Sea Grant Zebra Mussel Update: A 1995 Report of Research

Part 1 of 2

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. It will be published in two parts. Part 2, a report on outreach, is expected to be available in June 1996. Both parts 1 and 2 are updates of reports published in 1994 and 1995.

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Additional copies of Sea Grant Zebra Mussel Update: A 1995 Report of Research (Part 1 of 2) *are available from Ohio Sea Grant for $5.00.*

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Thanks to various staff at Sea Grant programs, industries, agencies, and universities who provided photographs.

Part 2 now published

The story of the zebra mussel's invasion of the Great Lakes is now legendary. *Dreissena polymorpha* is presumed to have entered Lake St. Clair in 1985 or '86, having been transported there by transoceanic ships that released contaminated ballast water taken up in foreign ports. In 1988 the mussel was officially identified and reported in Lake Erie, and was on its way to infest the Illinois, Ohio, and Mississippi River watersheds. Texas, Florida, and Maine are now preparing for the zebra mussel, given the incredible speed of its dissemination to Oklahoma, Alabama, and the northernmost reaches of Vermont.

Why all of this interest in a mollusk no bigger than a thumbnail? One female zebra mussel can produce a million eggs a year. As adults they colonize every available surface, including themselves. Their accumulated weight has sunk marker buoys in shipping channels, endangering boat traffic. They line the inside surface of water intake pipes reducing water flow so severely that an entire city lost its supply of drinking water. Fire hydrants that draw water from infested rivers have been reduced to a trickle. Other water users and suppliers have and will spend millions to protect themselves from the same fate.

Damage to physical property may approach billions, but arguably the mussel's greatest effect is on the environment. Because they eat plankton, zebra mussels disrupt the food web, from the bottom up, wherever they take hold. They are presumed to have contributed to, if not actually caused, blooms of toxic algae. And wherever they take up residence, they have wiped out native mollusks by colonizing their shells, causing them to starve.

This report, created by Ohio Sea Grant for the Sea Grant network, documents the results of Sea Grant-funded research on the zebra mussel and its possible control or mitigation. Furthermore, because Sea Grant's national focus has expanded to include other aquatic nuisance species, research on another Great Lakes invader, the ruffe, has been included. Results of Sea Grant research are transferred to the public in the form of "outreach" materials. Part 2 of this report will provide these results.

The National Sea Grant College Program is part of the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce.

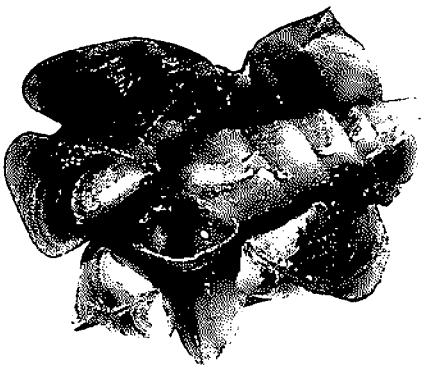
Some have called it a commitment. Others call it a bridge, a bond, a partnership.

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

Sea Grant today is what Congress intended — an agent for scientific discovery, technology transfer, economic growth, and social understanding. This report is testimony to Sea Grant's effort to combat zebra mussels and other aquatic nuisance species.

Table of Contents

This report (Part 1) updates the results of previously funded zebra mussel research and lists the objectives of the most recently funded research and outreach proposals from fiscal year 1995. Part 2 of this report, available in June, will provide updates on zebra mussel outreach projects.



PUBLIC LAW 101-646—
NOV. 29, 1990

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.

In response to the invasion of the Great Lakes by the zebra mussel (*Dreissena polymorpha*) in the mid 1980s, Congress passed the Nonindigenous Species Control Act in 1990. Congress also appropriated 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 1995, projects have been supported in 19 of the country's 29 Sea Grant Programs.

Sea Grant Zebra Mussel Research and Outreach Projects

fiscal year	millions appropriated	distribution of money research[1]	outreach	research proposals submitted	research proposals funded [2]
1991	$1.8	$1.3	$0.5	58	18
1992	$2.9	$1.9	$1.0	77	13
1993	$2.8	$1.8	$1.0	55	12
1994	$2.8	$1.8	$1.0	65	15
1995	$2.8	$1.5	$1.3	40	14

[1] Projects awarded in FY 91-94 received funds for duration of project. Projects funded in FY 95 received funds for first year only. (Most are two-year projects.)

[2] The number differs from number of projects described because, in some cases, more than one program is cooperating on same project. The number in this table reflects number of grants awarded.

Research Agenda and Results

Biology and Life History

To predict an ecosystem's response to an invading species, scientists need to understand its life history. Basic biological research into population dynamics, genetics, physiology, behavior, and parasites and diseases of the invader 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 their infestation and which native species and habitats are most likely to be affected.

Effects on Ecosystems

Any new organism introduced to an 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 other species. It is a high priority, then, to identify and evaluate the effects of an invader at each stage of its life history. Such information helps natural resource managers determine how to minimize the impacts invading organisms have on established biota and habitats.

Socio-Economic Analysis: Costs and Benefits

Invading organisms might introduce disease, concentrate pollutants, contaminate drinking water, or otherwise affect human health. 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.

Control and Mitigation

Temporary measures may mitigate the effects of invading species, but effective control requires long-term research. Control of invaders in the Great Lakes may be physical (redesigning water intakes, scraping, filtering), chemical (biocides, antifoulants), biological (parasites, predators), or physicochemical (heat, salinity, pH). To develop selective, effective controls that are ecologically responsible, researchers must determine an invader's physical, chemical, and biological requirements and its physiology, genetic make-up, and behavior.

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 already seriously disturbed or destroyed the ecosystem. Therefore, the prevention of unintended introductions is paramount.

Reducing the Spread of Established Populations

Most nonindigenous species are transported and spread by human activities. Scientists might then predict the 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.

In 1990 the U.S. Great Lakes Nonindigenous Species Coordinating Committee was formed to foster cooperation and collaboration and to develop a coordinated research agenda among the six Great Lakes Sea Grant programs, 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. Its research agenda comprises the six categories listed here.

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, more than 130 species have been introduced to the Great Lakes. Some of these exotics have no or little impact on the environment. Others are referred to as "nuisance" species, often belying their enormous biological harm and economic impacts. The zebra mussel is one such species. Discovered in Lake St. Clair in 1988, the mussel quickly spread to all of the lakes and is projected to eventually infest all hospitable lakes, rivers, and reservoirs in North America. The costs to water users will continue to rise as the mussel spreads; the toll on invaded ecosystems is incalculable. Six years of Sea Grant-funded 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.

DNA analysis shows that zebra mussels are one of the most genetically diverse organisms in existence.

Six years of Sea Grant-funded zebra mussel research have produced some notable results, a sample of which follows.

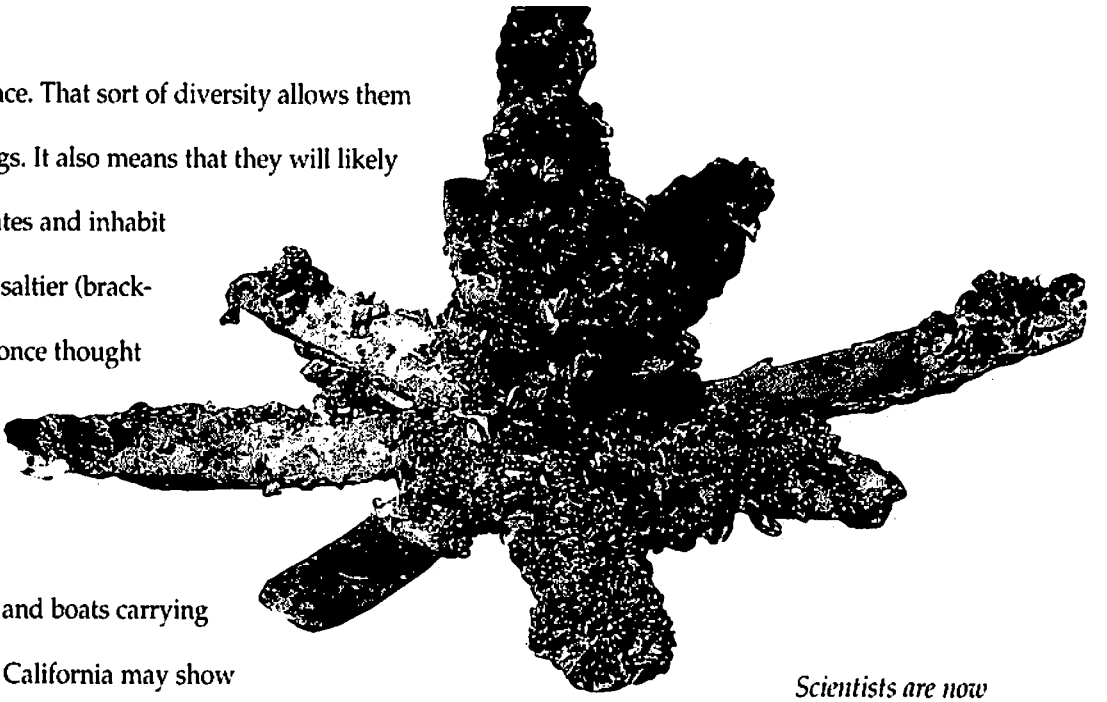
Biology and Life History

Before scientists can consider how to control an invader such as the zebra mussel, they have to understand the organism's life history. Researchers need to know what it eats, what it excretes, how it reproduces, how it travels, where it settles, to what it attaches, how it protects itself, and so on, to find any vulnerabilities that they can exploit to develop controls. By the same token, knowledge of the mussel's biological strengths can help focus control efforts.

For example, we now know a female mussel can release one million eggs in a year. That sort of prolific reproduction, given an environment that can sustain it, means that zebra mussels will likely not be controlled by large predators such as ducks or fish. There are simply too many mussels and too few predators. And laboratory studies show that the immature stage of the mussel, the veliger, can postpone attachment for up to 7 weeks, far longer than previously thought. This means that zebra mussels may travel longer and much further than anticipated—a warning to river systems once perceived to be immune.

Compounding the discovery that zebra mussels can travel longer and farther are the surprising results of their DNA analysis. Zebra mussels are one of the most genetically

diverse organisms in existence. That sort of diversity allows them to adapt to new surroundings. It also means that they will likely colonize unexpected substrates and inhabit warmer, cooler, deeper, and saltier (brackish) waters than what were once thought to be at the limits of the mussel's tolerance. DNA studies, ongoing lab studies of salinity tolerance, and boats carrying zebra mussels as far west as California may show that even west coast estuaries should not consider themselves immune.



Scientists are now testing for an association between zebra mussels and recent blooms of Microcystis *in Saginaw Bay and in western Lake Erie. Earlier studies of Lake Oneida, a large freshwater lake in New York, likewise showed an unprecedented bloom of another nuisance blue-green alga,* Aphanizomenon flos-aquae, *after zebra mussels invaded.*

On the other hand, a natural condition has also been discovered that limits the mussel's spread and development: low ambient levels of calcium. A body of water that contains less than the critical level of calcium may be protected from invasion, and knowledge of this could help direct zebra mussel control to where it is needed most.

Effects on Ecosystems

From an ecological perspective, zebra mussels are so devastating because they eat the primary producers in the food web. Every organism, therefore, is affected by the mussel's invasion. "Eating," however, doesn't quite capture a zebra mussel's food intake. Each mussel is reputed to filter phytoplankton and zooplankton from a liter of water a day. This puts billions of mussels in direct competition with fish that also eat plankton, and may give some explanation as to why numbers of yellow perch have fallen so dramatically in lakes Erie and Michigan. Studies in Lake Michigan's Saginaw Bay in the early 1990s showed high densities of larval yellow perch, meaning that eggs were being laid and hatching, but that fish were disappearing not long after.

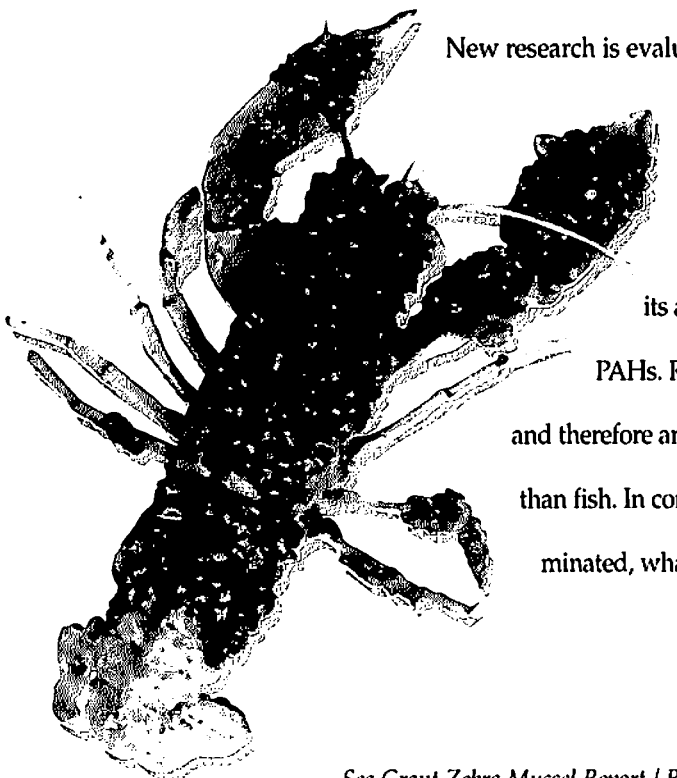
What the mussels don't eat, they spit out in a mucous-covered ball called pseudofeces. Recent laboratory videos of zebra mussels reveal that the mussels won't eat the blue-green alga

Microcystis, an alga known to produce toxins. Decades ago, before the Clean Water Act, blooms of *Microcystis* and other blue-green algae on Lake Erie were toxic enough to cause bird and fish kills. These sorts of toxic blooms (or any sort of algal bloom) were thought to be a thing of the past—until now. Scientists are now testing for an association between zebra mussels and recent blooms of *Microcystis* in Saginaw Bay and in western Lake Erie. Earlier studies of Lake Oneida, a large freshwater lake in New York, likewise showed an unprecedented bloom of another nuisance blue-green alga, *Aphanizomenon flos-aquae*, after zebra mussels invaded.

Until the shipping industry adopts a permanent method of eliminating exotic organisms in ballast water, mid-ocean exchange (MOE) is required of all transoceanic ships entering the Great Lakes.

The resurgence of other aquatic plants comes undoubtedly as a result of zebra mussels. Before the invasion, these large plants didn't receive enough sunlight to grow. The lake water's new transparency now allows not only their growth but their proliferation. In some cases, plant lovers are delighted to see plants return that haven't been seen in decades. In others cases, dismayed boaters must deal anew or for the first time with plants entangled in their outboard motors. And local officials occasionally have had to close local beaches after storms when bottom-dwelling filamentous algae have broken loose, washed ashore, and rotted.

Zebra mussels cause starvation among other organisms by eating their food. They also cause starvation to other mollusks indirectly: The mussels have locally wiped out dozens of species of indigenous mussels by colonizing their shells. This makes it impossible for them to eat, or adds so much extra weight that the native mussel couldn't take in enough nutrition. New research is evaluating the mussel's elimination of snails by the same means.



Any hope of some predator eating zebra mussels must be counterbalanced by what research has shown of the mussel's lipid content. The greater an organism's lipid content, the greater its ability to take up lipophilic toxic pollutants, such as PCBs and PAHs. Research shows that zebra mussels are extremely high in lipids and therefore are likely to concentrate contaminants at a level 100 times greater than fish. In contaminated waters, therefore, zebra mussels will be highly contaminated, what eats the mussel will be contaminated, and on up the food web.

Socio-Economic Analysis: Costs and Benefits

Calculations from surveys suggest that electric generation power plants, municipal water systems, and industrial water users with water intakes in the Great Lakes basin had spent more than $120 million controlling the zebra mussel by 1994. Sea Grant's research and outreach efforts helped keep what is still a large amount of money from being as great as some predicted. This is in part because Sea Grant's first goals were to determine ways cities, industries, and utilities along the Great Lakes could combat pipes being colonized by zebra mussels while minimizing the cost to the facilities and the impact to the environment. The amount of money spent by each facility varies greatly from year to year as plants retrofit, redesign, reconstruct, or rebuild in their efforts to learn to cohabit with zebra mussels. According to these calculations, on average, small plants (less than 5 million gallons per day) spent about $20,000 per year and large plants (greater than 300 mgpd) spent about $350,000 per year. Given the zebra mussel's continuing spread, these control methods and their costs will be of vital interest to other water users in the mussel's path.

Recreational users of some areas of the Great Lakes have formed a love/hate relationship with the zebra mussel. Many agree that in terms of aesthetics, the shallow, warm, nutrient-rich bays and basins have been most affected by the mussel's presence. The nearly crystal-clear water left by the mussel's voracious appetite makes these areas prettier than they have been in decades (although, see algal blooms in "Effects on Ecosystems").

Many believe, however, that for the yellow perch, walleye, and other sports fisheries, the price of clear water has been too dear. For, example, light-sensitive walleye are not as easy to catch as they once were in algal-green turbid waters, jeopardizing Lake Erie's reputation as "The Walleye Capital of the World." It's not just a reputation that's jeopardized, but a multi-million-dollar sport fish industry. Ohio has seen its sport fishing industry decline by $400 million annually. Charter boats are affected. Bait shops are affected. Hotels, motels, and restaurants that accommodate anglers are affected.

Michigan, New York, Ohio, Ontario, and Pennsylvania have imposed commercial and sports catch limits on yellow perch in all five Great Lakes. Yellow perch have declined dramatically during the last 10 years. Whether this precipitous decline is related to the zebra mussel is not known, but the years of yellow perch decline and the years of zebra mussel population explosion do overlap.

Likewise, Michigan, New York, Ohio, Ontario, and Pennsylvania have had to impose commercial and sports catch limits on yellow perch, which have declined dramatically during the last 10 years. Whether this precipitous decline is related to the zebra mussel is not yet known, but the years of yellow perch decline and the years of zebra mussel population explosion do overlap.

More than two-thirds of the nonindigenous species now found in the Great Lakes were introduced by ships traveling through the St. Lawrence Seaway, which opened in 1959.

Reducing, Controlling, and Preventing New Introductions

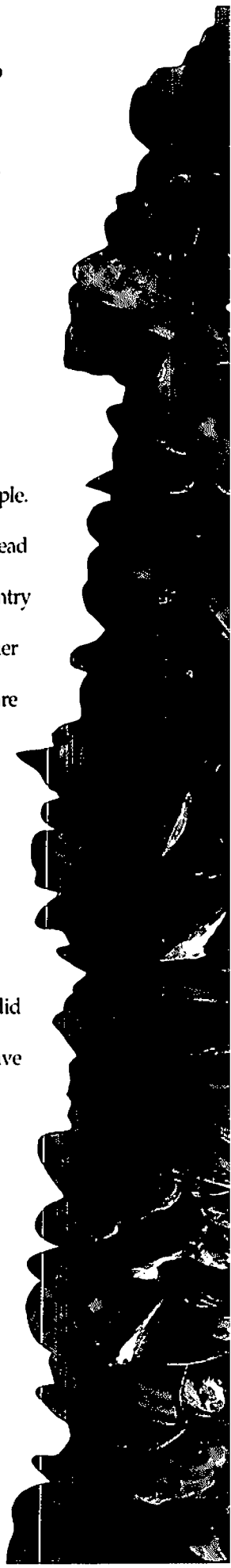
Reducing The Spread of Established Populations

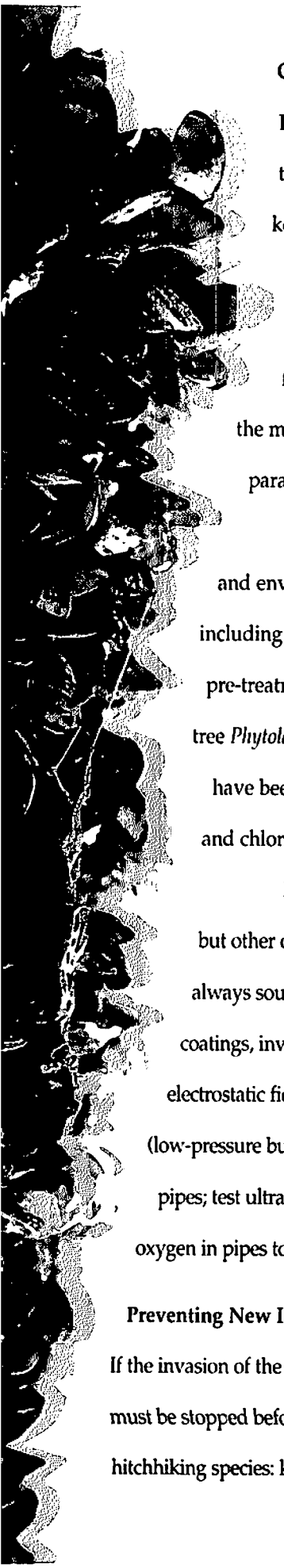
The most sure-fire method of control for any aquatic nuisance, of course, lies with people. We are the ones who brought them here in the first place. Natural water flow may spread mussels within a single watershed, but we are the ones who transport them cross-country from watershed to watershed. Sea Grant research has shown that it is not ducks or other water fowl that carry mussels. People who claim then that control efforts by humans are useless because animals will undermine them may actually be undermining efforts themselves.

The zebra mussel has motivated strategies to thwart new invasions of other aquatic species, but the mussel itself is undoubtedly here to stay. The question is, how much further will human activities distribute it?

Mussels that were presumed to inevitably infest the Great Lakes watershed did so far faster than anticipated, apparently due to barge traffic. Zebra mussel veligers have been found in recreational boat engine cooling systems, bilges, live wells, and in bait buckets. Boat trailers that entrap and rip out pieces of vegetation have transported attached adult mussels from infested lake to uninfested lake. And some divers are suspected of intentionally inoculating quarries with zebra mussels to improve diving conditions.

Research shows that enforced laws that penalize people for possession or transport of zebra mussels are effective, at the very least, for educating a large proportion of the public.





Control

Biological Control. In a warm, nutrient-rich environment like Lake Erie, the zebra mussel reproduces at a rate no larger predator could possibly keep up with. No matter how many mussels fish or ducks eat, there will always be plenty more. Besides, a predator acting as a control agent of zebra mussels creates the added concern of contaminants moving further into the food web. An organism smaller and more prolific than the mussels might control or eliminate them, such as a virus, bacterium, or parasite, but research hasn't yet found this.

Sea Grant support to scientists to research biological, chemical, and physical control of zebra mussels has found ways to induce spawning, prevent attachment, kill veligers and adult zebra mussels, and clean clogged pipes.

Chemical Control. Sea Grant research has determined the most effective and environmentally safe dosages of chemicals that can be used for control, including those that induce early or late spawning; carbon dioxide as a narcotizing pre-treatment control; chemicals called Lemmatoxins, from the fruit of the African tree *Phytolacca dodecandra*, for which two U.S. patents for molluscicides have been awarded; potassium salts to kill adults or prevent larval attachment; and chlorine, at present the most commonly used chemical.

Physical Control. Chemicals oftentimes affect not only zebra mussels but other organisms that live with them, so that more specific control methods are always sought. Sea Grant has funded research to formulate new substrates and coatings, investigate proteins that control byssal thread formation, apply high-voltage electrostatic fields with low currents, and apply ultrasonic and hydrodynamic cavitation (low-pressure bubbles), all for the purpose of preventing attachment; develop robots to clean pipes; test ultra-violet radiation to kill veligers; and mechanically eliminate dissolved oxygen in pipes to kill adults.

Preventing New Introductions

If the invasion of the zebra mussel has taught anything, it's that other aquatic nuisance species must be stopped before they even get here. There are two methods of ridding ballast water of hitchhiking species: killing the organisms outright within the ballast hold and MOE, or

mid-ocean (ballast water) exchange. Although methods have been devised for killing organisms in the hold, researchers have yet to settle on the best, most efficient, cost-effective, and environmentally friendly one. Therefore, MOE is the alternative for the short term.

The Lake Carriers Association, Canadian Shipowners Association, and the Seaway Port Authority of Duluth have devoloped and implemented a voluntary ballast exchange program for ships taking on ballast water in any area of ruffe infestation and heading to any other part of the Great Lakes. The program has 100% compliance.

During the process of ballast water exchange, ocean (salt) water is taken on as ballast in exchange for ballast (fresh) water that was taken on in a port. Freshwater organisms cannot live in salt water, nor salt water organisms in freshwater ports. Also, species that live in a port's relatively shallow and protected waters, are not equipped to live in the open, unprotected depths of the ocean.

Mid-ocean exchange is required of all transoceanic ships entering the Great Lakes, and, because aquatic invaders are a world-wide problem, will likely eventually be mandated of all ships. The process of water exchange, however, is dangerous in storms and is not as reliable when both ports are saltwater. MOE, therefore, is truly only an interim control until permanent technologies can be installed on individual ships.

The Newest Invader

Gymnocephalus cernuus, commonly referred to as ruffe, is the Great Lakes' most recent potentially threatening invader. This small bony fish, like the zebra mussel, was also presumably transported in ballast water, deposited in 1985 and officially identified in Lake Superior's Duluth/Superior harbor in 1987. Also like the zebra mussel, ruffe eat the same food as valued fish, such as walleye and yellow perch, and can tolerate a broad range of habitats.

In the western arm of Lake Superior where the ruffe has firmly taken hold, its numbers have overtaken all other fish. Like most pests, ruffe reproduce prolifically. They also out-compete walleye, perch, and small forage fish by having a faster first-year growth rate and by maturing earlier.

To control the spread of ruffe, Michigan, Minnesota, Wisconsin, and Ontario give much effort to public education and have rules and regulations that prohibit the transport of live ruffe. Likewise, the Lake Carriers Association, Canadian Shipowners Association, and the Seaway Port Authority of Duluth have developed and implemented a voluntary ballast exchange program for ships taking on ballast water in any area of ruffe infestation and heading to any other part of the Great Lakes. The program has 100% compliance and has clearly been effective, despite the fact that ballast exchange cannot always guarantee having rid a hold of transported species.

Biology and Life History

6/1/95 to 5/31/96

Comparative Life History and Microhabitat of a Freshwater Population of Dark False Mussel (*Mytilopsis leucophaeata*) and Zebra Mussel (*Dreissena polymorpha*) at the Southern Edge of Its Range

Bruce A. Thompson,
Louisiana State University
Louisian Sea Grant College Program
Project R/ZM-3

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Identify field-caught zebra mussel veligers to distinguish *Dreissena* from *Mytilopsis* and several other veliger morphs found during 1994.
- Describe the geographic distribution of the two target species.
- Estimate the age and growth rate of the species using caged, marked mussels.
- Describe the reproductive timing and patterns, and the fecundity of each species.
- Determine the water quality of each species' microhabitat.

7/1/95 to 6/30/96

Environmental Variables Associated with Imminent Zebra Mussel Infestation in Alabama

David R. Bayne and E. Cliff Webber,
Auburn University
Mississippi-Alabama Sea Grant Consortium
Project A/O-24-ZM3

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objective

- Document the environmental variables, such as pH, calcium, and salinity, associated with zebra mussel infestation by documenting the expansion of the mussel's range in Alabama and the variables associated with that expansion.

Research project numbers (such as R/ZM-3) are required to obtain details of a project from the state Sea Grant program.

9/1/94 to 8/31/97

The Population Dynamics and Ecology of Zebra Mussels in Inland Lakes

David W. Garton,
Indiana University at Kokomo, and
Ladd E. Johnson,
Université Laval, Quebec
Illinois-Indiana Sea Grant Program
Project NA

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.

Results

- Study lakes spanning a tenfold range in size with varying depth and substrate (and possibly food availability) have been selected.
- Very preliminary data suggest significant variation in adult density, size population and habitat utilization across lakes. Progress of mussel invasion within each lake also appears to vary.

8/1/94 to 7/31/95

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

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.
- Use this information to predict the geographic spread of *Dreissena polymorpha* and identify the estuarine areas that are at risk of invasion.

8/1/94 to 7/31/95

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

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.

5/1/94 to 4/1/95

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

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, N.Y.
- 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.

Results

- Despite an apparent introduction, three years of collecting shows no evidence of zebra mussels in the Susquehanna River watershed in New York state, despite over 200 collections and intensive sampling for veligers in the spring of 1995.

9/1/93 to 8/31/95

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
WHOI Sea Grant Program
Project R/B-119-PT

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.

9/1/93 to 8/31/95

Swimming and Settlement Behavior in the Quagga Mussel

Victor S. Kennedy,
University of Maryland
Maryland Sea Grant College Program
Project R/ZM-03

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

- 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 juveniles 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.

9/1/93 to 8/31/96

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

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

- 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.

7/1/93 to 6/30/95

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 Sea Grant Consortium Program
Project R/E-45ZM

Primary source of funds: Fiscal year 1993 zebra mussel federal appropriation

Objectives

- Develop a practical manual for identification of larval and postlarval dreissenids using routine optical microscopic examination of shell morphology and hinge structures.
- Prepare detailed scanning electron and light micrograph sequences of larvae and postlarvae for the zebra mussel *(Dreissena polymorpha)*, the quagga mussel *(D. bugensis)*, the dark false mussel *(Mytilopsis leucophaeata)*, and the wedge clam *(Rangia cuneata)*. (Micrographic sequences for bivalves from more estuarine waters [e.g., *Geukensia demissa*, *Mulinia lateralis*, *Macoma balthica*, and *Crassostrea virginica*], where early life history stages of *D. polymorpha* may conceivably occur, have already been prepared. This should help distinguish early life history stages of *D. polymorpha* from plankton and benthic samples.)
- Develop routine methods for rearing larvae of *D. polymorpha* and *D. bugensis* through to postlarval stages.
- Examine the larval and postlarval shell growth and morphology in animals grown in the laboratory under different temperature and salinity regimes and derived from geographically distinct parent populations to ascertain whether shell morphological features used for identification are altered by environmental conditions or differ with respect to the geographic location of parent populations.

Results

- 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)*, under controlled environmental conditions. This work has revealed that in the laboratory, mussel larvae could extend their "normal" larval period of 2 to 3 weeks up to 7 to 10 weeks if they didn't encounter proper metamorphic cues. This may have profound implications in estimating the potential dispersal capabilities of larvae, particularly in river systems.
- Under laboratory conditions, a relatively low percentage of gametes are fertilized and a relatively low percentage of these form viable larvae, suggesting that what is already considered a prolific breeder has an even greater reproductive potential.
- Larval shell shapes are similar at all developmental stages for all of the species investigated except for the Asian clam *(Corbicula fluminea)*. Larger specimens of zebra and quagga mussels, and other mussel species, however, can be distinguished from one another by their shell shapes. All postlarval mussels differ from clams in their shell shape, the mussels' development of a septum, and their lack of prominent cardinal teeth. Larval zebras and quaggas can be distinguished from other mussels by their prominent hinge teeth.
- Diagnostic differences in the nucleotide sequences of a 710 bp fragment of the mitochondrial cytochrome *c* oxidase subunit I gene (COI) from each of these species can be used to identify their free-living larvae.

9/1/92 to 9/1/94

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

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.

11/1/92 to 10/31/95

Osmoregulatory Physiology of the Zebra Mussel

Robert L. Preston,
Illinois State University
Illinois-Indiana Sea Grant Program
Project ZM/2

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.

Results

- Gill tissue ion concentrations in *D. polymorpha* were about 10 mM K, 4 mM Na, and 5 mM Ca, measured by atomic absorption spectroscopy.
- Compared with the external medium, tissue ion gradients ranged from 300:1 to 4:1, depending on the ion.
- K toxicity to *D. polymorpha* may be related to collapse of K gradients required for neuromuscular activity.
- Total free amino acid concentration in gill tissue was about 11 mM.
- Dissolved organic nutrients (amino acids and sugars) can be absorbed by *D. polymorpha* directly from the medium.
- Studies of unionid ions and amino acids show the solute concentrations in general resemble those observed for *D. polymorpha*.
- Studies show specific membrane transport proteins are involved in ion and solute regulation in these mussels

.9/1/92 to 8/31/94

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

Gary Rosenberg,
Academy of Natural Sciences of Philadelphia
New Jersey Sea Grant Consortium Program
Project R/E-30-ZM

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*.

8/1/92 to 5/31/93

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

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.

2/1/92 to 1/31/94

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

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.

9/1/91 to 8/31/94

The Byssal Adhesive of Zebra Mussels *Dreissena polymorpha*

J. Herbert Waite,
University of Delaware
Delaware Sea Grant College
Program Project R/B-26

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.

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.

8/1/91 to 7/31/92

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
WHOI Sea Grant Program
Project R/M-25

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.

8/1/91 to 7/31/93

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

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.

4/1/90 to 12/31/90

Seasonal Patterns of Metabolism, Feeding, and Growth of *Dreissena polymorpha* in Western Lake Erie

David W. Garton,
The Ohio State University
Ohio Sea Grant College Program
Project R/ER-20-PD

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.

Effects on Ecosystems

6/1/95 to 5/31/96

Testing of Crawfish Defenses Against Zebra Mussel Fouling

Raymond T. Bauer,
University of Southwestern Louisiana
Louisiana Sea Grant College Program
Project R/ZM-4

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objective

- Determine the intensity and pattern of biofouling of the exoskeleton of *Procambarus clarkii*, a commercially important crawfish, under natural conditions in native habitats and culture ponds flooded from natural waters.

8/1/95 to 8/31/98

The Effect of Zebra Mussel Infestation in Inland Lakes on Pelagic Benthic Coupling

David N. Edgington, Russel L. Cuhel, and Jerry L. Kaster,
University of Wisconsin-Milwaukee
Wisconsin Sea Grant Institute
Project R/LR-63

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Select Wisconsin lakes that represent a continuum from deep, oligotrophic, phytoplankton-limited environments to shallow and eutrophic environments and compare their response to zebra mussel invasion with a potential shift from pelagic, zooplankton-fish dominated systems to benthic, zebra mussel-fish dominated systems.
- Determine the potential for the zebra mussel infestation to affect the transfer of energy between primary producers and higher trophic levels.

9/1/95 to 8/31/98

Influences of Zebra Mussels on the Distribution and Fate of Coplanar PCB Congeners in the Green Bay Estuary

David E. Armstrong, William C. Sonzogni, and Jon B. Manchester,
University of Wisconsin-La Crosse
Wisconsin Sea Grant Institute
Project R/WM-57

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Measure the influence of zebra mussels on the distribution and fate of PCBs, especially coplanar congeners, and assess the resulting effects on the toxicity of PCBs in Green Bay.
- Develop a data set of coplanar PCBs and other congeners in Green Bay, including concentrations in veliger and adult zebra mussels, fecal matter, plankton, zooplankton, benthic invertebrates, sediments, and fish.
- Determine whether short-term temporal trends and spatial differences occur in concentrations of coplanar PCB congeners in zebra mussels and fish by sampling over a three-year period and in three or more areas.
- Assess the influence of zebra mussels on coplanar PCBs by comparing ratios, quantities, and fluxes of coplanar and non-coplanar congeners among compartments of the food web.

9/1/95 to 5/31/97

Trophic Interactions Between Zebra Mussels and Larval Fish: Experimental Tests of Competition for Planktonic Resources

Mark B. Sandheinrich,
University of Wisconsin-La Crosse,
William B. Richardson,
U.W.-La Crosse and National Biological Service,
and Barry Johnson, NBS
Wisconsin Sea Grant Institute
Project R/LR-66

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriations

Objectives

- Test hypothesized effects of filter feeding by zebra mussels and hydraulic turbulence on growth and survival of larval fish (bluegill). (Zebra mussel filter-feeding is presumed to depress plankton; turbulence may facilitate plankton depletion by zebra mussels and also exert high energetic stress on fish larvae.)
- Test if artificially elevated nutrient levels will stimulate planktonic production and offset zebra mussel impacts on larval bluegill growth and survival.
- Test if presence of aquatic macrophytes will offset the effects of zebra mussels on larval growth and survival by enhancing prey availability (epiphytic micro- and macroinvertebrates).
- Measure larval bluegill that survived the competitive bottleneck exerted by zebra mussels for elevated growth as juveniles (due to increased benthic production), especially in treatments with turbulence.

Results

- Lack of bluegill larvae necessitated the use of fathead minnow larvae (which share the same ontogenetic sequence of shifts in diet) during the first summer's experiment, which lasted four months at the (La Crosse) mesocosm facility of the NBS.
- The presence of zebra mussels significantly reduced production of fish biomass, independent of all other variables.
- Turbulent water movement decreased fish survivorship, probably by increasing the rate of water column resource depletion.
- Concentrations of soluble reactive phosphorus (SRP) were greater in the presence of zebra mussels than in treatments without; total phosphorus (TP) was unaffected.
- *Daphnia* (mainly *D. pulex*) populations declined in the presence of all treatments, most strongly in treatments of fish and/or turbulence, both to an unexpected degree. Very young larval fish (used here) are presumed unable to catch and consume large cladocerans; and although velocity measurements showed sufficient hydraulic dead zones to sustain *Daphnia*, their numbers plummeted in turbulence.
- The treatments of zebra mussels and turbulence combined have an increased effect on the reduction of turbidity and chlorophyll *a* than what is expected for the linear combination of the two treatments.
- Larval fish in the zebra mussels plus turbulence treatments experienced intense resource limitation, then apparently switched to benthic prey and grew rapidly.

9/1/94 to 2/28/97

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

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.

Results

- Field experiments reveal amphipod abundances on hard substrates were 3-fold higher in July than in August 1995.
- Amphipods prefer substrate with high habitat complexity provided by the presence of zebra mussels over low habitat complexity provided by bare rocks.
- Habitat preference appears to be a density-dependent response suggesting that as amphipod densities increase, the substrate providing high habitat complexity becomes limited and substrate providing low habitat complexity is utilized.

9/1/94 to 8/31/96

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)

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.

Results

- Plankton communities sampled in 1995, 1 m above the zebra mussel beds in the western basin of Lake Erie exhibited the same alteration in C- and P- dynamics previously seen in bottle experiments.
- Plankton communities exposed to zebra mussels over the long term showed elevated SRP and decreased uptake of phosphate, decreased release of DOP, and decreased uptake of 32P-phosphoryl from ATP (a model DOP compound).
- Bacterial incorporation of 3H-thymidine into DNA was diminished in plankton communities chronically exposed to zebra mussels.

9/1/94 to 8/31/96

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)

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.

Results

- Changes in substrata (from bare rock to zebra mussel encrusted rock) do not explain the changes in the benthic algae of Saginaw Bay.
- After initial zebra mussel colonization (1991) reduced phytoplankton densities, increases in light penetration, periphyton biomass, and phosphorus limitation were observed from 1992 to 1993.
- From 1991 to 1993, the dominant benthic algae shifted from diatoms to filamentous green algae (*Zygnematales*).
- During 1994 to 1995, increases in storm events and blooms of the blue-green phytoplankton *Microcystis* resulted in light penetration levels similar to pre-zebra mussel conditions. This reduction in light and increasing grazer densities may be responsible for a shift back to diatom dominance in the periphyton community and a decrease in benthic productivity.
- Light is now the major factor limiting total benthic algal biomass, although phosphorus limitation is still important.
- Current conditions could represent a post-zebra mussel equilibrium for the benthic algal community of Saginaw Bay.

9/1/94 to 6/1/97

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

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.

9/1/94 to 8/31/97

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

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.
- 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.

9/1/93 to 8/31/95

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

James B. Cotner,
Texas A & M University,
and Wayne S. Gardner,
GLERL at NOAA
Texas A & M University Sea Grant College Program
Project R/ES-60

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

- 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.

9/1/93 to 3/31/95

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

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 alga.
- 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 the contaminant is delivered sorbed to algal cells.

9/1/93 to 8/31/96

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)

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.

8/1/93 to 7/31/95

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

Primary source of funds: Fiscal year 1993 zebra mussel federal appropriation

Objective

- Determine how the 1992 zebra mussel invasion of the rock reef in southwestern Lake Michigan will affect the dynamics of the benthic food web by comparing pre-1992 data on benthic algal, macroinvertebrate, and crayfish abundances and composition with post-1992 data.

Results

- Zebra mussel densities have increased from 1,246/m^2 in 1992 to over 16,000/m^2 in 1995 at this rock reef habitat. In 1995, 70% of these individuals were of the smallest size class, indicating that the populations are still successfully reproducing and that densities may continue to rise.
- Zebra mussel filter feeding on phytoplankton has increased illumination to the benthos 4-fold over the past four years.
- Benthic algae have responded positively to the increase in light (and zebra mussel-derived nutrients), increasing from <1 g/m^2 in 1991 to >6 g/m^2 in 1995. The composition of benthic algae has switched from one dominated by diatoms before the zebra mussels invaded to one dominated now by filamentous green algae of the order Zygnematales (mostly *Mougeotia* spp. and *Spirogyra* spp.), and the branched green filamentous *Chara*.
- With the 6-fold increase in benthic algal biomass, benthic macroinvertebrates have increased in both density and diversity. Before 1992, macroinvertebrates were sparse and dominated by chironomids. Now, high densities of amphipods, isopods, gastropods, mayflies, diptera, and caddisflies are common.
- Crayfish densities have increased in response to the increase in algal and macroinvertebrate food availability. While we are presently measuring a 2-fold increase in crayfish densities, 75% of these organisms are young-of-the-year recruits, indicating that the populations are expanding. There has been a species shift from *Orconectes propinquus* dominating 4:1 over *O. virilis* before 1992, to an equal distribution of these two species in 1994 and 1995.
- We are presently constructing a mass-balance model of the benthic food web components to enable us to predict future impacts of changes in zebra mussel densities on this community.

5/24/93 to 5/23/96

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
Project NA

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 of this wetland.
- Determine direct and indirect effects of zebra mussels on wetland zooplankton.

Results

- Zebra mussel larvae were present in the marsh from July through October, with a peak in mid- to late-July in 1993 and 1994. There were very few larvae in 1995.
- Mussels are colonizing the offshore two-thirds 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.
- Tubificid oligochaete densities in the sediment were higher in areas colonized by mussels.
- Numbers of larval tanytarsid chironomids decreased in the sediment but increased on plant stems in mussel-colonized areas.

9/1/92 to 8/31/94

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

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.

Results

- High densities of zebra mussels (such as in western Lake Erie) have an impact on metal cycling: the major effect is an increased flux of metals from the water column to the lake bottom. Water column metal levels have decreased; sediment metal levels have increased, with zebra mussels at least doubling deposition rates.
- The increased flux of metals to the sediment is mainly due to an increase in the amount of sediment deposition, although the mussels also increase the metal concentration in this sediment.
- Increase in sediment deposition can be great if seston levels are high. A biodeposition rate of 28 $mg/cm^2/day$ was found near the mouth of the Maumee River.
- Net metal bioaccumulation by zebra mussels has also modified the pre-*Dreissena* metal cycling. However, this effect is much smaller than the increased metal biodeposition.
- Zebra mussels take up metals from solution and via the uptake of particles; the relative amounts of uptake from these two sources appear dependent on the amount of particles present.

9/1/92 to 8/31/93

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

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.

9/1/92 to 8/21/95

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

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

- 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 two-thirds 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.

9/1/92 to 8/31/93

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

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).

9/1/92 to 8/31/95

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

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.

9/1/92 to 8/31/94

Phosphorus Budget of a Zebra Mussel Population

Joseph C. Makarewicz,
SUNY College at Brockport
New York Sea Grant Institute
Project R/CE-4

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.

9/1/92 to 8/31/95

Nutrient Regeneration by Zebra Mussels and Its Impact on Phytoplankton

Michael J. Vanni,
Miami University
Ohio Sea Grant College Program
Project R/ZM-15

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

- 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.

8/1/92 to 7/31/94

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

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%.
- 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%.

8/1/92 to 7/31/94

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

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.
- 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.

6/1/92 to 12/31/92

Zebra Mussel's Directed Trophic Transfer

Susan W. Fisher,
The Ohio State University
Ohio Sea Grant College Program
Project R/PS-11-PD

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% of their body burden of PCBs and PAHs through ingestion of contaminated zebra mussel feces.
- 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.

6/1/92 to 12/31/92

The Areal and Vertical Distribution of *Cladocera glomerata* in Western Lake Erie and Its Interaction with the Zebra Mussel (*Dreissena polymorpha*)

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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

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 numbers of *Cladophora* are found on substrates colonized nearly 100% by zebra mussels.
- The blue-green alga *Phormidium* is present at many of the sampling sites, often colonized directly on zebra mussels and rocks.

5/1/92 to 4/30/93

Responses of Macrophytes to Zebra Mussel—Associated Reduction in Turbidity in Saginaw Bay

Thomas G. Coon and Ted Batterson,
Michigan State University
Michigan Sea Grant College Program
Project R/ZM-7

Primary source of funds: Fiscal year 1991 zebra mussel federal appropriation

Objectives

- Document how increased densities of zebra mussels affect water clarity in the littoral zone of Saginaw Bay during summer growing conditions.
- Describe changes or lack thereof in distribution, abundance, and species composition of submersed macrophytes associated with turbidity change.

Results

- From 1991 to 1993, turbidity decreased in the littoral zone of the northern portion of inner Saginaw Bay, but not in the southern portion of the bay.
- From 1991 to 1993, submersed macrophytes increased in relative abundance throughout Saginaw Bay, even though the water level was higher in 1992 and 1993 than in 1991.
- The greatest increase in abundance of submersed macrophytes occurred in the northern region of the bay, where turbidity reductions were greatest.
- Maximum depth of macrophyte colonization also increased from 1991 to 1993.
- Macrophytic chlorophytes, charophytes, and *Vallisneria americana* showed the greatest increase in relative abundance and maximum depth of colonization.
- The highly wind-mixed environment of Saginaw Bay and the sediment load from the Saginaw River appear to outweigh the ability of zebra mussels to clear water in the littoral zone of southern Saginaw Bay; however, in the littoral zone of the northern portion of the bay, conditions appear to favor zebra mussel effects on clarity.

2/1/92 to 1/31/95

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

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.

10/1/91 to 9/30/94

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

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.
- 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% and 37.3% 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% and 15% 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.

10/1/91 to 9/30/93

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

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% 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% 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.

9/1/91 to 8/31/92

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

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.

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%.
- 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.

8/1/91 to 7/31/93

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

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.

8/1/91 to 7/31/94

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

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

- 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.

4/4/91 to 12/31/91

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

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.

6/1/90 to 12/31/90

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

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.

5/1/90 to 12/31/90

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

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.

5/1/90 to 12/31/90

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

Primary source of funds: Local Sea Grant program from federal and nonfederal sources

Objective

- 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.

Regular monitoring beginning 4/1/90

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

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

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

4/1/90 to 12/31/90

Grazing Rates of Zebra Mussels

David A. Culver,
The Ohio State University
Ohio Sea Grant College Program
Project R/ER-21-PD

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.
- Zebra mussels in cages near the bottom grew only one-third as fast as those 2 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.

4/1/90 to 12/31/90

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

Primary source of funds: Local Sea Grant program from federal and nonfederal sources

Objective

- 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.

12/1/89 to 6/30/90

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

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.

11/15/88 to 8/31/92

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

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/day.
- At a density of 50,000 mussels/m^2, and assuming 1 kcal/g wet weight of algae and a seasonal range of 510 g wet weight algae/$meter^3$, then the zebra mussel population at a 7-m site in western Lake Erie could consume 24 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.

Socio-Economic Analysis

9/1/93 to 8/31/96

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

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

- Questionnaires seeking information about zebra mussel damages and zebra mussel control strategies were mailed to 1,494 facilities (electric generating power plants, municipal water systems, and industrial water users) with water intakes in the Great Lakes basin during November 1994.
- Of these, 1,412 were deliverable from which 420 surface water user respondents make up the database (30%). An additional 165 respondents (12%) (for a total of 585 respondents) use water from wells or purchase water and are not used in the analysis.
- A telephone follow-up of 100 nonrespondents resulted in 70 contacts; the remaining 30 may no longer exist. The contacted facilities showed that 79% were surface water users compared to 72% of the respondents; 44% of the contacts were electric power generating and municipal water users compared to 57% of the respondents; and 76% of the contacts were located on a Great Lake or Great Lake tributary compared to 82% of the respondents.
- Presuming that the 100 nonrespondents contacted is a representative sample of the total 827 nonrespondents (and therefore that the 30 of those 100 presumed defunct likewise represent 30% of the 827), then the original sample size of 1,412 is reduced to 1,164, and the response rate is adjusted to 50%-36% from surface water users, which are usable in the analysis, and 14% from other water users, which are not usable.
- One hundred sixty (160) respondents reported detecting zebra mussels at their facilities, of which 140 reported zebra mussel monitoring and control expenses of $60.2 million during the period 1989–1994. Eighty-six percent (86%) of expenditures were reported by facilities located on a Great Lake. A simple projection to nonrespondents based on the 50% response rate yields total monitoring and control expenditures of $120.4 million during 1989–1994.
- The responding facilities reporting monitoring and control costs spent an average of $430,000 over 1989–94: private utilities spent $869,000; public utilities, $383,000; municipal water, $318,000; and other industries, $339,000. Great Lakes facilities reported average cumulative expenditures of $538,000 compared to about $200,000 for those on tributaries or not connected to a Great Lake.

Present and Expected Economic Costs (continued)

- Expenditures per year vary considerably across years, increasing from $39,000 in 1990 to $137,000 in 1993 before dropping to $85,000 in 1994. A decrease in retrofit, redesign, reconstruction, or rebuilding costs account for 95% of the decrease in costs from 1993 to 1994. In a typical year, small facilities (less than 5 mgpd) can apparently expect costs of less than $20,000, and large facilities (greater than 300 mgpd) can expect costs of about $350,000.
- Only 2 respondents reported lost revenues from reduced production totalling $0.5 million, while 7 reported production losses in percentage terms. If there were production losses, they are largely unreported.
- The typical respondent with zebra mussels has 2.5 people responsible for zebra mussel monitoring, control, and research activities, devoting 0.5 full-time-equivalent person per year.
- Respondents reported receiving information on aquatic nuisance species prevention and control teaching techniques from conference workshops and trade shows (48%), trade publications (43%), Sea Grant programs (33%) and media (30%).
- In early 1995, 276 zebra mussel researchers were sent the questionnaire, which requested information about research expenditures and new strategies of zebra mussel control. Of the 87 responses (32% response rate), 72 reported a research program. Reported research budgets totaled $18.7 million, with 2 projects extending into 1998. The average budget was $96,000, with a duration of 2.4 years, and a typical investigator spending 30% of his/her time on research.

7/1/95 to 6/30/96

Potential Impact of Zebra Mussels on Aquaculture and Aquaculture's Potential to Disseminate Zebra Mussels into Public and Private Waters

Michael P. Masser,
Auburn University
Mississippi-Alabama Sea Grant Consortium
Project A/O-24-ZM4

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objective

- Examine the potential impact of the zebra mussel *Dreissena polymorpha* on the prosperous and diverse aquaculture industry in the states of Alabama, Louisiana, and Mississippi, and the potential for this industry to spread the zebra mussel into public and private waters across the Southeast

9/1/92 to 8/31/94

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

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.

Results

- A monitoring and enforcement strategy has been developed to reduce the risk of accidentally introducing nonindigenous species (NIS) via transoceanic shipping (Gollamudi). Case studies of the Great Lakes and Chesapeake Bay demonstrate the feasibility of attaining improved compliance at substantially reduced cost compared to current enforcement strategies in the Great Lakes.
- Using decision heuristics and principal-agent models, a model protocol has been developed for policy decisions about purposeful NIS introductions. A key principal is to de-emphasize *ex ante* (before hand) full information while maximizing the scope for revocability (the ability to revoke a decision and restore status quo) (Thomas).
- Empirical analysis of the social costs of the accidental introduction of the zebra mussel is focusing on the effects of the zebra mussel in the walleye recreational fishery in Lake Erie.

9/1/91 to 8/31/94

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

Primary source of funds: Fiscal year 1991 zebra mussel federal appropriation

Objectives

- Determine the contaminant levels in Great Lakes zebra mussels and develop a method to decontaminate harvested mussels.
- Compost zebra mussels and determine the value of the compost as a soil amendment.
- Determine the feasibility of using zebra mussels in animal feeds.

Results

- Contaminant levels of mussels harvested from several highly contaminated water sites were so low that the mussels did not warrant treatment as a hazardous waste.
- A decontamination method utilizing digestion and flocculation of the soft tissues was developed should a highly contaminated batch of zebra mussels be found.
- Zebra mussels were successfully composted by a low technology method in a mixture with poultry manure, sawdust, peat moss, and wood chips.
- Seed germination and growth tests of radishes and tomatoes along with chemical analysis show that the compost enhances the soil.
- A project investigating the use of mussel shells for calcium in poultry and cattle feed was reviewed, but the economics of the proposed process versus traditional sources of calcium make it unlikely that the avenue will be further developed.

8/1/91 to 7/31/93

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

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% (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.
- 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.
- However, a comparison of the Ohio respondents who made one or more trips to Lake Erie from this data base to those of the R/ME-12 data base (below) shows a decline in number of trips from 11.2 in 1990 to 6.3 in 1992.

9/1/90 to 8/31/92

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

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 2% 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.

4/1/90 to 12/31/91

The Economic Costs of the Zebra Mussel

Leroy J. Hushak,
The Ohio State University
Ohio Sea Grant College Program
Project R/ME-14-PD

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.

Control and Mitigation

9/1/94 to 8/31/95

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

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.

9/1/94 to 8/31/97

Silencing Expression of the Byssus in Zebra Mussels

J. Herbert Waite, University of Delaware
Delaware Sea Grant College Program Project NA

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.

9/1/94 to 3/31/96

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 Institute
Project R/NI-24

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.
- Include both a laboratory batch setup and a specially designed "flow-through" apparatus. While DC fields will be employed for most of the research, several runs using AC fields will also be conducted for comparative purposes.

8/1/93 to 7/31/95

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

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

- 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.

7/1/93 to 6/30/95

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

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

- 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.

7/1/93 to 6/30/95

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 Sea Grant Consortium Program
Project R/E-44ZM

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.

Results

- Tests show that boundary layer injection works at least as well as conventional chlorination by completely suppressing larval settlement on concrete test plates at temperatures 20 to 26°C, with 250 ppb total residual oxidant (TRO) downstream at the end of each test trough.
- Continuous bulk chlorination was no more effective than the control (<10% mortality) in eliminating pre-settled mussels exceeding 20 mm on concrete test plates, in declining river temperatures, with 100–120 ppb TRO.
- Under the same conditions (above), boundary layer injection created a mortality gradient, from over 90% within 20 cm of the injector, to control levels (<10% mortality) 2 meters downstream. Despite similar downstream concentrations, TRO levels along the wall of the boundary layer trough were much higher than levels in the bulk chlorination trough.

9/1/92 to 8/31/94

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)

Primary source of funds: Fiscal year 1992 zebra mussel federal appropriation

Objectives

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

Results

- Adult mussels demonstrate a limited ability to move away from UV exposure.
- While wide-range UV will eventually kill off adult populations, the killing time is so long as to be of doubtful use as a control mechanism for existing populations (using our existing UV source).
- Higher intensity UV sources show more promise in killing adults.
- Quagga mussels appear to be more resistant than zebra mussels.
- Planktonic larvae show a negative directional response to UV radiation and are killed rapidly (~2 hrs.), even under our existing UV source.
- Field experiments with 4166-L tanks and a 5000-watt UV source killed 100% of *Dreissena polymorpha* veligers at the slowest flow rates. (Mortality of control organisms was 20% – 30%, 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.

9/1/92 to 9/30/95

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

Dimitri M. Donskoy,
Stevens Institute of Technology
New Jersey Sea Grant Consortium Program
Project R/E-29ZM

Primary source of funds: Fiscal year 1992 zebra mussel federal appropriation

Objectives

- Test response of adults and veligers 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

- 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 mussels of all life stages from settling and translocating onto exposed surfaces.
- Ultrasound pulse-echo technique can be used for evaluation of mussel populations.

9/1/92 to 12/31/93

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

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 4 hours of the initiation of the treatment.

9/1/92 to 8/31/95

New Approaches to Control of Zebra Mussels by Targeted Microbial Products

Ralph Mitchell,
Harvard University
MIT Sea Grant College Program
Project RT-35

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

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

5/1/92 to 12/31/92

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

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.

2/1/92 to 1/31/94

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

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 hour.
- Cardiomyopathy may contribute to the toxicity of potassium.

8/1/91 to 7/31/93

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

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

- 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).
- 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.

8/1/91 to 7/31/92

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

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.

8/1/91 to 7/31/94

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

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.

7/1/91 to 6/30/93

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

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.

5/10/91 to 9/30/93

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

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.

12/1/90 to 6/15/91

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

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 hours 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.

4/1/90 to 3/31/91

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

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.

Preventing New Introductions

8/1/91 to 7/31/92

Ship Operational and 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

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.

2/1/95 to 1/31/96

Transfer of Aquatic Nuisance Species via Ships Ballast Water Operations

Charles E. Arbanas
and Jill Wilson,
National Research Council Marine Board
National Academy of Sciences
Project 95-CETS-032-01

Primary source of funds: Fiscal year 1995 zebra mussel federal appropriation and other federal agencies

Objectives

- Review existing knowledge of nonindigenous species introduction as the result of ship operations.
- Assess the state of practice of the prevention and control of nonindigenous species introduction in ship operation, including voluntary guidelines at the regional, national, and international levels.
- Appraise potential alternative control strategies and management options for biological efficacy, practicality, and cost-effectiveness and for their effects on vessel and human safety and the environment.
- Identify research and technology demonstration needs; develop framework for the demonstration project; and make recommendations for improved regulations, technology advancement and application, and for improved awareness of operations practices on the part of vessel operators.


GENUINE

Reducing the Spread of Established Populations

8/1/95 to 7/31/96

Vulnerability of Florida Waters to Zebra Mussel Invasion

E. D. Estevez, D. Hayward,
and Michael J. Marshall,
University of Florida
Florida Sea Grant College Program
Project E-ZM-3

Primary source of funds: Fiscal year 1995
aquatic nuisance federal appropriation

Objectives

- Predict the likelihood and geography of zebra mussel colonization in Florida waters for the purpose of informing subsequent outreach, monitoring, and intervention programs.
- Review and synthesize existing information on the environmental requirements of zebra mussels.
- Group Florida waters by their shared geographic, hydrological, chemical, and biological features.
- Describe the constituents and other environmental conditions in systems selected to represent Florida waters.
- Identify Florida water bodies carrying the most commercial and/or recreational vessel traffic originating in areas of zebra mussel provenance.

9/1/94 to 8/31/95

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

Mary D. Balcer,
University of Wisconsin-Superior
Wisconsin Sea Grant Institute
Project R/LR-57

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.

9/1/94 to 8/31/97

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
Wisconsin Sea Grant Institute/
Connecticut Sea Grant
Project R/LR-62

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 predictions of the importance of the "exposure" of inland systems to nearby source populations. Assess the initial efficacy of educational and outreach programs.

2/8/93 to 10/31/93

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

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.

7/1/91 to 6/30/93

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

James T. Carlton,
Williams College
Connecticut Sea Grant College Program
Project R/ES-5

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% 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% of the boat trailers transported mussels in this way.
- Based on reported destinations, larger inland lakes are predicted to be invaded first.

Great Lakes Ruffe Initiative

Biology and Life History

6/1/95 to 5/31/98

Geographic Variation and Colonization Patterns of Ruffe (*Gymnocephalus cernuus*) in the Great Lakes: Otolith Signatures and DNA Sequence Divergence

George R. Spangler,
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Minnesota Sea Grant College Program
Project R/F-30

Carol Stepien,
Case Western Reserve University
Ohio Sea Grant College Program
Project R/NIS-1

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objective

- Determine the European origins of ruffe *Gymnocephalus cernuus* within the Great Lakes and its colonization patterns within the streams and estuaries of Lake Superior.

6/1/95 to 5/31/98

Identification of the Ruffe Oocyte Maturation-Inducing Substance and Characterization of Its Receptor

Patrick K. Schoff,
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Minnesota Sea Grant College Program
Project R/F-29

Peter Thomas,
University of Texas, Austin
Texas Sea Grant College Program
Project R/F-66

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Determine the hormonal basis of ruffe oocyte maturation.
- Determine the hormonal genesis of ruffe sex pheromones.
- Characterize the response of ruffe to pheromonal signals.
- Characterize the intergametic signals and isolate such signals.
- Identify the molecules involved with sperm-egg binding during fertilization.
- Test the agents designed to block or interfere with hormonal development, pheromonal signaling at the organismal or cellular level, or gamete binding for their ability to reduce or eliminate ruffe reproduction.

Effects on Ecosystems

6/1/95 to 5/31/98

Potential Impacts of Invading Ruffe (*Gymnocephalus cernuus*) on Benthic and Pelagic Ecosystems of the Great Lakes

Carl Richards, Richard P. Axler, and
Anne E. Hershey,
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Minnesota Sea Grant College Program
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Gary A. Lamberti and David M. Lodge,
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Project R/EC-95-40.1

Michael C. Miller,
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Ohio Sea Grant College Program
Project R/NIS-2

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Identify the relationship between ruffe feeding and benthic communities.
- Delineate the extent and nature of interactions between ruffe and native Great Lakes fishes.
- Understand the effects of ruffe on nutrient cycling in lentic systems.
- Predict the magnitude of impact that ruffe may have on ecosystems with differing physical and trophic conditions within the Great Lakes.

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Page numbers in parentheses indicate location of research project(s).

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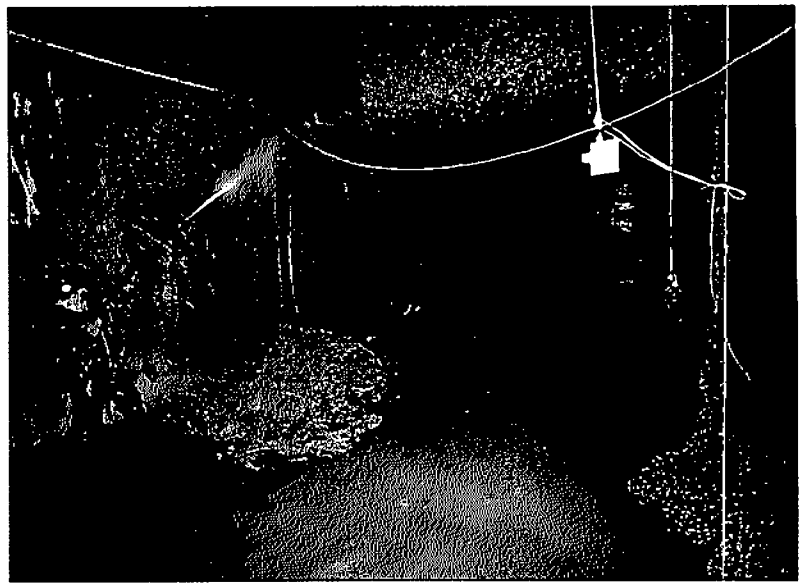


New Outreach Projects

The results of Sea Grant funded research are transferred to the general public and to more specific audiences through what are broadly referred to as the "outreach" components of the program. Sea Grant outreach employs extension agents and communication specialists to interpret research results and transfer this knowledge to the general public, water users, and decision-makers.

Only objectives of new outreach projects funded with fiscal year 1995 funds are included here. Part 2 of this report will document the progress of Sea Grant's ongoing outreach projects.

Outreach programs produce publications, such as fact sheets and newsletters; write media releases; maintain clearinghouses; produce videos, radio spots, and slide shows; sponsor workshops, conferences, and seminars; create displays; and disseminate information electronically through Internet.

8/1/95 to 7/31/97

Zebra Mussel Outreach Plan: A Continuing Program Project of the Great Lakes Network

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

A collaboration of the Great Lakes Network: Illinois-Indiana, Michigan, Minnesota, New York, Ohio, and Wisconsin cooperating. The collective objectives of the states are listed below, followed by a description of each project.

Objectives

Strengthen the regional and national outreach structure through

A. information transfer, initially of zebra mussel information using WWW and compact disks;
B. provision of slides and other graphics;
C. large-scale distribution of nonindigenous species information, through printing contributions of Brunswick Marine;
D. develop and conduct zebra mussel workshops and research conferences;
E. early detection education;
F. traveling trunks;
G. information on efficient zebra mussel control strategies;
H. expansion of a regional newsletter; and
I. develop a Eurasian ruffe education program.

A. Transferring Sea Grant Zebra Mussel Research and Outreach Results Using a Worldwide Web Server and Compact Disks
Allen H. Miller, Wisconsin Sea Grant
Michael K. Mclean, Minnesota Sea Grant
Brian K. Miller, Illinois-Indiana Sea Grant
Mildred J. Flory, Michigan Sea Grant

Objective

- Establish a World Wide Web information center and compact disk (CD) containing four major sections of zebra mussel information: the current status of the infestation, information for water users, training resources and educational materials, and research results.

B. Great Lakes Sea Grant Network Exotic Species Graphics Library
Mildred J. Flory, Michigan Sea Grant

Objective

- Maintain, update, and expand the present nonindigenous species graphics library with slides, illustrations, photographs, and videotapes of aquatic invaders, such as the zebra mussel, goby, spiny water flea, ruffe, purple loosestrife, Eurasian milfoil, and sea lamprey by commissioning photographers and artists and soliciting other areas of the U.S. and Canada affected by these species.

C. Creation of Publications on Exotic Invaders

Maran Brainard Hilgendorf, Ohio Sea Grant

Objective

- Publish fact sheets on the zebra mussel and other aquatic invaders researched and written by members of the Sea Grant Network and other agencies that will be printed through a donation by Brunswick Marine. This donation to date exceeds 1.5 million copies valued at $50,000. More than 200 agencies throughout the country serve as "distributors" of these publications.

D. An Outreach Education Program for Inland Water Users

Leroy Hushak, Ohio Sea Grant
Brain Miller, Illinois/Indiana Sea Grant
John Schwartz, Michigan Sea Grant

Objective

- Coordinate a Great Lakes Network outreach education program on zebra mussel control for inland water users by holding conferences in areas particularly vulnerable to the mussel, by developing publications for inland water users, and by establishing information points of contact specifically for inland water users.

E. Early Detection of Zebra Mussels in Midwestern Inland Lakes by Citizen Monitors

John Schwartz, Michigan Sea Grant
Douglas Jensen, Minnesota Sea Grant
Clifford Kraft, Wisconsin Sea Grant

Objectives

- Provide Wisconsin, Michigan, and Minnesota inland water users with information on whether zebra mussels and other planktonic exotic species (primarily *Bythotrephes cederstromii*) are likely to infest or cause problems at specific locations.
- Provide education for volunteers from inland lake associations in plankton sampling methods.
- Develop a tailor-made monitoring guide to teach people what to look for, when best to look, and how to mitigate the effects of infestation.
- Provide a point-of-contact for reporting zebra mussel observations and providing backup analysis for confirming observations.
- Provide educational assistance for natural resource agency personnel assisting in inland monitoring for nuisance aquatic exotic species.

F. An Intensive Marketing Effort to Provide the Zebra Mussel Traveling Trunk and Curriculum Materials to Educators Across the Country

Robin Goettel, Illinois-Indiana Sea Grant
Michael McLean and Douglas Jensen, Minnesota Sea Grant

Objectives

- At a minimum of four national and regional meetings of science teachers and environmental educators over a two-year period, demonstrate the "traveling trunk," which contains a curriculum guide and hands-on, easily replicable equipment and materials for use in experiments, games, and demonstrations, all of which provide education about the zebra mussel.
- Produce 20 additional traveling trunks and curriculum guides to meet the anticipated demand by teachers throughout the U.S., especially in those states more recently impacted by zebra mussels.
- Place traveling trunk information onto various on-line directories of educational materials and promote trunks in educational resource guides and bibliographies that serve science teachers.

G. Outreach Education on Efficient Zebra Mussel Control Strategies

Leroy Hushak, Ohio Sea Grant College Program

Objectives

- Develop economically efficient zebra mussel control strategies for representative electric generating plants, municipal water systems, and for representative industrial water users if there is sufficient similarity.
- Write publications that cover efficient zebra mussel control systems for electric utilities and for municipal water users.

H. *Zebra Mussel Update*

Cliff Kraft and Stephen Wittman, Wisconsin Sea Grant
Maran Brainard Hilgendorf, Ohio Sea Grant
Mike McLean, Minnesota Sea Grant
Julie Zeidner, New York Sea Grant
Mildred J. Flory, Michigan Sea Grant

Objectives

- Continue the quarterly *Zebra Mussel Update* newsletter (initiated in 1990) as a timely source of information on zebra mussel-related topics.
- Expand the scope and distribution of the newsletter to provide more consistent information for a regional or national audience.

I. Regional Ruffe Outreach Initiative

Jeffrey Gunderson, Douglas Jensen, Michael Mclean, and Dale Baker, Minnesota Sea Grant
John Schwartz, Michigan Sea Grant
Richard Hoops, Wisconsin Sea Grant
Maran Hilgendorf, Ohio Sea Grant
Dave White, New York Sea Grant

Objectives

- Enhance the current understanding of the ruffe infestation and its implications to North America by facilitating the efficient transfer of international outreach/research information, resulting in cost effective management decisions.
- Build upon citizen volunteer initiatives that promote programming for the early detection of zebra mussels and other exotic species by providing monitoring materials and training, technical assistance, and coordination as a point of contact for exotic species sightings.
- Conduct an international symposium and regional workshops, and produce outreach materials and a research bibliography.

9/1/94 to 7/31/97

Zebra Mussel Awareness and Prevention Program Project

Marion L. Clarke and Joe W. Nolin
Florida Sea Grant College Program
Project E-ZM-2

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Inform Florida and all of the southeastern U.S. of the hazards of a the zebra mussel such that people will be willing and able to retard, and possibly prevent, the mussel's infestation of this area by (1) establishing a statewide advisory committee from members of environmental groups, regulatory agencies, relevant industries, academic interests, and key experts; (2) modifying and updating Sea Grant zebra mussel publications to meet the region's needs; (3) distributing materials through the Florida Boaters and Anglers Pledge Program, and the Lake Watch Program; (4) including zebra mussels in the monitoring program of the Florida Lake Watch Program; (5) approaching the Florida Dept. of Transportation to explore alternatives for monitoring and education programs at Agriculture Inspection Stations and Welcome Centers; and (6) holding 10 workshops around the state of Florida.

6/1/95 to 5/31/96

Coordination and Outreach to Reduce or Control the Spread of Zebra Mussels (*Dreissena polymorpha*) for Surface Water-Using Industries and Commercial Navigation

Michael Liffmann,
Louisiana State University
Louisiana Sea Grant College Program
Project A/ZM-3

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Regionalize efforts to inform and educate surface water users and commercial navigation firms along southern waterways about the threat zebra mussels and the need for monitoring and techniques for prevention, control, and mitigation.
- Coordinate efforts to assist all of the targeted southern interest groups associated with zebra mussel issues in the program.

5/6/95 to 6/30/96

Marine Advisory Service Program

J.D. Murray,
North Carolina University
North Carolina Sea Grant College Program
Project A/EA-10

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Implement a professional, coordinated, responsive, *proactive* zebra mussel task force, which guides and coordinates statewide zebra mussel monitoring, education, and public awareness through meetings, mailings, maintenance of an inventory of monitoring sites, workshops, and conferences.
- Serve as the emergency response unit in the event of zebra mussel arrival.
- Inform aquaculturists about reducing the pathways for zebra mussel introduction and about zebra mussel control and elimination in the industry.

8/1/95 to 7/31/97

Video Tape and Videoconference Project: *Zebra Mussels: Lessons Learned in the Great Lakes*, An Overview of the Biology, Impacts, Prevention, and Control of a Freshwater Invader

Brian K. Miller and Tom Luna,
Illinois-Indiana Sea Grant Program
Project A/SE95-B76.1
Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriations

Objectives

- Transfer zebra mussel research results and outreach products developed in the Great Lakes region to scientists, extension professionals, and water users through a videoconference, one public service announcement, and four videotapes.

7/1/95 to 6/30/96

Zebra Mussel Awareness and Information for Alabama Youth

Emily Kling,
Mississippi-Alabama Sea Grant Consortium
Project A/O-24-ZM5

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Develop educational materials for school children, environmental center visitors in Mobile and Baldwin counties, 4-H members, and 4-H campers.
- Field test these materials in two coastal county 4-H and school enrichment programs, for which appropriate personnel will be provided in each county.

7/1/95 to 6/30/96

An Integrated Regional Program of Research, Education, and Outreach on Zebra Mussels in Southern Waters (Mississippi Component)

C. David Veal,
Mississippi-Alabama Sea Grant Consortium
Project A/O-24-ZM2

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Develop and encourage the use of a uniform zebra mussel monitoring protocol throughout the southern region, especially in the aquaculture and agricultural industries.
- Gather southern monitoring data from industries and academia at a central location for thorough regional and site-specific analysis to assist in the detection of emerging southern-specific trends in the zebra mussel's life cycle.
- Educate the southern general public, government-operated industries, private industry, and regulatory agencies about zebra mussels to help prevent or control the mussels's infestation and inevitable damage.

7/1/95 to 6/30/96

An Integrated Regional Program of Research, Education, and Outreach on Zebra Mussels in Southern Waters (Alabama Component)

William Hosking,
Mississippi-Alabama Sea Grant Consortium
Project A/O-24-ZM1

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriations

Objectives

- Prevent the spread of zebra mussels by recreational boaters in the waters isolated from commercial shipping to Alabama, Mississippi, and Louisiana.
- Inform the public about the threat that zebra mussels pose and enable the public to assist in monitoring the spread of zebra mussels.
- Work closely with Louisiana Sea Grant Program and Mississippi Sea Grant Extension Program in a coordinated effort to assist surface water users and the aquaculture industry dealing with zebra mussels.

6/1/95 to 5/31/96

Musseling Into the Classroom

Mary Gail Yeates,
Louisiana Sea Grant College Program
Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Produce *Musseling into the Classroom*, a computer-based learning tool with a zebra mussel focus, using extant scientific and educational information in the Sea Grant network.

New York Sea Grant's Dreissena *Clearinghouse provides scientific information to researchers at universities, agencies, and industries by making publications available on loan and by producing a research-orientated newsletter. For more information, phone 800/285-2285 Monday through Friday from 8 A.M. to 5 P.M.*

7/1/95 to 6/30/96

Nationwide Zebra Mussel Training Initiative—Louisiana's Part, Year Two

Michael Liffmann and Marilyn Barrett O'Leary,
Louisiana Sea Grant College Program
Project A/ZM-3
Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Expand original efforts to educate the general public by targeting the recreational sector, especially recreational boaters interested in the ecological impact of zebra mussels on natural systems and on industry; educate this group in their ability to unknowingly facilitate zebra mussel migration.
- continue to serve as a clearinghouse for monitoring reports submitted by industrial surface water users; facilitate information exchange on monitoring and control; and disseminate current research findings.

6/1/95 to 8/31/97

Facilitation of Exotic Species Information Exchange Between North America and the Former Soviet Union

Dianna K. Padilla,
University of Wisconsin, and
Ladd E. Johnson,
Université Laval, Quebec
Wisconsin Sea Grant Institute
Prooject R/LR-65

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriations

Objectives

- Facilitate the direct contact between European and North American scientists to (1) accelerate the dissemination of knowledge of exotic species gained by the long-term experience of European scientists; (2) use their extensive and unique data to test predictive models of population dynamics, spread, and ecological impacts of zebra mussels; and (3) use their advise and expertise to guide current studies on the ecology of zebra mussels, thereby permitting more direct comparisons of results found in the Old and New Worlds.

3/1/92 to 8/31/96

Maintain and Improve a National Zebra Mussel Information Clearinghouse

David G. White II and Charles R. O'Neill, Jr.,
Cornell University
New York Sea Grant Institute
Project A/EEP-4

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Expand the Clearinghouse's information database on current proposed and completed North American zebra mussel research, and use that information to provide the university, governmental, and private sector researchers with a central clearinghouse for information pertinent to the zebra mussel.

Sea Grant/USDA-Extension Service Nationwide Zebra Mussel Training Initiative with New York, Minnesota, and Connecticut Cooperating

9/1/94 to 8/31/96

New York Sea Grant Component

David G. White II and Charles R. O'Neill, Jr.,
Cornell University
New York Sea Grant Institute
Project A/EEP-7

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Develop interest in zebra mussel outreach programming by state Cooperative Extension Services (CES), Departments of Natural Resources, and other appropriate agencies and organizations nationally.
- Strengthen extension educational leadership in zebra mussel public policy and technical issues by providing quality, in-depth, in-service "teach the teacher" education programs targeted at state CES field staff.
- Establish an interagency advisory committee to oversee the development/implementation of the program.
- Work through state CESs to foster and facilitate the development of state Zebra Mussel Task Forces and regional early warning monitoring programs.
- Provide quality, in-depth continuing education credit opportunities to representatives of appropriate state natural resources agencies and other entities who have need to learn more about the zebra mussel, its impacts, and its control.

6/1/95 to 5/31/96

Minnesota Sea Grant Component

Jeffrey Gunderson, Douglas Jensen,
Michael McLean,
Minnesota Sea Grant College Program
Project A/SE-4

Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Continue developing and implementing zebra mussel outreach and technology transfer support programming for state Cooperative Extension Services (CES) and other agencies in non-Sea Grant states.
- Develop and refine existing Great Lakes training packages on zebra mussel spread and control for audiences in the Midwest and Great Plains regions, targeting particularly water, fisheries, and natural resource managers, and CES educators.
- Continue to provide training and educational materials for the aquaculture, bait, and aquarium industries, concerning chemical control and other strategies designed to minimize the risk of accidental introduction of zebra mussels or other exotic species via transport of ornamental fish, bait fish, and fish for stocking.
- Use and promote the use of a portable, self-explanatory zebra mussel and exotic species display unit, designed for audiences at boat and sport shows, conventions, regional aquaculture conferences, and county and state fairs.
- Continue the efficient transfer of the results of Minnesota Sea Grant Extension's 1994 "Exotic Species and Freshwater Boating Survey" to task forces, management agencies, and CES/Sea Grant programs, resulting in cost effective boater education programs and incentives to contain the mussel's spread.

8/1/95 to 7/31/96

Connecticut Sea Grant Component

Nancy C. Balcom,
Connecticut Sea Grant College Program
Project A/E-6
Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Continue to collaborate in national training initiative for Cooperative Extension Services (CES) and regulatory agencies in non-Sea Grant states in the area of zebra mussel public outreach and education
- Share expertise in introduction/spread/prevention programs for water companies, lake managers, and lake authorities in the form of educational materials, training sessions, videos, and radio public spot announcements.
- Participate in regional training sessions and/or teleconferences
- Provide technical assistance to state zebra mussel task forces and CES agents.

8/1/92 to 7/31/96

Connecticut Sea Grant College Program Zebra Mussel Outreach and Education Program

Nancy C. Balcom,
Connecticut Sea Grant College Program
Project A/E-5
Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Maintain and expand the ongoing public outreach program on zebra mussels and other nonindigenous aquatic nuisance species in Connecticut to continue regional cooperative effort.
- Continue coordinating and facilitation efforts of CT Zebra Mussel Task Force and strengthen regional communication among the Northeast individual statewide task forces.
- Continue Connecticut's zebra mussel monitoring program.
- Develop and distribute appropriate educational materials on zebra mussels and other nonindigenous aquatic nuisance species, including a regional newsletter.

8/1/95 to 7/31/96

Vermont Zebra Mussel Education and Outreach Program

Ann Bove,
Connecticut Sea Grant
Project A/E-7
Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Maintain and expand public education and outreach programs on zebra mussels in Vermont and cooperate in regional outreach efforts.
- Function as a statewide clearinghouse of current zebra mussel-related information.
- Expand two subprograms: the Zebra Mussel Citizen Action Program, a volunteer-based invading species prevention program; and the Zebra Mussel Watchers Program, a volunteer-based, statewide monitoring program.
- Determine the vulnerability of individual bodies of water in Vermont to zebra mussel infestation.
- Assist schools and teachers with incorporating information on monitoring and controls of nonindigenous species into their curricula.
- Help facility managers get information on nonindigenous species monitoring and controls.

8/1/95 to 7/31/96

Zebra Mussel Outreach

Madeline Hall-Arber,
MIT Sea Grant Program
Project A-O9
Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Delay infestation and the impact of infestation of zebra mussels on bodies of water in Massachusetts by targeting recreational boaters and swimmers (particularly children and their parents) with public outreach and education.
- Keep up-to-date on the most current research of the natural history and spread of zebra mussels.
- Maintain and enhance MIT's library of information on zebra mussels, particularly as it pertains to Massachusetts.

6/1/95 to 9/30/96

Zebra Mussel Outreach and Education Project

Brian Doyle and Julia Dahlgren,
New Hampshire/Maine Sea Grant College Program
Project A/P-14
Primary source of funds: Fiscal year 1995 aquatic nuisance federal appropriation

Objectives

- Familiarize at least 5,000 boaters, anglers, lake shore property owners, decision makers, and other surface water users with the impacts of zebra mussel introductions; to have at least 100 of these implement techniques to reduce the risk of infestation.
- Develop standard adult, juvenile, and veliger zebra mussel monitoring protocols within the region in accordance with national standards, implemented by at least 12 additional monitoring groups in New Hampshire and Maine.
- Augment baseline information of freshwater monitoring programs in New Hampshire and Maine to better predict infestation potential and monitor infestation progress.
- Provide utilities, agencies, and industries, with updated information on viable treatment and control alternatives, and on economic impacts based upon experiences of utilities and industries already dealing with zebra mussels.

Directory of Sea Grant Offices

Programs listed in color have received support for zebra mussel research and outreach projects.

National Offices

National Sea Grant College Program
NOAA, Sea Grant, R/ORI
SSMC-3
1335 East-West Highway
Silver Spring, MD 20910-3226
301/713-2431

National Sea Grant College Program
Media Relations Office
0112 Skinner Hall
University of Maryland
College Park, MD 20742-7640
301/405-6381, fax 301/314-9187
sherman@mbimail.umd.edu

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

Nonindigenous Species Graphics Library
Michigan Sea Grant
313/764-1138

Zebra Mussel Information Clearinghouse
New York Sea Grant Extension
250 Hartwell Hall
SUNY College at Brockport
Brockport, NY 14420-2928
Hotline (Mon.-Fri., 8:00-4:00 EST):
800/285-2285 or 716/395-2516,
fax 716/395-2729
zmussel@cce.cornell.edu

State Offices

Alaska Sea Grant College Program
University of Alaska
P.O. Box 755040
Fairbanks, AK 99775-5040
907/474-7086

California Sea Grant
University of California-San Diego
9500 Gilman Drive
La Jolla, CA 92093-0232
619/534-4440

Connecticut Sea Grant
University of Connecticut
1084 Shennecossett Road
Groton, CT 06340
203/445-3457 or 445-3455

Delaware Sea Grant
University of Delaware
Robinson Hall, Room 111
Newark, DE 19716-3501
302/831-2841

Florida Sea Grant
University of Florida
P.O. Box 110400
Gainesville, FL 32611-0400
904/392-5870
jcc@gnv.ifas.ufl.edu

Georgia Sea Grant
University of Georgia
Ecology Building
Athens, GA 30602-2206
706/542-7671, fax 706/542-5888
rrivers@uga.cc.uga.edu

Hawaii Sea Grant
University of Hawaii
1000 Pope Road, Room 220
Honolulu, HI 96822
808/956-7031

Illinois-Indiana Sea Grant
Purdue University
1159 Forestry Building
West Lafayette, IN 47907-1159
317/494-3573
phil_pope@acn.purdue.edu

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

Maine-New Hampshire Sea Grant
University of Maine
14 Coburn Hall
Orono, ME 04469-5715
207/581-1435

Maine-New Hampshire Sea Grant
University of New Hampshire
Kingman Farm
Durham, NH 03824
603/749-1565
julia.dahlgren@unh.edu

Maryland Sea Grant
University of Maryland
0112 Skinner Hall
College Park, MD 20742
301/405-6371
mdsg@mbimail.umd.edu

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

Minnesota Sea Grant
University of Minnesota-Duluth
2305 East 5th Street
Duluth, MN 55812
218/726-8712
djensen@mes.umn.edu

Mississippi-Alabama Sea Grant Consortium
P.O. Box 7000
703 East Beach Drive
Ocean Springs, MS 39566-7000
601/875-9341

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

New Jersey Sea Grant
NJ Marine Sciences Consortium
Building No. 22
Ft. Hancock, NJ 07732
908/872-1300, ext. 20

New York Sea Grant Institute
Nassau Hall
Stony Brook, NY 11794-5000
516/632-6905, fax 516/632-6917
nyseagrant@allin1.cc.sunysb.edu

North Carolina Sea Grant
North Carolina State University
Box 8605
Raleigh, NC 27695-8605
919/515-5287
barbara_doll@ncsu.edu

Ohio Sea Grant
Ohio State University
1314 Kinnear Road
Columbus, OH 43212-1194
614/292-8949, fax 614/292-4364
brainard.3@osu.edu

Oregon Sea Grant
Oregon State University
Administrative Services Building 500G
Corvallis, OR 97331-2131
503/737-2715

Puerto Rico Sea Grant
University of Puerto Rico
P.O. Box 5000
Mayaguez, PR 00681-5000
809/834-4726

Rhode Island Sea Grant
Communications Office
University of Rhode Island
Narragansett Bay Campus
Narragansett, RI 02882-1197
401/792-6842
malias@gsosun1.gso.uri.edu

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

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

University of Southern California Sea Grant
Hancock Institute for Marine Studies
University Park
Los Angeles, CA 90089-0373
213/740-1961
seagrant@mizar.usc.edu

Virginia Sea Grant
Virginia Graduate Marine Science Consortium
Madison House
170 Rugby Road
Charlottesville, VA 22903
804/924-5965, fax 804/982-3694
bhens@virginia.edu

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

WHOI Sea Grant
Woods Hole Oceanographic Institution
193 Oyster Pond Road
CRL 209
Woods Hole, MA 02543-1525
508/289-2398, fax 508/457-2172
seagrant@whoi.edu

Wisconsin Sea Grant
University of Wisconsin
1800 University Avenue
Madison, WI 53705-4094
608/262-0905

Research Project Index

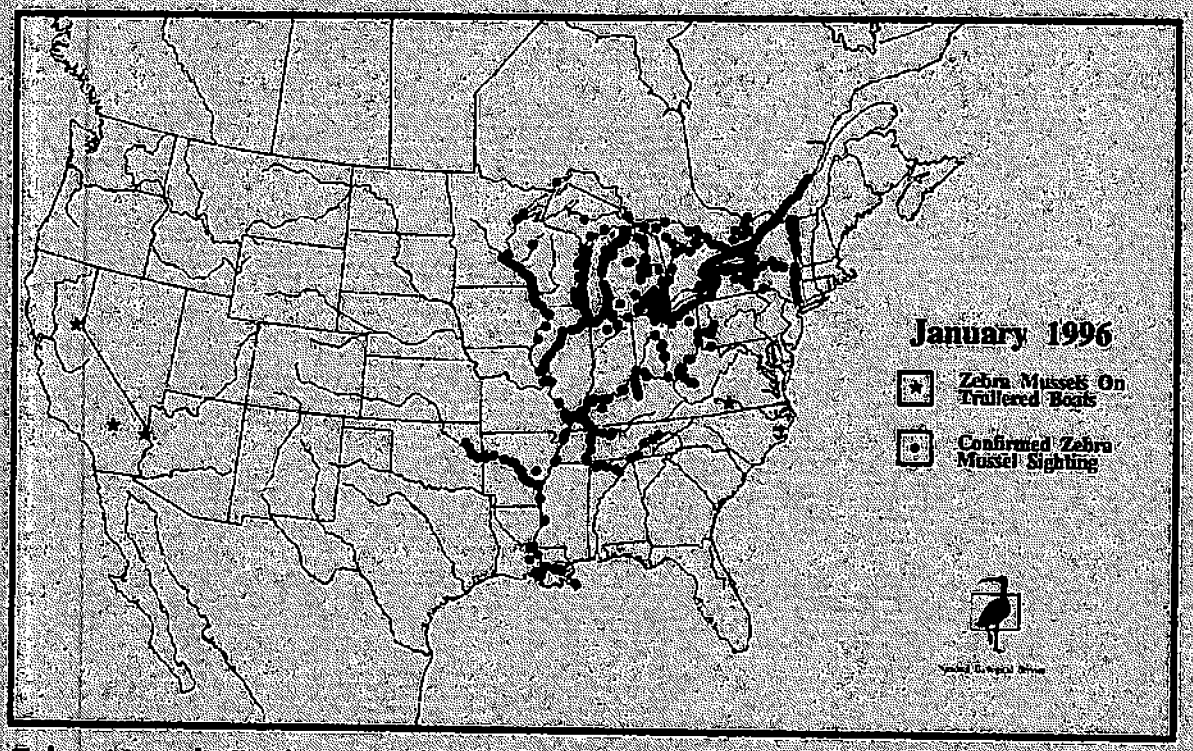
Biology and Life History

Effects on Ecosystems

Effects on Ecosystems Continued

Socio-Economic Analysis

Control and Mitigation



Zebra Mussel *(Dreissena polymorpha)* Distribution in North America

These data are a part of the National Biological Service's Nonindigenous Aquatic Species Data Base located at the Southeastern Biological Science Center in Gainesville, Florida. Information is collected from federal, state, and private agencies and is available upon request (904/378-8181).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