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
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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.

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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 Guswold, 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.

Zebra mussels were first officially reported in the Great Lakes in June 1988. However, given the mussels’ size, it is estimated that zebra mussels were introduced into the Great Lakes in 1985 or 1986, when one or more transoceanic ships discharged ballast water into Lake St. Clair.

Sea Grant researcher David Gar- ton discovered the first zebra mussel on the U.S. side of Lake Erie in October 1988 at The Ohio State University’s F.T. Stone Laboratory at Put-in-Bay, Ohio. Recognizing the significance of this introduction, the Great Lakes Sea Grant Network immediately went to work. Our programs attacked the problem of combating zebra mussels from all sides, combining research, education, technology transfer and outreach efforts.

Jeffrey M. Goodwin, Ph.D.
Director
Ohio Sea Grant College Program
Range of color patterns seen in zebra mussels
via Great Lakes
(photo by Richard Mansfield)

Zebra mussels feed on filtering plankton from the water. In this view, the mussels have their branchial siphons extended and open. The mussel on the right shows the front view. Zebra mussels filter 15-60 times more water than the mussels native to Lake Erie. (photo by Richard Mansfield)
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.

Zebra mussels look like small clams and are about the size of a thumbnail. A small tuft of fibers — called byssal threads — protrudes from the hinge on their bodies. These fibers allow the mussels to attach to any hard surface — including other mussels. 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 Pontos-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. 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 also have 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 eel grass to grow. 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 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.

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. Opinion Lake, ONT
5. Big Rideau Lake, ONT
6. Owen Sound Harbour, ONT
7. Collingwood Harbour, ONT
8. Mississagi Strait, ONT
10. Houghton Lake, Michigan
11. Cass Lake, Walled Lake, Michigan
12. Belleville Lake, Michigan
13. Lake Paw Paw, Michigan
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 spread 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 research

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

Researcher David Garton dives for zebra mussel samples. (photo by Lloyd Leirmann)
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 Kazirian, 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.
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 Dreissenid 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 8/31/93
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

The implications of a nonindigenous species invasion for the ecosystem, especially in terms of competition for food with other species, may be far-reaching. Any new organism introduced to an existing ecosystem can alter or disrupt existing relationships and environmental processes. The invading species can significantly affect populations that are important components of the existing food web, ultimately leading to either overpopulation or the demise of species. In addition, some invading organisms can influence — and possibly significantly change — both a lake’s water quality and its productivity. Therefore, it is a high priority to identify and evaluate the effects and changes the invader is likely to produce at each stage in its life history. Such information helps natural resource managers determine how to minimize the impacts invading organisms have on established biota and habitats.

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/FFB-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 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.
Ecosystem Effects of Nonindigenous Species

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.
- Biore concentration 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. Hubschman, 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.I. 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

- 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 nanoplankton 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 *Gummarus*.

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/ZM-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/ZM-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 algae 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 at 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 photosynthetic.
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 Lampsis solitudoidea 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. Frankovich, 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: 9/11/92 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

Nonindigenous species can affect both society and the economy. Experience with invading species tells us that the negative impacts usually prevail over the positive; nonetheless, research should address both for the benefit of society. Research should answer questions about how invading organisms might introduce disease, concentrate pollutants, contaminate drinking water or otherwise affect human health. Economic impact investigations should examine how invading species might hamper sport, commercial and tribal fishing industries, the recreation and tourism industry, the shipping and navigation industry and municipal and industrial water users. Using nonindigenous species in beneficial ways—as food for domestic animals or fertilizer for gardens and crops—should be explored. Finally, socioeconomic research results should be presented to policy makers and educators. These results should be a foundation for sound, science-based policy and environmental law, as well as for effective public education and technology transfer projects.

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, 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, 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 (scraping, filtering, etc.), chemical (antifoulants, biocides, etc.) biological (parasites, predators, etc.), and physico-chemical (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 Phytoleca 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 Phytoleca 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. Baiier 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

The Use of Acoustic and Hydrodynamic Techniques to Control Zebra Mussel Infestation
Dimitri 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 9/30/92
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.

Once introduced and established in an open aquatic system, nonindigenous species have proven impossible to eliminate. Though effective control methods are eventually found, in most cases, little can be done to minimize ecosystem impacts and the resulting resource losses. Emphasis, therefore, is on preventing introductions of new invaders. First, scientists identify the means of introduction. Then they attempt to develop cost-effective, realistic methods of prevention. For example, ballast water discharge is an important vector for introducing nonindigenous species in the Great Lakes. Strategies to eliminate this source of introduction — without imposing undue hardships on the shipping industry — must be developed. Strategies for eliminating other vectors (intentional releases, canal openings, accidental releases, etc.), must be developed in a similar fashion. In addition, not all invading species become widespread and abundant. By examining life history characteristics and past dispersal patterns in other aquatic environments, scientists can identify those species most likely to colonize the Great Lakes and other systems.
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. Gallagher 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. Stepie, 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 foodchain.
- 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 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 to 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-442M
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, chlorine 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.