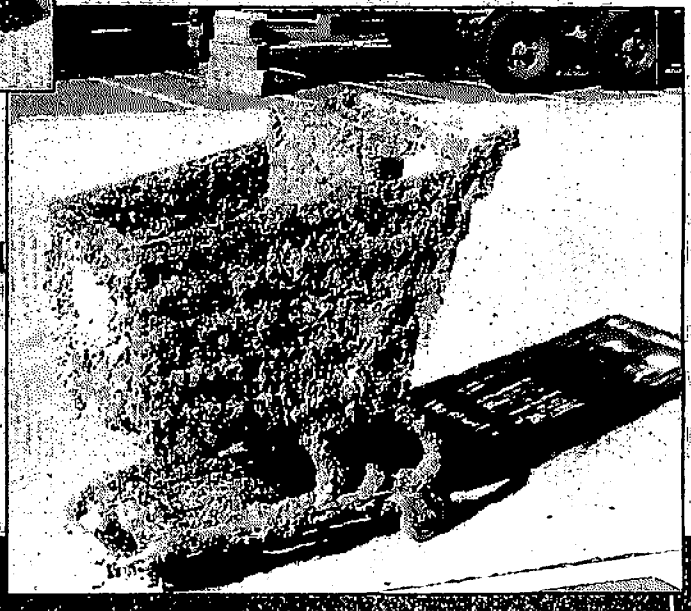
Sea Grant Zebra Mussel Report

An UPDATE of Research and Outreach



1988
1994

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 created in 1966 in the Department of Commerce. There is a Sea Grant program in Puerto Rico and in every coastal state, except for Pennsylvania. For more information, contact the Sea Grant program nearest you or the National Sea Grant office.

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

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Since the mid-1880s, 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.

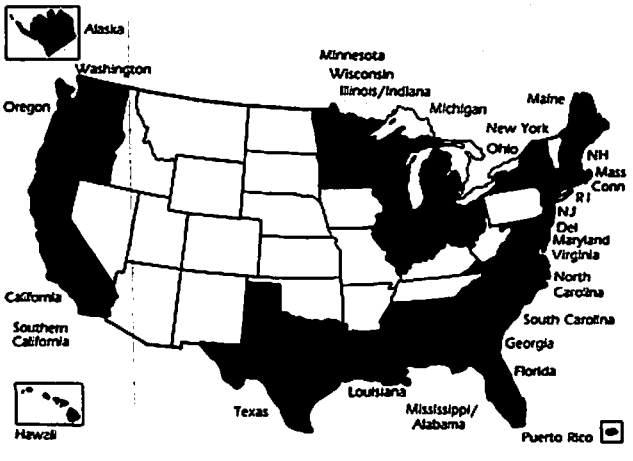
Through its long-standing partnership with academia and a competitive peer-reviewed research process, Sea Grant researchers have been able to address more basic areas of research, which the more mission-driven agencies are unable to do. Sea Grant's nonindigenous species research covers wide-ranging topics, 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 1994 fiscal year.

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

Network of Sea Grant Programs



Sea Grant has programs in coastal and Great Lakes states, and in Puerto Rico.

"The United States Great Lakes Nonindigenous Species Coordinating Committee was formed to foster cooperation and collaboration and to develop the coordinated research agenda."

On behalf of the directors of the Great Lakes Sea Grant Network (comprising six of the 29 programs in the National Sea Grant College Program of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce), I am very pleased to present this summary of our research and outreach efforts to address the problems and issues associated with the invasion of the Great Lakes region and eastern United States by the zebra mussel *Dreissena polymorpha* and the quagga mussel *Dreissena bugensis*.

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 Garton 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 combatting zebra mussels from all sides, combining research, education, technology transfer, and outreach efforts.

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. In addition to the six Great Lakes Sea Grant programs, the committee included the Great Lakes Environmental Research Laboratory (GLERL) of NOAA, the National Fisheries Research Center-Great Lakes of the U.S. Fish and Wildlife Service (now the National Biological Service), the Cooperative Institute for Limnology and Ecosystems Research (CILER), the U.S. Environmental Protection Agency, the Great Lakes Commission, the Great Lakes Fishery Commission, the U.S. Coast Guard, and the U.S. Army Corps of Engineers. Later, this committee expanded to become the Great Lakes Panel on Exotic Species of the Aquatic Nuisance Species Task Force.

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

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

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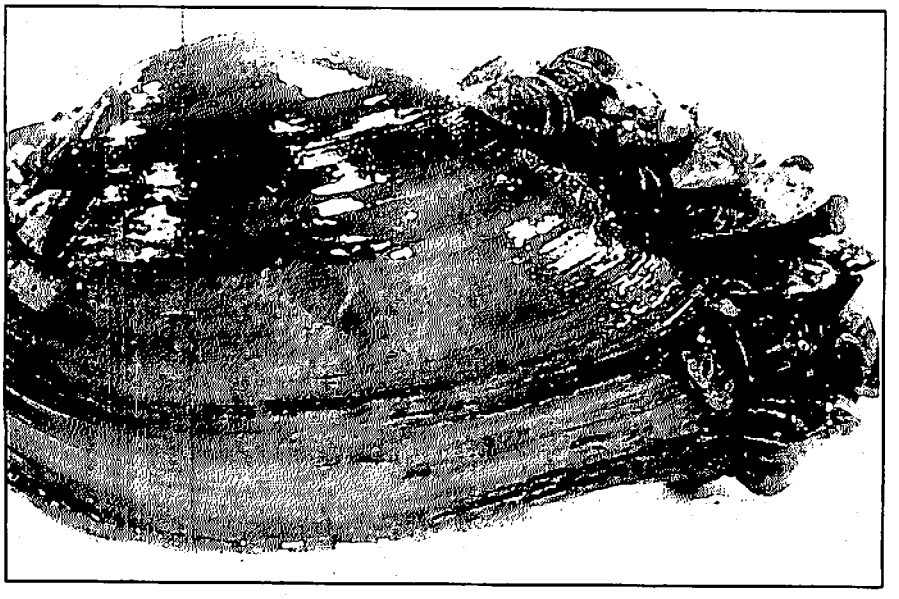
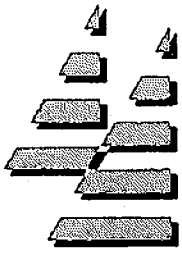
Summary

This zebra mussel report updates the results of previously funded projects and lists the objectives of the most recently funded proposals from fiscal year 1994.



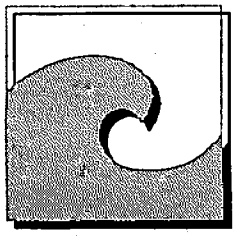
Ontario Ministry of Natural Resources

What is Sea Grant?



Some have called it a commitment. Others call it a bridge, a bond, a partnership. Congress called it Sea Grant. A national program created in 1966, Sea Grant is all of these things. It's a commitment to solve coastal problems and develop marine resources. It's a bridge between government and academia, scientist and private citizens. It's a bond uniting 29 state programs, 300 colleges and universities and millions of people. It's a partnership with a purpose—to help Americans understand and more wisely use our precious Great Lakes and ocean waters.

Sea Grant today is what Congress intended—an agent for scientific discovery, technology transfer, economic growth, and social understanding.

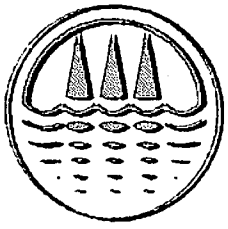


It's happening all over. Every day, Sea Grant scientists make progress on the important marine issues of our time. Extension agents quickly take this information out of the laboratory and into the field, working to help save a coastal business, a fishery, sometimes even a life. A dedicated corps of writers and communications specialists spreads the word to the public. And Sea Grant educators bring the discoveries into the nation's schools, using them to pioneer new and better ways of teaching, helping to create a new generation of scientifically literate Americans.

Together, separate elements create a cohesive whole, ensuring that Sea Grant meets the challenges of its mandate.

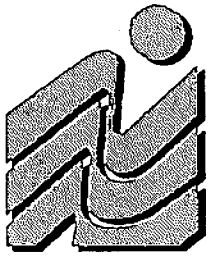
The returns are great—far exceeding the investment. In 1987, Sea Grant had an $842 million impact on the national economy—a return triple that of 1981 and more than 20 times the federal investment of $39 million. Not included in this figure are the impacts of better scientific knowledge and better education—important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

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



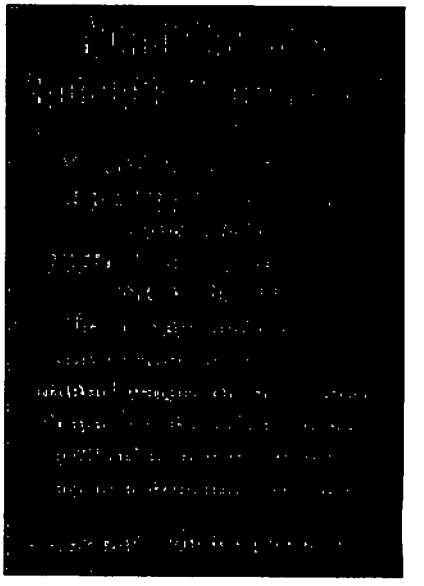
Today, one of those challenges is the zebra mussel. Sea Grant is meeting this challenge. Proceeding as it always has, Sea Grant is drawing on a wealth of scientific expertise to develop feasible solutions. But it's also keeping the public informed in all the effective and innovative ways that the collective 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. KK



Sea Grant Research

In response to the invasion of the Great Lakes by the zebra mussel *Dreissena polymorpha* in the mid 1980s, Congress voted into law the Nonindigenous Species Control Act in 1990. Congress also approved an appropriation of federal funds for research on zebra mussels and for public education to help control their spread. These funds were a welcome addition to zebra mussel research and outreach programs already begun in Ohio in 1988 and underway in all six Great Lakes Sea Grant programs by 1989.



Federal funding for research on aquatic nuisance species is distributed competitively through a national call for proposals and a peer review process. Through fiscal year 1994, research projects have been supported in 13 of the country's 29 Sea Grant Programs. The National Biological Service projects a cost of $5 billion to industry, municipalities, and private citizens by the year 2000 due to the zebra mussel's ability to settle on any hard surface. The ecological costs of the zebra mussel, however, could be even greater.

The following table explains how funds appropriated to Sea Grant for zebra mussel research and outreach have been distributed:

fiscal year	millions appropriated	distribution of money		research proposals submitted	research proposals funded
		research	outreach		
1991	$1.8	$1.3	$0.5	58	18
1992	$2.9	$1.9	$1.0	77	13
1993	$2.8	$1.7	$1.1	55	12
1994	$2.8	$1.5	$1.3	65	15

Sea Grant's zebra mussel research is divided into six categories, established in 1990 by the U.S. Great Lakes Nonindigenous Species Coordinating Committee. Both the U.S. and Canadian research communities use these categories to focus their research on nonindigenous nuisance species:

1. Biology and Life History
2. Effects on Ecosystems
3. Socio-Economic Analysis: Costs and Benefits
4. Control and Mitigation
5. Preventing New Introductions
6. Reducing the Spread

Ontario Ministry of Natural Resources

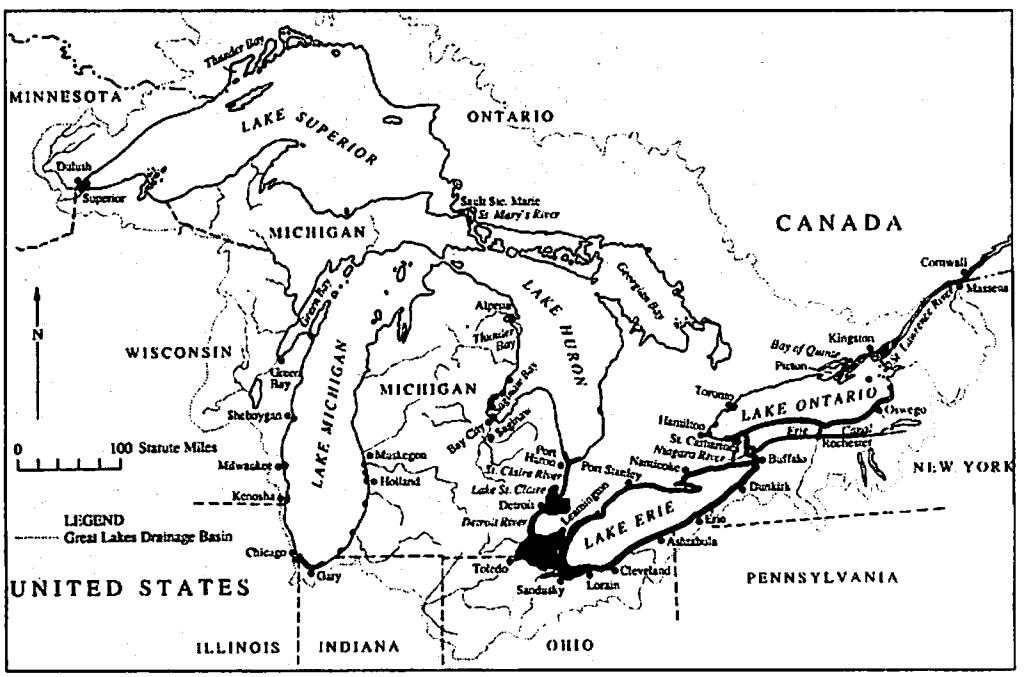
Zebra Mussel Distribution–1991

Compiled by New York Sea Grant with information from industries, agencies, and Sea Grant programs throughout North America.

J. Ellen Marsden

Range of color patterns seen in zebra mussels in North America.

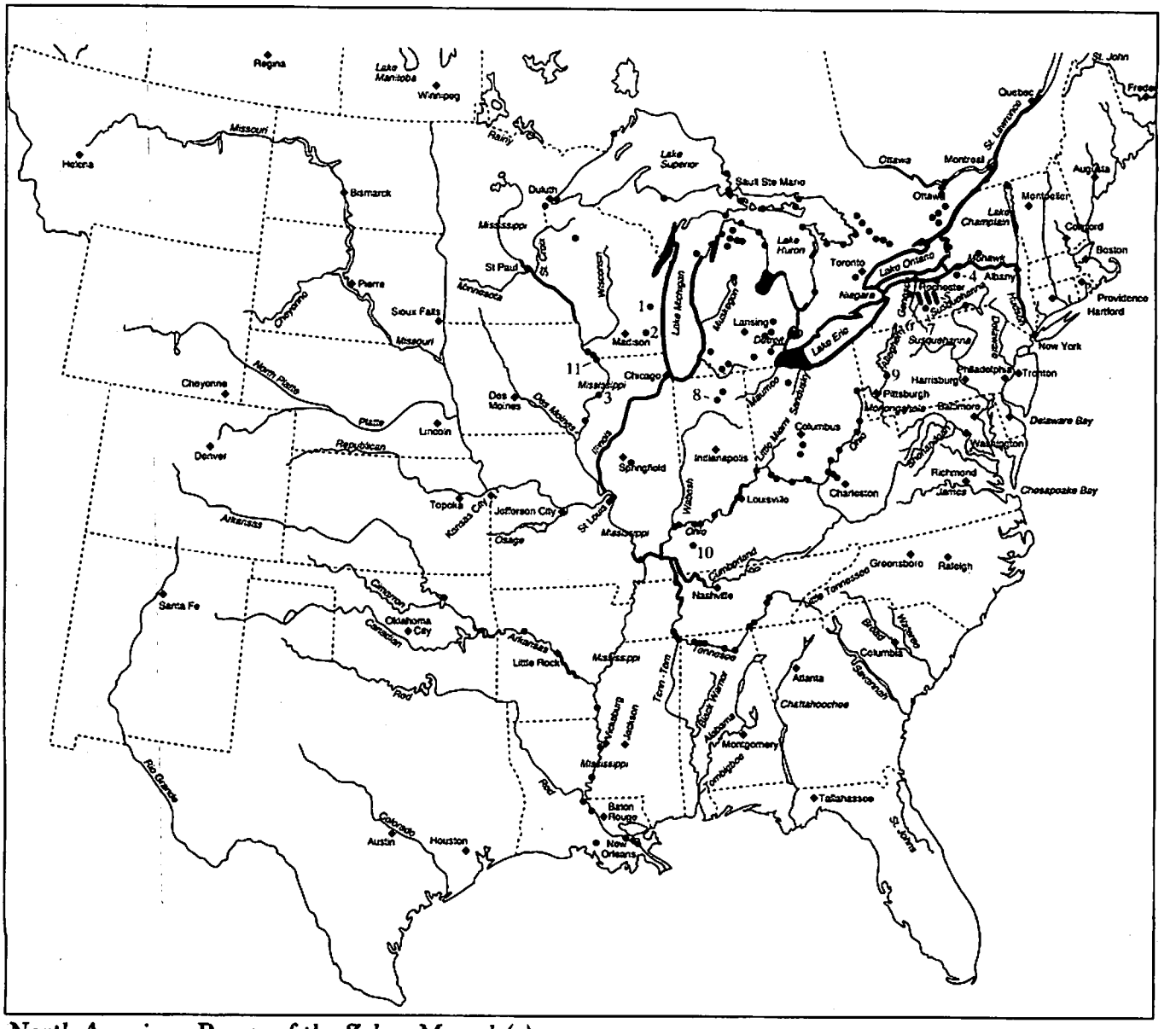
North American Range of the Zebra Mussel (•) as of January 1991



Zebra Mussel Distribution–1994

Most Recent Sightings

1. Big Elkhart Lake, WI
2. Okauchee Lake, WI
3. Mississippi River, Davenport, IA
4. Onondaga Lake, Syracuse, NY
5. Cayuga Lake – entire lake
6. Canandaigua Lake – entire lake
7. Keuka Lake, Penn Yan, NY
8. Tippecanoe Lake, IN
9. Allegheny River, river mile 45.7 (lock 7), Kittanning, PA
10. Green River, river mile 74, Livermore, KY
11. Mississippi River, Pool 11, river mile 586, Dubuque, IA



North American Range of the Zebra Mussel (•) as of September 1994

Public Law 101-646
101st Congress

An Act

To prevent and control infestations of the coastal inland waters of the United States by the zebra mussel and other nonindigenous aquatic nuisance species, to reauthorize the National Sea Grant College Program, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

"TITLE I—AQUATIC NUISANCE PREVENTION AND CONTROL

Subtitle A—General Provisions

"SECTION 1001.SHORT TITLE.

"This title may be cited as the "Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990".

"SEC. 1002.FINDINGS AND PURPOSES.

"(a) FINDINGS.—The Congress finds that—

"(1) the discharge of untreated water in the ballast tanks of vessels and through other means results in unintentional introductions of nonindigenous species to fresh, brackish, and saltwater environments;

"(2) when environmental conditions are favorable, nonindigenous species, such as the zebra mussel (*Dreissena polymorpha*), become established and may disrupt the aquatic environment and economy of affected coastal areas;

"(3) the zebra mussel was unintentionally introduced into the Great Lakes and, if left uncontrolled, is expected to infest over two-thirds of the continental United States through the unintentional transportation of larvae and adults by vessels operating in inland waters; and

"(4) the potential economic disruption of communities affected by the zebra mussel due to its colonization of water pipes, boat hulls and other hard surfaces has been estimated at $5,000,000,000 by the year 2000, and the potential disruption to the diversity and abundance of native fish and other species could be severe.

"(b) PURPOSES.—The purposes of this Act are—

"(1) to prevent unintentional introduction and dispersal of nonindigenous species into waters of the United States through ballast water management and other requirements;

"(2) to coordinate federally conducted, funded or authorized research, prevention control, information dissemination and other activities regarding the zebra mussel and other aquatic nuisance species;

"(3) to develop and carry out environmentally sound control methods to prevent, monitor and control unintentional introductions of nonindigenous species from pathways other than ballast water exchange;

"(4) to understand and minimize economic and ecological impacts of nonindigenous aquatic nuisance species that become established, including the zebra mussel; and

"(5) to establish a program of research and technology development and assistance to States in the management and removal of zebra mussels.

"SEC. 1003.DEFINITIONS.

"As used in this Act, the term—

"(1) 'appropriate Committees' means the Committee on Merchant Marine and Fisheries in the House of Representatives and the Committee on Environment and Public Works and Committee on Commerce, Science, and Transportation in the Senate; and

"(2) 'aquatic nuisance species' means a nonindigenous species that threatens the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent on such waters;

"(3) 'assistant Secretary' means the Assistant Secretary of the Army (Civil Works);

"(4) 'ballast water' means any water and associated sediments used to manipulate the trim and stability of a vessel;

"(5) 'Director' means the Director of the United States Fish and Wildlife Service;

"(6) 'exclusive economic zone' means the Exclusive Economic Zone of the United States established by Proclamation Number 5030, dated March 10, 1983, and the equivalent zone of Canada;

"(7) 'environmentally sound' methods, efforts, actions or programs means methods, efforts, actions or programs to prevent introductions or control infestations of aquatic nuisance species that minimize adverse impacts to the structure and function of an ecosystem and adverse effects on non-target organisms and ecosystems and emphasize integrated pest management techniques and nonchemical measures;

"(8) 'Great Lakes' means Lake Ontario, Lake Erie, Lake Huron (including Lake St. Clair), Lake Michigan, Lake Superior, and the connecting channels (Saint Mary's River, Saint Clair River, Detroit River, Niagara River, and Saint Lawrence River to the Canadian Border), and includes all other bodies of water within the drainage basin of such lakes and connecting channels.

"(9) 'nonindigenous species' means any species or other viable biological material that enters an ecosystem beyond its historic range, including any such organism transferred from one country into another;

"(10) 'Secretary' means the Secretary of the department in which the Coast Guard is operating;

"(11) 'Task Force' means the Aquatic Nuisance Species Task Force established under section 1201 of this Act;

"(12) 'territorial sea' means the belt of the sea measured from the baseline of the United States determined in accordance with international law, as set forth in Presidential Proclamation Number 5928, dated December 27, 1988;

"(13) 'Under Secretary' means the Under Secretary of Commerce for Oceans and Atmosphere;

"(14) 'waters of the United States' means the navigable waters and the territorial sea of the United States; and

"(15) 'unintentional introduction' means an introduction of nonindigenous species that occurs as the result of activities other than the purposeful or intentional introduction of the species involved, such as the transport of nonindigenous species in ballast or in water used to transport fish, mollusks or crustaceans for aquaculture or other purposes.

"Subtitle B—Prevention of Unintentional Introductions of Aquatic Nuisance Species

"SEC. 1101.AQUATIC NUISANCE SPECIES IN THE GREAT LAKES.

"(a) GUIDELINES.—

(1) Not later than 6 months after the date of enactment of the Act, the Secretary shall issue voluntary guidelines to prevent the introduction and spread of aquatic nuisance species into the Great Lakes through the exchange of ballast water of vessels prior to entering those waters.

"(2) The guidelines issued under this subsection shall—

"(A) ensure to the maximum extent practicable that ballast water containing aquatic nuisance species is not discharged into the Great Lakes;

"(B) protect the safety of each vessel, its crew, and passengers;

"(C) take into consideration different vessel operating conditions; and

"(D) be based on the best scientific information available.

"(3) Within 12 months after the date of enactment of this Act, the Secretary shall carry out education and technical assistance programs and other measures to encourage compliance with the guidelines issued under this subsection.

"(b) AUTHORITY OF SECRETARY.—

(1) Within 24 months after the date of enactment of this Act, the Secretary, in consultation with the Task Force, shall issue regulations to prevent the introduction and spread of aquatic nuisance species into the Great Lakes through the ballast water of vessels.

"(2) The regulations issued under this subsection shall—

"(A) require all vessels that carry ballast water and enter a United States port on the Great Lakes after operating on the waters beyond the exclusive economic zone;

"(B) require a vessel to—

"(i) carry out exchange of ballast water on the waters beyond the exclusive economic zone prior to entry into any port within the Great Lakes;

"(ii) carry out an exchange of ballast water in other waters where the exchange does not pose a threat of infestation or spread of aquatic nuisance species in the Great Lakes and other waters of the United States, as recommended by the Task Force under section 1102(a)(1); or

"(iii) use environmentally sound alternative ballast water management methods if the Secretary determines that such alternative methods are as effective as ballast water exchange in preventing and controlling infestations of aquatic nuisance species.

"(C) not affect or supersede any requirements or prohibitions pertaining to the discharge of ballast water into waters of the United States under the Federal Water Pollution Control Act (33 U.S.C. 1251 et seq.);

"(D) provide for sampling procedures to monitor compliance with the requirements of the regulations;

"(E) prohibit the operation of a vessel in the Great Lakes if the master of the vessel has not certified to the Secretary or the Secretary's designee by not later than the departure of that vessel from the first lock in the St. Lawrence Seaway that the vessel has complied with the requirements of the regulations;

"(F) request the Secretary of the Treasury to withhold or revoke the clearance required by section 4197 of the Revised Statutes (46 App. U.S.C. 91) of a vessel, the owner or operator of which is in violation of the regulations;

"(G) protect the safety of each vessel, its crew, and passengers;

"(H) take into consideration different vessel operating conditions; and

"(I) be based on the best scientific information available.

"(c) CIVIL PENALTIES.—Any person who violates the regulations issued under subsection (b) shall be liable for a civil penalty in an amount not to exceed $25,000. Each day of a continuing violation constitutes a separate violation. A vessel operated in violation of the regulations is liable in rem for any civil penalty assessed under this subsection for that violation.

"(d) CRIMINAL PENALTIES.—Any person who knowingly violates the regulations issued under subsection (b) is guilty of a class C felony.

"(e) CONSULTATION WITH CANADA.—In developing the guidelines and regulations, the Secretary is encouraged to consult with the Government of Canada to develop an effective international program for preventing the introduction and spread of aquatic nuisance species in the Great Lakes from the ballast water of vessels.

Research Overview

The opening of the St. Lawrence Seaway in 1959 opened the Great Lakes to international shipping—and to the transport and introduction of nonindigenous aquatic species. To date, over 130 species have been introduced to the Great Lakes area. Some of these exotics have little impact on the environment. Others are referred to as "nuisance" species, often belying their seriously harmful biological and economic impacts. The zebra mussel is one such species. Discovered in Lake St. Clair in 1988 (and presumed to have been introduced in 1985 or '86 in ballast water), the mussel is projected to infest all hospitable lakes, rivers, and reservoirs by the year 2000. The toll on invaded ecosystems is incalculable, as are the economic costs. Six years of zebra mussel research in the six categories developed in 1990 by the U.S. Great Lakes Nonindigenous Species Coordinating Committee have produced some notable results, a sample of which follows:

Biology and Life History

The ability of the zebra mussel to colonize almost any surface, including colonies of itself, is by now legendary. The weight of colonies have sunk buoys marking channels and dangerous areas. The mussel has wiped out many local populations of other species of mussels and clams. Snails are now being examined for the same effects. Tests on *Dreissena polymorpha* show it to be one of the most genetically diverse organisms known, which will allow it to spread and adapt to new environments. Lab-reared larvae were recently observed to postpone settlement and attachment and prolong a free-swimming larval period for an additional seven weeks. The effects of this delay on the dispersal capabilities of larvae, particularly in river systems, may be profound.

Effects on Ecosystems

The mussel's phenomenal numbers (a mature, thumbnail-sized female can produce a million eggs) and prodigious appetite have had three striking effects on the water they inhabit: planktonic populations have dropped precipitously; fewer plankton mean, in some cases, a four-fold increase in water clarity; and more transparent water means increased penetration of sunlight allowing the growth of filamentous green algae. The result is a shift in the algal community structure.

Socio-Economic Analysis

Without a doubt, the phenomenal monetary costs of zebra mussel control has been felt most directly by those who must draw mussel-infested water into intake pipes. Surveys suggest, on the other hand, that few people have decreased their recreational activities because of the mussel. Perhaps associated with the mussel, however, are yellow perch trawl catches that have declined precipitously in recent years in Lake Michigan. Observations in Saginaw Bay show high densities of larval yellow perch; suggesting recruitment failure somewhere between the larval fish and juvenile fish stages.

Control and Mitigation

Elimination of the zebra mussel is impossible; control is absolutely necessary for industrial and municipal water users. Sea Grant has funded research in the use of robots to clean pipes; ultra-violet radiation to kill veligers; potassium to kill adults or prevent larval attachment; formulated substrates that prevent attachment; the mechanical elimination of dissolved oxygen to kill adults; chemicals that induce spawning; and chemicals from the fruit of *Phytolacca dodecandra*, for which two U.S. patents for molluscicides have been awarded (brand name, Endod).

Preventing New Introductions

The Aquatic Nuisance Prevention and Control Act specifies that ship ballast water be exchanged at sea or be otherwise treated to rid it of invader species. Funded work on ballast water exchange shows during what conditions the exchange can or cannot be safely made.

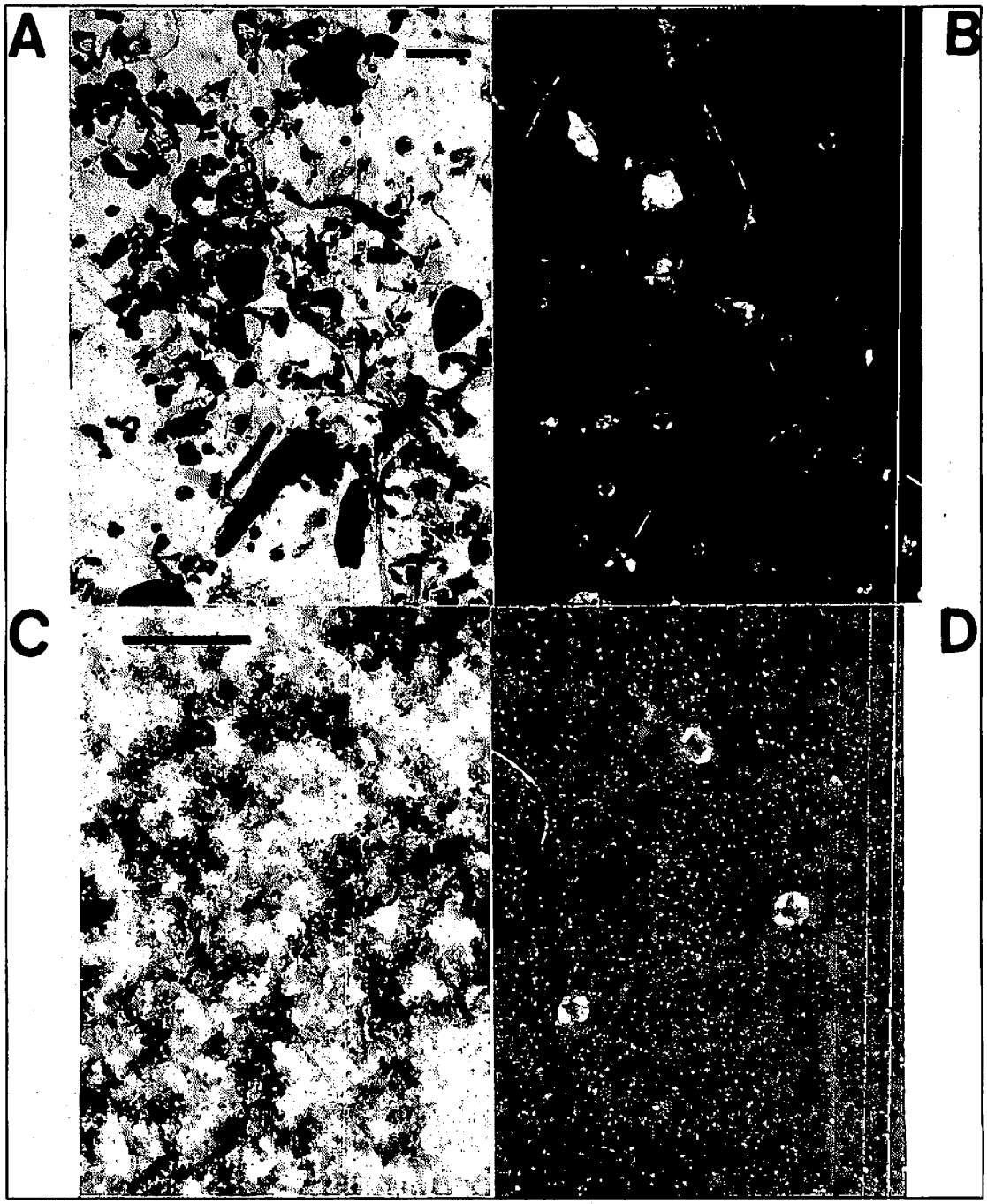
Reducing the Spread of Established Populations

Zebra mussels are spread almost exclusively by natural water flow and by human activities. Their larvae (veligers) have been found in boat engine cooling systems, bilges, live wells, and in bait buckets. Adult mussels have been found on the vegetation caught on boat trailers. Enforced laws that penalize people for possession or transport of zebra mussels are shown to be effective, at the very least, for educating a large proportion of the public.

Like the zebra mussel, two newly introduced small fish—the Eurasian ruffe and the goby—threaten to infest the entire Great Lakes with serious consequences. The ruffe is small, bony, and unpalatable to other fish and to humans and has overwhelmed the natural fish populations in many of Lake Superior's harbors and tributaries. Biologists presume that the ruffe would thrive even more in Lake Erie. The goby, fried and eaten in China as we eat smelt, now thrives in Lakes Erie and Michigan. Unfortunately, it heartily feeds on zebra mussels, which are high in lipids and known to concentrate contaminants in their body tissues. The goby, therefore, is yet another link in the chain of contaminant bioaccumulation. Research proposals are being submitted to Sea Grant now to study the ruffe and the goby.

Early detection of zebra mussel veligers using cross-polarized light.

Zooplankton with calcium-based skeletons are easily distinguished from clutter using cross-polarized light, improving the accuracy of veliger counts by 15 percent and reducing the time required for counts by more than half. (Johnson and Carlton, p. 36; additional photo, p. 37.)



Two plankton samples viewed under polarized light (A & C) and under cross-polarized light (B & D) to illustrate the enhanced visualization of bivalve larvae when using this technique. A & B: "cluttered" nearshore plankton sample with four veligers present; scale bar = 500µm. C & D: silty sample from larval collector with three veligers present; scale bar = 500µm.

Research Projects

Initiated in 1988 by the National Sea Grant College Program and the Great Lakes Sea Grant Network Programs.

Biology and Life History

In order to predict an ecosystem's response to an invading species, scientists need to understand the life history and population dynamics of the invader. Basic biological research into population dynamics, physiology and behavior, genetics, parasites, and diseases may lead to the discovery of ecologically safe, effective, and inexpensive control. Further, research on the ecological and environmental tolerances of nonindigenous species answers important questions about the geographic limits of infestation and which native species and habitats are most likely to be affected.

▲ The Population Dynamics and Ecology of Zebra Mussels in Inland Lakes

David W. Garton, Indiana University at Kokomo, and Ladd E. Johnson, University of California, Santa Barbara

Illinois-Indiana Sea Grant College Program Project NA

Date: 9/1/94 to 8/31/97

Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Determine population dynamics of mussels of inland lakes by measuring their reproduction, growth, and settlement.
- Provide information of the dispersal success of zebra mussels as they invade inland lakes, and the possible role of these lakes as "stepping stones" in the geographic spread of zebra mussels across North America.

▲ Salinity Tolerance and Specific Ion Balances Are the Appropriate Predictors of Geographic Spread of Zebra Mussels into Estuaries

Thomas H. Dietz, John W. Lynn, and Harold Silverman, Louisiana State University

Louisiana Sea Grant College Program Project R/ZMM-1

Date: 8/1/94 to 7/31/95

Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Define the ionic constituents required by zebra mussels for survival in oligohaline water.
- To use this information to predict the geographic spread of *Dreissena polymorpha* and identify the estuarine areas that are at risk of invasion.

▲ *Dreissena polymorpha*: Reproductive Ability in Various Ionic Environments Relating to Geographic Spread into Estuarine Environments

John W. Lynn and Harold Silverman, Louisiana State University

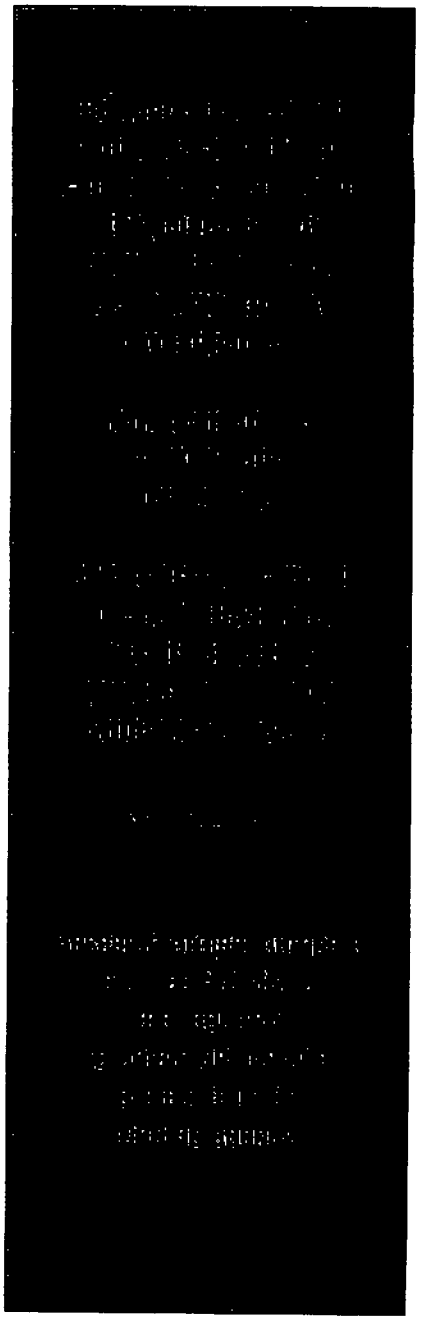
Louisiana Sea Grant College Program Project R/ZMM-2

Date: 8/1/94 to 7/31/95

Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Identify the minimal and maximal ion requirements of the gametes for successful fertilization and early development.
- Determine the minimal and maximal number of gametes required for successful fertilization.
- Build predictive models of reproductive success in environments of varying ion concentration and recruitment in areas of low population densities.



Biology and Life History

▲ Zebra Mussels in the Susqhehanna: Yes or No? Why or Why Not?

Willard N. Harman, State University of New York at Oneonta
New York Sea Grant Institute Project R/CMB-8
Date: 5/1/94 to 4/1/95
Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Verify the presence of *Dreissena* veligers in the Susqhehanna River at Johnson City, NY.
- Determine the location(s) of colonies of adults upstream from that site.
- Locate habitats in nearby drainage basins that are chemically and physically similar to the Susqhehanna River at Johnson City, and are also exposed to veligers but not supporting colonies of adults.
- Propose a plan of study to ascertain why further colonization has not occurred in the Susqhehanna River.

Assessing the Spatial and Temporal Distribution of Zebra Mussel Larvae in Saginaw Bay, Michigan, Using the Video Plankton Recorder

Scott M. Gallager and Cabell S. Davis, Woods Hole Oceanographic Institution
Massachusetts Sea Grant College Program Project R/B-119-PT
Date: 9/1/93 to 8/31/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

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

2 Swimming and Settlement Behavior in the Quagga Mussel

Victor S. Kennedy, University of Maryland
Maryland Sea Grant College Program Project R/ZM-03
Date: 9/1/93 to 8/31/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

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

Results to Date

◊ In cooperation with Dr. D. Wright at Chesapeake Biological Laboratory, larvae have been reared to advanced stages. Settlement has occurred at CBL.

◊ The effects of salinity have been studied on the first 24 hours of embryonic development; on survival and growth of newly settled spat; and on survival, movement, and attachment of juvenile and adults.

◊ Embryonic development does not occur at 6 and 8 ppt (parts per thousand) salinity, is nearly 100% inhibited at 4 ppt, and is successful at 2 and 0 ppt. [Full-strength sea water is 30–35 ppt salinity —ed.] Newly settled spat survive at 0, 2 and 4 ppt, with higher mortality at 6 ppt and complete mortality at 8 ppt. Juveniles and adults are more sensitive to higher salinities than are spat.

Biology and Life History

Genetics of the Zebra and Quagga Mussels: A Comparative Analysis of Mitochondrial DNA Sequence Data

Carol A. Stepien, Case Western Reserve University

Ohio Sea Grant College Program Project R/ZM-9
Date: 9/1/93 to 8/31/96
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

- 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.
- Determine whether there are additional cryptic species in this North American nonindigenous complex.
- 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.
- Pinpoint the original European source of mussel parental stocks.
- 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.

Results to Date

◊ The first DNA sequence data for dreissenid mussels has recently been obtained from two mitochondrial regions, cytochrome b and ND4.

◊ Analysis of DNA substitutions in these regions confirm species-level separation between the zebra and quagga mussels.

◊ The North American zebra mussel is genetically diverse, suggesting that the population was founded by relatively large numbers of divergent individuals.

◊ An extremely high level of genetic divergence was found in the cytochrome b gene, suggesting that variation within this species makes the zebra mussel one of the most genetically diverse known. For example, two individuals from the same location share only 82.3% of the sequence and are unique at 17.6% of the bases, suggesting a key factor in the mussel's ability to rapidly colonize new habitats and adapt to new environments.

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

New Jersey Marine Sciences Consortium Sea Grant Program Project R/E-45ZM
Date: 7/1/93 to 6/30/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

- Develop a practical way to identify larval and postlarval stages of the zebra mussel *Dreissena polymorpha, D. bugensis* (quagga mussel), *Mytilopsis leucophaeata* (dark false mussel), and other co-occurring bivalve species in freshwater and oligohaline habitats by using SEM and other routine optical microscopic examination of shell and hinge form and structure.
- Develop routine methods for rearing zebra and quagga mussel larvae through to postlarval stages.

Results to Date

◊ Routine methods have been developed to spawn adults and rear larvae and postlarvae of both the zebra mussel (*D. polymorpha*) and the quagga mussel (*D. bugensis*). This work has revealed that in addition to the minimum 2–3 week period required for larvae to develop to their settling stage, these larvae can postpone settlement and attachment and prolong this free-swimming larval period for an additional 7 weeks. This may have profound implications in our estimation of the potential dispersal capabilities of larvae, particularly in river systems.

◊ SEM analyses show subtle differences in shell shape among larval specimens of *D. polymorpha, D. bugensis, M. leucophaeata*, and the clam *Rangia cuneata*, whereas the shape of the clam *Corbicula fluminea* is distinctly different.

◊ Differences in shell shapes among all species becomes more marked in postlarval specimens.

◊ Differences in shell hinge structure of larval and postlarval *D. polymorpha* and *D. bugensis* are subtle, but both species are distinctly different from the other three.

Biology and Life History

Osmoregulatory Physiology of the Zebra Mussel

Robert L. Preston, Illinois State University

Illinois-Indiana Sea Grant Program Project ZM/2

Date: 11/1/92 to 10/31/95

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

Objectives

- Characterize how zebra mussels osmoregulate at the cellular level.
- Test the hypothesis that ion balance is regulated by membrane processes that are potentially sensitive to chemical agents.
- Test specific agents that disrupt osmoregulation in zebra mussels.

An Investigation of the Larval Development and Shell Morphology of the Zebra Mussel *Dreissena polymorpha* (Pallas)

Gail M. Lima, Illinois Wesleyan University

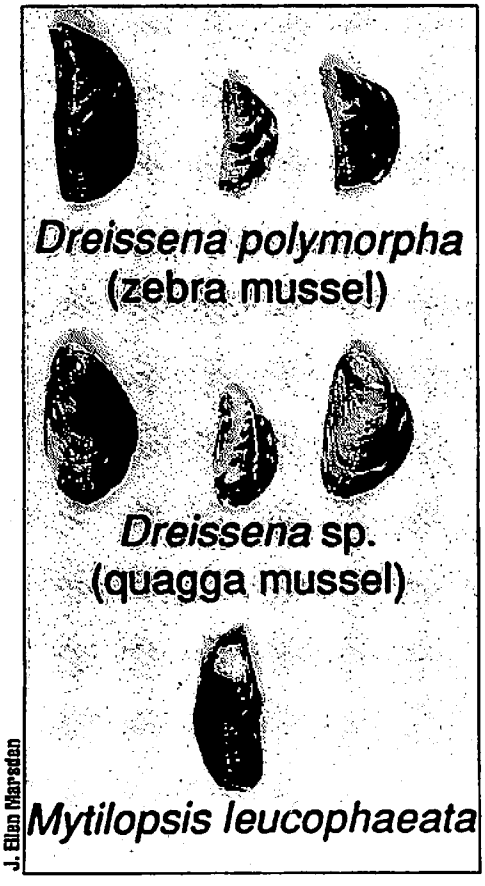
Illinois-Indiana Sea Grant Program Project ZM/3

Date: 9/1/92 to 9/1/94

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

- Determine the maximum time zebra mussel veligers can remain planktonic.
- Determine whether veligers can delay metamorphosis and which environmental factors could influence this.
- Describe larval and postlarval zebra mussel shell morphology.
- Propose control techniques that interfere with larval settlement and metamorphosis.



Species Identities and Relationships of North American and European *Dreissena* (Bivalvia: Dreissenidae)

Gary Rosenberg, Academy of Natural Sciences of Philadelphia

New Jersey Marine Sciences Consortium Sea Grant Program Project R/E-30-ZM

Date: 9/1/92 to 8/31/94

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

- Confirm that a second *Dreissena* species is present in North America.
- Evaluate genetic variability in European *Dreissena* and compare it with North American populations.
- Quantify how many existing *Dreissena* species occur in Europe.
- Determine whether it's possible to identify *Dreissena* species by shell and anatomy alone (as opposed to genetic gel tests).

Results

◊ The correct name for the quagga mussel is *Dreissena bugensis* Andrusov, 1897.

◊ *D. bugensis* can be distinguished from *D. polymorpha* both morphologically and genetically.

◊ Both introductions probably originated from the Dnieper River Drainage of the Dnieper/Bug Liman, an estuary where the Dnieper enters the Black Sea.

◊ Genetic variability is being analyzed based on data from allozyme electrophoresis of European, Ukrainian, and Russian populations of *Dreissena*.

Zebra mussels, quagga mussels, and the false dark mussel (native to the U.S.)

Biology and Life History

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

New York Sea Grant Institute Project R/CMB-5

Date: 8/1/92 to 5/31/93

Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objectives

- Measure the quagga's genetic variability and its natural hybridization with the zebra mussel.
- Determine the quagga's tolerance to salinity and heat.

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.

Influences of Temperature and Diet on Physiological Energetics of Growth and Reproduction of *Dreissena polymorpha*

David W. Garton, The Ohio State University

Ohio Sea Grant College Program Project R/ZM-10

Date: 2/1/92 to 1/31/94

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

Objectives

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

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.

◊ Food quality determines the energy allocation strategy of zebra mussels, across all combinations of ration and temperature.

◊ More energy is allocated to reproduction when food quality is low than when food quality is high.

◊ Allocation of energy to reproduction in stressful conditions results in a significant increase in mortality.

The Byssal Adhesive of Zebra Mussels *Dreissena polymorpha*

J. Herbert Waite, University of Delaware

Delaware Sea Grant College Program Project R/B-26

Date: 9/1/91 to 8/31/94

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

Objectives

- Purify the substance that is the precursor of zebra mussel byssal adhesive.
- Determine the sequence and physical properties of this substance.
- Localize this substance immunochemically.

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Results

- Several families of DOPA-containing precursor proteins have been purified from the foot of zebra mussel byssal precursor.
- 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.
- ◊ Byssal precursor proteins appear to consist of tandemly repeated peptide sequences.
- ◊ Byssal precursor proteins from *Dreissena polymorpha* and *D. bugensis* are distinct.

Biomineralization and the Requirement for Strontium During Larval Development of the Zebra Mussel (*Dreissena polymorpha*)

Scott M. Gallager, Judith E. McDowell, and Alan Kuzirian, Woods Hole Oceanographic Institution; and Joseph P. Bidwell, University of Massachusetts

Woods Hole Oceanographic Institution Sea Grant Program Project R/M-25
Date: 8/1/91 to 7/31/92
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives

- Determine how much strontium and calcium zebra mussel larvae need to mineralize their first shells.
- Pinpoint the period in the life cycle when larvae need these minerals.
- Further describe how zebra mussels develop as embryos and larvae using electron microscopy.
- 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, and Bernie May, Cornell University

Illinois-Indiana Sea Grant Program Project ZM/1
Date: 8/1/91 to 7/31/93
Primary Source of Funds: Pass-through from EPA

Objectives

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

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.
- ◊ Average heterozygosity among seven European populations examined was similar, indicating that little genetic variation was lost when zebra mussels were transported to North America.

Physiology of Zebra Mussels

David W. Garton, The Ohio State University

Ohio Sea Grant College Program Project 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

- 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.

Research Projects

New projects are marked with a triangle(▲). All results are current through 1994. New results of earlier projects are marked with a diamond (◊).

Effects on Ecosystems

Any new organism introduced to an established 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. 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.

▲ The Effect of Zebra Mussels on *Gammarus* Populations: A Mechanistic Approach

Maria J. Gonzalez, Wright State University

Ohio Sea Grant College Program Project R/ZM-23

Date: 9/1/94 to 2/28/97

Primary source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Determine precisely to what extent *Gammarus* sp. is affected by the presence of zebra mussels.
- Determine if the high abundances of *Gammarus* sp. observed in areas colonized by zebra mussels is caused by an increase in habitat complexity and/or an increase in food resources.

▲ Influence of Zebra Mussels on C- and P-Dynamics in Plankton Communities: Long-Term Effects in the Western Basin of Lake Erie and Saginaw Bay

Robert T. Heath, Kent State University

Ohio Sea Grant College Program Project R/ZM-25 (continuation of R/ZM-6)

Date: 9/1/94 to 8/31/96

Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Test the hypothesis that the long-term effects of zebra mussels will result in a diminished efficiency of carbon-flux from algae to microcrustaceans, decreased uptake of phosphate by bacteria, and diminished transfer of phosphorus from bacteria to microcrustaceans.
- Test whether the community composition will shift to less edible species of phytoplankton resistant to zebra mussel grazing.

▲ Zebra Mussel-Mediated Shifts in Benthic Algal Communities in Saginaw Bay, Lake Huron

Rex L. Lowe and Robert W. Pillsbury, Bowling Green State University

Ohio Sea Grant College Program Project R/ZM-17 (continuation of R/ZM-5)

Date 9/1/94 to 8/31/96

Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Determine how increased densities of zebra mussels affect the structure and function of benthic algal communities.
- Determine which environmental factors are important to the benthic algal community and how these factors have changed with the invasion of zebra mussels.
- Determine if primary consumers are able to utilize new benthic algal resources in Saginaw Bay.
- Develop a model useful for predicting the effects of zebra mussels in other systems by sampling a wider range of sites within Saginaw Bay in 1996.

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Results to Date

- Changes in substrata (from bare rock to zebra mussel encrusted rock) are not important in explaining the observed changes in the benthic algae of Saginaw Bay.
- Availability of light to benthic algae has increased in Saginaw Bay following the zebra mussel invasion.
- Benthic algal growth and productivity has substantially increased following the zebra mussel invasion in Saginaw Bay.
- Benthic algal community structure has shifted from a diatom dominated community to a system dominated by filamentous green algae following the zebra mussel invasion in Saginaw Bay. (Photo, p.23.)
- Benthic algal biomass has gradually shifted from light-limitation before zebra mussels to nutrient-limitation (both phosphorus and nitrogen) after the zebra mussel invasion.

▲Population and Energetic Consequences of Zebra Mussel Fouling on Native Gastropod Fauna of Lake Michigan

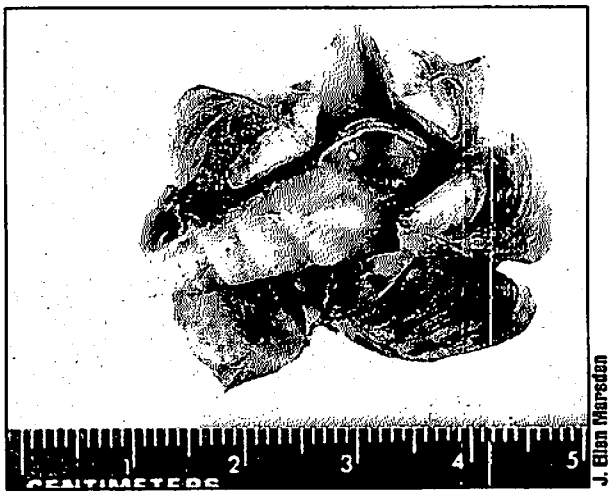
J. Ellen Marsden, and Daniel W. Schneider, Illinois Natural History Survey; Sharook Madon, University of Maryland-Eastern Shore; Dianna K. Padilla, University of Wisconsin

Illinois-Indiana Sea Grant and Wisconsin Sea Grant Programs Project R/LR-60
Date: 9/1/94 to 6/1/97
Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Document the extent of fouling by zebra mussels on native gastropod fauna among habitats, among species, and among individuals.
- Determine the population level impacts of zebra mussel fouling on native gastropod fauna.
- Determine impacts of zebra mussel fouling on individual snail metabolic and life history parameters (consumption, respiration, fecundity, and growth).
- Determine the species characteristics (behavior, shell characteristics, habitat, mucus) that influence differential susceptibility to fouling within and among gastropod species.

Zebra mussels foul snail shells in addition to native clam shells and are likely to have negative impacts on snail energetics, movement, feeding, and ultimately on their fecundity due to reduced growth rates.



Zebra mussels fouling a live pleurocerid snail from Lake Erie, 1991

▲Compensatory Responses of Fish Populations to the Invasion of the Zebra Mussel (*Dreissena polymorpha*): Benthic-Pelagic Coupling

Edward L. Mills and Lars G. Rudstam, Cornell University

New York Sea Grant Institute Project R/CE-9
Date: 9/1/94 to 8/31/97
Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Assess the indirect effects of zebra mussels on benthic invertebrates (studying *Gammarus fasciatus*).
- Assess the indirect effects of zebra mussels on feeding by larval, juvenile, and adult yellow perch.

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- Examine compensatory responses of yellow perch based on long-term field observations in Oneida Lake.
- Assess linkages in the benthic-pelagic food web of Oneida Lake using stable isotopes.
- Model the effect of hypothesized and measured effects of zebra mussels on the population dynamics of walleye and yellow perch in Oneida Lake.

Zebra Mussel and Sediment Interactions: Is There an Effect on Nitrogen and Phosphorus Regeneration Ratios?

James B. Cotner, Texas A & M University

Texas A & M University Sea Grant College Program Project R/ES-60
Date: 9/1/93 to 8/31/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

- Determine whether zebra mussels change the dissolved nitrogen/phosphorus supply ratio in areas of Lake St. Clair where they are abundant.
- 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.
- Test the hypothesis that increased benthic microbial activity results in lower nitrogen/phosphorus ratios.

Results to Date

◊ Evidence suggests that zebra mussels exert significant impact on the oxygen demand of the sediments either directly through their own respiration or by increasing particulate matter fluxes to the surrounding sediments. Direct respiration seems to be most important.

◊ Mussels have a significant impact on nutrient fluxes from the sediments. In mussel clumps there were some striking increases in ammonium fluxes from the sediments.

◊ Impact of mussels on denitrification rates appears to be negligible. Direct effects through their respiration and nutrient excretion seem to be most important.

Food Chain Contamination of Edible Fish Through Zebra Mussel Directed Trophic Transfer

Susan W. Fisher, The Ohio State University, and Peter F. Landrum, GLERL at NOAA

Ohio Sea Grant College Program Project R/ZM-21
Date: 9/1/93 to 3/31/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

- Quantify partition coefficients for four priority pollutants for three species of algae.
- Measure filtering rates for three species of algae as a function of algal concentration.
- Measure processing of contaminated algae by zebra mussels.
- Quantify contaminant concentrations in zebra mussel tissue, feces, and pseudofeces.
- Measure contaminant transfer from zebra mussel tissue to crayfish and yellow perch.
- Measure contaminant transfer from zebra mussels to feces to gammarids.

Results

◊ Partitioning of four hydrophobic pollutants that vary in log K_{ow} varied significantly with the species of algae.

◊ Log partition coefficients were highest for *Chlamydomonas* and lowest for *Ankistrodesmus*.

◊ Filtering rates for all three algal species varied significantly with algal cell concentration. As cell concentration increased, filtering rate declined such that the total biomass filtered was similar in all cases.

◊ The processing of the three species of algae varied significantly. *Chlamydomonas* and *Chorella* were highly palatable, producing pseudofeces only at high cell concentrations. In contrast, *Ankistrodesmus* consistently produced a high quantity of pseudofeces.

◊ The differential processing of the three algal species is hypothesized to produce significant differences in contaminant distribution when contaminant is delivered sorbed to algal cells.

Effects on Ecosystems

Remote Sensing Studies of Zebra Mussel Impacts in Saginaw Bay

W. Charles Kerfoot and Ann L. Maclean, Michigan Technological University
Michigan Sea Grant College Program Project R/ZM-9 (continuation of R/ZM-6)
Date: 9/1/93 to 8/31/96
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

- Determine whether changes in water quality caused by zebra mussels can be detected, mapped, and quantified using remotely sensed images.
- Determine whether computer-assisted image and analysis procedures that use spectral information can be used to quantify spatial and temporal changes in water quality variables.
- 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
Illinois-Indiana Sea Grant Program Project RZM-5
Date: 8/1/93 through 7/31/95
Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

- Determine how the 1992 zebra mussel invasion of the rock reef in southwestern Lake Michigan will affect the dynamics of the benthic food web.
- Compare pre-1992 data on benthic algal, macroinvertebrate, and crayfish composition and crayfish diet, abundance, and size class distribution with post-1992 data.
- Determine the relative contribution of the benthic and the limnetic littoral communities on total littoral zone primary production.

Results to Date

- Light penetration to the lake-bottom community has increased significantly since the 1992 zebra mussel invasion.
- ◊ The benthic algal community first became dominated by filamentous green zygnematalean algae in 1992 and 1993, and in 1994 these algae were replaced by *Chara*.
- ◊ Densities of amphipods have increased significantly, probably due to their exploitation of zebra mussel feces and pseudofeces.
- ◊ Young-of-the-year crayfish (*Orconectes propinquus* and *O. virilis*) have increased in number, suggesting an increased reproduction or recruitment as a result of increased food availability (algae and macroinvertebrates).

The Effects of Zebra Mussels on the Invertebrate Communities of Saginaw Bay, Michigan, Wetlands

Thomas M. Burton and Valerie J. Brady, Michigan State University
Michigan Sea Grant College Program
Date: 5/24/93 to 5/23/96
Primary Source of Funds: Pass-through from EPA

Objectives

- Investigate the dynamics of zebra mussel colonization of the dominant vegetation *Scirpus americanus* in a coastal wetland.
- Observe how zebra mussels affect the invertebrate community in a coastal wetland.
- Determine direct and indirect effects of zebra mussels on wetland zooplankton.

Results to Date

- ◊ Veligers were present in the marsh from July through October, with a peak in mid- to late-July.
- ◊ Mussels are colonizing the offshore 2/3 of the marsh, with up to 100 mussels per stem of vegetation.
- ◊ Zebra mussels are able to survive the winter in the deeper areas (>75 cm) of the marsh.
- ◊ Rotifers and some small cladocerans are directly filtered by zebra mussels.

Effects on Ecosystems

The Impact of Zebra Mussels on the Dynamics of Heavy Metals

Peter C. Fraleigh, University of Toledo, and Paul L. Klerks, University of Southwestern Louisiana

Ohio Sea Grant College Program Project R/ZM-2
Date: 9/1/92 to 8/31/94
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

- Determine whether zebra mussels increase biodeposition of heavy metals to the lake bottom.
- Test whether zebra mussels increase flux of heavy metals from the water column to the lake bottom.

Direct Experimental Assessment of the Impact of *Dreissena polymorpha* on Unionid Growth, Mortality, and Condition in Lake St. Clair

R. Douglas Hunter, Oakland University

Michigan Sea Grant College Program Project R/ZM-4
Date: 9/1/92 to 8/31/93
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

- Provide direct experimental evidence that zebra mussels cause the death of unionids in Lake St. Clair.
- Evaluate whether zebra mussels also cause reduced growth and emaciation in Lake St. Clair unionids.

Results

- Massive *Dreissena* colonization of *Lampsilis soliquoidea* 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.

The Influence of Zebra Mussels on the Recruitment of Saginaw Bay Fishes

David J. Jude, University of Michigan

Michigan Sea Grant College Program Project R/ZM-5
Date: 9/1/92 to 8/21/95
Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

- Determine which environmental factors are most important in fish year-class strength.
- Test whether zebra mussel and zooplankton abundances affect fish hatching, growth, and mortality.

Results to Date

◊ The 1993 larval fish data indicate that as was found in 1973-75 by O'Gorman, similar species dominate the pelagia: alewife, rainbow smelt, and yellow perch.

◊ Larval fish aged so far appear to be growing well.

◊ Diets of larval fish examined to date consist of the smaller invertebrates, rotifers, nauplii, *Bosmina*, zebra mussel veligers, and *Cyclops*, with very few incidents of *Daphnia* appearing in stomachs, creating a strong suspicion that adequate sizes and quantities of larger zooplankton may not be available for larger sizes (>15 mm) of species, such as alewife and yellow perch.

◊ According to collaborator Tom Nalepa (Great Lakes Environmental Research Laboratory), the populations of rotifers have declined by 2/3 over the period 1991–1993, and *Bosmina* has also declined over this same period.

◊ According to collaborator Robert Haas (Michigan Department of Natural Resources), yellow perch trawl catches have declined precipitously in recent years despite our findings of high densities of larval yellow perch in our spring samples for the same year, implying recruitment failure somewhere between the larval fish and juvenile fish stages in Saginaw Bay.

Effects on Ecosystems

Remote Sensing Studies of Zebra Mussel Impacts in Saginaw Bay

W. Charles Kerfoot and Ann L. Maclean, Michigan Technological University

Michigan Sea Grant College Program Project R/ZM-6

Date: 9/1/92 to 8/31/93

Primary Source of Funding: Pass-through from Michigan DNR

Objectives

- Determine whether changes in water quality caused by zebra mussels can be detected, mapped, and quantified using remotely sensed images.
- Use Advanced Very High Resolution Radiometer (AVHRR) techniques to monitor changes in water temperature, turbidity, and chlorophyll *a* content.
- 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.

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).

The Impact of Zebra Mussels on the Benthic Food Web in Saginaw Bay, Lake Huron

Rex L. Lowe, Bowling Green State University

Ohio Sea Grant College Program Project R/ZM-5

Date: 9/1/92 to 8/31/95

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

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

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.

Phosphorus Budget of a Zebra Mussel Population

Joseph C. Makarewicz, SUNY College at Brockport

New York Sea Grant Institute Project R/CE-4

Date: 9/1/92 to 8/31/94

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

- Determine a phosphorus budget for a zebra mussel population.
- Compare phosphorus cycling in zebra mussels with downstream transport of phosphorus in the Erie Canal.

Effects on Ecosystems

Nutrient Regeneration by Zebra Mussels and its Impact on Phytoplankton

Michael J. Vanni, Miami University

Ohio Sea Grant College Program Project R/ZM-15

Date: 9/1/92 to 8/31/95

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

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

Results to Date

- 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.

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

Ruth Holland Beeton, University of Michigan

Michigan Sea Grant College Program Project R/ZM-3

Date: 8/1/92 to 7/31/94

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objective

- Evaluate how zebra mussels affect the water transparency, nutrient chemistry, and community structure of plankton diatoms in western Lake Erie and the community structure of plankton diatoms in Saginaw Bay.

Results

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

◊ During the same period, water transparency increased by 100 percent.

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

Ohio Sea Grant College Program Project R/ZM-7

Date: 8/1/92 to 7/31/94

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

- 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.
- Confirm that changes in bacterial nutrient dynamics are caused by loss of labile dissolved organic carbon (LDOC, i.e., carbon normally released by algae).

Results

◊ Phosphate uptake by bacteria was consistently greatly diminished when phytoplankton were heavily grazed by zebra mussels.

◊ Phosphorus dynamics in communities dominated by large inedible blue-green algae or colonial chrysophytes were less affected by zebra mussels than communities dominated by small diatoms and edible green algae.

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◊ Phytoplankton communities in eutrophic regions of Saginaw Bay containing large populations of zebra mussels became dominated by large inedible blue-green algae and colonial chrysophytes.

◊ Experimental enclosures placed in the dark to compare bacterial phosphate uptake tested the hypothesis that zebra mussels affect bacterial activities by depriving them of LDOC. Light deprivation of the community led to similar declines in bacterial activities. Also, these activities were partially restored in dark bottles amended with a mixture of amino acids.

Zebra Mussel's Directed Trophic Transfer

Susan W. Fisher, The Ohio State University

Ohio Sea Grant College Program Project 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

- 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 10 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 III, The Ohio State University

Ohio Sea Grant College Program Project 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

- 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 *C. 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 *Phomidium* is present at many of the sampling sites, often colonized directly on zebra mussels and rocks.

Effects on Ecosystems

Responses of Macrophytes and Associated Fish Larvae to Zebra Mussels in Saginaw Bay

Thomas G. Coon and Ted Batterson, Michigan State University

Michigan Sea Grant College Program Project R/ZM-7

Date: 5/1/92 to 4/30/93

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

Objectives

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

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.

The Impact of Zebra Mussel Filtering on Pelagic Food Webs

David A. Culver and Robert M. Sykes, The Ohio State University

Ohio Sea Grant College Program Project R/ZM-3

Date: 2/1/92 to 1/31/95

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

Objectives

- Determine how zebra mussel grazing affects open-water communities.
- Gauge how the benthic boundary layer affects the food available to zebra mussels.

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.

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

Ohio Sea Grant College Program Project R/ZM-4

Date: 10/1/91 to 9/30/94

Primary Source of Funds: Pass-through from EPA

Objectives

- Determine if various sizes of freshwater drum and yellow perch exhibit size-selective predation on zebra mussels.
- Measure prey handling times of various sizes of freshwater drum and yellow perch preying on various sizes of zebra mussels.
- 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.
- Determine digestibility of different sizes of mussels as food for various sizes of freshwater drum and yellow perch.
- Determine the metabolic rates of oxygen consumption and ammonia excretion as a function of swimming speed in freshwater drum and yellow perch.
- Determine energy and protein balance in freshwater drum and yellow perch feeding on zebra mussels, as compared to reference diets.
- Estimate ecological significance of freshwater drum and yellow perch preying on zebra mussels in terms of energy flow in Lake Erie.
- 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.

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- Determine the ability of drum to bioaccumulate various polychlorinated aromatic isomers by feeding on environmentally contaminated zebra mussels.

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.

Accumulation and Trophic Transfer of Organic Xenobiotics 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

Ohio Sea Grant College Program Project R/ZM-1

Date: 10/1/91 to 9/30/93

Primary Source of Funds: Pass-through from EPA

Objectives

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

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 mussels accumulate significant contaminant loads from contaminated water, algae, and sediment.
  - ◊ At low or trace aqueous concentrations of contaminants, ingestion of contaminated particles contributes greater than 50 percent of a zebra mussel's tissue concentration.
  - ◊ Unassimilated contaminants pass through the zebra mussel digestive tract and are present in zebra mussel feces
  - ◊ Zebra mussel feces are readily ingested by invertebrates, such as gammarids.
  - ◊ If gammarids ingest contaminated zebra mussel feces, more than 80 percent of the total contamination load will be transferred from feces to gammarids.
  - ◊ Due to food chain magnification, a fish that ingests equivalent masses of contaminated zebra mussels and gammarids will experience 4–5 times more contaminant exposure by eating gammarids.
  - ◊ Zebra mussels are significantly altering contaminant cycling in the Great Lakes.

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

Ohio Sea Grant College Program Project R/ZM-6

Date: 9/1/91 to 8/31/92

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

Objectives

- Test the hypothesis that zebra mussels alter carbon and phosphorus dynamics at the base of the food web by grazing selectively on phytoplankton but not on bacteria.
- Determine whether these effects are related to the trophic state of the community and zebra mussel density.

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Results

- Zebra mussels preferentially graze diatoms and small green algae.
- Bacteria are grazed only slightly or not at all; their populations do not change significantly in the presence of zebra mussels.
- Communities with large portions of large, inedible, blue-green algae were less affected in these experiments.
- ◊ Bacterial productivity (3H-thymidine method) is reduced in the presence of zebra mussels by as much as 70 percent.
- ◊ Phosphate is released by zebra mussels and phosphate uptake by bacteria is greatly reduced.
- ◊ Dissolved organic phosphorus (DOP) release is slowed in the presence of zebra mussels.
- ◊ Oligotrophic, mesotrophic, and eutrophic communities were all affected in these ways.

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

Dianna K. Padilla and Stanley I. Dodson, University of Wisconsin

Wisconsin Sea Grant Institute Project R/LR-41
Date: 8/1/91 to 7/31/93
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives

- Develop models to predict zebra mussel abundance, distribution, population dynamics, and ecological effects in North America.
- Determine which factors are most important in predicting population performance.
- Predict areas likely to be invaded and how zebra mussels might change those ecosystems.

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 and Myron J. Mitchell, SUNY College at Stony Brook; Edward L. Mills and John L. Forney, Cornell Biological Field Station

New York Sea Grant Institute Project R/CE-3
Date: 8/1/91 to 7/31/94
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives

- Test the hypothesis that open-water production of zooplankton will decline in response to colonization by zebra mussels.
- Create a computer model of nutrient-plankton interactions to predict Oneida Lake's response to invasion by zebra mussels.
- Gauge how zebra mussels might affect nutrients, phytoplankton, zooplankton, and larval fish.

Results to Date

- 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.
- ◊ The spring clearwater phase in both 1992 and 1993 was especially clear and the lake experienced a nearly unprecedented bloom of blue-green algae late in the summer of 1992.

Effects on Ecosystems

Epilithic Benthos in the Western Basin of Lake Erie

Jerry H. Hubschman, Wright State University

Ohio Sea Grant College Program Project 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

- 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—53 macroinvertebrate taxa have been identified in samples.

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

Joseph C. Makarewicz, SUNY College at Brockport

New York Sea Grant Institute Project 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

- Test the ability of the pelagic *Daphnia* and the benthic 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.

The Fate of Phytoplankton Following Processing by the Zebra Mussel

Rex L. Lowe, Bowling Green State University

Ohio Sea Grant College Program Project 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

- Determine which algal species become zebra mussel feces and pseudofeces.
- Determine the survival of algae following zebra mussel planktivory.
- 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.

Effects on Ecosystems

Monitoring the Ecological Impact of Zebra Mussels in the Eastern Basin of Lake Erie

Howard P. Riessen, SUNY College at Buffalo

New York Sea Grant Institute Project 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

Objectives

- Monitor and follow the population dynamics of the first invading zebra mussel veligers in the eastern end of Lake Erie.

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.

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

Ohio Sea Grant College Program Project 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

- Follow changes in zooplankton as the zebra mussel population grows.
- Determine the effects of mussel competition and predation on community structures.

Results to Date

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

Grazing Rates of Zebra Mussels

David A. Culver, The Ohio State University

Ohio Sea Grant College Program Project 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

- 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.
- Examine the effects of vertical mixing rates of the western basin of Lake Erie 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.

Effects on Ecosystems

Concentration of Hydrophobic Carcinogens by Zebra Mussels: Effects on Aquatic Food Chains

Susan W. Fisher, The Ohio State University, Paul C. Baumann, U.S. Fish and Wildlife Service National Contaminant Research Center

Ohio Sea Grant College Program Project R/PS-6-PD
Date: 4/1/90 to 12/31/90
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective

- To make toxicokinetic and physiological measures to examine the movement and importance of contaminants passing through zebra mussels into the greater Great Lakes food web.

Results

- Accumulation rates drop by a factor of two for each 10°C change in temperature.
- Zebra mussels are likely to concentrate contaminants at a level 100 times greater than would be expected in fish.
- Bioconcentration of contaminants in zebra mussels depends on environmental temperature and the contaminant's affinity for water.

The Effects of Zebra Mussels on Pelagic Communities

David A. Culver, The Ohio State University

Ohio Sea Grant College Program Project 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

- 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.

Interactions Between Newly-Introduced Zebra Mussel *Dreissena polymorpha* and Pelagic Communities

David W. Garton and David A. Culver, The Ohio State University

Ohio Sea Grant College Program Project 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

- Examine whether zebra mussels have diverted a significant amount of energy from the open-water food web to the lake bottom.
- Determine whether zooplankton growth slows as zebra mussel production increases.

Results

◊ Individual consumption rates determined from seasonal energy budgets are estimated to be 2.8 cal per day.

◊ At a density of 50,000 mussels per square meter, and assuming 1 kcal per gram wet weight of algae and a seasonal range of 5–10 grams wet weight algae per cubic meter, then the zebra mussel population at a 7-m site in western Lake Erie could consume 2–4 times the standing phytoplankton biomass per day.

◊ These calculations indicate that the present population of zebra mussels in western Lake Erie consumes a significant proportion of annual primary production, thus altering lake food web dynamics.

Research Projects

New projects are marked with a triangle(▲). All results are current through 1994. New results of earlier projects are marked with a diamond (◊).

Socio-Economic Analysis: Costs and Benefits

Experience with invading species tells us that their negative impacts usually outnumber the positive; researchers should investigate both. In the case of the Great Lakes, invading organisms might introduce disease, concentrate pollutants, contaminate drinking water, or otherwise affect human health. On the other hand, invading species might also be used as food for domestic animals or fertilizer for gardens and crops. Research here must also examine how invading species affect sport, commercial, and tribal fishing industries, the recreation and tourism industry, the shipping and navigation industry, and municipal and industrial water users. These research results become the foundation for sound science-based policy and environmental law, and for useful public education and outreach projects.

Present and Expected Economic Costs of Zebra Mussel Damages to Water Users with Great Lakes Water Intakes

Leroy J. Hushak, The Ohio State University

Ohio Sea Grant College Program Project R/ZM-12

Date: 9/1/93 to 8/31/95

Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

- 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).
- Survey public organizations and researchers about annual spending on zebra mussel control research.
- Survey researchers at public and private institutions about the feasibility of zebra mussel control research resulting in annual cost reductions for industry.
- Estimate the expected annual rate of return of investment in zebra mussel control research to industries with Great Lakes water intakes.

Results to Date

◊ Questionnaires seeking information about zebra mussel damages and zebra mussel control strategies were mailed to about 1,500 facilities (electric generating power plants, municipal water systems, and industrial water users) with water intakes in the Great Lakes basin during November 1994. As of December 1, 1994, 70 were returned as undeliverable and about 200 had responded, for a response rate of 14 percent.

◊ About 300 zebra mussel research investigators have been identified to receive the research questionnaire in early 1995, which seeks information about research expenditures and new discoveries affecting zebra mussel control strategies.

A Policy Framework for Nonindigenous Species in the Great Lakes

Alan J. Randall, The Ohio State University

Ohio Sea Grant College Program Project R/ZM-14

Date: 9/1/92 to 8/31/94

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

- Develop policy approaches that are appropriate for accidental introductions, purposeful private introductions, and purposeful public introductions of exotic species.
- Develop a method to identify the costs and benefits of both accidental and planned introductions of exotics.
- Complete a cost-benefit analysis of an introduction that has already occurred in the Great Lakes.

Socio-Economic Analysis

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

New York Sea Grant Institute Project R/SWM-1

Date: 9/1/91 to 8/31/94

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

Objectives

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

Results to Date

◊ Zebra mussels successfully composted in a mixture with poultry manure, sawdust, peat moss, and wood chips.

◊ There are good preliminary results in plant growth trials with compost, although more work on shell size reduction and consumer perception is needed.

The Economic Costs of the Zebra Mussel to Ohio's North Coast Economy

Leroy J. Hushak, The Ohio State University

Ohio Sea Grant College Program Project R/ZM-13

Date: 8/1/91 to 7/31/93

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

Objectives

- Survey Ohio and Michigan licensed drivers about their current and future recreational activities on Lake Erie and costs incurred as a result of zebra mussels.
- Estimate the economic value and impact of Lake Erie tourism and recreational fishing, and how they have been affected by zebra mussels.

Results

◊ About 27 percent (828 of 3,072) of Ohio and Michigan licensed drivers responded to a survey of recreational participation at Lake Erie during 1992 and how it was affected by the zebra mussel and other changes in the lake environment.

◊ While more visitors view the zebra mussel as directly decreasing Lake Erie satisfaction than increasing it (34% vs 6%), more visitors view increased water clarity as increasing satisfaction than decreasing it (34% vs 21%).

◊ Of respondents who visited Lake Erie, 28 (11%) said the zebra mussel had affected the amount of time spent at Lake Erie. Of these 28, 22 said they had decreased the amount of time at Lake Erie, while 5 reported increased time at Lake Erie.

◊ Relatively few reported increased boating costs due to the zebra mussel: 14 reported increased paint costs averaging $81; three reported maintenance costs averaging $60; two increased repair costs of $88; and three moved their boats to dry storage at an average cost of $178.

◊ Preliminary statistical tests do not support the hypothesis that the zebra mussel has reduced recreational participation at Lake Erie.

Socio-Economic Analysis

The Role of Fishing and the Zebra Mussel on the Tourism Industry

Leroy J. Hushak, The Ohio State University

Ohio Sea Grant College Program Project R/ME-12

Date: 9/1/90 to 8/31/92

Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objectives

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

Results

- Only two 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 zebra mussel has had minimal impacts on the recreational behavior of visitors to Ohio's portion of Lake Erie.

The Economic Costs of the Zebra Mussel

Leroy J. Hushak, The Ohio State University

Ohio Sea Grant College Program Project R/ME-14-PD

Date: 4/1/90 to 12/31/91

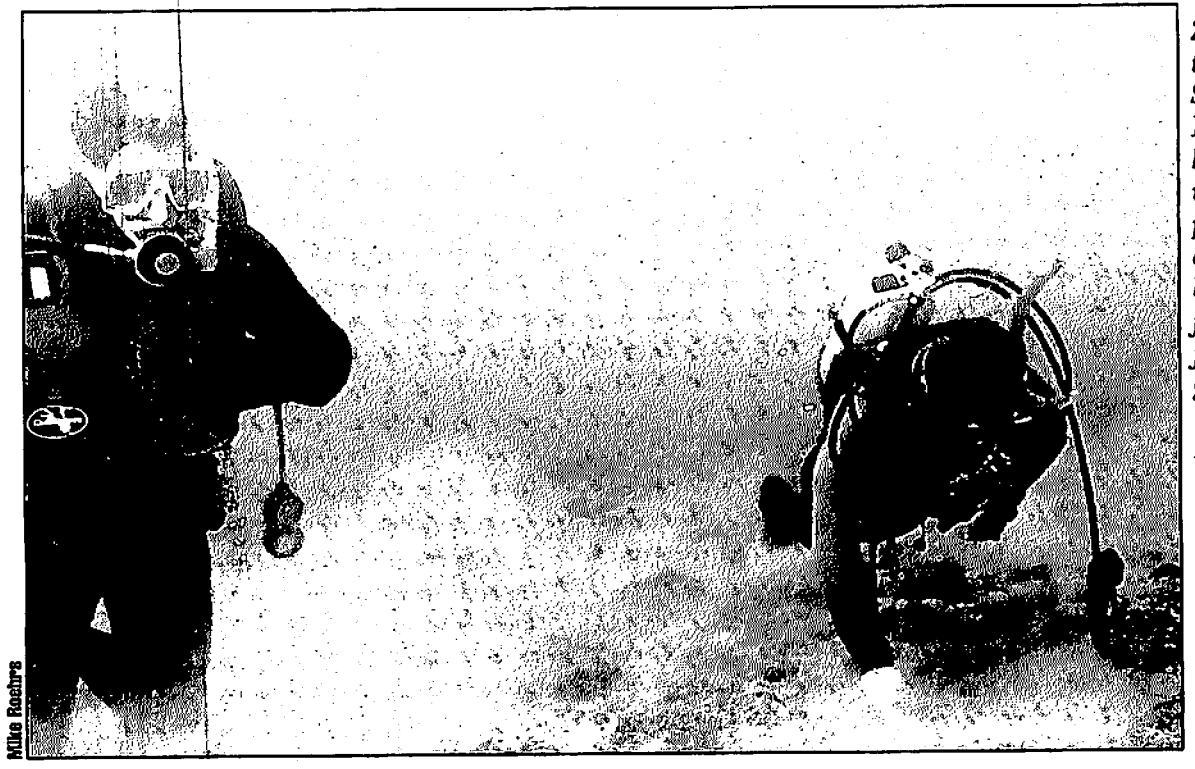
Primary Source of Funds: Local Sea Grant program from federal and nonfederal sources

Objective

- 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.



Mike Roche

Zebra mussels at the bottom of Saginaw Bay, Lake Huron, have clarified the water (as this photo testifies), causing a shift in benthic algae from diatoms to filamentous green algae (Zygnematales). In the summer of 1992, much of this algae became detached and washed ashore closing many public beaches. (Lowe and Pillsbury, p. 7)

Research Projects

New projects are marked with a triangle(▲). All results are current through 1994. New results of earlier projects are marked with a diamond (◊).

Control and Mitigation

Temporary measures may mitigate the effects of invading species, but effective control requires long-term research. Control of the sea lamprey in the Great Lakes is an example of this. Control of other invaders in the Great Lakes may be physical (redesigning water intakes, scraping, filtering), chemical (biocides, antifoulants), biological (parasites, predators), or physicochemical (heat, salinity, pH). Research to determine an invader's physical, chemical, and biological requirements and its physiology, genetic make-up, and behavior is necessary to develop selective, effective controls that must also be ecologically responsible. Biocides, for example, must be tested to be sure they are not toxic to other organisms and are not persistent or likely to bioaccumulate, causing even greater problems in the future.

▲ Design and Test of a Novel Device for the Control of Zebra Mussel Infestation in Water Piping Systems

Tiao J. Chang, Ohio University
Ohio Sea Grant College Program Project R/ZM-26
Date: 9/1/94 to 8/31/95
Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Develop a strategy for zebra mussel control that relies on physical rather than chemical methods.
- Capitalize on the observation that reduction in dissolved oxygen was effective in removing zebra mussels from an infested pipe.
- Design and test the effectiveness of a device that mechanically reduces the dissolved oxygen in a zebra mussel infested piping system.

▲ Silencing Expression of the Byssus in Zebra Mussels

J. Herbert Waite, University of Delaware
Delaware Sea Grant College Program Project NA
Date: 9/1/94 to 8/31/97
Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Derive the complete cDNA-derived sequence of the byssal precursor proteins dpfp-1 and dpfp-2 in the zebra mussel *Dreissena polymorpha*.
- Perform *in vitro* translation of zebra mussel mRNA and hybrid arrest of dpfp-1 and dpfp-2 by antisense mRNA.
- Prepare nuclease-resistant analogs of antisense oligonucleotides that silence expression of byssal precursor proteins.

▲ Effect of High Voltage Electrostatic Fields on the Control of Zebra Mussels

Alphonse E. Zanoni, James S. Maki, and Zack A. Shana, Marquette University
Wisconsin Sea Grant College Program Project R/NI-24
Date: 9/1/94 to 8/31/96
Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Apply continuous high voltage electrostatic fields (up to 20 KV/cm) with extremely low currents (in the nanoampere range) to inhibit the attachment of zebra mussels to water intake pipes and other water system components.
- Experimentally determine the optimal electrostatic field environment that will discourage the attachment of post-veligers and juvenile mussels to surrounding surfaces.
- Evaluate the effect of electrostatic fields on nontarget organisms.
- Test a field flow-through device with continuous application of an electrostatic field in Lake Michigan.

Control and Mitigation

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

John E. Van Benschoten and Joseph F. Atkinson, State University of New York at Buffalo

New York Sea Grant Institute Project R/EMS-7

Date: 8/1/93 through 7/31/95

Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

- Characterize how coagulants affect veliger behavior.
- Characterize the particle stability characteristics of both veliger and nonveliger particulates.
- Identify how adding coagulants at water intakes affects solid-liquid separation processes.
- Measure particle aggregation/disaggregation characteristics of veligers at varying coagulant doses and turbulence levels.
- Develop a model predicting how coagulant additions would affect different water intakes.

Results to Date

◊ Aluminum based coagulants can induce mortality in veligers, but the effects appear to be related more to the acidity of the coagulant than aluminum toxicity.

◊ Veliger mortality is induced below a critical pH of about 6.5.

◊ Veligers do not appear to be enmeshed in aluminum precipitates formed by aluminum coagulants.

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

Mary D. Balcer, University of Wisconsin

Wisconsin Sea Grant Institute Project R/LR-47

Date: 7/1/93 to 6/30/95

Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

- 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.
- Estimate how many zebra mussel veligers and juveniles are introduced yearly to Duluth-Superior harbor from ballast water discharge and boat hull transport.
- Explore how continuous introductions help mussel populations reach the numbers necessary for self-sustaining population growth.

Results to Date

- 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 G. Guida and Nenad Sarunac, Lehigh University

New Jersey Marine Sciences Consortium Sea Grant Program Project R/E-44ZM

Date: 7/1/93 to 6/30/95

Primary Source of Funds: Fiscal Year 1993 Zebra Mussel Federal Appropriation

Objectives

- 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.
- Determine the optimal level of continuous chlorine necessary to control zebra mussel settlement in a Hudson River water intake.
- Test the degree of control, chlorine consumption, and chlorine discharge associated with boundary layer chlorination.

Control and Mitigation

Application of Wide-Range Ultraviolet Radiation for Zebra Mussel Control

Linda Chalker-Scott, SUNY College at Buffalo

New York Sea Grant Institute Project R/EMS-6 (continuation of R/EMS-3)

Date: 9/1/92 to 8/31/94

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

- Determine the minimum level of ultraviolet exposure necessary to prevent larval settling, and the minimum chronic level necessary to kill existing populations.
- Gauge the effects of ultraviolet light on veliger behavior.
- Develop a prototype instrument that will deliver ultraviolet radiation in restricted locations.

Results to Date

- 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.

◊ Field experiments with 4166 L tanks and a 5000 watt UV source killed 100 percent of *Dreissena polymorpha* veligers at the slowest flow rates. (Mortality of control organisms was 20–30 percent, typical of larvae gathered in the field and reared in the lab.) Faster flow rates produced lower mortality, but this may be attributable as much to the prototype design as to the efficacy of UV radiation.

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

Dimitri M. Donskoy, Stevens Institute of Technology

New Jersey Marine Sciences Consortium Sea Grant Program Project R/E-29ZM

Date: 9/1/92 to 9/30/95

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

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

Results to Date

◊ Ultrasonic and hydrodynamic cavitation destroys veligers.

◊ Hydrodynamic cavitation treatment is more energy efficient than ultrasound cavitation.

◊ Solidborne vibration can protect pipe and tank walls against mussel settling.

◊ Low frequency (20–1000 Hz) waterborne sound waves stress veligers and prevent juvenile and adult mussels from settling and translocating onto exposed surfaces.

◊ Ultrasound pulse-echo technique can be used for evaluation of mussel populations.

Control and Mitigation

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

William Elzinga, Environmental Science and Engineering, Inc.

Illinois-Indiana Sea Grant Program Project ZM/4

Date: 9/1/92 to 12/31/93

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

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

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

Massachusetts Institute of Technology Sea Grant College Program Project RT-35

Date: 9/1/92 to 8/31/95

Primary Source of Funds: Fiscal Year 1992 Zebra Mussel Federal Appropriation

Objectives

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

Results to Date

◊ A library of antagonistic microorganisms is being isolated. Culture filtrates are being concentrated and analyzed for activity against zebra mussels.

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

David W. Garton, The Ohio State University

Ohio Sea Grant College Program Project 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

- 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.

Control and Mitigation

The Use of Potassium in Control of the Zebra Mussel *Dreissena polymorpha* (Pallas)

Susan W. Fisher and Paul C. Stromberg, The Ohio State University

Ohio Sea Grant College Program Project R/ZM-11
Date: 2/1/92 to 1/31/94
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives

- Evaluate potassium salts as molluscicides.
- Determine whether low levels of potassium deter zebra mussel attachment.
- Measure potassium's toxicity to nontarget animals.

Results

◊ Potassium is highly toxic to adult mussels. It is 10–100 times less toxic to eight species of fish tested than to the zebra mussels.

◊ Potassium chloride (KCl), the most economical and environmentally compatible form, kills zebra mussel veligers and plantigrades at concentrations below those that kill larval fish.

◊ Potassium appears to have no adverse effects on other aquatic animals—even at 10 times the dose used to kill zebra mussels.

◊ Pulsed exposure (2 hr on/2 hr off) to 50 ppm K^+ prevents settling of veligers.

◊ Exposure to potassium causes ciliostasis.

◊ The mode of action for K^+ toxicity appears to be asphyxiation as intoxicated mussels can be maintained by simultaneous exposure to 20 ppm O_2.

◊ Degassing of water with N_2 mimics the effect of K^+ exposure and is consistent with asphyxiation as a cause of death.

◊ NMR [nuclear magnetic resonance] spectroscopy shows that ATP decreases while AMP and ADP increase during potassium exposure.

◊ Histological studies reveal two levels of toxicity. The first, which is reversible, results in appearance of vacuoles and loss of mitochondria. The second is the irreversible destruction of the gill epithelium.

◊ Uptake studies with ^{86}Rb tracers (as a substitute for K^+) show rapid uptake and dissemination of K^+ in the zebra mussel tissue.

◊ Electrocardiograms, taken during K^+ exposure, have shown that cardiac cilia continue to beat even at concentrations sufficient to cause cardiac arrest.

◊ Zebra mussels can recover from cardiac arrest of up to 1 hr.

◊ Cardiomyopathy may contribute to the toxicity of potassium.

Nonpolluting Control of Biosurface Fouling

Robert E. Baier and Anne E. Meyer, State University of New York at Buffalo

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

Objectives

- Determine how zebra mussel attachment and settling relate to the surface energy of the substrate and other substrate characteristics.
- 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.
- Identify coatings that prevent attachment without harming the environment.

Results to Date

◊ Zebra mussel veliger settling and attachment to diverse substrata were essentially indifferent to variations in the substrata characteristics. The main segregation occurred after attachment into substrate groups that either retained the deposited biomass tenaciously or allowed its easy mechanical dehiscence.

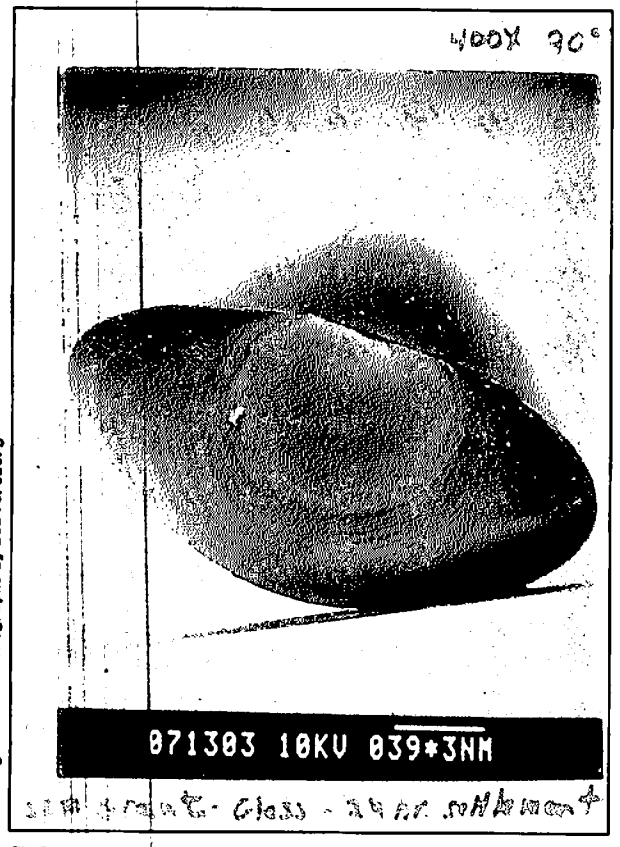
◊ Within 7 days of field exposure of various clean substrata to freshwater sites throughout upstate New York, spontaneously deposited films of glycoproteins, followed by bacteria and diatoms, preceded attachment of zebra mussel veligers (even when veligers were simultaneously abundant in the water column).

☛

Control and Mitigation

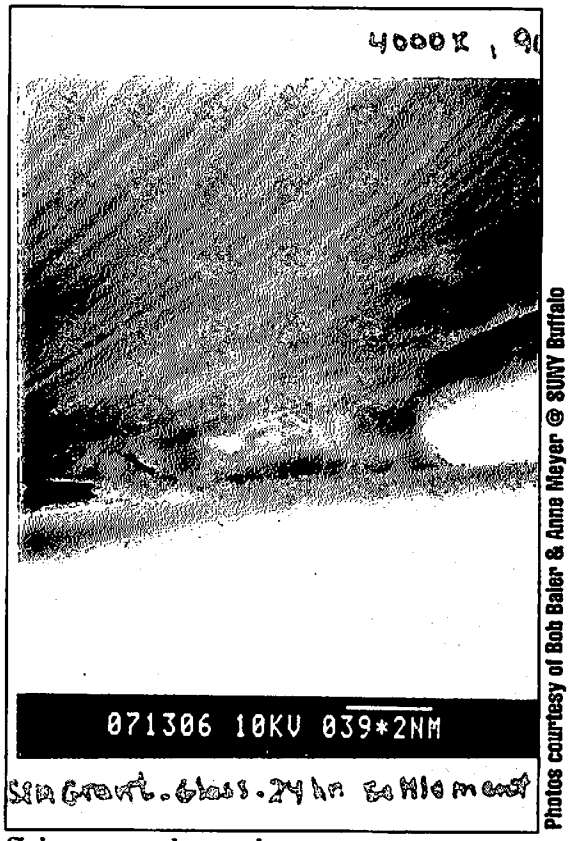
- The range of surface energies, described via the empirical parameter of Critical Surface Tension, that allowed zebra mussel attachment strength to achieve levels of only 50 psi or less (in the best cases, below 20 psi) were 20–30 mN/m [milli-Newtons/meter]. Common Teflon™, polyethylene, and polystyrene materials are not in this favorable range.
- Based on these results, it is unlikely that the flow rates prevailing in power plant intake structures will be sufficient to *completely prevent* zebra mussel attachment from taking place.
- Collaboration with Dr. Tom Bonner (SUNY/Brockport) provided evidence for an hypothesized mechanism of a cellular phagocytosis that "cleans" pre-existing biofilm from attachment sites.
- Collaboration with Dr. Herbert Waite (University of Delaware) provided data that should allow molecular configurations of the adhesive proteins to be better specified by future molecular modeling studies.

Zebra Mussel Attachment and Dehiscence



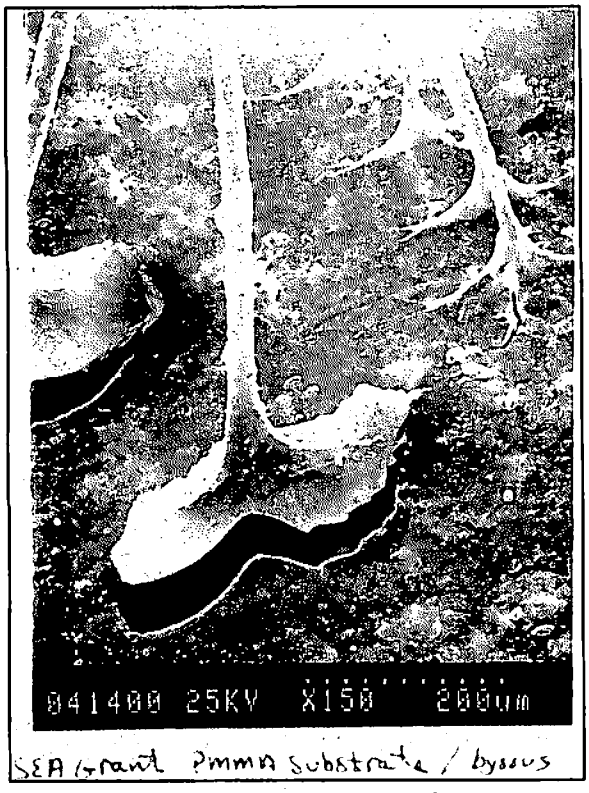
Scanning Electron Micrographs by Bob Forsberg

Zebra mussel pediveliger attachment to clean glass.



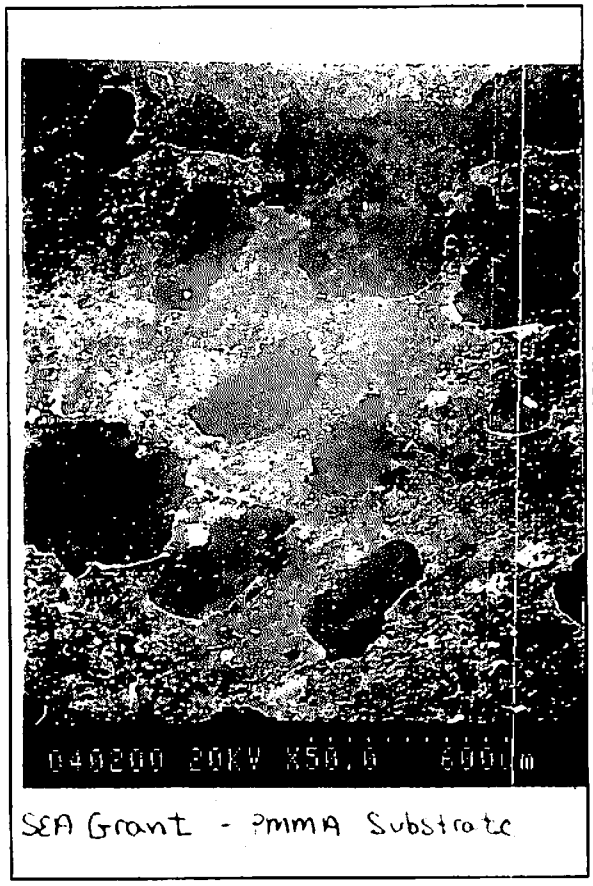
Photos courtesy of Bob Baier & Anne Meyer @ SUNY Buffalo

Zebra mussel attachment uses a glycoproteinaceous cement rich in dihydroxyphenylalanine.



Scanning Electron Micrographs by Bob Forsberg

Adult zebra mussel byssus attachment engulfs pre-existing biofilm debris within the foamy glycoprotein glue.



Photos courtesy of Bob Baier & Anne Meyer @ SUNY Buffalo

Removal of zebra mussel byssal structures also engulfed biofilm components, trapped within the original attachment "foam."

Effect of Ultraviolet-B Radiation (280–320 mm) on Survivorship of Zebra Mussel (*Dreissena polymorpha*): A Potential Control Strategy

Linda Chalker-Scott, Howard P. Riessen, and James D. Scott, SUNY College at Buffalo

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

Objectives

- Determine which zebra mussel life stages are sensitive to UV-B radiation.
- Determine minimum dose needed for significant mortality.
- 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.

Control and Mitigation

Approaches to Zebra Mussel Control Through Intervention in Reproduction

Jeffrey L. Ram and Peter Fong, Wayne State University

Michigan Sea Grant College Program Project R/ZM-1

Date: 8/1/91 to 7/31/94

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

Objectives

- Determine internal and external spawning triggers in male and female zebra mussels.
- Determine the chemical structure of spawning inducers.
- Develop inhibitors to zebra mussel spawning.
- Identify a field site for testing spawning inducers and inhibitors.

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.

Application of Underwater Robots to Perform Inspection, Cleaning, and Maintenance of Intake Pipes

Samuel E. Landsberger, Cornell University

New York Sea Grant Institute Project 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

- Develop a prototype robot that will clean and inspect water intake pipes.
- Design and test technology for underwater robots that will perform work in constrained environments.

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.

Evaluation of Molluscicides for Zebra Mussel Control

Susan W. Fisher and Jeffrey M. Reutter, The Ohio State University

Ohio Sea Grant College Program Project: NA

Date: 5/10/91 to 9/30/93

Primary Source of Funds: Pass through from U.S. Fish and Wildlife Service

Objective

- Evaluate a series of candidate molluscicides.

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

The unripe berries of Phytolacca dodecandra

Harold H. Lee

Control of Zebra Mussels with Lemmatoxins, A Natural Molluscicide from *Phytolacca dodecandra*

Harold H. Lee, The University of Toledo

Ohio Sea Grant College Program Project 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

- Determine the efficacy of Endod, a natural molluscicide from *Phytolacca dodecandra*, in zebra mussel control.

Results

◊ Lemmatoxin (Endod) doses of 15 mg/L are lethal to adult mussels and veligers for an exposure duration of 4 or 6 hrs in static assay or running raw water in field testing, respectively. Lower doses prevent formation of byssal threads, prevent adhesion of veligers, and reduce adhesion force and aggregation of adults.

◊ Only intermittent treatment of infested water pipes with Endod is needed.

◊ Endod may be used in tandem with other mechanical and chemical agents. The target organ(s) may be the byssus apparatus and the gills.

◊ Two U.S. patents have been granted for Endod for which this was the initial work.

Testing of Mechanical, Molluscicidal, Antiattachment, Antibiofouling Agents on the Zebra Mussel

Susan W. Fisher, The Ohio State University

Ohio Sea Grant College Program Project 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

- 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 ppm .
- These chemicals are effective under a wide variety of environmental conditions.

Research Projects

New projects are marked with a triangle(▲). All results are current through 1994. New results of earlier projects are marked with a diamond (◊).

Preventing New Introductions

Once established in an open aquatic system, most nonindigenous species prove impossible to eliminate. While they may eventually be controlled, it is usually expensive and frequently they have disturbed the ecosystem. Therefore, the prevention of unintended introductions is paramount. Ballast water discharge, for example, is an important vector of exotic species to the Great Lakes. Research must find ways to eliminate this means of introduction, without undue hardship to the shipping industry or the economy.

Ship Operational & Safety Aspects of Ballast Water Exchange at Sea

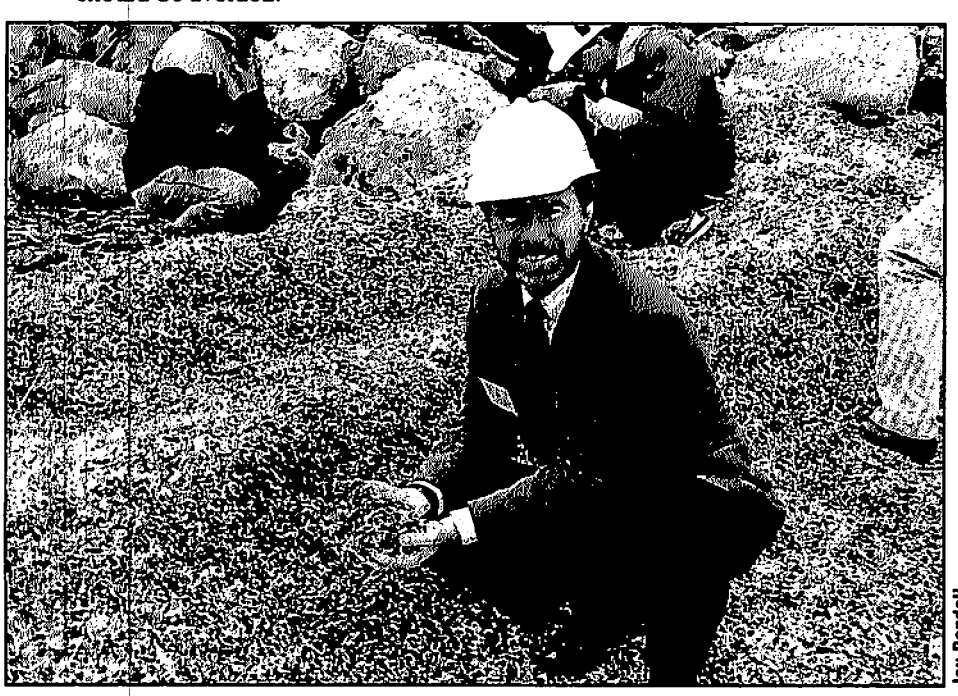
John B. Woodward, Michael G. Parsons and Armin W. Troesch, University of Michigan
Michigan Sea Grant College Program Project R/ZM-2
Date: 8/1/91 to 7/31/92
Primary Source of Funds: Fiscal Year 1991 Zebra Mussel Federal Appropriation

Objectives

- Analyze how hull bending stresses change during at-sea ballast water exchanges.
- Describe the consequences of ballast exchange during bad weather.
- Determine whether slowing or rerouting may result from ballast exchange in bad weather.
- Make ballast exchange recommendations to the U.S. Coast Guard.

Results

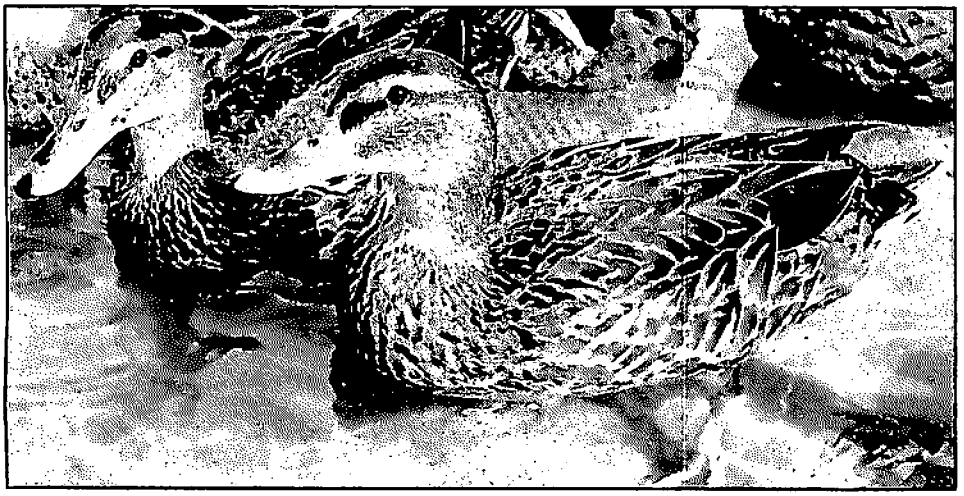
- Ballast water exchange is not likely to affect metacentric height—a measure of ship stability.
- Ballast water exchange during storms that produce a significant wave height of 10 feet appears to be safe—it creates bending and shear values still within American Bureau of Shipping safety guidelines.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

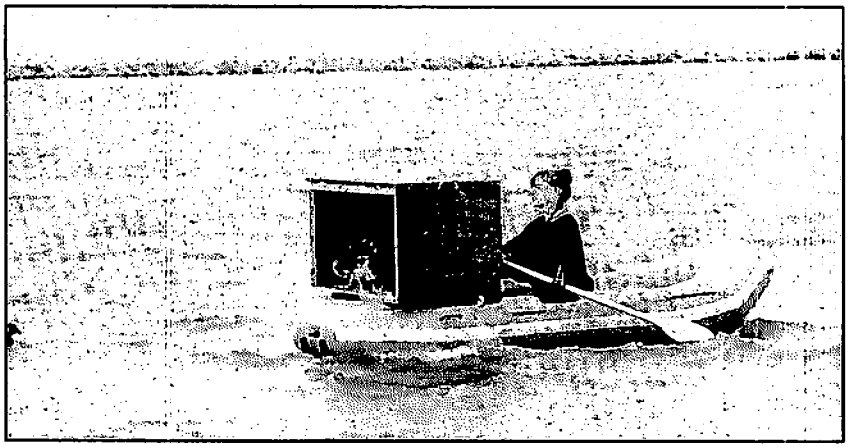


Jay Randall

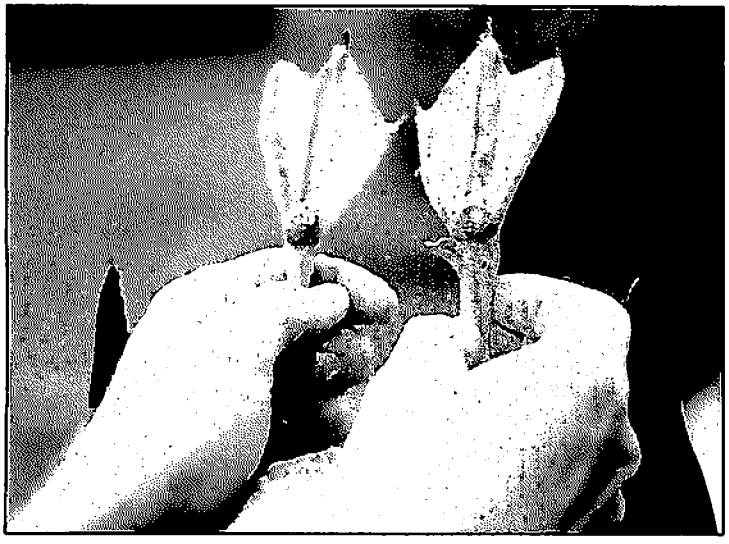
Zebra mussels are so numerous in Lake Erie that their spent shells form windrows.

Ducking Responsibility





photos by Ladd E. Johnson



Work by Johnson and Carlton concluded that ducks do not significantly contribute to the transportation and spread of zebra mussels. Transport, then, is likely exclusively from human activities, so that laws and policies governing human behavior should be the most effective means of controlling the mussel's spread.

Research Projects

New projects are marked with a triangle(▲). All results are current through 1994. New results of earlier projects are marked with a diamond (◊).

Reducing the Spread of Established Populations

Most nonindigenous species are knowingly or accidently transported and spread by human activities. Scientists might then predict the greater spread of an invader by analyzing what it requires and can tolerate in its environment and by its dispersal mechanisms. Dispersal mechanisms and tolerable habitats, however, are discovered usually only as an organism extends it range. This requires swift action from the time of discovery of the mechanism(s) and tolerances to the development of safeguards and international protocols to prevent and/or slow the spread of invaders to uninfested areas.

▲ Range of Expansion of Zebra Mussels: Are Rivers Less Susceptible to Colonization Than Lakes?

Mary D. Balcer, University of Wisconsin-Superior
University of Wisconsin Sea Grant Institute Project R/LR-57
Date: 9/1/94 to 8/31/95
Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Investigate whether the seasonal fluctuations in river systems, due to spring and summer runoff that greatly reduce calcium and pH levels, affect the survival, growth, sexual maturation, and spawning success of zebra mussels.
- Examine the susceptibility of several genetic strains of zebra mussels to the above conditions to determine if any adaptations are occurring that might influence colonization success.
- Determine if some rivers systems are actually protected from zebra mussel invasion by runoff conditions so that efforts for mitigation can be redirected to more high-risk areas.

▲ An Assessment of the Overland Dispersal of Zebra Mussels into Inland North American Lakes

Ladd E. Johnson, Williams College-Mystic Seaport, and Clifford Kraft, University of Wisconsin-Green Bay
University of Wisconsin Sea Grant Institute/Connecticut Sea Grant Project R/LR-62
Date: 9/1/94 to 8/31/97
Primary Source of Funds: Fiscal Year 1994 Zebra Mussel Federal Appropriation

Objectives

- Document the spatial and temporal pattern of the spread of zebra mussels within local systems of inland waters using standardized methods for detecting the presence of zebra mussels.
- Compare the characteristics of invaded and noninvaded lakes to determine correlates of invasion susceptibility and infer likely mechanisms of dispersal.
- Assess the relative importance of primary and secondary invasion events on the spread of zebra mussels within local systems of inland waters.
- Compare patterns of local invasions in different regions to observe any patterns and test predications of the importance of the "exposure" of inland systems to nearby source populations. Assess the initial efficacy of educational and outreach programs.

Reducing the Spread

Prediction and Early Detection of Zebra Mussel Invasions of the Inland Waters of Michigan

Ladd E. Johnson and James T. Carlton, Maritime Studies Program

Michigan Sea Grant College Program Project 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

- Determine the likely rate, direction, and pattern of the spread of zebra mussels to Michigan's inland waters.
- Test the hypothesis that recreational boat traffic between the Great Lakes and inland waters is responsible for initial invasions.
- Detect the early stages of zebra mussel invasion of Michigan's inland lakes.

Results

◊ The presence of zebra mussels was detected in 10 of 33 lakes in Michigan considered to be at high risk to invasion due to high levels of transient boating activity.

◊ Invasibility of lakes does not clearly depend on any one risk factor (e.g., lake size, proximity to infested waters, public access).

◊ The use of plankton samples combined with cross-polarized light microscopy appears to be the most effective means of early detection of "cryptic" zebra mussel populations in inland lakes. (see photos, pp. x and 37.)

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

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Connecticut Sea Grant Program Project R/ES-5

Date: 7/1/91 to 6/30/93

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

Objectives

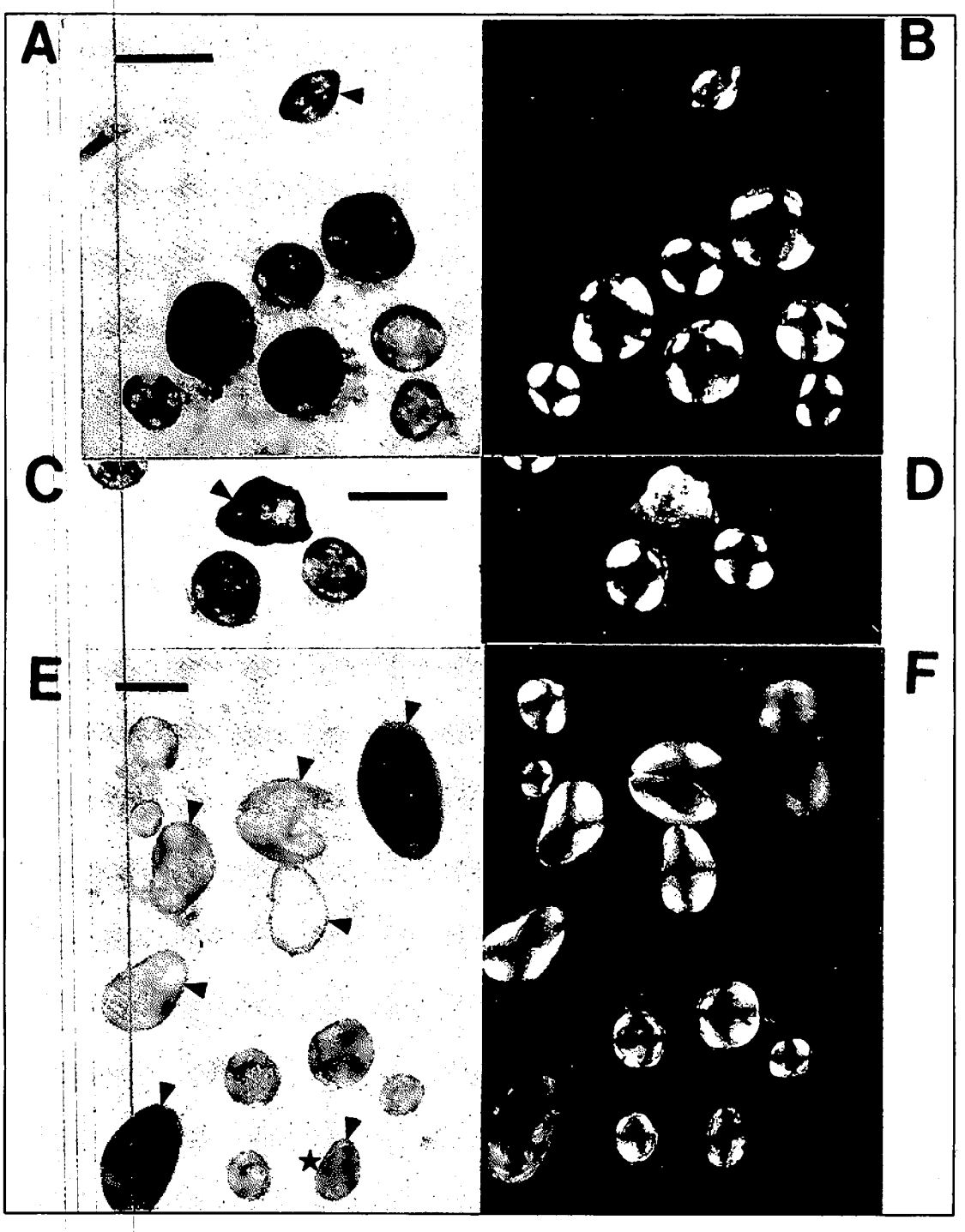
- Quantify the role of sport boats, commercial craft, and sport fishing in dispersing zebra mussels in the Great Lakes basin.
- Conduct experiments to test how vessels and sport fishing affect zebra mussel dispersal.
- Conduct preliminary investigations on natural dispersal vectors, especially aquatic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

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.

Enhancing zebra mussel veliger detection with cross-polarized light.

Various plankton samples seen under polarized light (A, C, & E) and under cross-polarized light (B, D, & F) (Polarized light was used instead of unpolarized light because the use of non-polarized light would have required the repetitive removal and installation of the polarizing filters.) A & B: zebra mussel veligers without extraneous material. Note that the distinctive "Maltese cross" pattern of birefringence of veligers on their sides is not evident when the veliger is viewed edge on (arrowhead); scale bar = 200 µm. C & D: veligers and sand grain (arrowhead). Note that sand grain does not produce the "Maltese cross" pattern. Sand grains are also usually multi-colored while veligers are always white; scale bar = 200µm. E & F: mixed collection of veligers and ostracods (arrowhead). Note that size ranges of veligers and ostracods overlap (e.g. star) and that empty ostracod "shells" (lighter individuals in E) are more birefringent, and thus more similar to veligers, than whole animals due to the lack of interfering body tissue. Certain morphological features that distinguish veligers from ostracods are not visible at this magnification, e.g., shell ornamentation; scale bar = 200µm (Johnson and Carlton, p.36; additional photo, p. x.)



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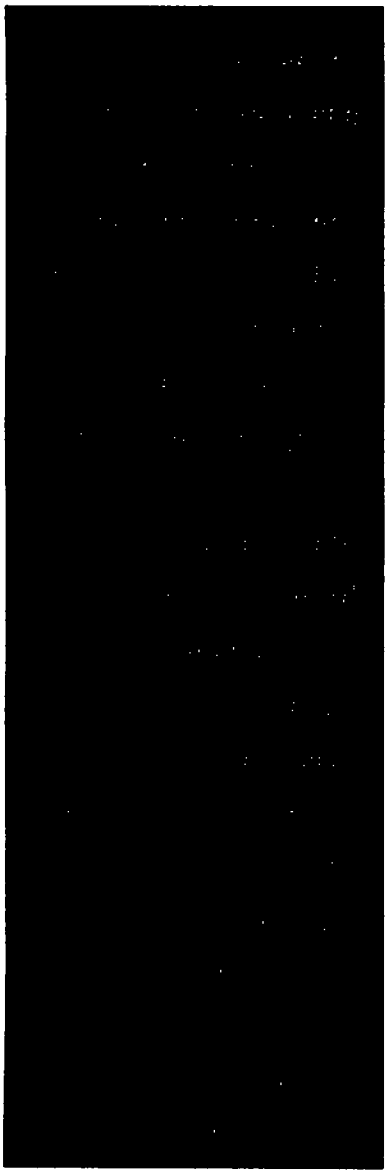
Outreach Projects and Resources

State program office directory on page 54.

The results of Sea Grant funded research are transferred to the general public through what are broadly referred to as the "outreach" components of the program. The six Great Lakes Sea Grant programs employ more than 30 agents, specialists, and communication experts. The agents interpret research results and transfer technical knowledge to the lakes' users.

With the invasion of the zebra mussel, the machinery that is the core all 29 Sea Grant outreach programs was set in full motion. The following products are at the heart of outreach activities in educating the public: fact sheets, brochures, posters, maps, news releases, newsletters, radio spots, videos, slide shows, workshops, conferences, seminars, and displays at public shows. (See the following pages for a sample of these.) Beyond this, some activities provide such a distinct usefulness that they are featured here, along with newly funded projects (marked with a triangle), which have been especially funded beyond the core outreach activities.



▲Sea Grant/USDA Extension Service Nationwide Zebra Mussel Training Initiative

Connecticut, Louisiana, North Carolina, Minnesota, and New York Sea Grant College Programs

Objectives

Because the zebra mussel is predicted to infest all hospitable North American lakes, rivers, and reservoirs by the year 2000, the present responsibilities of Sea Grant outreach must be extended nationwide to inland states to the Cooperative Extension Services (CES). This training initiative, conducted in cooperation with the United States Department of Agriculture Extension Service (USDA-ES), will assist states throughout the entire country that are destined for zebra mussel invasion but as yet have no early warning monitoring systems or viable defense measures against accidental introductions.

This transfer of responsibilities for educating and preparing the general public presupposes the transfer of all the knowledge that Sea Grant, the Great Lakes Sea Grant Network in particular, has gained in contending with the zebra mussel for the past eight years.

▲The Zebra Mussel Traveling Trunk

Illinois-Indiana Sea Grant Program

Objectives

Traveling Trunks are an effective, efficient means of getting up-to-date scientific information to school-age youth. A set of Traveling Trunks will provide fifth- and sixth-graders a first-hand, "up close and personal" look at zebra mussels. The trunks' diverse activities and "Zebra Mussel Mania" curriculum guide integrate science with other disciplines, including math, social studies, language arts, music, and art. Teaching young people about invading species at this age may help them realize their responsibilities as adults in handling and curtailing the spread of all exotic species. The Trunks have been developed with the help of teachers in Illinois and Indiana and through the guidance of curriculum development specialists at the Illinois Rivers project and the Bell Museum of Natural History in Minnesota. These science education resource kits complement Minnesota's Traveling Trunks.

Outreach Projects and Resources

▲ The Traveling Trunk

Minnesota Sea Grant Program

Objectives

Traveling trunks have been shown to be a reliable, cost-effective way to get information to a large, diverse audience. Emphasizing the portability of the trunk, Minnesota has developed a "true" traveling trunk that will transport a video and museum-quality samples of an array of aquatic invaders. The trunk will travel to National Park Service nature centers, and complements Illinois-Indiana's curriculum-based Traveling Trunk. Additional contributors to the trunk are the National Park Service, Minnesota Department of Natural Resources, and the University of Minnesota Bell Museum of Natural History.

▲ Zebra Mussel Workshop for the Gulf and South Atlantic Region of the United States

Florida Sea Grant College Program

Objectives

By the year 2000, experts predict the zebra mussel to have invaded all hospitable North American rivers, lakes, and reservoirs. Four southeastern states (North Carolina, South Carolina, Georgia, and Florida) have so far escaped invasion. To delay the spread and inevitable damage of zebra mussels to this area, a single, two-day regional workshop for the southeastern U.S. will discuss identification, range, biology, impacts, control, monitoring, and economic and policy implications. Three hundred professionals from key groups such as electric generating utilities; water resource commissions; and local, state, and federal agencies from 11 southeastern states are invited. The workshop will be offered via satellite up-link.

Great Lakes Sea Grant Network Surveys
Evaluation of the Great Lakes Sea Grant Network's Zebra Mussel Outreach Activities for Industrial and Municipal Water Users

Conducted by Michigan Sea Grant Extension

Objective

Evaluate zebra mussel outreach activities serving industrial and municipal water users for their effectiveness and usefulness with these questions in mind: (1) Has the Network achieved its goals and objectives for meeting Great Lakes industrial and municipal water user needs? (2) Has the Network made effective use of resources? (3) Have the needs of these users been met with materials and services? assistance to make better decisions? the means to save time and money? (4) How can the materials, services, and activities of the Network better meet municipal and industrial water users' needs in the future?

Results

A usable response rate of 85.2 percent (224 contact persons) showed these results:

- Over two-thirds of the plants surveyed showed the presence of zebra mussels, but fewer than half of the plants (47.5%) have monitoring systems, and one-third indicated that they have any employee(s) devoted to monitoring or controlling zebra mussels.
- Slightly over half knew of the existence of an information office or contact on zebra mussels in their state. About half said they learned about this office or contact through Sea Grant agents and/or educational events. Four-fifths indicated having received information and/or educational materials about zebra mussels. Information packets/fact sheets/brochures, newsletters, and the *Zebra Mussel Update* (Wisconsin) have been received most frequently.
- Respondents rated conferences and personal contacts with Sea Grant agents/specialists as more useful than printed material.
- Few respondents indicated using the Internet, graphics library, or the Clearinghouse 800 number (these were not these information groups' primary target).
- This group is most interested in the zebra mussel's spread and control and want to learn more about it.
- All Great Lakes Sea Grant offices should develop, update, and share a comprehensive mailing list of industrial and municipal water users that includes water users of the Great Lakes and inland rivers and waterways.

Three-State Exotic Species and Freshwater Boating Survey: What do boaters know and do they care?

Conducted by Minnesota Sea Grant Extension

Objective

Survey boaters in Minnesota, Ohio, and Wisconsin to (1) evaluate the effectiveness of programs that educate boaters about invading aquatic nuisance species (2) help define the risks that boaters pose for spreading exotics (3) find out what boaters know about exotics, and (4) determine how best to reach boaters.

Preliminary Analysis

An overall mail response rate of 56 percent (Minnesota: 64%, Wisconsin: 59%, and Ohio: 44%) had these results:

- Boater education does change behavior, as evidenced by Minnesota's more far-reaching program (with laws and penalties) to slow the spread of exotics. The boater's greater knowledge of the exotic species issues have resulted in their having changed their behavior to a greater extent.
- Boaters believe it is important to prevent the spread of aquatic exotics
- The most effective sources of information for boaters were the media (especially newspapers and television) and signs at boat accesses. Other sources were brochures, and fishing and boating pamphlets.
- Boaters present a significant risk for spreading aquatic nuisance species, and many still have not changed their behavior so that education must continue.

Zebra Mussel Monitoring for the Illinois Rivers Project

Illinois-Indiana Sea Grant

Objective

Find an efficient, cost-effective means of monitoring the inevitable spread of the zebra mussel down the Illinois River from Chicago to St. Louis.

Results

- Illinois-Indiana Sea Grant funds the zebra mussel monitoring component of the Illinois Rivers Curriculum Project, a four-year-old project that involves over 300 Illinois high schools and thousands of students in gathering data on the Mississippi, Illinois, and other major rivers and lakes in the state.
- Ten schools reported mussel sightings to Illinois Natural History Survey in 1992.
- National Geographic covered this work in a feature story.
- Zebra mussel monitoring efforts are increasing throughout the area.
- New federal funding will support pilot training for selected teachers to introduce the zebra mussel and other exotic invaders to students in grades 8–12.

Exotic Species Graphics Library

Michigan Sea Grant

Objective

Satisfy the requests of government agencies, industries, museums, media organizations, university researchers, and other Sea Grant programs for graphics of zebra mussels and other invading aquatic species.

Results

The Great Lakes Sea Grant Network's Exotic Species Graphics Library contains over 200 graphics—slides, illustrations, and black-and-white prints. While the collection features the zebra mussel, it also includes graphics of the goby, spiny water flea, ruffe, purple loosestrife, Eurasian milfoil, and sea lamprey. Since the library's inception in 1991, Michigan Sea Grant has filled over 9500 requests for graphics, which have appeared in publications across the country, such as *Southern Outdoors Magazine, Bassmaster Magazine, Vermont Sunday Magazine,* the *Detroit News,* and *Wildlife in North Carolina Magazine.* In addition, the U.S. Coast guard, BP Oil, U.S. Army Corp of Engineers, Great Lakes Fishery Commission, The Environmental Defense Fund, NOAA, Edison Electric, Project Wild, and state DNRs have used these graphics to educate staff, clientele, and others about aquatic invaders.

Outreach Projects and Resources

Exotic Aquatics of the Great Lakes Region

Minnesota Sea Grant

Objective

Create a museum-quality display that can teach people about the threat of invasive nonindigenous species that is also portable, which allows it to reach a large audience.

Results

- "Exotic Aquatics of the Great Lakes Region" (a year-long collaborative effort of Minnesota Sea Grant with many others) was first displayed at the University of Minnesota's Bell Museum of Natural History in 1992. The 12-panel display reaches two audiences: children, because it is large, colorful, and interactive; and adults, who typically accompany their children to such things and for whom the environmental message was developed that we are responsible for the environment's caretaking, and for its neglect. The display was designed for easy set-up and easy maintenance, which allows it to tour other museums and park visitors' centers.
- The success of this display led to Minnesota's Traveling Trunk on exotic aquatic invaders, a traveling trunk with video and samples of exotics.

Zebra Mussel Information Clearinghouse

New York Sea Grant

Objective

Create a single location to which anyone could go or call to get any sort of zebra mussel information or be given a reliable contact who has the information.

Results

- The Zebra Mussel Information Clearinghouse opened in 1990 and is a technical library for all zebra mussel research papers that appear in peer-reviewed journals. Hundreds of these are in Cyrillic, for which a bibliography is being translated. Major papers in other languages are also in the process of translation. The library fields requests predominantly from consulting engineers, researchers, industrial employees, and government officials. In addition, the clearing house acts as liaison for design engineers, applied scientists, and theoretical scientists.
- The Clearinghouse yearly publishes six regular issues and occasional special issues of the newsletter *Dreissena!* (formerly Dreissena polymorpha *Information Review*), which publishes preliminary zebra mussel research findings.
- Funding has been granted to expand the clearinghouse's technical collection and its capabilities on-line.

Annual International Zebra Mussel Conference

Ohio Sea Grant

Objective

Develop a forum for national and international zebra mussel researchers to exchange research results and ideas.

Results

- The Annual International Zebra Mussel Research Conference was initiated and hosted first by Ohio Sea Grant in 1990, with an audience of 200 from 20 states and Canada. Thirty-four papers were presented.
- The second conference, hosted by New York in 1991, drew 361 from 29 states, the District of Columbia, and Canada, with 70 presentations.
- The most recent conference, hosted by Wisconsin in 1994, drew over 600 people to hear 182 presentations. Since 1993, the conference planning and location has alternated between the U.S. and Canada.
- The 1996 conference will be hosted by Michigan Sea Grant and is scheduled for March 3–7 in Dearborn, Michigan.

Identification Cards—the Zebra Mussel Watch Card

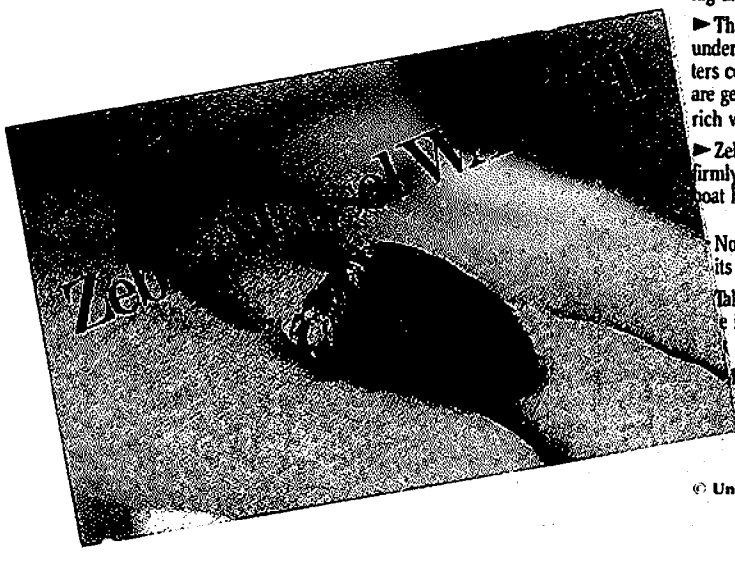
Wisconsin Sea Grant

Objective

Develop a means to alert the general public to the threat of zebra mussels and the means by which they can instantly identify a zebra mussel when they encounter it in nature.

Results

- In 1990 Wisconsin Sea Grant began printing 4.5- by 3.5-inch zebra mussel information cards (which are folded in half and slip into a wallet) and have since distributed more than a million. The photograph of the mussel shows its distinctive stripes, and the fingers that hold it provide scale. The information inside succinctly describes the threat of zebra mussels, their identifying characteristics, how to note the location of and store the sample for proper identification, and to whom to report the sighting should it be new or rare. The cards are customized for their location distribution, and are currently used by more than 30 Sea Grant programs, government agencies, and private businesses in 20 states and the Province of Ontario.
- Minnesota has developed a similar card for the Great Lakes' newest exotic invader, the ruffe.



Zebra Mussel Alert

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

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

How to Identify It

► Zebra mussels look like small clams with a yellowish and/or brownish "D"-shaped shell, usually with alternating dark and light bands of color (thus the name "zebra").

► They can grow up to two inches long, but most are under an inch long. Zebra mussels usually grow in clusters containing numerous individuals (see photo), and are generally found in shallow (6 to 30 feet deep), algae-rich water.

► Zebra mussels are the ONLY freshwater mollusk that firmly attaches itself to solid objects, including rocks, boat hulls, etc.

Note the date and precise location where the mussel its shell(s) were found;

Take the mussel with you (several, if possible) and e in rubbing alcohol (in any case, DON'T throw it t in the water), and

IMEDIATELY contact the nearest Ohio Sea Grant tory Service field office in Elyria, Painesville or Port n, or phone (614) 292-8949.

Outreach Projects and Resources

GREAT LAKES REGION

Illinois-Indiana

The HELM. Eight-page quarterly newsletter. Free. — This newsletter addresses current zebra mussel problems and potential control measures through research and outreach efforts.

Sea Grant's Zelda the Zebra Mussel. This life-sized costumed character serves as a "spokesmussel" on zebra mussel and other nonindigenous issues. Useful at educational events, environmental conferences, schools, fairs, nature centers, etc. $30 rental fee plus shipping.

Zebra Mussel Information Needs Survey for Municipal and Industrial Water Users. Eight-page report. May 1992. Single copies free. —A survey of 29 southern Lake Michigan municipal and industrial water users provided findings on what types of zebra mussel information were most needed and in what form the information could be best delivered.

Zebra Mussel Mania. A traveling trunk for teaching about nonindigenous species. Available August 1995. — This science resource kit includes 10 hands-on activities to teach 5th- and 6th-grade students about problems caused by nonindigenous species and preventive measures to control their spread.

To order, contact: Illinois-Indiana Sea Grant Program, University of Illinois, 65 Mumford Hall, 1301 W. Gregory Dr., Urbana, IL 61801, phone 217/333-9448.

Michigan

Upwellings, quarterly newsletter. Free.

Exotic Species Graphics Library catalog. Single copies free. — Includes a brief description of over 200 items in the graphics library, which contains slides, photographs, and illustrations primarily of zebra mussels, but also including other exotic species. Materials are distributed on a two-week loan basis, or copies may be purchased for the cost of duplication.

New Concerns Emerge as Zebra Mussels Spread. Fact sheet. 1992. Single copies free. — Describes the threats posed by the zebra mussel as it spreads inland, including damage to navigational and flood-control structures and to native freshwater clams. Control methods being researched or tried also are described. MICHU-SG-92-702.

Potential Control of Zebra Mussels Through Reproductive Intervention. Fact sheet. 1994. Single copies free. — Report on efforts to control zebra mussels through mechanisms that interrupt their reproduction. MICHU-SG-94-703. Also available online through gopher and mosaic under the Great Lakes Information Network (GLIN).

Safe Use of Zebra Mussels in Classroom and Laboratories. Two-page fact sheet. 1993. — Gives teachers and students tips to ensure that zebra mussels used in labs or classrooms don't end up in plumbing systems or inland waters. Also available online through gopher and mosaic under the Great Lakes Information Network (GLIN).

The Spread of Zebra Mussels to Inland Lakes—Implications and Actions. Slide show. 1994. $10.00 — This 15-minute slide show includes 66 slides, taped narration, and a full script. Portrays where zebra mussels have spread, economic and environmental changes that may occur after zebra mussels colonize, how to monitor for mussels, how to avoid damage to boats and water intakes, and how to prevent spreading the mussel. MICHU-SG-94-706.

Zebra Mussel Distribution in Michigan. Map. Free. — Updated monthly, this map shows where there have been confirmed sightings of established zebra mussel colonies in Michigan; also lists all sighting locations and dates since 1989.

Zebra Mussel Features. Video news packages. — A collection of 90-second feature stories produced by Outreach Communications TV at Michigan State University. Contact Carol Swinehart at (517) 353-9723.

Zebra Mussels in the Great Lakes. Fact sheet. 1992. Single copies free. — Describes how zebra mussels were introduced into the Great Lakes, and potential impacts on industry, recreation, and the Great Lakes ecosystem. MICHU-SG-92-700.

Zebra Mussels May Clog Irrigation Systems. Fact sheet. Single copies free. 1993. — One-page document outlines how zebra mussels clog irrigation systems, especially those on farms. MICHU-SG-93-70. Also available online through gopher and mosaic under the Great Lakes Information Network.

To order, contact Michigan Sea Grant Communications, University of Michigan, 2200 Bonisteel Blvd., Ann Arbor, MI 48109, phone 313/764-1138.

Minnesota

The Seiche, quarterly newsletter. Free.

Don't let these invaders hijack your boat! 17 x 22 poster. Free. — This humorous cartoon poster tells boaters what to do to slow the spread of zebra mussels. For use in fishing/bait shops, marina offices, etc.

Exotic Species and Freshwater Boating Survey: Results and Technical Report. 61-page booklet. 1994. Available upon request. — Contains the results of a combined mail and telephone survey of boaters to determine the effectiveness of boater education programs, how to best reach boaters, the risks

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(compiled by Wisconsin Sea Grant)

boaters pose for spreading exotics, and boaters' knowledge concerning exotics.

Exotic Species and Freshwater Boating Survey: What Do Boaters Know and Do They Care? Fact sheet. 1995. Single copies free; multiple copy prices available upon request. — Two-page fact sheet based on the results of a boater survey designed to guide future boater-education programs and incentives aimed at preventing the spread of nuisance aquatic exotic species.

A Field Guide to Aquatic Exotic Plants and Animals. Brochure. 1992. Single copies free; multiple copies $0.15 each. — This 10-page, full-color brochure describes the zebra mussel along with 10 other common exotics in the Great Lakes region.

Mussel Menace! Zebra Mussels and You. Training package. Updated 1994. — This leadership training package is designed to teach the problems caused by zebra mussels and how to slow the mussels' spread. Contains a printed manual, slide/audiotape set, and/or videotape. Prices: manual and videotape, $25.00; manual and slide/audiotape set, $30.00; manual, videotape and slide/audiotape set, $35.00.

To order, contact: Minnesota Sea Grant College Program, University of Minnesota-Duluth, 2305 East 5th Street, Duluth, MN 55812, phone 218/726-8712.

New York

Coastlines, quarterly newsletter. Free.

Control of Zebra Mussels in Residential Water Systems. 12-page illustrated fact sheet. Revised 1994. Single copies free, multiple copies $0.75 each. — Outlines on-shore and off-shore zebra mussel-control measures for owners of residences with private water systems.

Don't Pick Up Hitchhikers! Stop the Zebra Mussel! 11 x 17 paper poster. 1994. Single copies free, multiple copies (up to 1,000) $0.05 each. — Designed for indoor use at marina offices, boating supply stores, etc., to create awareness of zebra mussel-control techniques among boaters.

Don't Pick Up Hitchhikers! Stop the Zebra Mussel! Flyer. 1994. Single copies free, multiple copies $0.20 each. — Information for boaters on controlling the spread of zebra mussels.

"Dunkirk Steam Station," Video. Video footage of zebra mussels in a fossil fuel electric generation facility. Professionally videotaped and available as 19 minutes of unedited shots with shot sheet on 3/4" broadcast-quality UMatic-format tape for $25.00. Also available in nonbroadcast-quality VHS format for $15.00.

Guide to the Identification of Larval and Postlarval Stages of Zebra Mussels *Dreissena* spp. and the Dark False Mussel *Mytilopsis leucophaeata.* 22-page booklet. 1993. $2 each. — Provides photomicrographs and information to help identify mussels and distinguish between the two genera.

Identification of Juvenile *Dreissena polymorpha* and *Mytilopsis leucophaeata.* Flyer. 1992. Single copies free, multiple copies $0.05 each. — Technically oriented three-fold flyer with illustrations.

Protect Your Boat From Zebra Mussels. 15-minute video. 1993. $10 each. — Gives pointers on preventing damage to your recreational boat and tips on preventing the spread of zebra mussels to inland waters.

The Zebra Mussel (*Dreissena polymorpha*): An Unwelcome North American Invader. 12-page fact sheet 1991. Multiple copies $0.75 each.

Zebra Mussel Distribution Map. One copy free, multiple copies $0.10 each. — Compiled from the latest issue of the newsletter *Dreissena!* Shows the latest range of zebra mussel expansion throughout North America.

Zebra Mussels television documentary. 30-minute video. 1993. $12 each. — This documentary features a history and introduction of the zebra mussel to American waters; description of the mussels biology, impacts and control measures; and interviews with various key politicians.

To order, contact: New York Sea Grant Communications, 52 Swetman Hall, SUNY Oswego, Oswego, NY 13126, phone 315/341-3042.

Dreissena! Bimonthly newsletter. $60 annual subscription. — Includes summaries of research, meetings, and legislation about zebra mussels. Also features a monthly map of zebra mussel sightings nationwide. Contact the Zebra Mussel Information Clearinghouse at 1-800-285-2285 (8:30–4:00 EST, Mon.–Fri.) or 716/395-2516.

Zebra Mussel Information Clearinghouse. This special project of the New York Sea Grant Extension Program was established in 1990 as a national focal point for zebra mussel information. Its purpose is to assist researchers, government agencies, industries, and others by providing easy access to the most current research, technological and policy information available on the biology, spread, impact, and control of zebra mussels. The Clearinghouse maintains North America's larg-

est, most comprehensive library of research and other relevant information on the zebra mussel and related biological macrofoulers. Contact the Zebra Mussel Information Clearinghouse at New York Sea Grant Extension, 250 Hartwell Hall, SUNY College at Brockport, Brockport, NY 14420-2928, phone 716/395-2516 or 1-800-285-2285 (8:30–4:00 EST, Mon.–Fri.); Fax 716/395-2729; or Internet e-mail: zmussel@cce.cornell.edu.

Ohio*

Twine Line, eight-page, bimonthly newsletter. $4.50/year. Each issue since December 1989 has included a one-page update on nonindigenous species.

Safe Use of Zebra Mussels in Classroom and Laboratories. Two-page fact sheet. 1993. — Gives teachers and students tips to ensure that zebra mussels used in labs or classrooms don't end up in plumbing systems or inland waters. OHSU-FS-059. Also available online through gopher and mosaic under the Great Lakes Information Network (GLIN).

Slow the Spread of Zebra Mussels and Protect Your Boat and Motor, Too. Two-page fact sheet targeting boaters. 1992. Free for any size order. OHSU-FS-054.

Showing Sea Grant's Muscle with the Zebra Mussel. Two-page fact sheet. 1994. Contains the introductory text from the "Showing Our Mussel" technical bulletin. OHSU-FS-060.

Showing Our Mussel: The Great Lakes Sea Grant Network Report on Zebra Mussel Research and Outreach. Technical bulletin. 1994. $5 each. — This 72-page report summarizes zebra mussel research and outreach efforts of the National Sea Grant College Program from 1988 through 1993. OHSU-TB-026.

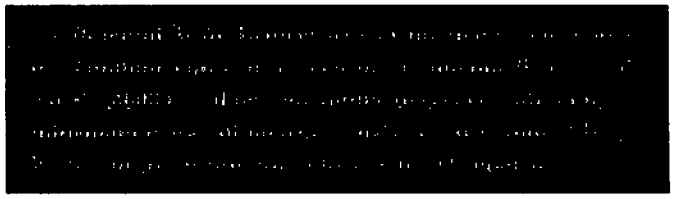
Too Much Mussel. Videotape. 1991. $15 each. — This 5½ minute, video provides an overview of the impact of zebra mussels to Lake Erie.

Zebra Mussel Migration to Inland Lakes and Reservoirs: A Guide for Lake Managers. Four-page fact sheet. 1993. — Outlines optimum habitat requirements, economic impacts, ecological effects, and prevention and remediation strategies for zebra mussels in inland lakes. OHSU-FS-058.

Zebra Mussels: From Spawning to Settlement. Video tape. 1993. $15 each. — This 20-minute video follows the life cycle of zebra mussels.

Zebra Mussels in North America: The Invasion and Its Implications. Four-page fact sheet. 1994. OHSU-FS-045.

To order, contact: Ohio Sea Grant College Program, The Ohio State University, 1314 Kinnear Road, Columbus, OH 43212-1194, phone 614/292-8949.



Wisconsin

Littoral Drift, monthly newsletter. Free.

4th International Zebra Mussel Conference Proceedings. 718-page document. 1994. — Features 50 papers delivered at the 1994 conference in Madison, Wis. Topics include chemical and non-chemical control of zebra mussels, population dynamics, general biology and socio-economic issues.

Boaters Advisory. 12 x 14 plastic poster. — Designed for outdoor use at boat launches to create awareness of the zebra mussel among boaters.

Engineering Notes. 1992. Free.

#1: Case studies of constructed filter bed intakes. A description of 10 such systems in the western Great Lakes that range from one to 100 years old. Included is information on operational experience and whom to contact (plant operators and design engineers) for further information, plus commentary from marine contractors and design engineers. 16 pp.

#2: Infiltration intakes for very large water supplies: Feasible? A review of four 20-year-old papers that considered design feasibility as a means of protecting larval organisms from entrainment in power plant and water diversion project intakes. 11 pp.

#3: Zebra Mussel (*Dreissena polymorpha*) distribution: Reported size, depth, and temperature variables. A summary of relevant data about zebra mussels intended for project design engineers. 7 pp.

#4: Using filtration and induced infiltration intakes to exclude organisms from water supply systems. A literature review plus an overview of slow sand filtration and infiltration systems. 13 pp.

Sand filter intakes could safeguard vital water-supply systems from zebra mussels. Four-page document. 1991. Free.

Zebra Mussel PSAs. Four public service announcements on cassette tape. Two 15-second and two 30-second PSAs for use in broadcast media.

Zebra Mussel Update. Newsletter. Single copies free. — Reports on the status of the zebra mussel invasion in the Great Lakes region, zebra mussel-related research, upcoming conferences, new publications, etc.

Zebra Mussel Watch Identification Card. Wallet-sized card. Single cards free; 20 cards for $1. — Cards feature color photo of zebra mussel with text describing their appearance and what to do if you find a mussel. Customized to different states and regions.

To order, contact: University of Wisconsin Sea Grant Institute, 1800 University Avenue, Madison, WI 53705-4094, phone 608/263-3259.

NORTHEAST REGION

Connecticut

Aquatic Exotics News. Newsletter. — Features regional news on zebra mussels and other aquatic exotics in the Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont areas.

Zebra Mussel Awareness and Boat Use Patterns. 17-page booklet. 1994. Free. — Summary of 325 interviews of boaters using three lakes in western Connecticut. The survey shows that pleasure boat and jet ski operators need additional educational programs. CTSG-94-03.

To order, contact: Connecticut Sea Grant Marine Advisory Program, University of Connecticut, 1084 Shennecossett Road, Groton, CT 06340-6097, phone 203/789-6454.

New Hampshire

Stop the Zebra Mussel. Brochure. 1993. Single copies free. — Provides background, identification, and precautionary information about the zebra mussel for the general and boating public.

Stop the Zebra Mussel. Plastic sign. $1 each. — Designed for outdoor use at boat launches to create awareness of the zebra mussel among boaters.

Exotic Species Profile — The Zebra Mussel. Fact sheet. 1994. — General information about zebra mussels.

To order, contact: Sea Grant Communications Office, Kingman Farm/UNH, Durham, NH 03824-3512, phone 603/749-1565.

Rhode Island

Zebra Mussel: An Unwelcome Invader. Fact sheet. 1993. Single copies free. Publication no. P1326.

To order, contact: Rhode Island Sea Grant, University of Rhode Island Bay Campus, Narragansett, RI 02882-1197, phone 401/792-6842.

MID-ATLANTIC REGION

Delaware

Can the Pesky Zebra Mussel Change Its Stripes? 1993. Single copies free. — This three-page article highlights research on the glue the zebra mussel produces to attach to objects underwater.

Zebra Mussel Alert! 3.5 x 7 decal. Single copies free. — Alerts boaters and anglers to the steps they can take to help control the zebra mussel.

Zebra Mussel: Present Threat, Future Danger? 12-page booklet. 1992-93. — Focuses on the dangers posed to the mid-Atlantic states by the zebra mussel. Color photographs and illustrations.

To order, contact: University of Delaware Sea Grant College Program, Marine Communications Office, Newark, DE 19716-3530, phone 302/831-8083.

Maryland

Have You Seen This Intruder? Plastic poster. 1994. Free. — Intended for outdoor use at marinas, landings, etc. Produced in cooperation with the Maryland Department of Natural Resources.

Zebra Mussels and the Mid-Atlantic. Conference proceedings. 1994. $7 each. — Summary of a 1993 conference in Baltimore, Md.

Zebra Mussels: A Threat to Maryland Waters. Brochure. — Identifies the zebra mussel ways to stop its spread.

Zebra Mussel Watch. Wallet-sized cards. Free. — A quick way to identify zebra mussels and what to do if you find them.

To order, contact: Communications Office, Maryland Sea Grant College Program, University of Maryland, College Park, MD 20742, phone 301/405-6376. ☛

North Carolina

Mid-Atlantic Zebra Mussel Fact Sheet. Six-page fact sheet. 1993 (updated 1994). Single copies free; $0.35 each in quantities of 10 or more. — Examines potential for zebra mussel infestation of waters in mid-Atlantic states based on lessons learned in the Great Lakes region. Also examines zebra mussel biology, dispersal, and control methods. Aimed at potentially affected boaters, property owners, educators, extension workers, and water users. Request publication no. UNC-SG-FS-93-01.

Zebra Mussel Poster. Available May 1995. Water-resistant poster for boat landings and tackle shops. The poster shows a zebra mussel and features detachable information fact sheets or zebra mussel identification cards.

Zebra Mussels: A Costly Threat to North Carolina. Brochure. 1992. — Describes the zebra mussel threat and control measures. Request publication no. UNC-SG-92-11.

To order, contact: North Carolina Sea Grant, Box 8605, North Carolina State University, Raleigh, NC 27695, phone 919/515-2454. Request by publication number.

Virginia

Criteria for Predicting Zebra Mussel Invasions in the Mid-Atlantic Region. Booklet. 1994. Single copies free. — Summarizes water quality and other criteria used to predict whether zebra mussels are likely to become established in specific bodies of water in and near Virginia. Publication no. VSG-93-03.

Invasion of an Exotic Species: Stop the Zebra Mussel! Free. — A resource packet of fact sheets and classroom activities for grades 8-12. Educational series no. 41.

Potential Range of the Zebra Mussel (*Dreissena polymorpha*) in and Near Virginia. 12-page booklet. 1994. Single copies free. — Summarizes the physiological requirements, dispersal mechanisms (both natural and human-mediated), and the potential range of the zebra mussel in Virginia. Publication no. VSG-93-04.

Zebra Mussel Alert. Wallet-sized card. — Tips on how to identify a zebra mussel and what to do if you find one. Includes color photographs.

Zebra Mussels in Virginia's Future. Fact sheet. 1993. Single copies free. — Provides background information on zebra mussels and addresses the probability of Virginia's major rivers and lakes being colonized. Publication no. VSG-93-05.

Zebra Mussels Pose a Threat to Virginia's Waters. Fold-out fact sheet. 1991. Single copies free. — Provides background information on zebra mussels; designed to serve as a citizens' alert. Publication no. 420-900.

To order, contact: Sea Grant Communications, Virginia Institute of Marine Science, P.O. Box 1346, Gloucester Point, VA 23062, phone 804/642-7170.

GULF REGION

Louisiana

Invasion of the Zebra Mussels. Fact sheet. 1993. Single copies free.

Lower Mississippi River Valley Zebra Mussel Newsletter. 1994. Single copies free — Vol. 1, (1,2). Biannual newsletter coordinating zebra mussel monitoring and control efforts in the Lower Mississippi region.

Zebra Mussel Information and Monitoring. Available by April 1995. $10 — Proceedings of a January 1995 workshop held at Louisiana State University that focused on zebra mussels in southern waters.

To order, contact: Office of Communications, Louisiana Sea Grant College Program, Louisiana State University, Baton Rouge, LA 70803-7507, phone 504/388-6349.

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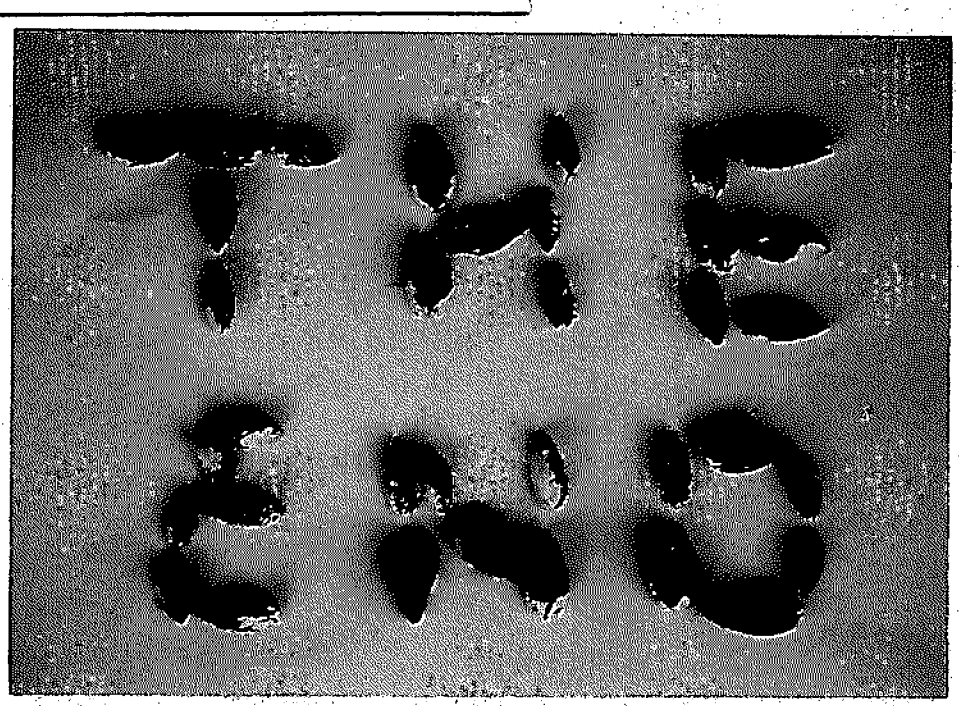

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