestrife

Ludran salicaria

Purple loosestrife is a wetland plant from Europe and Asia. It was introduced into the east coast of North America in the 1800s. First spreading along roads, canals, and drainage ditches, then later distributed as an ornamental, this exotic plant is in 40 states and all Canadian border provinces.

Purple loosestrife invades marshes and lakeshores, replacing cattails and other wetland plants. The plant can form dense, impenetrable stands which are unsuitable as cover, food, or nesting sites for a wide range of native wetland animals including ducks, geese, rails, bitterns, muskrats, frogs, toads, and turtles. Many rare and endangered wetland plants and animals are also at risk.

Purple loosestrife thrives on disturbed, moist soils, often invading after some type of construction activity. Eradicating an established stand is difficult because of an enormous number of seeds in the soil. One adult plant can disperse 2 million seeds annually. The plant is able to resprout from roots and broken stems that fall to the ground or into the water.

A major reason for purple loosestrife's expansion is a lack of effective predators in North America. Several European insects that only attack purple loosestrife are being tested as a possible long-term biological control of purple loosestrife in North America.

Likely means of spread: Seeds escape from gardens and nurseries into wetlands, lakes, and rivers. Once in aquatic systems, seeds are easily spread by moving water and wetland animals.

Illustrations by: Don Luce, Jim McEvoy and M. Barnadat.
CHECKLIST

Clean boats, clean waters...

If you are a water recreationalist — a boater, an angler, a waterskier, sailor, or canoeist — there are some important things you can do. **DON'T** transport water, animals, or plants from one lake or river to another. In many states and provinces it is illegal to transport exotic species.

- **Remove** plants and animals from your boat, trailer, and accessory equipment (anchors, centerboards, trailer hitch, wheels, rollers, cables, and axles) before leaving the water access area.

- **Drain** your livewells, bilge water, and transom wells before leaving the water access area.

- **Empty** your bait bucket on land, never into the water. Never dip your bait or minnow bucket into one lake if it has water in it from another. And never dump live fish from one water body into other waters.

- **Wash** your boat, tackle, downriggers, and trailer with hot water when you get home. Flush water through your motor's cooling system and other boat parts that normally get wet. If possible, let everything dry for three days before transporting your boat to another body of water. (Both hot water and drying will kill zebra mussel larvae and spiny waterfleas.)

- **Learn** what these organisms look like (at least those you can see). If you suspect a new infestation of an exotic plant or animal, report it to the Minnesota Department of Natural Resources.

- **Consult** the DNR for recommendations and permits before you try to control or eradicate an exotic “pest.” Remember, exotic “pest” species thrive on disturbance. Do-it-yourself control treatments often make matters worse and can harm native species.

For more information...

If you would like more information about aquatic exotic species, the problems they cause, regulations to prevent their spread, or methods and permits for their control, contact one of the following offices:

- **Minnesota Department of Natural Resources**
  Exotic Species Programs
  500 Lafayette Road
  St. Paul, MN 55155-4025
  (612) 296-2835

- **Minnesota Sea Grant**
  Zebra Mussel Information Center
  208 Washburn Hall
  University of Minnesota
  Duluth, MN 55812
  (218) 726-8106 Duluth or
  (612) 625-9288 St. Paul

This publication is also sponsored by:

- **The U.S. Fish and Wildlife Service**
- **U.S. Army Corps of Engineers**

If you would like information about booking a traveling exhibit on aquatic exotic species, contact:

- **The Bell Museum of Natural History**
  10 Church St. SE
  University of Minnesota
  Minneapolis, MN 55455
  (612) 624-2090

You may also contact:

This information is available in an alternative format upon request.

© 1993 Minnesota Department of Natural Resources

Printed on recycled paper that contains a minimum of 10% post-consumer waste.
Boaters:

DON'T LET YOUR BOAT BE A ZEBRA MUSSLE CARRIER

Zebra Mussels are fingernail-sized freshwater mussels with alternating light and dark bands on their shells, and can live in freshwater and low salinity waters. They were accidently introduced into the Great Lakes in 1986. Since then, these voracious filter feeders have caused monumental economic and environmental damage including: fouling industrial and public water intake pipes, damaging boats, docks, and navigation buoys, fouling beaches and changing the aquatic habitat.

It's estimated zebra mussels will make their way into New Jersey waters within the next few years. Dispersed by human activity, by birds, turtles and currents, mussel larvae can be transported in boat bilge water, live wells, bait buckets, and engine cooling systems.

Juvenile and adult mussels can attach to any hard surface such as boat hulls, engine drive units, and boat trailers and be transported to other waterbodies. The mature mussel can live for several days out of water and if kept moist, may survive out of water for more than one week.

To date, no zebra mussels have been found in New Jersey's waters. But the zebra mussel is present in the nearby Great Lakes and their tributaries, several Finger Lakes, the Hudson River, the Susquehanna River (in New York State), Allegheny River, Lake Champlain and other waterbodies in the region.

How can you slow the spread?

(Please Turn Over)
When leaving a lake or river:

- REMOVE aquatic vegetation (weeds) from boat, propeller, anchor, lines and trailer and discard in trash.
- DISCARD all live aquatic bait in a suitable container. DO NOT RELEASE bait into any New Jersey waters.
- EMPTY live wells and bait buckets before leaving the lake or river.

If you take your boat from one waterbody to another, please take the following additional steps:

- DRY out your boat for at least TWO days OR wash down the hull with tap water before launching again.
- FLUSH engine cooling system, blige areas and live wells with tap water.

DON'T SPREAD THESE EXOTIC ANIMALS

Protect New Jersey's Waters and Your Boat!

For additional information on zebra mussels or other exotic nuisance species, please contact Dr. Eleanor Bochenek, NJ Sea Grant Marine Advisory Service, Rutgers Cooperative Extension, 1623 Whitesville Rd. Toms River, NJ 08755 or call 908-349-1152.

This work is the result of research sponsored by NOAA, Office of Sea Grant, Department of Commerce, under Grant No. NA36-RG0505 (Project No. AVS-52M). The U.S. Government is authorized to produce and distribute reprints for governmental purpose notwithstanding any copyright notation that may appear hereon. NJSG-95-305.

Cooperating Agencies: Rutgers, The State University of New Jersey, NJ Marine Sciences Consortium, U.S. Department of Commerce, NOAA Sea Grant College Program, U.S. Department of Agriculture, County Board of Chosen Freeholders, and the New Jersey Commission on Science and Technology. Educational programs are offered without regard to race, sex, handicap, color, national origin, or age. Rutgers Cooperative Extension is an Equal Opportunity Employer.
ZEBRA MUSSEL:
Present Threat, Future Danger?

A REPORT FROM THE MID-ATLANTIC SEA GRANT NETWORK
— 1992-1993 —
The Mid-Atlantic Sea Grant Network

In 1966, Congress established the National Sea Grant College Program to conduct research, education, and public service in support of the nation's ocean, coastal, and Great Lakes resources. The name "Sea Grant" was chosen to emphasize the parallel between this program focusing on the sea, and the Land Grant program created more than a century earlier to develop our agricultural resources.

Today, there are 29 Sea Grant programs in the United States— at major academic institutions in every coastal state. Each program has a common goal: to foster the wise use, conservation, and management of marine and coastal resources. Each program receives funding from the National Oceanic and Atmospheric Administration (NOAA) in the U.S. Department of Commerce, as well as state and/or university funds.

This report highlights the threat the zebra mussel poses to the Mid-Atlantic region— New Jersey, Delaware, Maryland, Virginia, and North Carolina—and the Mid-Atlantic Sea Grant Network's efforts to prepare the region for a possible zebra mussel "invasion."
In July 1988, the zebra mussel (*Dreissena polymorpha*)—a creature new to North American waters—was sighted in Lake St. Clair, near Detroit, Michigan. A native of the Black Sea, the small black and-white striped mussel apparently hitched a ride to the United States in the ballast water of Eurasian tankers bound for the Great Lakes.

Soon after it arrived in the Great Lakes, the zebra mussel began wreaking havoc, for the tiny mollusk (average size: 1½ inches) can attach itself firmly to virtually any solid object in fresh or slightly brackish water, with often disastrous results.

In the Great Lakes region, the zebra mussel has clogged the intake pipes of municipal water plants and power companies and even the water systems of golf courses. It has glued itself to the shells of other freshwater mollusks, including several species of endangered clams, effectively smothering them.

The zebra mussel's sheer numbers combined with its method of feeding—filtering tiny plants and other organic matter from the water—have caused a reduction in the food supply needed by other shellfish and the larval stages of some finfish in the Great Lakes.

In addition to changing the aquatic ecosystem, the zebra mussel's impact on fishing, boating, and beach use also has been significant—and costly. The costs associated with zebra mussel control in the Great Lakes are expected to approach $5 billion by the end of this decade.

And now the zebra mussel may be headed our way. Since the first sighting in Lake St. Clair in 1988, the zebra mussel has spread beyond the Great Lakes to the Hudson, Mohawk, Illinois, Ohio, Mississippi, Tennessee, and upper Susquehanna rivers. Biologists believe it ultimately will infest most North American waters south of central Canada and north of the Florida Panhandle.

The National Sea Grant College Program has launched major initiatives focusing on research to determine better methods to control the zebra mussel and on outreach efforts to assist water users affected or threatened by the pest.

In the Mid-Atlantic region, Sea Grant programs in New Jersey, Delaware, Maryland, Virginia, and North Carolina are working to alert the public we serve about the mussel and its threat to our fresh and brackish waters. Combining a strong program of applied research and public outreach, and coordinating with partners at agencies and industries throughout the region, our goal is to prepare the region to respond effectively to the zebra mussel if the pest sets foot in our waters.
ASSessing the mid-atlantic threat

In June 1993, a boater spotted an unfamiliar mollusk on the hull of his boat docked at a marina along the Chesapeake and Delaware Canal. He had heard of the zebra mussel and contacted the Sea Grant program at the University of Delaware for assistance. Fortunately, the tiny shellfish was not the destructive foreign invader, Dreissena polymorpha, more commonly known as the zebra mussel. For the Mid-Atlantic region, however, the zebra mussel’s arrival may only be a matter of time.

So far, the zebra mussel has not been discovered in the waters of New Jersey, Delaware, Maryland, Virginia, and North Carolina. But it is moving closer to us.

The zebra mussel was identified in the headwaters of the Susquehanna River in New York in 1991, but so far it has not been found farther downstream. However, it has infested several neighboring waterways, including the Hudson River and Ohio River. The proximity of these waterways to the region lends even more strength to scientists’ predictions that a zebra mussel infestation in the Mid-Atlantic is no longer a question of “if” but “when.”

How Will the Zebra Mussel Get Here? While it is possible that waterfowl, turtles, and other animals could help disperse the zebra mussel to new areas, human activity will be the most likely means of transport.

Ships, barges, and boats may all accidentally shuttle the zebra mussel to new waters. Eurasian tankers introduced the zebra mussel to the Great Lakes when these vessels discharged their infested ballast water.

In the Mississippi and Ohio rivers, zebra mussels may attach to the hulls of barges and thus travel to new territory.

Even the recreational boater or angler may unknowingly transport the zebra mussel to a new home. Boats and boat trailers, bait buckets, and hair may harbor the mussel or its microscopic larvae, called veligers.

Yet a water body’s susceptibility to zebra mussel infestation depends primarily on its chemistry and certain environmental parameters.
What Does the Zebra Mussel Need to Survive?
What makes the zebra mussel such a formidable pest is its resilience. It can survive as long as a week out of water. It can also tolerate a fairly wide range of environmental conditions. It can withstand salinities as high as 12 parts per thousand, a pH range from 7.0 to 9.0, and water temperatures from just above freezing to 91°F (33°C).

Given such conditions, the zebra mussel could survive in a variety of aquatic areas in the Mid-Atlantic region, from freshwater ponds, reservoirs, and lakes to the less salty, upper reaches of such expansive estuaries as the Delaware Bay and the Chesapeake Bay.

Many of the water bodies that are at risk of zebra mussel infestation in the Mid-Atlantic are

Research Puts Muscle into Mussel Control

Combating the zebra mussel requires a coordinated program of research and outreach—Sea Grant scientists focus on learning more about the mussel's biology to devise better methods to control the pest; Sea Grant outreach specialists then relay the results to water users.

Several zebra mussel research projects are under way in the Mid-Atlantic region:
◆ At New Jersey Sea Grant, Dr. Dimitri Donskoy is examining the use of acoustic, vibrational, and hydrodynamic techniques to control zebra mussel infestation in water intake systems.
◆ At Maryland Sea Grant, Dr. David Wright is investigating the temperature and salinity tolerance of zebra mussel larvae under conditions common to northern Chesapeake Bay during spawning season. Results of survival and growth observations will aid scientists in further predicting the mussel's potential behavior in and impact on the estuary.
◆ At Delaware Sea Grant, Dr. Herbert Walte (above) is examining the zebra mussel's foot, the muscular appendage that produces the glue that enables the animal to bond to surfaces underwater. If he can decode the gluey foot's chemistry, a chemical control could be developed to "shoot the mussel in the foot" and prevent it from attaching to intake pipes and other objects. Scientists would also have the chemical recipe needed to create a synthetic mussel glue for use in dentistry and other fields where strong adhesion is needed on wet surfaces.
The Zebra Mussel: Are We Crying Wolf?

How do you educate people about a creature that threatens the region but has not yet arrived here? That's the challenge facing the Mid-Atlantic Sea Grant Network.

In the Great Lakes region, many residents have had to learn the hard way about the zebra mussel. For example, the water treatment plant in Monroe, Michigan, was shut down by zebra mussels clogging the plant's intakes. "All the people who thought zebra mussels were not their problem woke up one morning and found they couldn't make coffee, they couldn't flush the toilet," said Fred Snyder, an extension specialist at Ohio Sea Grant. "All of a sudden, the zebra mussel was their problem."

The Great Lakes region had no advance warning of the zebra mussel's arrival in 1986. To deal with the invasion, Sea Grant staff needed to quickly become experts on the mussel. It is these colleagues—from Sea Grant programs in New York, Ohio, Illinois, Indiana, Michigan, Wisconsin, and Minnesota—who have helped train Sea Grant outreach staff in the Mid-Atlantic region, as well as in New England and the Southeast.

In 1990, a key resource was established at New York Sea Grant with funding from electric utilities, public water authorities, industry, and the National Sea Grant College Program: the Zebra Mussel Information Clearinghouse. This public, non-profit organization maintains an extensive library of publications and audiovisuals on the zebra mussel and related biofoulers, publishes the bimonthly *Dreissena polymorpha Information Review*, and offers print and electronic databases of its Technical Collection Bibliography. The Mid-Atlantic Sea Grant Network routinely refers clients to the clearinghouse. For more information, please contact the clearinghouse at (716) 395-2516 or (800) 285-2285.

the same waterways that provide us with drinking water, and supply such major industries as electric and nuclear power, farming, shipping, oil refining, pulp and paper manufacturing, aquaculture, and recreational fishing and boating.

How Could the Zebra Mussel Affect These Operations? At a municipal water plant, for example, the mussel colonizes the intake pipes because they offer exceptionally good habitat: the water flow provides a continuous source of food (plankton) and oxygen and carries away the mussel's wastes, while the structures protect the mussel from predators, such as ducks and some species of fish.

The zebra mussel responds to these optimum conditions by extensively colonizing the pipes, leading to severely reduced water supplies and many other problems.

Ridding a facility of the zebra mussel is often an expensive proposition since industries in the United States have not encountered the pest before and coping with it requires new control strategies, ranging from chlorine dosing to hydroblasting and often costly retrofitting.
ASSISTING MID-ATLANTIC WATER USERS

In 1992, Sea Grant outreach specialists from New Jersey, Delaware, Maryland, Virginia, and North Carolina were awarded a federal grant to increase public awareness of the zebra mussel and begin preparing the Mid-Atlantic region for a possible invasion.

From hands-on zebra mussel identification programs to radio public service announcements, the mussel were to appear in local waters. The Mid-Atlantic Sea Grant Network continues to inform more than 500 industries of the mussel's status and control methods and is helping many develop monitoring programs.

For example, Maryland Sea Grant hosted the region's first Mid-Atlantic Zebra Mussel Conference in March 1993 in Baltimore. The event included a hands-on training session to help 80 participants identify zebra mussels at various life stages.

Working with local power companies, North Carolina Sea Grant produced a Geographical Information System (GIS) map of all sites currently being monitored for zebra mussels in the state and nearby areas of Virginia and South Carolina.

Mid-Atlantic Sea Grant Network has developed a variety of approaches to reach water users who could be seriously affected by the zebra mussel. The following are selected highlights.

Industry Assistance.
Power companies, water treatment facilities, manufacturing plants, and other industries in the Mid-Atlantic region could be faced with significant risks if the zebra

The conference provided timely information to 115 representatives from regional industries and other groups. Several local power companies helped sponsor the event.

The North Carolina and Virginia Sea Grant staffs hosted a conference for industrial water users, resource agency personnel, and others in June 1993 in Greensboro, North Carolina.

Delaware Sea Grant surveyed every industrial water user in the state to learn what water-quality parameters each facility monitors. This information is being used to establish a zebra mussel monitoring program in the Delaware River and other watersheds.

Agency Partnerships.
Forming partnerships with resource management agencies and other groups maximizes
Sea Grant's zebra mussel awareness efforts. The following are just a few of the ties that have been developed between Sea Grant and neighboring agencies in the region.

Virginia Sea Grant joined with a host of agencies and industries to co-sponsor the Virginia Water Resources Conference presented by the Virginia Water Resources Research Center and Virginian Lakes Association in April 1993 in Richmond. During the conference, Virginia Sea Grant presented a special seminar, "Zebra Mussels Update for Virginia," for an audience of 80 representatives from natural resource agencies, industry, and local government.

New Jersey Sea Grant was appointed chair of the state's Zebra Mussel Task Force, comprising members from private industry, state and federal agencies, and natural resource groups. The task force later hosted a regional meeting of governmental agencies and other groups that are monitoring for zebra mussels in Pennsylvania, New Jersey, and New York.

In conjunction with the North Carolina Department of Environment, Health, and Natural Resources, North Carolina Sea Grant organized a 17-member Zebra Mussel Task Force comprising representatives from power companies and government agencies such as the U.S. Army Corps of Engineers and the North Carolina Department of Agriculture. The task force designated North Carolina Sea Grant as chair and center for reporting monitoring results and for obtaining updated information.

Legislative and Policy-making Activities. The Mid-Atlantic Sea Grant Network is keeping decision makers abreast of the zebra mussel's status and laying the groundwork for future management strategies.

In June 1993, Delaware Sea Grant briefed the House Committee on the Environment and Natural Resources of the Delaware General Assembly about the zebra mussel and distributed information packets to committee members, natural resource agency staff, and legislative aides. The committee sought Sea Grant's advice in determining if legislative action needed to be taken immediately to minimize the state's risk of infestation.

The Exotic Species Work Group (of the Living Resources Subcommittee of the Chesapeake Bay Program) chaired by
Network Activities Prep Region for Zebra Mussel

A major goal of the Mid-Atlantic Sea Grant programs is to work cooperatively to reach water users with zebra mussel information in an efficient and cost-effective manner. The following are examples of individual state efforts that serve the entire region:

- New Jersey Sea Grant produced a Geographical Information System (GIS) map of the Mid-Atlantic region depicting potential zebra mussel infestation areas. The map will be used to help water users assess their risk of infestation.

- Delaware Sea Grant developed a decal for boaters and anglers to alert them about the zebra mussel and how to lessen their odds of transporting it into the Mid-Atlantic region.

- Maryland Sea Grant hosted the first Mid-Atlantic Zebra Mussel Conference on March 10–12, 1993, in Baltimore. The conference brought together 115 representatives from academia, industry, resource management, government, and the media to learn more about the mussel’s history, biology, method of transport, and status in the region. A trade show featuring 11 vendors highlighted zebra mussel control and monitoring devices and services.

- Virginia Sea Grant scientists compiled Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region, an 11-page review of the region’s probability and susceptibility of invasion by Dreissena polymorpha.

- North Carolina Sea Grant produced the Mid-Atlantic Zebra Mussel Fact Sheet, which has been used throughout the region to introduce readers to the mussel and its potential impacts.
Mid-Atlantic Sea Grant Publications

The Mid-Atlantic Sea Grant Network published the following zebra mussel information in 1992–1993.

For a list of all Sea Grant publications on the zebra mussel, call the Zebra Mussel Information Clearinghouse at (716) 395-2516 or (800) 285-2285.

◆ “Can the Pesky Zebra Mussel Change Its Stripes?” University of Delaware Sea Grant Reporter (winter 1993). Highlights research on the glue the zebra mussel produces to attach to objects underwater. By Delaware Sea Grant.

◆ Citizens Alert: Zebra Mussels Pose a Threat to Virginia’s Waters. This brochure alerts residents about the mussel, its potential economic impacts, and control. By Virginia Sea Grant, Virginia Coop. Extension, Virginia Water Resources Research Center, and Virginia Dept. of Game and Inland Fisheries.

◆ Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region and Potential Range of the Zebra Mussel In and Near Virginia. These reports review the region’s and Virginia’s risk of mussel invasion. By Virginia Sea Grant.

◆ “Don’t Pick Up Hitchhikers!” The Jersey Shoreline (summer 1992). Outlines precautions to take to help prevent the mussel from invading state waters. By New Jersey Sea Grant.

◆ “Exotic Species Introductions: Devastation or Deliverance?” Marine Notes (spring 1992). Reviews the impact of zebra mussels and other non-native species on U.S. waters. By Maryland Sea Grant.

◆ Mid-Atlantic Zebra Mussel Fact Sheet. Provides an overview of the mussel and its threat to the region. By North Carolina Sea Grant.

◆ “Mid-Atlantic Zebra Mussel Outreach Plan.” Tideline (summer 1992). Reviews Sea Grant’s planned effort and Virginia’s contribution to it. By Virginia Sea Grant.


◆ Zebra Mussel Decal. This 3 1/2 x 7-inch decal alerts boaters and anglers about the zebra mussel and the steps they can take to thwart the hitchhiker. By Delaware Sea Grant and Delaware Dept. of Natural Resources and Environmental Control.

◆ Zebra Mussel Identification Card. This wallet-sized card tells how to identify the mussel and what to do if you find one. Created by Wisconsin Sea Grant, the card is tailored to each state in the Mid-Atlantic region.

◆ Zebra Mussels: A Costly Threat to North Carolina. This brochure describes the mussel and what citizens can do to keep it out of the state. By North Carolina Sea Grant.

◆ Zebra Mussels: A Threat to Maryland Waters. This brochure identifies the mussel and steps to take to stop its spread. By Maryland Sea Grant and Maryland Dept. of Natural Resources.

Media Awareness and Public Information. Sea Grant’s outreach team also has targeted the news media and the general public for zebra mussel information. So far, the network has distributed more than 100,000 publications to industry representatives, boaters, anglers, resource managers, teachers, and other Mid-Atlantic residents. The following are other high-impact efforts.

New Jersey Sea Grant produced a series of customized radio public service announcements for broadcast in New Jersey, Delaware, Maryland, Virginia, and North Carolina, reaching a potential listening audience of 20 million.

News releases and articles have resulted in coverage by a variety of newspapers, from the Philadelphia Inquirer to the Delmarva Farmer, and magazines such as Wildlife in North Carolina, New Jersey Fish and Wildlife Digest, and Outdoor Delaware.

All programs in the network have been developing audiovisuals to use at workshops and meetings. Maryland Sea Grant’s “Zebra Mussels: A Threat to Maryland Waters,” has been used to train Maryland park managers, state natural resource managers, engineering companies, and private citizens in fishing and hunting clubs and other groups.

Future Efforts. In 1992–1993, the Mid-Atlantic Sea Grant Network played a key role in alerting the region’s water users of the zebra mussel’s threat.

During the next year, the network’s goal is to continue delivering timely, accurate information to prepare the region for the zebra mussel’s eventual arrival.

Mid-Atlantic Sea Grant Contacts

The following programs are members of the Mid-Atlantic Sea Grant Network. Please contact the program in your state for more zebra mussel information:

University of Delaware Sea Grant College Program
Marine Advisory Service
700 Pilottown Road
Lewes, DE 19958
Contact: James Falk
(302) 645-4235

University of Maryland Sea Grant College Program
Sea Grant Extension/NOAA
410 Severn Avenue
Annapolis, MD 21403
Contact: Dan Terlizzi
(410) 267-5660

University of North Carolina Sea Grant College Program
Sea Grant Extension
1130 Jordan Hall, Box 8208
Raleigh, NC 27695–8208
Contact: Barbara Dool
(919) 515-5287

Virginia Sea Grant College Program
Marine Advisory Program
Virginia Institute of Marine Science
Gloucester Point, VA 23062
Contact: William DuPaul or Vicki Clark
(804) 642-7164

North Carolina Sea Grant College Program
North Carolina State Univ.
1130 Jordan Hall, Box 8208
Raleigh, NC 27695–8208
Contact: Barbara Dool
(919) 515-5287

New Jersey Sea Grant College Program
Rutgers Coop. Extension
1623 Whitesville Road
Toms River, NJ 08755
Contact: Eleanor Roche
(908) 349-1152

This report was written by Tracey L. Bryant and James M. Falk of the University of Delaware Sea Grant College Program, a member of a national network of universities committed to research, education, and technology transfer designed to meet the changing needs of our ocean, coastal, and Great Lakes regions. The program is financially supported by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce, the State of Delaware, and the university. This publication was produced by Tracey Bryant, editor; David Barczak, art director, and Pamela Donnelly, production manager. For more information, contact the University of Delaware Marine Communications Office, Newark, DE 19716-3530. Phone: (302) 831-8083.

Photo Credits: Cover—Zebra Mussel Cluster, E. Manden; Zebra Mussel in Cupped Hands, C. Ramscar, Wisconsin Sea Grant; Salton Nuclear Power Plant, Delaware Sea Grant (also on p. 7); Zebra Mussels on Clam, Wisconsin Sea Grant; p. 2—Zebra Mussel, Ohio Sea Grant; p. 3—Zebra Mussel Veligers, Ontario Ministry of Natural Resources; Dr. Tanzer, Delaware Sea Grant; Mussel-Encrusted Boat Hull, Michigan Sea Grant; p. 4—Oil Refinery at Night, Bob Bowden; Colonized Pipe from Lake Erie, C. Czarnecki, Michigan Sea Grant; Dr. Herbert Waite, Bob Bowden, p. 5—Mussel Watch Card, Wisconsin Sea Grant; Zebra Mussel on Mussel, C. Ramscar, Wisconsin Sea Grant; p. 6—Champion Paper, and Marshall Lake, Ken Taylor, North Carolina Wildlife; Mussel-Covered Crayfish, Ontario Ministry of Natural Resources; p. 7—Ontario Hydro Conducting Zooplankton Studies, Ontario Ministry of Natural Resources; p. 8—Filmstrip, created from Angler by Ken Taylor, North Carolina Wildlife, photos by Delaware Sea Grant, and Mussel Cluster by E. Manden.