PB91-196675

United States
Environmental Protection
Agency

Office of Research and
Development
Washington DC 20460

EPA/600/3-91/003
February 1991

EPA

Ecology and Management of the Zebra Mussel and other Introduced Aquatic Nuisance Species

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A Report Based on Presentations and Discussions
at the
EPA Workshop on Zebra Mussels
and other Introduced Aquatic Nuisance Species
Saginaw Valley State University
Saginaw, Michigan, USA
September 26-28, 1990

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Prepared with the assistance of
ESSA Environmental and Social Systems Analysts Ltd.

and

AScI Corporation

December, 1990

Printed on Recycled Paper

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Acknowledgements

We thank all the participants of the workshop. Their creativity and insights contribute greatly the success of the project. We are especially grateful to our overseas participants who brought a new perspective - H. Smit, P. Maitland, V.N Karnaukhov, N.F. Smirnova, and G.A. Vinogradov. Special thanks are extended to Chris Wedeles, Carol Murray, Mike Rose, and Pille Bunnell of ESSA, Ltd. for facilitating the workshop breakout groups and plenary sessions, and to Pille Bunnell for organizing the workgroup reports. Gail Irving of ASCI, Duluth, coordinated workshop logistics. We are grateful to Congressman John D. Dingell's office for providing translated manuscripts from the Soviet participants.

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1. Introduction and Summary

This report presents the content of presentations and discussions held over 2 1/2 days in a plenary session and in working groups at the Environmental Protection Agency's Introduced Species Workshop held in Saginaw, Michigan on Sept 26 - 28, 1990. The purpose of the workshop was to review and evaluate existing information on the ecology and management of introduced aquatic nuisance species, with a particular emphasis on the zebra mussel (*Dreissena polymorpha*), and make recommendations on how to extend our knowledge and understanding in critical areas.

The first day of the workshop consisted of a public session. In this session, a series of formal presentations were made by invited experts on the biology and ecology of introduced species, and on their sources, prevention and management. Speakers were asked to provide extended abstracts of their presentations, which are included here in Appendix A. Two of the speakers, from the Soviet Union, submitted their entire manuscripts. Rather than attempt to abstract these manuscripts, they are included, with minor editing, as submitted.

The following 1 1/2 days were devoted to discussions among invited participants. Although the range of expertise available to the workshop discussions was extensive, it was not exhaustive, and the time was not long enough to allow for detailed discussions of scientific, technical, or institutional knowledge. Therefore the report should be read as an overview of current knowledge and concerns. More importantly, the assembled wisdom of the workshop participants generated insights and recommendations with respect to research needs, management options, information coordination, and potential policy and legislation. The discussions from each working group are presented in the relevant sections. Recommendations are presented in the introductory section.

Background

Zebra mussels (*Dreissena polymorpha*) are a new invading species in North America with such an enormous feeding and reproductive capacity that they are spreading in epidemic fashion throughout the Great Lakes. In some areas of the Great Lakes, they have been reported to reach population densities of greater than 30,000 individuals/m^2 and will likely spread to other freshwater systems. Although the mussels are of immediate economic concern because they clog water intake pipes, the greatest concern is the possibility of catastrophic changes in the ecology of the Great Lakes. It has been estimated that the zebra mussels currently filter all the water in Lake St. Clair several times a day, dramatically shunting the energy flow in the aquatic food web away from fish. Zebra mussels can strongly outcompete other indigenous benthic organisms in many temperate aquatic habitats. The success of this mussel will have severe and dramatic consequences on the ecological integrity of surface waters due to major shifts in trophic interactions the movement of nutrients and toxic materials, and competition with native species.

The Environmental Protection Agency responded to the zebra mussel crisis by sponsoring this workshop of experts from the Soviet Union, Europe, Canada, and the United States to discuss approaches to prevention, control, and potential environmental impacts of invading species, particularly the zebra mussel. It was attended by scientists representing government research laboratories, academic institutions, state and federal regulatory agencies, and shipping and water supply organizations.

The important issue of determining institutional responsibilities for carrying out these recommendations was not on the agenda for this workshop, and in any case was not within the authority of most participants to define. Since this workshop the U.S. Congress has passed and the President has signed into law, the "Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990", (PL 101-646) which, among other actions, defines federal agency responsibilities. This Act will be discussed briefly below.

Earlier Initiatives on Introduced Species

The need for an overview of available knowledge and an integrated research plan for the zebra mussel is obvious, and several agencies have taken an initiative in this direction. Some of the 1990 initiatives which were referred to by participants at the workshop include:

February: Department of Zoology, University of Guelph conference identifying current, proposed, and required research on the zebra mussel.

April: Great Lakes Research Consortium and New York Sea Grant workshop to develop research and data needs on the ecological impacts of zebra mussels in New York waters.

June: First (organizational) meeting of the United States Great Lakes Non-Indigenous Species Coordination Committee.

July: Michigan Department of Natural Resources Office of the Great Lakes compilation of zebra mussel research on the Great Lakes.

August: United States Great Lakes Non-Indigenous Species Coordination Committee definition of areas of research for a coordinated research program.

August: U.S. Environmental Protection Agency Great Lakes National Program Office organized a series of conference calls to develop an assessment paper on exotic species, with emphasis on the zebra mussel.

The September workshop hosted by EPA was intended primarily to inform state and federal regulatory and national resource management agencies who are charged with implementing existing legislation. The workshop considered a broad spectrum of issues and users, and brought in European and Soviet scientists who had not previously been consulted. It was not intended to be definitive, but rather to be a substantial step towards developing a clearly defined strategy based on both scientifically and practically defined needs.

Events following Workshop

In October the United States Congress passed the "Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990" (P.L. 101-646). The purposes of this Act are "(1) to prevent unintentional introduction and dispersal of non-indigenous species into waters of the United States through ballast water management and other requirements; (2) to coordinate federally conducted, funded or authorized research, prevention, control, information dissemination and other activities regarding the zebra mussel and other aquatic nuisance species; (3) to develop and carry out environmentally sound control methods to prevent, monitor and control unintentional introductions of non-indigenous species from pathways other than ballast water exchange; (4) to understand and minimize economic and ecological impacts of non-indigenous aquatic nuisance species that become established, including the zebra mussel; and (5) to establish a program of research and technology development and assistance to states in the management and removal of zebra mussels." By this Act many of the recommendations made in this report have become law.

The Act directs the Secretary of the Department of Transportation (through the U.S. Coast Guard) to issue voluntary guidelines within 6 months to "prevent the introduction and spread at aquatic nuisance species into the Great Lakes through the exchange of ballast water of vessels prior to entering those waters." Within 24 months the Secretary of Transportation, in consultation with the "Task Force", is directed to issue <u>regulations</u> for the above purpose.

The Task Force, co-chaired by the Director of the U.S. Fish and Wildlife Service and the Secretary of Commerce for Oceans and Atmosphere, consists also of the Administrator of the U.S. EPA, the Commandant of the U.S. Coast Guard, the Assistant Secretary of the Army (Civil Works), and the heads of any other federal agencies deemed appropriate by the chairpersons. The Task Force members (or their official representatives) are charged with implementing most of the provisions of the Act. These include development of an aquatic nuisance species program; development of Great Lakes regional coordination; and review of policy on <u>intentional</u>

introductions. In addition, some of the Task Force members have broad authorization in areas related to introduced species. The U.S. EPA, for example, is charged with conducting basic ecological research on factors that affect the well-being of ecosystems, and on indicators of ecosystem health.

The U.S. Great Lakes Non-Indigenous Species Coordination Committee, referred to above, met again in early December to develop a coordinated research plan. At this meeting members voted to include U.S. industrial organizations who are funding zebra mussel research, and to invite participation by appropriate Canadian groups.

Workshop Objectives

The formal objectives of the workshop were to:

1. Identify the information gaps in our knowledge of zebra mussels and other introduced aquatic species that inhibit our ability to make management decisions;

2. Identify the research needs to fill the information gaps;

3. Identify advantages and disadvantages of management alternatives; and

4. Prepare recommendations for managing introduced species and preventing future invasions.

From the outset it was recognized that the short workshop would not be able to produce all the answers. However, it is also recognized that this workshop is an early step in a much larger process to develop a coordinated program of research and management of non-indigenous species in the Great Lakes.

Workshop Process

In order to accomplish as much as possible during the day and a half available for the workshop, most of the time was spent in working groups. Four working groups were defined.

Prediction	Control
1. Predicting the rate and extent of spread.	2. Prevention of new introductions
3. *Predicting Ecological effects*	4. *Control of established species*

Because of limited time, the scope of discussion in three of the groups was limited to zebra mussels. However, the group discussing the prevention of new introductions clearly emphasized introductions in general, since the zebra mussel is already present. All discussions primarily focussed on the Great Lakes Basin, adding more localized or continent-wide consideration where appropriate. Each of the following chapters summarizes the discussions from one of the working groups.

Summary of Recommendations

Each of the four working groups developed a set of recommendations which ranged from specific research needs to overall coordination of the issues related to introduced species. Although the combined list appears long, and in implementing the recommendations one would have to consider the details, it is possible to extract a few basic themes that help to synthesize and summarize the recommendations.

The need for an information clearing house, database, or series of databases became apparent - the short time that we have had to deal with the zebra mussel and the urgency of the problems have led to a burst of research and management effort which would be far more effective if it were well coordinated. Similarly, a commission to help coordinate the effort on an international scale is highly desirable.

A number of specific activities are recommended to ensure that the information in the database(s) is current and credible. These include the translation of the European and Soviet literature, monitoring programs, and the review and evaluation of control methods. Modelling is proposed as a method to help guide research, predict spread, evaluate control methods, and manage activities. Some management activities are singled out as particularly timely; namely, clarification of permitting procedures for control methods, development of a ballast water management plan, and the implementation of a public information system aimed at reduction of spread, effectiveness of management, and public support for the required research. Research designed to provide critical basic information is highlighted as a basic recommendation.

The next step is to provide a forum which will allow the people concerned to prioritize recommendations and to propose appropriate action and develop a strategy for its implementation. The research and management community are willing; what is needed is the institutional support necessary to fund, coordinate, and implement a set of integrated programs.

Ecological Research Needs and Recommendations

For most of the ideas described below, there is an explicit need for studies on the basic biology and autecology of zebra mussels. To understand the ecological effects that zebra mussels cause we need basic information such as:

- genetic characteristics of populations;
- chemical and physical requirements;
- parasites of zebra mussels;
- behavior and spatial distribution of different life stages;
- preferred prey species;
- preferred prey sizes;
- rates of uptake of contaminants.

Zebra mussels will impose dramatic effects upon the aquatic ecosystems in which they become established. The following list summarizes the possible effects of zebra mussels which should be addressed through research:

1) effects of water clarity caused by predation on phytoplankton and detritus;

2) effects on aquatic food webs and fish community structure including:

   - effects on higher trophic levels of competition for food;

   - effects of concentrating biomass in the benthic layer;

   - effects of use by higher trophic levels of zebra mussel veligers and adults as prey;

   - effects of temporal "pulse" of zebra mussel veligers both as predators and prey; and

   - effects of changes in benthic and planktonic bioenergetics

3) effects on nesting and spawning habitats of native fish species as a result of competition for space;

4) effects on native clam species with special regard to rare and endangered species;

5) effects on distribution of toxics in the aquatic community; and

6) effects as vectors of disease and parasites.

Recommendations for Predicting Rate and Extent of Spread

The prediction of the rate and extent of spread of zebra mussels is a complicated and difficult issue given the resilience and adaptability of the organism. Mapping exercises using a Geographic Information System would provide useful tools to document where zebra mussels are found now and where they are likely to move given the availability of adequate habitat. In order to make credible predictions the GIS analysis must be recalibrated and updated as new information becomes available.

Throughout the course of discussion the group listed several recommendations to increase our understanding of zebra mussel dynamics. These included:

1) Define threshold limits for zebra mussel habitat suitability for North America. Replace European information with more relevant data from the North American experience. This increase in knowledge of habitat constraints would be used to calibrate population growth models and to predict the potential distribution of the mussels.

2) Document present zebra mussel locations and estimate population stability using a population growth modelling approach.

3) Define future distribution of zebra mussels in North America. This would be accomplished through a GIS analysis.

4) Develop a central depository of zebra mussel literature to facilitate information availability and provide a list of on-going zebra mussel research projects citing researcher and location.

5) Assign an international commission to coordinate the proposed GIS work.

6) Increase public education to inform citizens of what zebra mussels are, what they do, how they do it and what ordinary citizens can do to control them.

Recommendations for Control of Established Species

1. Monitor existing zebra mussel population levels in infested lakes. Since there is some indication that the natural course of the invading zebra mussel population is to decline, we should continue to monitor existing populations. Similarly, we should identify any biological control agent that is in place or increasing, whether it be native or inadvertently introduced.

2. Begin a review of potential biological control methods. Although there is a reluctance to expose ourselves to the risks inherent in introducing new organisms to an ecosystem, it would certainly be useful to have a better understanding of long-term control options. Since research to identify and possibly modify a predator, parasite or disease-based control is time consuming, this should begin at once.

3. Implement a review of all control actions. In order to appropriately review all the control actions that can be used to manage problems caused by zebra mussels the appropriate expertise will be required for each type of problem and each type of action. Working groups could be formed to review suitable groups of actions. The purpose of the review would be not only to evaluate suitability and acceptability of the actions, but to synthesize the knowledge so that it can be included in a database and accessed by a clearing house. The review can be structured to identify uncertainties and to prioritize research requirements. Mathematical modelling of the effectiveness and of the potential ecological and social impacts of control actions is recommended as an evaluation tool. Generic models could be developed, which could then be fitted to various facilities through use of appropriate parameters and/or modules.

4. Initiate a process to review and evaluate chemicals for environmental and health effects. This recommendation advocates that chemical treatment methods be evaluated first. Many chemicals are already in use, and have not been fully evaluated. Therefore, a suitable review process is needed immediately. The review will require use of ecological and medical expertise, and there will be institutional and regulatory implications to the permitting procedures.

5. Develop an information base of zebra mussel control methods. This is a variant of the recommendation for an information clearing house, and is conceived to be part of a larger introduced species clearing house/information system. Although an informal information network currently exists among the major industries affected, this network will inevitably become less efficient as the extent of the problem grows, and new inquiries will not have ready access. There is a need for ready access to the details pertinent to the application of control actions, particularly those related to impacts and effectiveness. The information base would include the results of the expert review, and would be designed to enable easy updating.

6. Enlist engineers to investigate design solutions and physical control methods. Long-term environmentally benign solutions are most likely to be based on design innovations. Although engineers are probably working on this within major industries, a broader encouragement of this direction may be socially desirable. Inclusion of engineers in the control method review process will encourage exchange of information among industries and disciplines, and may result in specific initiatives which could be funded through a mixture a sources.

Recommendations for Preventing New Introductions

Ships, specifically ballast water, were identified as the most important as well as the most manageable anthropogenic vector for the introduction of new species, and much discussion focused on management actions targeting this vector. Major gaps were recognized in our current knowledge of ballast water treatment methods. As a result, research requirements were identified concerning possible treatment methods (e.g., ozone, heat, ultra violet light, chemicals, ultrasound, electric current, filtering). The research should include the relative effectiveness of various methods, and their feasibility from an engineering point of view.

Although this workshop did not address the problems of mixing gene pools within species, this issue should be considered in future discussions.

Six recommendations are offered toward preventing the introduction of new species:

1. Implement a ballast water management plan for ships entering the Great Lakes Basin. This plan would adopt a variety of techniques and options targeting the ballast vector. Under the Management Plan incoming ships would be required to provide the coordinates locating where the ballast water was exchanged and to cite the amount of ballast exchanged. Otherwise, incoming ships would be required to provide information on the origin of their ballast water (which may include multiple sources).

2. Evaluate ballast water treatment methods. Once research has been conducted, each treatment should be evaluated (environmental, economic, social - including health and safety - and political) to identify the optimum method(s).

3. Initiate widespread education programs immediately to: a) inform the general public as well as those responsible for the various vectors about the seriousness of the issue, their potential unwitting contribution to the problem, and the role they may play in the prevention of new introductions, b) encourage research within institutions and industries by advertising a need for information and technology, and c) inform regulating bodies about initiatives in other jurisdictions. The media, as well as non-governmental organizations could play a role, with the Canadian and United States governments taking the lead in initiating programs and ensuring that the information is accurate and appropriate.

4. Strive for communities with increased resistance to invasion. Since disturbed communities are more susceptible to the establishment of invading exotic species, any environmental policy or strategy in the United States should be designed to encourage healthy natural communities. This might require the evaluation of "legally-sanctioned" introductions (e.g., aquaculture, planned introductions for biological control, industry or sport) that were not included in our discussions.

5. The goal of any prevention program should be no introduction of new species. Although this goal may be impossible to achieve, aiming for less increases the rate of failure.

6. Establish an information clearing house to deal with the many aspects of exotic species presence. This would include environmental effects, the rate and extent of spread, the control of established populations or the prevention of new introductions and would ensure information transfer between governments, industries, research institutions and countries. The clearing house role would be to maintain and update a database of the existing information and its location.

Invading exotic species, and their environmental and subsequent economic effects, is a serious issue. The zebra mussel in the Great Lakes may provide a real-life worst-case-scenario. While dealing with the zebra mussel problem, approaches should not be limited to a single species but should also consider communities or whole ecosystems. The successful prevention of new introductions will likely require interdisciplinary global effort.

2. Ecological Effects of the Zebra Mussel

At the workshop no attempt was made to prepare a comprehensive review of the ecological effects, but rather to provide an overview of processes and pathways that may be affected by zebra mussels. This was accomplished by constructing simple conceptual models or hypotheses of effect (sometimes referred to as impact hypotheses) that specify the chain of events through which effects may occur. By specifying the chain of events (links in the hypotheses) it was possible to identify those processes and pathways that are poorly understood and need to be studied.

2.1 Issues

A list of issues related to possible ecological effects of zebra mussels was compiled, and hypotheses of effect were built for many of them. Some of the issues did not lend themselves to the construction of these hypotheses, either because they were very broad, or because they were concerned with reasons for our lack of understanding of the effects of zebra mussels. The identified issues are:

1) **Basic Biological Information** - Before we can expect significant insight into the ecological effects of mussels, it will be necessary to have more complete information on the autecology of mussels in North America. Although much is

known on the biology of European and Soviet mussels, it is not reasonable to assume that North American mussels "behave" or function identically.

2) **Translation of European and Soviet Science** - Many studies on the ecological effects of zebra mussels have been carried out in Europe and in the Soviet Union, where they have existed for much longer than in North America. Relatively little of this information is available in English. Therefore, there is a need for a concerted effort to translate existing (and future) European and Soviet publications into English.

3) **Ecosystem Database** - To facilitate analyses of the effects of zebra mussels, an ecosystem database should be developed. The database should contain information from many different lakes and streams, on biological, physical and chemical parameters related to ecosystem functions possibly affected by mussels. This effort would be most effective if it were to be coordinated by a central agency or body.

4) **Separation of Mussel Effects from Other Effects** - Several of the hypothesized effects of mussels could also be caused, or contributed to, by other ecological mechanisms. For example, increases in water clarity could result not only from the proliferation of zebra mussels, but from decreases in nutrient concentrations of water bodies related to controls on phosphorus and nitrogen loads from industrial and municipal effluents. It is important that researchers and analysts consider these potentially confounding factors so that the role of zebra mussels can be understood.

5) **Differences in Aquatic Ecosystems** - It is not reasonable to expect that the effects of zebra mussels will be the same on every lake or stream. Just as aquatic systems are not identical in their ecological, physical, and chemical properties, so the effects of mussels will not be the same. This does not mean that research need be carried out on every system that mussels colonize in order to understand their effects, but rather that care be taken in extrapolating between systems in terms of anticipating effects and responses to any control measures.

6) **Destabilization of Ecosystems** - Disturbance to ecosystems through the influx of exotics and the loss of native species renders them prone to further native extirpations and exotic introductions. The Great Lakes of today bear little resemblance to their pristine state. Changes induced by the introduction of zebra mussels will likely facilitate the proliferation of further exotic species. For example, non-native predators of mussels as well as mussel-borne diseases and parasites may become established in the Great Lakes.

2.2 Hypotheses of Effect

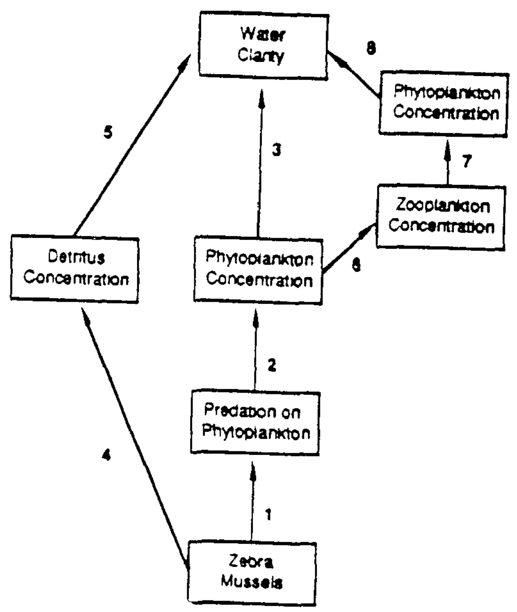
Issues for which hypotheses of effect were constructed were grouped into three broad categories: 1) food related effects; 2) habitat related effects, and 3) effects caused by pathogens, parasites and toxics. There are many overlappings between the effects discussed below, and some do not fit neatly into any category. They are presented according to this scheme for convenience.

The hypotheses are presented in the following pages as diagrams. The text describes the key steps in the pathways or "links" between the cause and effect and summarizes the key unknowns.

Food Related Effects

There are, in general, three types of food related effects: 1) those caused by predation by zebra mussels; 2) those caused by the use of zebra mussels as food by other organisms; and 3) those caused by competition for food between mussels and other organisms. Hypotheses one to four illustrate mechanisms whereby one or more of these types of effects may cause ecological changes.

Hypothesis 1: Zebra mussel predation on phytoplankton and detritus may lead to changes in water clarity.



Link 1. Zebra mussels prey on a variety of phytoplankton species.

Link 2. Predation by zebra mussels will cause a decline in phytoplankton populations.

Link 3. Decreased phytoplankton concentrations will lead to increases in water clarity.

Link 4. Zebra mussel "predation" on detritus will cause a decrease in detritus concentration.

Link 5. Decreased detritus concentration will lead to increases in water clarity.

Link 6. Decreases in phytoplankton populations will cause a decline in zooplankton populations that prey on the same species of phytoplankton as the mussels do.

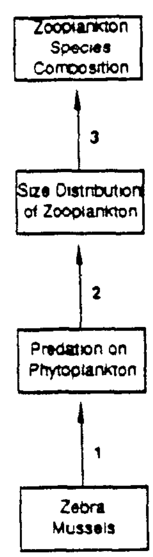
Link 7. Decreases in zooplankton populations will cause an increase in phytoplankton that the zooplankton prey upon.

Link 8. Increases in populations of some species of phytoplankton will cause a decline in water clarity.

Although there is evidence linking zebra mussel colonization to changes in water clarity in Lake Erie (Mackie, presentation at workshop), many uncertainties remain regarding the extent and mechanisms by which this effect may occur. There are important uncertainties associated with several of the links in this hypothesis. We know that zebra mussels prey on a variety of phytoplankton species and detritus, but we don't know the species and size spectrum of the items consumed, or feeding rates of the mussel. The species of phytoplankton that will be affected, and the functional response of phytoplankton to zebra mussel predation is also unknown. Similarly neither the species nor the functional response of zooplankton to declines in phytoplankton densities is known, and the feedback of changed zooplankton populations on the phytoplankton community is uncertain.

Answers to these unknowns will contribute to a general understanding of the relationship between zebra mussels and water clarity.

Hypothesis 2: Zebra mussel predation on phytoplankton may lead to changes in the size and species composition of zooplankton.



Link 1. Zebra mussels prey on a variety of phytoplankton species and predation rates may be related to phytoplankton size.

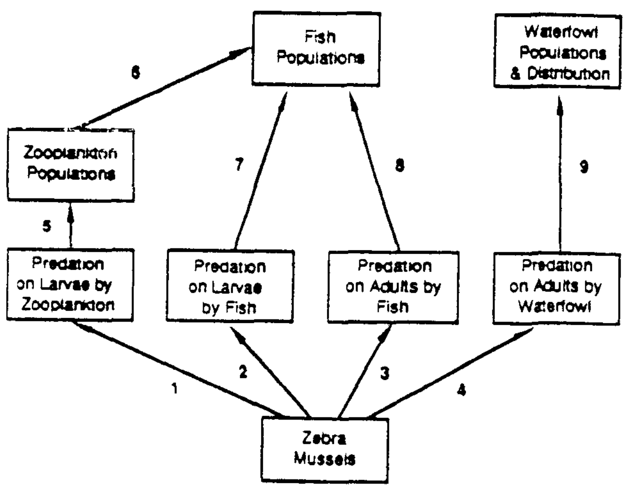
Link 2. Changes in the size distribution of phytoplankton will lead to changes in the size distribution of zooplankton.

Link 3. Zooplankton species composition will change as size distribution changes.

Although this hypothesis is similar to part of *Hypothesis 1*, it is included separately here to emphasize the species distribution of zooplankton as a valued ecosystem component in its own right (in addition to its influence on water clarity). Similarly, several of the uncertainties related to this hypothesis are comparable to those of *Hypothesis 1*.

As noted above, mussel behavior may be different in different ecological settings. Hence it would be useful to know whether the susceptible species and sizes of phytoplankton in North America differ from those in Eurasia. This would help in our efforts to understand the ecology of mussels and to predict the effects of mussel colonization.

Hypothesis 3: Predation on zebra mussel larvae and adults may lead to changes in fish and waterfowl populations.



Link 1. Zooplankton feeds on zebra mussel veligers.

Link 2. Some fish species feed on zebra mussel veligers.

Link 3. Some fish species feed on zebra mussel adults.

Link 4. Some waterfowl species feed on zebra mussel adults.

Link 5. Zooplankton populations will increase in response to additional food.

Link 6. Populations of some fish species will increase in response to increased zooplankton densities.

Link 7. Populations of some fish species will increase in response to increased use of veligers as food.

Link 8. Population of some fish species will increase in response to increased use of mussels as food.

Link 9. Populations of some waterfowl species will increase in response to increased use of mussels as food, and population distributions may also change.

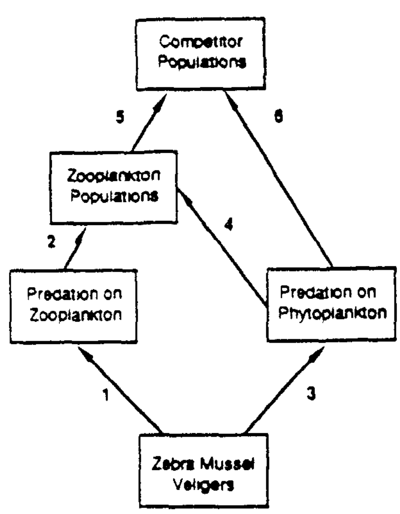
This hypothesis portrays the idea that predators of mussel larvae and adults may respond to increased food availability. Many of the uncertainties related to this hypothesis can be summarized in the following questions: What species of predators prey on mussel veligers and adults and to what extent are they used as food? What is the functional response of the predators to the increased food supply?

Several different responses to increased mussel availability are possible. Some prey species may experience a "release" from predation as predators shift their diets to take advantage of the abundant prey available. Others may experience greater predation pressure should the predator continue to use them in addition to mussels.

Veligers are available as food for a relatively short time. The effect of this "pulse" of food on predators may also be important. If an over-abundance of food for a short period of time causes predators to become "out of sync" with their environment, the effect could be significant, not only for the predator species, but also for their prey and any other predators that prey on them.

The web of possible ecological effects outlined above illustrates that many uncertainties exist concerning the potential effects that zebra mussels may have on ecosystems by serving as a new source of food for predatory species.

Hypothesis 4: Populations of aquatic species which feed on the same phyto/zooplankton species as zebra mussel veligers may decrease as a result of competition.



Link 1. Zebra mussel veligers prey on some species of zooplankton.

Link 2. Zooplankton populations which are preyed on will decline.

Link 3. Zebra mussel veligers prey on some species of phytoplankton.

Link 4. Populations of zooplankton species that prey on the same species of phytoplankton as veligers will decline.

Link 5. Fish and other organisms that feed on zooplankton affected by veligers will decline.

Link 6. Fish and other organisms that feed on the same species of phytoplankton as veligers will decline.

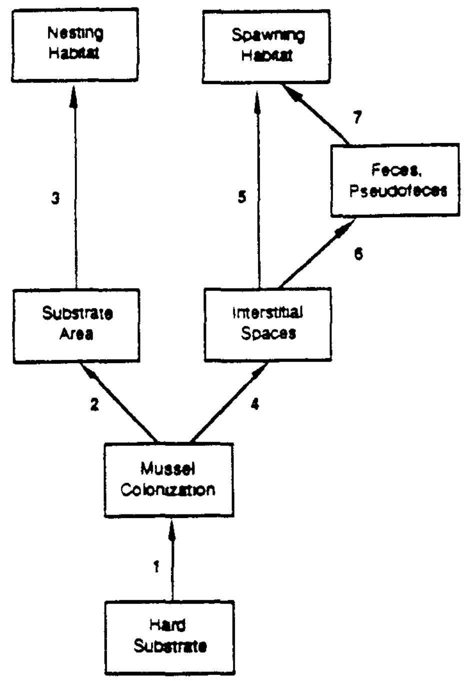
This hypothesis illustrates possible mechanisms by which exploitation competition may affect species which use the same prey species as zebra mussel larvae. To understand the effect on species higher up in the food chain, we need to gain an understanding of what species and sizes of phytoplankton and zooplankton are the preferred prey of veligers.

For the same reasons that veligers are available as food for a relatively short amount of time (in *Hypothesis 3*), they are present as predators for only a short time. The effect of this "pulse" of predators may be as important as the effect of the "pulse" of food that veligers supply for some species.

<u>Habitat Effects</u>

Zebra mussels influence the habitat of other organisms both directly and indirectly. They compete with other bivalves for substrate, and their presence can affect nesting and spawning habitat of fish. Their presence can also influence benthic flow regimes, water clarity, and macrophyte populations, all of which can impact other species.

Hypothesis 5: Mussel colonization of hard substrates may reduce the availability of fish nesting and spawning habitat.



Link 1. Hard Substrates are colonized by zebra mussels.

Link 2. Zebra mussel colonization will reduce the area of free hard substrate.

Link 3. Reduced area of free substrate will reduce the area of nesting habitat available for some fish species.

Link 4. Interstitial spaces will be created by mussel colonies.

Link 5. Interstitial spaces will be used as spawning habitat by some fish species.

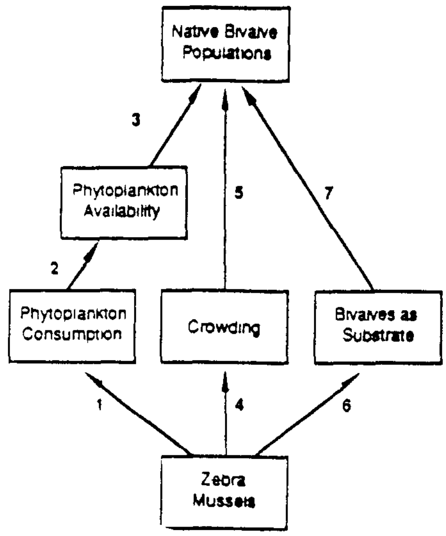
Link 6. Interstitial spaces will become filled with mussel feces and pseudofeces.

Link 7. Mussel feces and pseudofeces in interstitial spaces will affect their use as spawning habitat

This hypothesis expresses the notion that the establishment of zebra mussel colonies on hard substrates may change the availability of nesting and spawning habitats for some fish species. Some species which use hard lake bottoms for nesting may suffer deleterious effects as they loose suitable spawning habitat due to mussels. Other species may be able to use the interstitial spaces created by mussel colonies as spawning habitat.

The main uncertainties associated with this hypothesis lie in the identification of what species are affected by each pathway and the extent to which they are affected.

Hypothesis 6: Zebra mussels may reduce populations of native bivalves through competition for food and space, and by using bivalves for substrate.



Link 1. Zebra mussels prey on a variety of phytoplankton species.

Link 2. As a result of zebra mussel use, the availability of phytoplankton for native bivalves will be reduced.

Link 3. Native bivalve populations will decline as a result of decreased phytoplankton availability.

Link 4. Zebra mussels will compete with native bivalves for living space (i.e. hard substrates)

Link 5. Native bivalve populations will decline as a result of competition for space with zebra mussels.

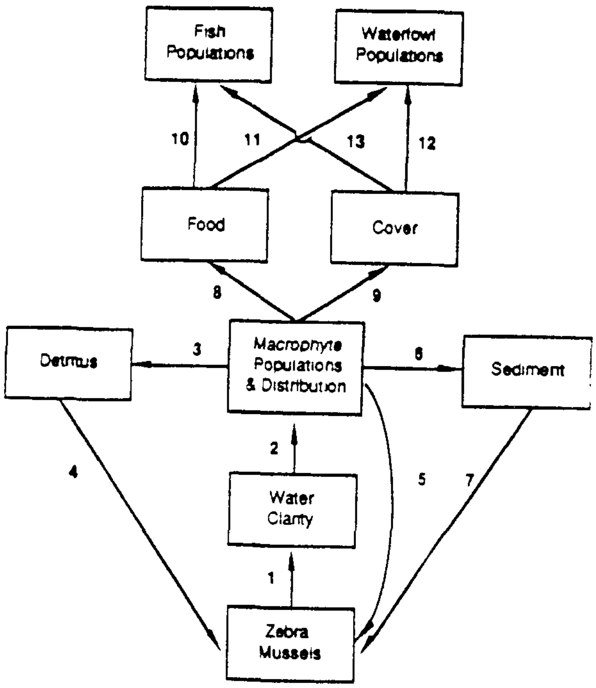
Link 6. Zebra mussels will use native bivalves themselves as substrate.

Link 7. Native bivalves populations will decline as a result of their use as substrate by zebra mussels.

This hypothesis contains three pathways by which zebra mussels may reduce populations of native bivalves. Links 1 - 3 represent exploitation competition and links 4 and 5 represent interference competition. Links 6 and 7 represent the notion that zebra mussels, in their use of native bivalves as substrate, may impair the normal functioning of the bivalves to such a degree that their populations decline.

Key uncertainties of this hypothesis concern the identification of bivalve species affected by each pathway, and quantification of the degree of effect. Since there are several species of endangered clams in the Mississippi River and the Great Lakes, special consideration should be given to resolving these uncertainties.

Hypothesis 7: Changes in macrophyte distribution and abundance caused by zebra mussels may affect fish and waterfowl populations.



Link 1. Zebra mussel colonization will lead to increases in water clarity (*Hypothesis 1*).

Link 2. Increased water clarity will lead to increases in the abundance and distribution of macrophytes.

Link 3. The amount of detritus in the water column and settling on the bottom will increase as a result of increased abundance of macrophytes.

Link 4. Detritus will be used as food by mussels and increase or sustain their populations.

Link 5. Macrophytes themselves will be used as substrate and will increase mussel populations.

Link 6. Increased macrophyte populations will increase bottom sediment.

Link 7. Increased bottom sediment will decrease substrate suitability for zebra mussels.

Link 8. Macrophytes will be used as food by fish and waterfowl species.

Link 9. Macrophytes will be used as cover by fish and waterfowl species.

Link 10. Populations of some fish species will increase as a result of increased macrophyte food.

Link 11. Populations of some waterfowl species will increase as a result of increased macrophyte food.

Link 12. Populations of some fish species will increase as a result of increased macrophyte cover.

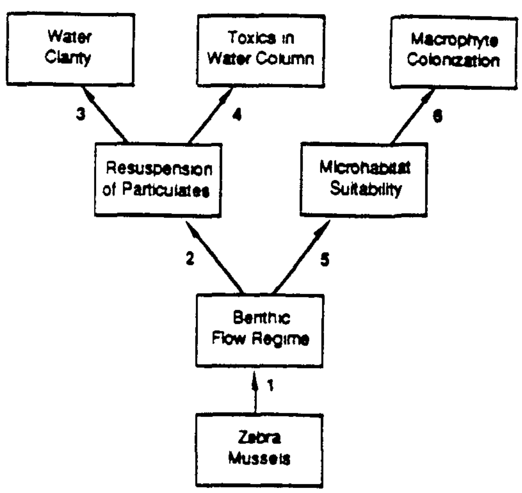
Link 13. Populations of some waterfowl species will increase as a result of increased macrophyte cover.

This complex hypothesis portrays the means by which fish and waterfowl populations may be affected by changes in macrophyte abundance caused by zebra mussels. Fish and waterfowl populations will likely benefit from the additional food and cover provided by the increase in macrophytes caused by zebra mussel colonization. Link 1 is a summary of *Hypothesis 1*. Links 4 and 5 represent positive feedbacks between macrophyte establishment and mussel populations; links 6 and 7 represent negative feedback. Links 8 - 13 represent the response of fish and waterfowl populations to macrophytes.

Many significant questions arise from this hypothesis. Since *Hypothesis 1* is represented in Link 1, all the uncertainties relevant to that hypothesis are also relevant here. All of the feedback mechanisms are hypothetical at present; quantification of each of them would be useful in understanding the relationship between zebra mussels and macrophytes. Similarly, observation of the quantitative response of fish and waterfowl species to increases in macrophytes caused by zebra mussels could add significantly to understanding the ecological effects of mussels.

A key issue related to this hypothesis is the distinction of zebra mussel-related effects from other effects. Many ecological processes affect fish and waterfowl populations; how can the effects represented in this hypothesis be distinguished from those caused by other mechanisms?

Hypothesis 8: Zebra mussel colonies may affect benthic flow regimes which in turn may affect aquatic habitats.



Link 1. Zebra mussel colonization of bottom substrate will cause changes in benthic flow regimes.

Link 2. Particulate re-suspension will be increased due to changes in benthic flow.

Link 3. Water clarity will decrease in response to increased particulate re-suspension.

Link 4. Toxics concentrations in the water column will increase with particulate re-suspension.

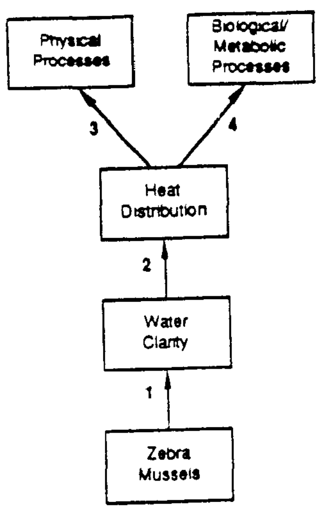
Link 5. Changes in benthic flow will cause changes in suitability of micro-habitat for macrophytes.

Link 6. Macrophyte colonization will be affected by changes in micro-habitat suitability.

This hypothesis portrays some of the impacts that could result from changes in bottom flow caused by mussel colonization. The effects of changes in benthic flow could be far more extensive than those represented in this hypothesis (e.g., change in water clarity could cause changes in macrophyte distribution and vertebrate populations similar to those in *Hypothesis 6*, increased toxic concentrations in the water column could have deleterious effects on biota, etc.).

Before addressing the magnitude of effects on the endpoints in the hypothesis (water clarity, toxics in water column, and macrophyte colonization), some effort should be devoted to understanding and quantifying the first link, namely, determining how much mussel colonies alter benthic flows. Similarly, the impacts of a changed flow regime on particulates and microhabitat need to be understood, and possibly quantified, in order to understand the final links in the hypothesis.

Hypothesis 9: Increases in water clarity caused by zebra mussels may lead to changes in the heat distribution of the aquatic environment and therefore changes in physical and biological processes.



Link 1. Zebra mussel colonization will lead to increases in water clarity (*Hypothesis 1*).

Link 2. Heat distribution of the aquatic environments will be affected by changes in water clarity.

Link 3. Aquatic physical processes will be affected by changes in heat distribution.

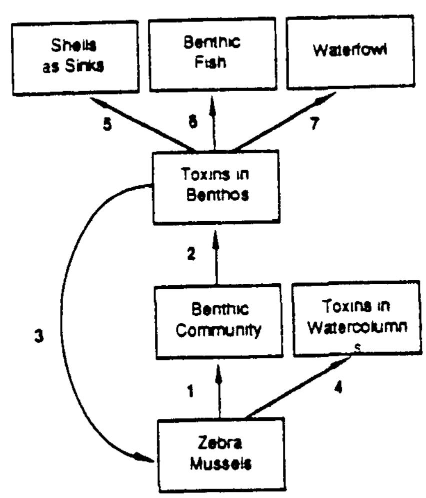
Link 4. Biological and metabolic processes will be affected by changes in heat distribution.

This hypothesis represents a substantial series of ecological and physical effects. As in other hypotheses presented here, the endpoints of this hypothesis are also the initial steps in far-reaching ecological chains of events. Since Link 1 in this hypothesis represents all of *Hypothesis 1*, all the uncertainties and questions related to *Hypothesis 1* are applicable. A key in this hypothesis is the quantification of the relationship between water clarity and heat distribution. This is an enormous issue with many permutations and side-tracks (e.g., considerations such as ambient temperature and light regimes must be considered). Answering this question alone would be a significant research effort.

Pathogens, Parasites and Toxins

The last group of hypotheses are concerned with the introduction or redistribution of new parasites, pathogens and toxins, along with or through the impact of zebra mussels.

Hypothesis 10: Zebra mussel colonization may lead to a re-distribution of toxins in the aquatic community.



Link 1. Zebra mussel colonization will cause a shift to a benthically-oriented community.

Link 2. The total amount of toxins in the benthos will increase as a result of increases in benthic biomass.

Link 3. Zebra mussel toxin loads will increase as a result of increased toxins in the benthos.

Link 4. The total amount of toxins in the water column will decrease as a result of increases in benthic biomass.

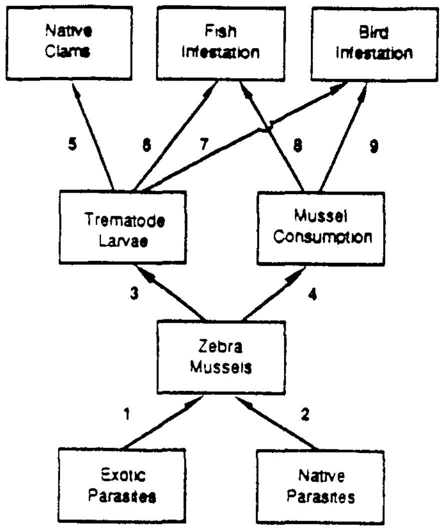
Link 5. Zebra mussel shells will act as sinks for toxins.

Link 6. Toxin concentrations in benthic fish will increase as a result of predation on zebra mussels and other benthos.

Link 7. Toxin concentrations in waterfowl will increase as a result of predation on zebra mussels.

This hypothesis illustrates mechanisms by which toxins in the aquatic ecosystem may be redistributed as a result of zebra mussel colonization. Link 1 represents the series of ecological events that could lead to a re-distribution of energy and biomass in aquatic communities. This link in itself could be the subject of an intensive research effort. Each subsequent link in this hypothesis has uncertainties and questions associated with it. Basically these questions relate to determining whether the hypothesized link actually exists, and if so, quantifying the magnitude of the effect. For example, for Link 7 the two questions would be: 1) do waterfowl accumulate toxins as a result of eating mussels and other benthic organisms?, and 2) what is the effect on waterfowl of ingesting toxins from mussels and other benthic organisms?

Hypothesis 11: Zebra mussels may pass exotic and native parasites on to native clams, fish, and birds.



Link 1. Zebra mussels may act as intermediate hosts for exotic parasites (most likely trematodes).

Link 2. Zebra mussels may act as intermediate hosts for native parasites (most likely trematodes).

Link 3. Trematode parasites have a free-swimming larval stage.

Link 4. Zebra mussels will be used as food by some fish and bird species.

Link 5. Trematode larvae will infest native bivalves.

Link 6. Trematode larvae will infest local fish populations.

Link 7. Trematode larvae will infest local waterfowl populations.

Link 8. Fish which feed on infested mussels will become infested.

Link 9. Waterfowl which feed on infested mussels will become infested.

This hypothesis illustrates mechanisms by which some fish and waterfowl species may become infested by native and exotic parasites which use zebra mussels as an intermediate host. There are two significant issues related to this hypothesis. First, we must identify zebra mussel parasites. At present there is no complete listing of organisms which parasitize zebra mussels in North America, and little work on this is being done. Second, we need to quantify what effect, if any, parasites which use zebra mussels as an intermediate host have on fish and waterfowl species.

3. Rate and Extent of Spread of the Zebra Mussel

There is no question that zebra mussels are spreading in North America. The question is, can we predict how quickly they will spread, and to which area. The rate and extent of spread is generally influenced by the suitability of the habitat and by the means or vectors available to enable the organisms to move from one location to another. Habitat suitability constraints are important at the scale of a water body, whereas dispersal vectors are important both at this scale and on a larger scale. Four distinct scales with distinct questions were identified related to both rate and extent of spread:

1) Water-body
   How do zebra mussels spread within a lake and how may they be transported from a lake to an adjacent water body?

2) Catchment
   How do zebra mussels spread through a catchment and what are the limiting factors?

3) North America
   How are zebra mussels capable of spreading throughout North American waterways and what are the limiting factors to continental spread?

4) Global
   How are zebra mussels capable of spreading across ocean bodies and what are the limiting factors to global spread?

Discussion was likened to a model-building exercise. A list of factors was developed that constrain the suitability of zebra mussel habitat. The number and strength of influence of these limiting variables defines the ability of zebra mussels to succeed in a particular area. Where a habitat has many limiting components (e.g., temperature, calcium, etc.) we can predict a low probability of colonization and minimal threat of spread. Conversely, where few limiting constraints exist we can predict a high probability of colonization and a maximum threat of spread.

Movement from lake to lake is largely a function of vectors, but these are difficult to model. Instead, a geographic information system was proposed that would assist in keeping track of current mussel distribution and areas to which they may spread based on both habitat constraints and dispersal vectors.

3.1 Habitat Constraints

The following section presents our understanding of the habitat constraints that affect the spread of zebra mussels. For each constraining factor it was determined whether or not the limits are known for Europe or North America or both. Where possible, interacting and confounding factors that limit the rate of zebra mussel spread were identified. A more thorough review would require an explicit definition of the relationships between factors that constrain zebra mussel spread and the factors that determine zebra mussel abundance.

Where insufficient knowledge existed to adequately define key habitat constraints, an information gap was identified, and a research question was posed. The constraints are divided into chemical, physical and biological categories, and are summarized in the following tables.

Table 3.1 Chemical constraints on zebra mussel growth

Parameter	Threshold Value	Origin of Data	Research Questions	Notes
Ca2+	12 mg/L 13 mg/L	U.S.S.R L. Sup.	1 What are the other limiting cations? 2 What are the upper ionic calcium concentration limits in North American waters? 3 How do the calcium thresholds change in response to changes in pH?	
Mg^{2+}	≥ 8mg/L	U.S.S.R		
dissolved O_2	limiting < 36% sat. optimum: 80-85% sat. unfavourable 5 6 mg/L	Jonassen 1972 Dugga 1966 U.S.S.R	4 What are the differences in dissolved oxygen needs between adult and veliger?	• at increased temperatures, zebra mussels need more dissolved oxygen
temperature	• filtration stops at <3°C and >30°C • a significant decrease in growth occurs at 10-15°C • ≥12°C needed for oocyte release • upper limit of successful veliger development is 26-27°C • optimal growth at 17-24°C	U.S.S.R	5 What are the winter temperature thresholds of zebra mussels in North America? 6 How do zebra mussels respond to temperature fluctuations?	
pH	<6.5 • 50% mortality within 6-9 hours at pH 5.0	U.S.S.R	7 What are the effects of organic acids on zebra mussels? Why are zebra mussels not found in North American bogs streams, which have an increased concentration of organic acids?	• at pH 5 0, toxicity effects expressed through sodium and water increase • in the absence of sodium, zebra mussels live approximately 12 hr with "normal" pH
Na^+	• need > 1.5-2mg/L • upper limit 16-17 mg/L salinity NaCl • a stable reproducing population will establish at 600-800 mg/L chloride U.S.S.R	U.S.S.R North America	8 What are the effects of sodium in North American lakes?	
toxins			9 What toxic elements do zebra mussels bioaccumulate and in what concentrations?	• zebra mussels can accumulate toxins and not perish

Table 3.2 Physical constraints on zebra mussel growth

Parameter	Limiting Constraint	Origin of Data	Research Questions	Notes
water movement	• optimum 0.1-1.0 m/s	U.S.S.R.		• water movement through flow and waves considered the most important factor • water movement allows for constant import of food sources (phytoplankton) and refreshes oxygen
substrate	• need hard, solid surface	U.S.S.R. North America		• shallow water bodies with a lot of silt will limit zebra mussel growth
depth			1 If food and oxygen are sufficient, is depth limiting? If so, what does this imply for municipal water intake?	
length of growing season			2 Does the length of the freeze effect zebra mussel reproductive cycles and population growth?	
water level fluctuation	• can spend 6-7 days out of water before desiccation	U.S.S.R.		

Table 3.3 Biological constraints on zebra mussel growth

Organism	Limiting Constraint	Origin of Data	Research Questions	Notes
fish: sheephead bream roach eels yellow perch	• possible prey species • prey species	North America	1 What native North American organisms prey on zebra mussels? 2 What role may leeches play as predators?	• fish as prey are likely to have little effect in dampening the rate of zebra mussel spread
diving ducks	• up to 90-95% elimination of zebra mussels in small, shallow lakes	Netherlands		
phyto-plankton	• the veliger is dependent on ample small plankton populations • sufficient chlorophyll necessary for normal shell growth • need 20-50 mg/L in flowing water (eutrophic streams)	Sprung 1988	3 What is the effect of limited phytoplankton in oligotrophic systems?	• zebra mussel diet is 10% phytoplankton, 90% detritus • at 1mm in length feed on dead organic matter • at 1cm, start feeding on zooplankton
diseases			4 What diseases may limit the rate of zebra mussel growth?	
parasites: *Aspigogaster*	• potential for reduction of zebra mussel growth rate and elimination of the population	U.S.S.R.	5 Does this parasite exist in North America and can it be effectively used as a control mechanism?	• *Aspigogaster* appears to be zebra mussel-specific; causes sterility through action in the gut; this effects reproductive success and population viability.
bacteria	• bacteria known to have little effect on zebra mussel populations	U.S.S.R.		

A significant amount of the information regarding the chemical thresholds to zebra mussel survival and the limiting biological and physical factors comes from Soviet and European research. Although this data is important as a starting point, the physical and chemical properties of North American lakes are not all similar to these European lakes in which zebra mussels were studied. Because the North American zebra mussel may be genetically different from the organisms studied overseas, the limiting factors to zebra mussel spread cited in the European literature may not be relevant to North America. Although we should utilize the valuable European experience and information, it is necessary to continue work to identify constraints to zebra mussel growth in North American lakes.

3.2 Population Growth and Spread within a Lake

The list of constraints to zebra mussel success indicates factors which may limit population growth and slow the rate of spread. The rate of increase will be rapid or slow, depending on the constraints (such as water temperature, calcium and magnesium availability, pH, chlorophyll availability, water flow, dissolved oxygen levels and the length of the growing season) present in the lake. Some of the constraints operate through density dependent mechanisms, so that their influence becomes more significant at high population levels. This means that the rate of increase declines over time and the total number of zebra mussels in the lake reaches a maximum level. The number of mussels is a function of mortality rates, recruitment levels and rate of growth, which are dependent upon the influence of the habitat constraints. By determining these rates in response to habitat constrains, we can predict how a population of zebra mussels in a lake will increase over time.

The maximum population level achieved is very much influenced by the area of suitable bed or habitat available to the mussel. Where the area of bed is small, the maximum population will be small. A specified population level will be reached sooner in a lake where bed area is not constrained than in a lake where there is only a small area of suitable bed. Physical constraints such as unsuitable substrate will prevent zebra mussel growth across the whole lake.

Finally, some population control mechanisms such as parasites, diseases and predators may become effective only after an initial peak has been reached. There may be lag times related to their appearance in the water body or in their ability to reach high enough levels to be effective. Zebra mussels may reach a stable high level, or they may reach a peak that declines over time to a lower stable level. The Soviet experience of introductions to new areas has been a peak population followed by a rapid decline to a lower more stable level.

As control measures are applied, the rate of increase of zebra mussels in the lake should decrease. Effective controls will either slow the increase or decrease the maximum population size.

Increased knowledge of the effectiveness of various chemical, physical and biological constraints to zebra mussel population growth will provide useful information to those attempting to develop effective local or lakewide control programs. Hence research on limiting constraints is not only relevant for predicting the rate and extent of spread, but also for the development of viable control programs.

3.3 Extent of Spread

Due to the adaptive nature of zebra mussels and the poor knowledge of dispersal mechanisms, it would be difficult to adequately predict the extent of spread at any specific time. Instead the group focused on the potential range limits of the mussel. Quite simply, the range limits are defined by habitat constraints.

The simplest way to represent the impact of all the identified constraints would be through the use of a Geographic Information System (GIS). This will permit the user to provide a series of overlays based on maps that represent various constraining parameters to zebra mussel colonization. As an example, one map may show calcium levels throughout the Great Lakes basin, another may show temperature gradients, a third may represent pH levels, etc. On each map, areas with limiting zebra mussel habitat are highlighted. The aggregation of these constraint maps will result in a product that shows which geographic areas are the most likely to be invaded by zebra mussels due to a lack of limiting conditions. As map data is digitized to be used in a GIS, it becomes easy to edit and manipulate, so the GIS would serve as a vehicle for maintaining a current database.

From the evidence that exists now the group estimated that in Europe the zebra mussel range extends from the Caspian Sea in the south to the White Sea in the north. The mussel has yet to be identified in Asia or Siberia. It's Asian absence may be a function of the turbulent waters common to the area, while the Siberian constraint is the cold and pristine waters where the amount of phytoplankton as a food source is limiting.

In North America, the present information indicates that the species occurs throughout the Great Lakes, from Thunder Bay, Ontario, south to southwestern Lake Erie, and from Duluth, Minnesota, east to Quebec City where salt water meets fresh water. The species is not yet close to being limited by habitat constraints and is expected to eventually spread throughout most of North America.

3.4 Rate of Spread from Lake to Lake

Modelling the rate of spread of zebra mussels from water body to water body, across North American and from continent to continent would be very difficult and full of uncertainties. The difficulty stems from the fact that rates of spread from one water body to another are completely dependent on the dynamics (type, frequency, distance, substrate) of the dispersal vector. If there is frequent opportunity for the organism to interact with a vector and to be transported in favorable conditions to new habitats, rates of spread across water bodies may be quite high. On the other hand, restricted opportunity to contact favorable vectors will result in low rates of spread across water bodies. The prediction of rates of spread between lakes requires knowledge of the frequency and probability of spread by specifically identified vectors as well as information on where the vectors are going.

Two major categories of vectors were identified: natural, and those based on human activities. The human influenced methods of zebra mussel dispersal include:

1) recreational boating and angling;
2) commercial vessels;
3) man-made canals/ irrigation ditches;
4) aircraft pontoons;

5) intentional release of zebra mussels;
6) research equipment;
7) litter (garbage).

The natural dispersal mechanisms include:

1) currents;
2) waterfowl (i.e., on feet);
3) insects.

A veliger requires a moist medium to successfully disperse (e.g., ballast tanks, canals, bait buckets, currents), whereas an adult requires a solid substrate onto which it may attach (e.g., boat hulls).

An estimate of the rate of spread across North America may most effectively be accomplished through mapping exercises. The maps would show known areas of zebra mussel colonization and display canal routes and shipping lanes, since these are the most common and most efficient vectors. By knowing the routes of the major vectors we can estimate the route of dispersal of the mussels.

A Geographic Information System (GIS) would be an ideal way to display the maps and vectors. A GIS would give the user the ability to visually observe where mussels are now and where they will probably end up given the nature of the constraints and dispersal vectors in the surrounding water bodies. For example, if an area of high concentration of mussels rests adjacent to an area that the map displays as having few limiting constraints and the lakes are connected by canals, the probability of mussel infiltration into the new lake is high. The GIS system would have the ability to represent:

1) prime zebra mussel habitat (constraints map);
2) where the mussels are found now;
3) major movement corridors;
4) an indication of potential range limits.

By knowing where zebra mussels are, what habitat they like, and what vectors are available for movement, it should be possible to estimate not only where they will go, but also to predict the routes of spread and the order of arrival in various water bodies. A simulation model could be used in conjunction with the GIS model to predict colonization probabilities and rates of spread. The combined system would perform a series of analyses to determine successive infestations given the routes and probabilities for dispersal as well as the habitat constraints. Predictions of the pattern, extent and relative timing of spread could then be made.

4. Control of Established Species

The control of established introduced species, or even of zebra mussels specifically, could be the subject of extensive scientific and practical management literature. Discussion was limited to 1) general issues related to population-wide control of established aquatic species, with some specific consideration of the zebra mussel, and 2) local control of the zebra mussel in response to specific problems caused by this organism. A framework was developed to evaluate local control measures.

4.1 Population Control of Established Species

Once an organism has been introduced and is successfully exploiting its new habitat, it will be difficult or impossible to totally eradicate it. There are no poisons that are entirely specific to any organism; even those that are designed to target a certain taxonomic group are only relatively more poisonous to that group than to other groups. Thus it is not possible to get rid of one species without at the same time affecting others, often including humans. Alternatively one could try to alter the environment in such a way that it is no longer hospitable to the new organism; but this is likely to have ecosystem-wide ramifications. Even biological control methods, such as predators, parasites and diseases that affect the introduced species are rarely so narrow in their impact that other parts of the ecosystem are unaffected. Any attempt to control a natural system requires us to address the complexity of the whole system.

In order to control a whole population one must target a significant proportion of either the individuals or the habitat. Control on a continent wide level is unlikely; the natural system generally overwhelms any human actions. To control any organism that has the ability to disperse (such as the zebra mussel in its larval stage), action would have to be taken at least on the scale of a continuous body of water, such as a lake. Since this is a daunting task for anything as large as the Great Lakes, one would only consider population scale control if the ecosystem effects of the invading organism were unacceptable or had serious socio-economic consequences, such as an adverse impact on fisheries.

Even though population level control in the Great Lakes is not a feasible alternative, methods were discussed which one might consider if drastic measures were to be required. Furthermore, populations in small, isolated bodies of water could be managed, and hence the potential methods may interest some people.

Changes to Habitat

Lake chemistry could be changed to make it unattractive to the zebra mussel through judicious additions of chemicals which would change the level of Ca, K, Mg, oxygen or pH to an unacceptable range for the mussel. Other organisms would of course also be affected. Such changes may already be happening either naturally or unintentionally in some lakes; for example, changes in lake pH as a result of acid rain. Similarly in small bodies of water we could influence physical factors which limit zebra mussel distribution, such as the nature of the substrate, temperature, current, depth, and turbidity. It is possible to deposit sand on the bottom of a lake in order to discourage settling of the mussel larvae.

Biological Control

Since biological control is the only population control measure which has the potential to both persist and amplify over time, it is the only method we could use over extensive areas or a long time period. The use of imported predators, parasites and diseases is very risky, but some effort should go into investigating the options now, as responsible research of biological control methods requires a long time.

Several of the natural enemies of the zebra mussel, (e.g., European carp, Caspian goby, and a bacterial disease) may already have been inadvertently imported. In a few more years these biological control agents may become well established and cause a crash in the mussel population. The European experience with introductions of the zebra mussel to new areas suggests a general pattern starting with a high build-up followed by a crash and then a lower stable level.

Finally, native species may over time learn to exploit the zebra mussel and play a part in controlling their population levels. Diving ducks, such as scaup, are already becoming more abundant in zebra mussel areas, and it is known that in shallow European lakes ducks are a significant mussel predator. Similarly, native fish such as the drum, sheepshead, and buffalo may become important predators. Investigations concerning potential control (and other impacts) by existing native and non-native species are in progress.

4.2 Control of Problems Caused by Zebra Mussel

The difficulty in controlling whole populations does not imply helplessness in dealing with local abundances which cause problems. In the few years that the zebra mussel has made its presence known, many potential control methods have been identified, some of which are currently in use and are effective, and others are being developed. The chief concern is to identify and develop methods which have no adverse effects.

It was not possible to evaluate or prioritize all the potential control actions at this workshop. To do so would take much longer and will require expertise in a wide range of specialties ranging from ecology to engineering to chemistry, hydrology, invertebrate physiology, sociology, etc. Because the problems caused by the zebra mussel are tangible and the impacts are felt by many people, the funding available for the research of control methods is larger than that usually available to combat introduced species. Our knowledge is growing quickly. However, not all of the current research information is available, as some of it is proprietary with the intention of commercializing solutions to problems caused by the zebra mussel.

Problems caused by the zebra mussel

Many of the problems caused by the zebra mussel are well-known, but most discussions focus on one problem or one perceived issue. The following table provides examples of the types of problems encountered:

Table 4.1 Typical problems caused by the zebra mussel

Shipping	all shipboard systems using cooling water, including ship power, fire control, etc.
Boating	cooling water for engines, hulls
Navigation Structures	bridges, docks, buoys, etc
Domestic Water Supply	intake clogging water quality
Industrial and Power (once-through cooling systems)	intake clogging fouling of internal machinery/pipes
Recreational	cottage water supplies fouling of beaches with shells etc

Actions available to control the zebra mussel

Many lists of actions have already been developed. The following table, which is not exhaustive, presents the major types of actions suitable for controlling the zebra mussel. Since any action detrimental to life can potentially be used to control the zebra mussel if it can be applied in a suitably contained fashion, the list of actions is long. Some of them have been used for other problems, some of them are currently being developed, and some are only ideas.

Table 4.2 Actions for controlling the zebra mussel

	Chemical	Mechanical	Biological	Physical
Shipping	ablative coatings	scraping hydrolancing		heat coatings electromagnetic acoustic flushing
Boating	ablating coatings immersion baths	scraping hydrolancing		coatings flushing acoustic
Navigation. Structures	ablative coatings	scraping	local predator populations	heat electricity
Domestic water supply	oxidizing chem.	all		filters ultraviolet acoustic electromagnetic
Industrial Cooling	oxidizing chem. other chemic.	all		filters ultraviolet acoustic electromagnetic
Recreation		scraping (bulldozing)	local predator populations	

Suitability of actions to problem types

Although it was not feasible to evaluate control actions in detail, we did attempt to identify which of the above actions were most suitable or promising for each problem area.

Table 4.3 Control actions suitable for major zebra mussel problem areas

Chemical	Mechanical	Physical	Biological
oxidizing chemicals chlorine, various forms ozone permanganate hydrogen peroxide **non-oxidizing chemicals** molluscicides fatty acids (e.g. soaps) dispersants carbon dioxide bisulfite scaling agents ablative coatings	**removal** flow brushes pigging scraping hydrolancing robotic scrapers **Engineering/Design** closed loop cooling deep water intakes double or large pipes	**screens and filters** strainers backwash strainers vortex strainers infiltration beds sand filters biofilters **other** barrier coatings heat ultraviolet pressurization acoustics (ultra + infrasound) flushing magnetic fields electro-shocking irradiation cathodic protection	parasites diseases, natural and bioengineered genetic sterilization pheromones, attractants predators human predation (e.g. clam-meal industry)

4.3 Framework for Evaluating Local Control Actions

In order to evaluate the suitability of any action for controlling various problems induced by zebra mussels, a number of questions must be asked. The discussion group identified a list of questions which should be incorporated in an evaluation framework:

1. **Is this a crisis, short-term, or long-term control effort?**
   An unanticipated and relatively sudden realization of a problem generated by the zebra mussel can easily be regarded as a crisis situation, especially if critical water supplies are being drastically curtailed. The control methods suitable for dealing with this situation are different than those one would wish to use on a recurring basis, or for a long-term problem management or prevention procedure. Furthermore, different levels of impact may be deemed acceptable for dealing with a crisis than for on-going control.

2. **What is the control strategy?**
   Control may be designed to prevent settling or to kill and/or remove the mussels from the site where they cause problems. Timing, intensity, frequency and site of the action must be specific to each installation. In order to evaluate the effects, the details of the control strategy should be specified. In order to develop an appropriate strategy the effects of alternate strategies must be considered. A control strategy is likely to consist of a mixture of control actions; and both effectiveness and impact need to be evaluated for the whole package. Unfortunately there is no simple solution, though some generalities do hold and experience will enable rapid designs of effective and non-impacting strategies.

   Specific attributes to be specified in a control strategy include:

   - Under what circumstances will the control be required? What tolerance levels of mussel infestation need to be identified.
   - When will the control be applied? - this should be specified in terms of time of year, timing with respect to the life cycle of the mussel, and timing with respect to the process being protected.
   - Where? - in what geographic areas, and where in the system being protected.
   - How will the control be applied? - not only in terms of specific practices, but also in terms of how often and how long.
   - What intensity level of control is considered adequate? For example how much chemical or other application (heat, UV, etc.) will be used?

- What contraindications to the use of this control should the user consider? Are there any potential interactions with the existing process? (chemical interactions, corrosion, etc.)

- How will the end products of the control be disposed of (including the organisms removed or killed)?

3. **What are the costs?**
Both start-up and maintenance costs must be considered; the relative importance of each will vary depending on anticipated future need for control. If costs are too high, the control may be unacceptable to the user or may invite undesirable shortcuts.

4. **How effective is the control method?**
The user will need to know how effective the method is, and will need to have some measure of the probability of a desired level of effectiveness. This may entail some form of on-going monitoring for level of control achieved.

5. **Are there any environmental effects?**
One of the prime concerns associated with many control measures, particularly the chemical ones, is what other environmental impacts they will have. This includes not only direct effects of a control action, but also the effects of any by-products or end products. It is also necessary to consider effects of the disposal of mussels that are removed from problem areas. Since there is considerable uncertainty in respect to environmental impacts, there is a need to research and to monitor. In order to monitor, suitable measurable indicators will have to be identified.

6. **Are there any social, economic, or health effects?**
This is similar to the environmental effects issue, except that the domain is socio-economic rather than ecosystem. Some socioeconomic effects may be mediated through the ecosystem (as in bioaccumulation of toxins). Again, uncertainties, indicators, monitoring and research needs should be specified.

In summary, we can characterize a desirable control action as one that is facility-specific and consists of several actions in an integrated control strategy. The strategy should be relatively inexpensive, and the environmental and socioeconomic impacts must be socially acceptable. In general, a good strategy will be *adaptive*, both in terms of being responsive to changes in the problem or available control methods and in terms of learning to live with the problem rather than trying to eliminate it.

Sample Applications of Framework

In the process of developing the evaluation framework, three of the control methods were considered in some detail. These were chosen to represent a fairly well understood measure (chlorination), a measure which has not yet been applied but which is likely to be non-controversial (treatment of ship water systems with heat), and a treatment method with a large number of uncertainties related to environmental effects (molluscicide). The following discussion is not intended to be complete, but rather to provide a superficial view of how the evaluation framework could be applied. A focussed effort would synthesize a more extensive set of information, and the framework is likely to be modified as a first step in the process of a serious evaluation effort.

Chlorination with Sodium Hypochloride

Chlorination is the best understood and most commonly used control method. It is already practiced for reasons other than zebra mussel control in most municipal water supply systems, and in Europe it is routinely used to control zebra mussels in industrial water systems.

1. **Is this a crisis, short-term, or long-term control effort?**
   Chlorination is considered a short-term solution in North America, though it is known that some level of chlorination for zebra mussel control is routinely used in Europe.

2. **What is the control strategy?**
   Several strategies are possible, and the one chosen would depend on the specific purpose, the population level of the mussels, and the installation:

   - a high dosage to kill the mussels could be intermittent, a pulsed high dose, or continuous for a specific period (e.g., 3 weeks at the end of the season)
   - a low dosage to prevent settling of veligers would be used continually during the season when dispersal occurs

   System characteristics which determine the control strategy include:

   - flow rate of system
   - plumbing of system
   - interaction with other chemicals in system
   - byproducts which may be generated
   - potential corrosion problems (oxidants promote corrosion)

3. **What are the costs?**
   Chlorination is one of the least expensive alternatives:

   - \$50,000 to \$5 million to retrofit system
   - operating cost for $2x10^6$ m^3 day = \$80,000

4. **How effective is the control method?**
   Chlorine is effective; it is already used, and the effectiveness characteristics are relatively well understood. The problem is translating the theory to practice;

many factors influence the concentration levels in the water system. A monitoring system, such as on-line chlorine analyzers or a bioassay at the end of the line is needed.

Uncertainties

- In spite of the well-understood nature of this chemical, there are still unknowns with respect to minimal effective levels.

5. **Are there any environmental effects?**
Chlorine kills indiscriminately; it is dangerous to all life forms.

Uncertainties

- Dechlorination by-products and the mitigation of these are not well understood.

- Should we use total loading standards rather than emission limits? Which is the better indicator to monitor?

6. **Are there any social, economic, or health effects?**
Chlorine gas is a safety issue.

Uncertainty

- Dechlorination by-products, such as THM effects in water treatment plants are not well understood. Standards of use for chlorination and dechlorination are needed.

Two general observations emerged from the discussion of chlorination as a control method. First, although this is the chemical control method with which we have the most experience there are still uncertainties associated with its effects. Second, it became clear that the strategy for use is dependent on individual circumstances; no single guideline or application technology will be suitable for all situations.

The possibility of biomonitoring for low levels was discussed. Although biological detectors may be better, they may not be acceptable in regulatory and compliance matters. It may be easier to specify and enforce regulations based on instrumentation than on biological responses, and some people may distrust the accuracy of the latter.

Heat for Control of Ship Water Systems

Heating the water in the sea chest (the multiply screened water intake area in the hull of a ship) promises to be a relatively simple and benign control method. This has not yet been tried, but heat has been used in other water systems.

1. **Is this a crisis, short-term, or long-term control effort?**
At the moment the use of heat as a control mechanisms is considered a temporary solution, until something better can be found.

2. **What is the control strategy?**
The water system would be subjected to periodic heat shock; at about 1-2 week frequency in the sea chest, with piping treated during shut-down.

3. **What are the costs?**

   - for a ship less than 200 feet the retrofitting will be about $15-$20,000; price will increase nonlinearly with bigger ships.

   - maintenance costs will be minimal, as existing heat and staff would be used.

4. **How effective is the control method?**
   The effectiveness of temperature for killing mussels is fairly well understood and the relationship between temperature and duration of exposure is documented.

   Uncertainty

   - There may be temperature effects on the plumbing system. Heat causes expansion, and the rate of heat conduction to adjacent areas may cause some minimal mechanical problems.

5. **Are there any environmental effects?**
   The total amount of heat to be diffused is minimal in respect to the volume of water involved.

   Uncertainty

   - As the mussels are removed in port there may be an accumulation of dead mussels on the lake bed which may have further impacts either through decay processes or changes in the substrate.

6. **Are there any social, economic, or health effects?**
   None are anticipated.

Molluscicide in Industrial/Power Plant Cooling System

Any biocide is potentially harmful, even if not lethal, to organisms other than the target organism, and hence should be used with great caution. As many users believe that molluscicides are totally harmless to other species, the required caution is not always observed. These products are in use, but there are still many uncertainties in respect to their effects.

1. **Is this a crisis, short-term, or long-term control effort?**
   The use of a molluscicide is a crisis solution, one that is generally far more powerful than required. Molluscicides may possibly be appropriate when there is an immediate and unexpected threat to critical services. However, as the zebra mussel becomes established, an unexpected crisis should not emerge as there should already be a control strategy in place.

2. **What is the control strategy?**
   Molluscicides are generally applied for a period of 6-7 hours, and where they are used as a general control, this would be repeated 3-4 times a year.

3. **What are the costs?**
   The use of molluscicides is particularly attractive from an operational point of view. No retrofitting is required, there are no worker safety concerns,

and currently there is no time consuming regulatory procedure. Furthermore, molluscicides are relatively inexpensive.

4. **How effective is the control method?**
Molluscicides are known to kill zebra mussels at high doses.

Uncertainties

- Dosage requirements are not understood. Dosage is expected to vary depending on whether the intention is to kill or to detach, and whether adults or veligers are targeted.
- The effect of the molluscicide is temperature dependent (related to metabolic rate), but the exact nature of this is not known.
- It is not clear how dead organisms are to be removed from the system being treated.

5. **Are there any environmental effects?**
The normal procedure for "detoxification" is to use bentonite clay to bind the molluscicide after it has had a chance to affect the zebra mussels. The poison binds to the clay in the form of a cation.

Uncertainties

- The molluscicide may be easily displaced from the clay by a stronger cation and thus released to environment.
- The persistence of the molluscicide in the ecosystem is not known; there may even be bioaccumulation.
- Molluscicides are not specific to the zebra mussel, so all mollusks in a system are at risk. Furthermore molluscicides may have impacts on other aquatic organisms over time.

6. **Are there any social, economic, or health effects?**
None are known.

5. Prevention of New Introductions

There are two aspects to the prevention of new introductions; namely methods for preventing future introductions of new exotic aquatic species into the Great Lakes, and methods for preventing established exotics in the Great Lakes basin from spreading to other regions. The group discussed unintentional introductions as well as intentional "non-legally sanctioned" introductions such as smuggling exotic flora/fauna and introduction by amateurs, but did not consider "legally sanctioned" introductions such as exotic species brought in for aquaculture or for biological control programs (although it was recognized that not all legally sanctioned introductions were beneficial). Rather than focusing on the zebra mussel, the group decided to consider the general problem of introductions.

Potential vectors through which exotic species may be introduced were identified, then ranked according to their relative importance and manageability. Possible management actions were identified to target each of these vectors. Finally, some of the more promising management actions were considered in greater detail, then evaluated according to specific criteria. During this discussion, a number of research needs and recommendations were identified.

5.1 Vectors

Species enter a new system in a variety of ways or vectors. Each of these vectors has different characteristics, and is amenable to different levels of control and different control methods. The following possible vectors for the introduction of new species in aquatic systems were identified:

- natural
  - abiotic dispersal mechanisms such as wind or currents
  - dispersal on or in other mobile organisms (waterfowl)
- ships
  - ballast water
  - solid ballast
  - biofouling
  - cargo
- canals
  - and other water diversions or water transport
- accidental
  - bait, and the water in which bait is contained
  - aquaculture escape
  - escape from aquaria/ponds
  - importation with aquaria/aquaculture species
- recreation
  - pleasure craft
  - aquatic equipment (e.g., windsurfers, scuba gear)
- deliberate
  - releasing exotics for aesthetic reasons or profit
- aircraft transport
- ground transport
  - trucking
  - rail
- nursery material
- scientific collection
  - collected material
  - collection equipment/vessels

• tourists

• construction and building materials
  dredged material
  sand for sandblasting

Natural vectors are those on which humans have little or no influence; they have been present throughout history and account for the slow but geologically important distribution of species over the earth's surface. These natural dispersal mechanisms are not likely to be controllable.

Vectors that are part of human systems are potentially more manageable. Of these, ships, specifically ballast water, are both the most significant and the most manageable vector for the introduction of new aquatic species. Another highly manageable vector is also related to shipping; namely the canals through which ships travel can also serve as corridors for the movement of aquatic species. Recreational or pleasure boats can unintentionally carry species from one water body to another, and because this is a widely dispersed vector with the potential for significant human error, it is only moderately controllable. Other accidental introductions, such as release of live bait or release of specimens from home aquaria, are also only moderately controllable. Intentional introductions can be partially managed through more effective enforcement and through increased public awareness of the potentially disastrous consequences.

5.2 Management Alternatives

A number of possible management alternatives that might target introduction vectors are listed below. The list was the result of a brain-storming exercise in which the constraints of environmental, economic, political and social cost were temporarily disregarded in order to generate a list of possible options. It is not a list of recommended actions.

Ships

- Seal off the Great Lakes basin, preventing all in-coming and out-going vessel traffic. This would require closing the St. Lawrence Seaway and other points of entry.

- Require inspections of the hull, ballast and cargo of all ships entering and leaving the Great Lakes, for the presence of exotic species.

- Require that the hull, ballast and cargo of all incoming ships be treated to remove or kill any exotic species that may be present

- Re-design ships to minimize the transport of invading species. This could include designs to minimize organism attachment, as well as to prevent organism entry into on-board water systems.

Canals

- Ban the future construction of canals and other water diversions.

- Close existing canals and other water diversions.

- Require frequent inspections of locks, to monitor for the presence of exotic species.

- Design entry lock disinfection systems, which will likely require some sort of closed basin retention system.

- Replace locks with marine railways, on which boats could be pulled up dry ramps from one waterbody to the next. This is currently done with pleasure boats in the Trent-Severn waterway, although this may be impossible for large vessels. A system for disinfecting ships between waterbodies could be incorporated.

- Install barriers to discourage organism movement through canals. These could be electrical weirs, sonic barriers or bubble curtains, or even mechanical barriers if no vessels use the canal/diversion.

Recreation

- Require inspections of the hulls and live wells of pleasure craft entering waterbodies.

- Require that the hulls of pleasure craft be treated with biocides or by scraping before entering waterbodies.

- Require that live wells in pleasure craft be drained and dried, or heated, to destroy any exotic species that might be present.

- Restrict pleasure craft access to waterbodies, and require that all incoming and outgoing craft be disinfected.

- Establish education programs targeting all waterbody users, to increase awareness of the issue and of ways to minimize the risk, e.g., post notices in various locations, including the doors of public restroom stalls at day-use facilities at docks, beaches and launch ramps.

- Provide hoses to rinse boats and other aquatic equipment at all marinas, beaches and other waterfront areas used for recreation.

Accidental

- Establish education programs targeting aquaculture facilities and the points of purchase for bait and pond/aquarium species, to increase awareness of the dangers and to offer ways to minimize the risk.

- Require that fail-safe designs be incorporated into aquaculture facilities, to minimize the risk of escape.

- Ban the use of live bait.

- Regulate the sale of live bait, to avoid between-lake transfer of bait and bait water. One method might be to require that bait purchases be registered, and that the bait bucket and any unused bait be returned to the point of purchase. A penalty could be levied in cases of non-compliance, and offenders would be identified through the purchase registration.

- Quarantine incoming bait fish, and aquaculture and aquarium species, to minimize parasite transfer.

- Require that incoming fish for aquaculture be disinfected to kill external parasites.

Deliberate

- Implement better regulations.

- Improve enforcement. One method might be to make those responsible for introducing an exotic species (if they can be identified) pay for the cost of any necessary control and environmental restoration measures.

- Improve communication, both to the public and between regulating bodies. This type of public education could be facilitated by distributing fliers at state lines and at national borders.

- Standardize regulations across jurisdictions, with respect to which species may be removed or brought in. This could begin with national standards (i.e., the same regulations across states), or even global standards.

- Ban the commercial sale of exotic species.

- Decrease market demand for exotic species.

Information gathering and monitoring are important components of any prevention program. Useful information might include a list of injurious or potentially problematic species that should be considered in designing prevention programs. This would require information exchange on a global scale. Monitoring should be conducted for compliance as well as for effectiveness, to determine whether 1) people are abiding by the requirements/regulations, and 2) the measures taken are working.

Bans of various kinds and education programs are most likely to be workable management approaches. Although some of the bans listed above are unrealistic, the problem was considered to be sufficiently serious to consider the bans. Education programs, however, are relatively easy to implement and can be started immediately.

5.3 Evaluation of Management Options

Three of the management alternatives listed above were evaluated according to whether they were advantageous or disadvantageous from an environmental, economic, social, and political perspective. These options were chosen because they target the most important and manageable introduction vectors. They are not meant to be interpreted as our preference or recommendation.

Closing Boat Access into and out of the Great Lakes

Closing access to the Great Lakes would be beneficial from an environmental perspective. Closure would mean fewer spills and less dumping of waste from ships, and there would be a reduced need for dredging in the lakes. A disadvantage would be the probable switch to ground transport (trucks, rail) which increases air pollution and fuel consumption. It is also likely that such a measure would only displace the threat of new introductions from the Great Lakes to other areas.

From an economic perspective, this measure would probably benefit the rail, trucking and air cargo industries, but would also increase the need for road and rail maintenance. The cost of decommissioning the St. Lawrence Seaway and other entry points would be substantial, and the shipping industry as well as harbor facilities in the area would be devastated; these industries would be forced to move or shut down.

The social effects would encompass the displacement of workers from the shipping and harbor industries into ground transport industries. Tourism might benefit from a more favorable environment for recreational activity and the improved aesthetic value of the area, but would suffer the loss of tourists who visit locks to watch the boats go through.

Although this measure could be highly effective, it is unlikely that any Great Lakes area politician would support such drastic action. There might, however, be regional support in areas that could benefit from the shift in transportation mode.

Inspections of Ship Hulls, Ballast, and Cargo

This measure would be environmentally and socially neutral. It would be hard to enforce, and therefore from an economic perspective it would be resource-intensive. It would likely cause delays to incoming vessels. It would, however, provide the teeth with which to enforce treatment requirements. Politically, such a measure could be viewed as favorable because it is cautious and relatively non-disruptive. This measure could be very effective in the Great Lakes.

Treatment of Hull, Cargo, and Ballast

The subgroup did not have the necessary information or expertise to evaluate different treatment options, as the environmental, economic, social and political implications would be treatment-specific. In general, however, the subgroup recognized that the use of toxic substances could have negative environmental and social effects, but that treatment measures could be politically favorable because once the technology is available it would be a relatively quick solution.

The location of the ship when ballast treatment is performed is important; different countries have different laws for chemical use. If global standards cannot be developed for the use of biocides or other treatment methods, this issue should be taken into account.

Evaluation Criteria

The subgroup agreed that future evaluation criteria for any prevention measure should consider:

1) the costs and benefits of implementing that measure;
2) the cost of not implementing that measure; and
3) the effectiveness of that measure with respect to
   a) the goal of the prevention program, and
   b) other alternatives.

INTRODUCED SPECIES WORKSHOP
Saginaw Valley University Theater
September 26, 1990

MORNING SCHEDULE

SOURCES, PREVENTION AND MANAGEMENT

J. David Yount, Organizer and Moderator

8:15 Welcome

Erich Bretthauer - Assistant Administrator for Research & Development, USEPA

BIOLOGY AND ECOLOGY

8:30 *Ecology of introduced fishes and aquatic invertebrates in North America*

Peter Moyle - Department of Wildlife and Fisheries Biology
University of California, Davis

9:00 *Ecology of the Ruffe (Gymnocephalus cernuus) in Europe*

Craig Sandgren - Center for Great Lakes Studies, Milwaukee, WI
John Lehman - University of Michigan Department of Biology, Ann Arbor

9:30 Ecology of the Cladoceran Bythothephes cederstroemi (spinywater flea or "BC") in the Laurentian Great Lakes.

10:00 Break

10:15 *Invasive introduced plant species in the Great Lakes*

Tony Reznicek, University of Michigan Herbarium, Ann Arbor, MI

10:45 *Biology & ecology of Dreissena polymorpha* from the European USSR

N.F. Smirnova - Institute for the Biology of Inland Water Bodies, USSR

11:15 *Ecology and Use of Zebra Mussels in the Netherlands (Europe)*

Henk Smit, Institute for Inland Water Management, Dordrecht, the Netherlands

11:45 *Zebra Mussel biology and ecology in North America*

Gerry Mackie - Department of Zoology, University of Guelph, Guelph, Ontario

INTRODUCED SPECIES WORKSHOP
Saginaw Valley University Theater
September 26, 1990

AFTERNOON SCHEDULE

SOURCES, PREVENTION AND MANAGEMENT

J. David Yount, Organizer and Moderator

1:30	*Species invasions in the Great Lakes: Historical Trends and Entry Vectors.*
	Ed Mills - Cornell University, Biological Field Station, Wheatley, Ontario *Joe Leach - Ministry of Natural Resources, Lake Erie Fisheries Station, Wheatley, Ontario*
2:00	Preventing introductions of species into the Great Lakes via shipping
	Lt. Cmdr. Randy Helland - U.S. Coast Guard, Washington, DC
2:15	*Ship ballast water designs to kill organisms before discharge*
	Jack Woodward - University of Michigan, Department of Naval Architecture and Marine Engineering, Ann Arbor
2:45	Break
3:00	Strategy for controlling the Dreissena population in North America.
	V.N. Karnaukhov - Institute of Biophysics, USSR Academy of Sciences
3:30	*The Zebra Mussel: Chemical and physical control methods* for industry
	Donald Lewis - Aquatic Sciences, Inc., Ontario, Canada
4:00	*Successful management of an introduced species. Sea Lamprey: past, present and future control species.*
	Terry Morse - US Fish & Wildlife Service, Marquette Biological Station
4:30	Questions and comments from the audience

ECOLOGY OF INTRODUCED FISHES AND AQUATIC INVERTEBRATES IN NORTH AMERICA.

Peter B. Moyle, Department of Wildlife and Fisheries Biology, University of California, Davis, Davis, CA 95616.

The introduced aquatic organisms in the Great Lakes have received a great deal of attention, but they are only one of the most visible parts of a worldwide phenomenon of species introductions. I will discuss the problem of introduced species in North America by addressing four questions:

1. What is the extent of introduction of aquatic organisms in North America?
2. What has been the impact of these introductions on native species and ecosystems?
3. What allows introduced aquatic organisms to become established?
4. Do introduced species fill vacant niches?

Extent of introductions. Introduced aquatic organisms are found throughout North America, although some regions have a higher percentage of introduced fauna than others. The southwestern United States has particularly large numbers; in California, for example, 48 of 137 freshwater fish species have been introduced. Other freshwater regions with large numbers of introductions are the Great Lakes, drainages of the Eastern Seaboard, and freshwaters of Florida. Some organisms brought in from abroad, such as common carp and *Corbicula* clams, are found in suitable habitats throughout the continent, while many North American species, such as green sunfish and opossum shrimp, have had their ranges greatly expanded. Most successful introductions quickly expand their populations far beyond the water into which they were introduced. The inland silverside, for example, spread from Clear Lake in northern California (where it was introduced for insect control) to reservoirs in southern California in less than 20 years, becoming one of the most abundant fish species in the state.

Prior to 1970 or so, most aquatic introductions were made deliberately, often to improve fishing. For the past 100 years there has also been a steady stream of accidental introductions as organisms have moved through canals or hitched rides in or on ships. In recent years, however, there has been a dramatic rise in the number of introductions, either accidental (e.g. via ballast water) or unauthorized (e.g. via bait buckets or aquaria). This coincides with major changes in transportation systems combined with major ecological changes in inland waters and in the Great Lakes or the Sacramento-San Joaquin estuary.

Impact of introductions. To succeed, an introduced species almost always has to change the environment into which it is introduced, most commonly by reducing the numbers of native organisms. For example, 24 of the 48 fish species introduced into California have documented negative effects on native fishes, 22 have not been studied enough to document effects (or lack of them) and 2 are known to be benign (but have very limited distributions). In the Sacramento-San Joaquin estuary, two introduced species of copepod appear to be displacing the dominant native species, and both of the new species are less vulnerable to predation by larval fish than the native species. Also, in the estuary, a recently introduced species of clam has become enormously abundant and may be causing (through efficient filtration) the record low numbers of phytoplankton observed with consequent reduction of zooplankton. This species is quite likely causing major parts of the estuary to shift from planktonic to benthic food webs. The estuary is already highly disturbed, and about half the fish species are not native, including a small oriental goby which has become very abundant in the past four years.

Characteristics of successful introduced species. Successful introduced species usually have several of the following characteristics: (1) They are hardy, thus can survive transport under adverse conditions. (2) They are aggressive, either behaviorally or physiologically, thus can displace native organisms. (3) They have reproductive strategies that allow them to expand their populations rapidly. (4) They have the ability to disperse rapidly. These characteristics are especially helpful when the species invades an environment that is highly disturbed by human activities. Thus 44 of the 48 introduced fishes in California thrive primarily in disturbed environments.

Vacant Niches. This concept is brought up because it is used so frequently to justify an introduction or to 'excuse' one that has already been made. Basically, niches cannot be "vacant" because they are characteristic of the organism, not the environment. Therefore, an invading species carries its niche with it and almost always displaces or shrinks the niche of another species (or many others) when it invades. Introduced species often appear to have no effect because the time frames of studies are too short or researchers do not study the appropriate native species (e.g., clams can compete with larval fish for food).

Understanding the effects of introduced species, regulating these effects, and preventing further introductions into aquatic systems are important activities for many reasons. Perhaps the most important, however, is that introduced species are contributing in a major way to the worldwide loss of biodiversity.

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ECOLOGY OF THE RUFFE GYMNOCEPHALUS CERNUA (LINNAEUS 1758) IN EUROPE.

Peter S. Maitland, Fish Conservation Centre, Easter Cringate, Stirling, Scotland.

The Ruffe (sometimes called the Pope) is a small member of the perch family. Ruffe are found in lakes, slow flowing rivers and canals throughout northern Europe and across central and northern Asia. It is a recent introduction to North America. The species also occurs in the low salinity areas of the Baltic Sea where it reaches its maximum size of 45-50 cm and about 750 gm. Elsewhere, it seldom reaches more than 20 cm, except in a few favorable habitats.

In the British Isles it is indigenous to eastern and southeastern England and is common locally, but it has been redistributed to some extent by canal networks within the English midlands and has now reached the lower Severn and Welsh Dee systems. It is absent from Ireland, and was absent from Scotland until very recently when it became established in Loch Lomond, evidently brought in as bait by Pike anglers. It has also appeared recently in southwest Scotland in Loch Ken.

Gonad development and sexual maturation are temperature dependent. Spawning takes place from March to May, when shoals of Ruffe move into shallow water. The spawning migration starts at some 4°C and spawning itself can occur at 6-8°C, although the normal range is 11-18°C. The eggs are yellowish white in color (the yolk sac contains a large oil globule) and 0.5-1.0 mm in diameter. Each female can produce 4,000-100,000 eggs depending on her size, but spawning is sometimes intermittent and the eggs may be laid in one or more batches. The adhesive eggs are deposited individually, sticking to stones and vegetation. The eggs hatch in some 8-12 days when water temperatures are between 10 and 15°C.

In some ways, Ruffe are very similar to Perch; indeed the two species can hybridize and this appears to occur naturally in some parts of the River Danube. The progeny, however, are sterile. In general, the range of the Ruffe is more northerly than that of the Perch, and one author has referred to it as an "Arctic Perch." Ruffe have a lower oxygen requirement than Perch and are thus able to occupy habitats where Perch would be under stress (e.g. mildly polluted waters).

Newly hatched fry are transparent and 3-4 mm in length. By the end of the first year they may reach 3-6 cm, and 7-9 cm by the end of the second year. Growth then seems to slow and by the time they are four years of age they may only be around 10 cm. In many waters, very few Ruffe seem to live beyond five years of age. They mature at an early age - males in their first or second years and females in their second or third years.

Ruffe are gregarious fish, often feeding in shoals - though these are rarely as large as some Perch shoals. Usually they feed actively during the day, with a peak towards dusk. At night Ruffe lie concealed on the bottom. They are exclusively carnivorous, feeding on bottom-living invertebrates, especially mollusks, crustaceans and insect larvae (notably midge larvae, which form a significant proportion of their diet). They take approximately the same range of organisms as Perch, but because they are more benthic in habit than Perch, Ruffe appear to take a greater proportion of mud dwelling invertebrates. They also take fish eggs (e.g. of Smelt Osmerus eperlanus) and small fish, and it has been shown in some large Russian lakes that where Ruffe and whitefish (Coregonus) occur together, the Ruffe exert a significant control over the production of whitefish because of the enormous number of whitefish eggs which they consume. Unlike Perch, they feed throughout the winter but at a reduced level.

Ruffe have several natural predators and in some waters form an important item in the diet of Pike (Esox lucius), Pikeperch (Stizostedion lucioperca) and Burbot (Lota lota). The species is also eaten by piscivorous birds. Ruffe also have a number of parasites including various Cestoda, Trematoda and Nematoda.

Ruffe are easily caught by angling with bait such as maggots or worms, but they are not considered to be an important sport fish. The present British rod-caught record is for a fish of 148 gm caught in 1980 in a pond at West View Farm in Cumbria. Often, small Ruffe and small Perch may be caught at the same time at the same spot. Many anglers consider them to be a great nuisance, taking the bait before a more acceptable species can get to it. As a dead bait they are favored by Pike anglers. Their flesh is well flavored, like that of Perch, and there was originally an extensive fishery for Ruffe in the lagoons of the Baltic Sea. This has declined greatly in recent years owing to lack of demand.

Studies of the ecology of the new population of Ruffe in Loch Lomond, first detected in 1982, have indicated an enormous increase in population size. Numbers taken on the intake screens of a water supply facility have increased from nil in 1981 and 17 in 1982 (8.1% of the catch) to 1280 in 1987 and 3015 in 1988 (91.6 and 88.9% of the catch). The species is now very widespread through the whole of Loch Lomond ($71 km^2$) and its major inflow and outflow. The biology is similar to that reported in other waters, though in the early 1980's only a few year classes (0-4+) were caught. Growth is variable but most fish reach 7-9 cm by the end of their second year and 9-11 cm by the end of their fourth year. Spawning occurs in April and May. The main food is aquatic benthic invertebrates, but eggs of the Powan Coregonus lavaretus (occurring in only two lochs in Scotland) are eaten extensively in winter when Ruffe are still very active. Ruffe now form an important part of the diet of Pike in Loch Lomond.

ECOLOGY OF THE CLADOCERAN BYTHOTREPHES CEDERSTROEMII (spiny water flea or "BC") IN THE LAURENTIAN GREAT LAKES.

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Bythotrephes cederstroemii is a predatory zooplankter that has recently invaded the Great Lakes region. Bythotrephes is morphologically distinctive, having a large protruding pigmented eye, an enlarged dorsal brood sac, and a very long caudal spine. The animal is very large for a zooplankter, and is easily seen with the naked eye; total length of adults can be as great as 13-15 millimeters including the spine. It was first reported in southern Lake Huron in December 1984, and subsequently spread east to Lakes Erie and Ontario in 1985, west into Lake Michigan in late summer 1986, and into Lake Superior in 1987. It seems most probable that this animal entered the Great Lakes system via ballast water from ships frequenting European ports with low salinity harbors. Bythotrephes is native to lakes in Europe and the western Soviet Union, where it is typically a minor component of the planktonic invertebrate assemblage and has been little studied.

Each Laurentian Great Lake has responded to Bythotrephes in a different manner, probably as a result of their different fish communities since planktivorous fish can act as predators on Bythotrephes. The most dramatic response and probably the best studied invasion sequence has been in Lake Michigan. The information reported here is a summary of the basic biology of this animal and its impact on the Lake Michigan food web, as documented over the last four years.

The reproductive biology, seasonal population cycle, and distribution pattern of Bythotrephes within Lake Michigan are the subjects of intense current research efforts. The annual cycle of population development is generally similar to native cladoceran crustaceans. The first animals entering the plankton are females recruited from sedimentary resting eggs in early summer. Summer populations result from repeated cycles of asexual or parthenogenetic reproduction by females. They produce from 4-12 embryos in a brood; the neonates are subsequently released with well-formed spines. Development rates are strongly dependent on temperature; the reproductive cycle from mature female to a new mature female is estimated to require as little as 10 days under optimal conditions. Maximum population abundances occur in late July and August, and have been estimated to be as high as 1,000 animals per square meter of lake surface.

Bythothrephes populations are usually restricted to the epilimnion and upper metalimnion; they do not exhibit strong or consistent diurnal vertical migration patterns. Abundances are generally higher offshore than in shallow water, but the horizontal distribution appears to be very patchy and local areas of very high nearshore abundances have been reported by fishermen. Populations become food limited at times during the summer, inducing a switch to sexual reproduction, the production of resting eggs, and a decline in numerical abundance. Sediments of Lake Michigan have been estimated to now contain as many as 10,000-50,000 resting eggs per square meter.

The Bythotrephes invasion has resulted in many biological changes throughout the Lake Michigan food web. The most profound changes have concerned the structure of the zooplankton community. In Europe, Bythotrephes is reported to feed on diverse size classes of herbivorous zooplankton; however in Lake Michigan it appears to have specialized on species of Daphnia, the dominant herbivores in the system. Daphnia abundances declined drastically in 1987. Subsequently, the helmeted species D. galeata-mendotae has been able to coexist in the presence of Bythotrephes but the smaller species, D. retrocurva and the unhelmeted D. pulicaria have been severely reduced in abundance compared with pre-invasion levels. Associated with the Bythotrephes invasion of Lake Michigan has been a decline in recruitment success of the bloater chub (Coregonus hoyi), the dominant planktivorous fish in the offshore region and an increasingly important food item in the diet of the lake's highly managed salmon populations. Bythotrephes may be successfully out-competing young-of-the-year bloaters for the same food resource - Daphnia. Bythotrephes may thus be serving as a food web "bottleneck", diverting resources from the managed fishery. The native zooplankton community has also been impacted. Leptodora kindti, a native predatory cladoceran, has declined in importance, and two of its primary food items, the colonial rotifer Conochilus unicornus and the small herbivorous cladoceran Bosmina longirostris, have subsequently increased in abundance. Other small zooplankters have also increased in importance, perhaps signalling a shift to a generally smaller-bodied zooplankton assemblage as Daphnia has declined. The phytoplankton community has also responded, but in unsuspected ways. Despite the dramatic changes in the herbivorous zooplankton assemblage, the algal biomass (as chlorophyll), size distribution and dominant species have remained unchanged. There has, however, been an apparent increase in biomass-specific production and potential growth rates of the dominant small-sized algae. It is unclear at this point where this additional production is going, but it does not appear to be entering the traditional large zooplankton-to-fish food chain.

All these changes may be influencing the flux of carbon and energy through the food web in such a manner that the future may require fundamental changes in fisheries management practices and a reevaluation of realistic sport fishing expectations. Unlike the zebra mussel invasion, where economic impact can be measured in terms of direct costs to clean up mussel-fouled water intake systems, an assessment of the economic impact of Bythotrephes must wait until a clear fisheries response to the fundamental and complex food web alterations of the last few years can be ascertained.

INVASIVE INTRODUCED PLANT SPECIES IN THE GREAT LAKES.

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Invasive plant species of Great Lakes wetlands and aquatic systems form a complex topic. There is no such thing as an intrinsically invasive species. Many of the worst pests in the Great Lakes region are rare plants in parts of their native range. There are species, however, both native and introduced, that find conditions at a certain point suitable for their spread. Although this means that one cannot fully understand invasive species without a full environmental context, such a context is beyond the scope of this abstract.

Introduced species are also not intrinsically harmful. In eastern North America, about 20% of the flora is introduced. Most of these species are rare waifs, and most are terrestrial. In western Lake Erie, the most affected portion of the Great Lakes, about 10% of the flora is introduced. Other areas of the Great Lakes (with a total wetland flora of about 450 species) would have a somewhat lower percentage. Considering the excellent dispersability of aquatic organisms, this is not high. Of these introduced species, most are ruderals and merely facultative aquatics, or else are rare and strong competitors. However, the percentages do not reflect the communities in western Lake Erie, and many wetland communities elsewhere in the Great Lakes are dominated by introduced species.

The following plants, listed with annotations, are the major species of invasive plants in the Great Lakes, based on current knowledge, with comments on the timing of their spread, if available, and their actual or potential impact, as far as is known.

Purple loosestrife, Lythrum salicaria, is the best documented invasive introduced species, and the one with the greatest pest potential. It is an extremely good competitor with a tremendous seed bank of up to 21,000 seeds per m^2, which makes control very difficult. Although purple loosestrife has been in the Great Lakes region since the 1880's, extensive spread to become a severe pest has been much more recent. Nevertheless, purple loosestrife has been recognized locally as a problem by botanists since the 1930's. Purple loosestrife has a severe impact on wetlands. It is unpalatable, therefore of little value as wildlife food, and crowds out other vegetation, sharply reducing diversity.

Hybrid cattail, Typha x glauca, is poorly documented in terms of overall occurrence, but extensively studied from the viewpoint of systematics and ecology. It is a hybrid of the native T. latifolia and T. angustifolia, introduced from the east coast of North America. The hybrid is now widespread and is an extremely strong competitor. It is much more tolerant of salt and other pollutants, because the T. angustifolia parent is a salt marsh species and, with hybrid vigor, is more able to take advantage of excess nutrients. The impact of hybrid cattail is as an extremely strong competitor able to generate monodominant, low diversity vegetation.

Common reed, Phragmites australis, is native to the Great Lakes region generally, but was almost certainly rare and sporadic in Great Lakes wetlands in pre-settlement times. It is a very recent rapid invader, having become abundant since about 1970. The species is a very strong competitor, able to spread vegetatively with tremendous rapidity by stolons up to 30 m long, as well as by rhizomes. It is very salt and pollution tolerant, and has also spread along heavily salted roadsides, especially expressways, as well as wetlands. It forms extremely dense monodominant stands of unpalatable vegetation, greatly decreasing diversity of wetlands.

Frog's bit, Hydrocharis morsus-ranae, is probably the most recent potentially serious invader, having entered North American wetlands as recently as 1939, and the Great Lakes substantially later. Frog's bit is now present in Lakes Ontario and Erie. It is a free-floating aquatic that forms monodominant stands not limited by water depth. Its full impact is unknown, but potentially severe. The absolute coverage of the water surface in areas where it is abundant substantially reduces submerged aquatic species and may even suppress emergents.

Eurasian water milfoil, Myriophyllum spicatum, is another well-studied invader. It was recognized late due to confusion with native species and is somewhat poorly collected, but is evidently a recent spreader. It is now present in all the Great Lakes but is only locally a problem. It is most likely an opportunistic species that will invade holes under optimal conditions. Although a submerged aquatic, since it branches close to the water surface, it is able to grow in turbid water, as well as to shade out other submerged aquatics if any are present. Fruit production is low, so the species is less valuable as wildlife food than the plants it displaces.

Curly-leaved pondweed, Potamogeton crispus, is another well-studied species. It has long been present in the Great Lakes, but has only relatively recently been a major invader of wetlands. It is only a local problem, and like Eurasian water milfoil is a surface brancher able to grow in turbid water and displace other species if any are present. Also like Eurasian water milfoil, it is an opportunistic species that probably invades areas where other species have been eliminated. Its impact is probably low, but it can shade out submerged aquatics and reduce diversity of wetlands. Fruit production is low, so it has only modest value to wildlife.

Additional presently-minor introduced species that may cause problems locally or may spread in the future are reed canary grass (Phalaris arundinacea), slender naiad (Najas minor), small-flowered willow herb (Epilobium parviflorum), and flowering rush (Butomus umbellatus).

In the most basic terms, the reason that introduced species are a problem is because the ecosystem has been perturbed, and is responding with the resources available to it, which includes introduced species and genotypes. This may sound trivial, but is an essential concept since it mandates ecosystem-based solutions to the problem of introduced species if any solutions are possible. Past responses to introduced aquatic weed problems have typically been at the level of "this is a bad plant, we must kill it", hardly an ecosystem approach and one reminiscent of the discredited concept that predators are bad and must be killed. In all cases, when dealing with introduced species, it is essential to try to understand the system before taking action.

Weed problems in the Great Lakes are, on a broad scale, due to the interplay of three classes of environmental parameters: turbidity, nutrient levels, and the competitive ability of participating species under existing conditions. All three of these factors are complex and other variables may also play a role locally, including levels of non-nutrient pollutants and marsh management schemes. Fundamentally, turbidity reduces the depth to which aquatic species can grow. This is most serious, since it greatly reduces the area that macrophytes can occupy on a lake bottom. It also gives an advantage to species such as Eurasian water milfoil, elodea, curly-leaved pondweed, sago pondweed, and coontail, which are surface branching submerged macrophytes; as well as floating-leaved and entirely floating species. The effect of nutrients is largely to provide a few very good competitors with sufficient nutrients that they can completely dominate sites. These species can be either native or introduced, and are simply showing a natural response to altered ecosystem parameters. Competitive ability then is a predictor of those species that are likely to become serious pests if nutrients become available in excess.

Solutions to the problem of invading introduced species are, in the long run, to improve water quality in the Great Lakes, especially decreasing nutrient loading and turbidity, and to ensure the natural water level cycling and concomitant flushing and rejuvenation of shoreline wetlands. Little can be done in the short term, although physical removal of the offending biomass is as effective as anything on a local scale, and at least removes nutrients from the system. Attempts to simply kill the offending species do nothing to ameliorate the basic causes of the problems. In this light, the tremendous filtering ability of the zebra mussel may be of benefit to aquatic macrophytes.

BIOLOGY AND ECOLOGY OF DREISSENA POLYMORPHA FROM THE EUROPEAN USSR

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Dreissena was first found in the lower course of the Ural river in 1769 by a famous traveller and well-known Russian zoologist Piter Pallas. As a zoological species Dreissena polymorpha (Pallas) was described by him in 1771. Dreissena became of great interest during the third decade of the 19th century when it was found in London docks, in Kurishgaf, and then in different places of Western Europe. In Germany, it acquired the name of wandering mussel ("Wundermuschel"). A little later, alarm signals appeared when this mollusc blocked pipes and spoiled water in the water supply system of Budapest (1878), Hamburg (1886), Paris and Arli (1893), Berlin (1895), and many other towns in Europe.

In the USSR., many water pipes, hydrotechnical structures, and ships suffer from Dreissena. It would be erroneous, however, to consider Dreissena as only a menace in the economy. It is undoubtedly useful as an effective freshwater filtrator, which forms a powerful filtratory belt, improving the water quality (Stenczykowska, 1968; Lvova-Kachanova, 1971; Lvova, 1977). This ability of Dreissena is just becoming necessary in connection with increasing anthropogenic eutrophication and water pollution, especially if the water is used for drinking or technical purposes.

In addition, Dreissena serves as a food for some commercial fish species (Vorobyev, 1949; Kondratiev, 1958; Yablonskaya, 1975). A rapid dispersal of Dreissena is facilitated by its biological peculiarities.

Dreissena is a dioecious organism. Fertilization occurs in the external water, which is associated with a high absolute fecundity. The gonad weight makes up 10.0-17.0% of the total wet weight in females and 4.0-12.0% in males (Spiridonov, 1971). The mollusks rapidly attain maturity. Mature individuals occur among 6mm long males and 7mm long females; all Dreissenas 10mm long are mature.

The trochophor, 60-70 microns in size, develops from the egg. The larva is termed veliger from the moment of shell formation until attachment to a substrate. The veliger floats in the water with the help of a velum. The organs of digestion, blood circulation, excretion and others develop in it. Boundaries between separate periods of growth become visible on the veliger's shell. The veliger dimensions are 250-255 microns. In the water-bodies of the European USSR, the larvae stay in the plankton for 7-10 days according to many authors (Kirpichenko, 1965; Skalskaya, 1976; Karataev, 1983; and others).

The veliger which settles on a substratum quickly develops into a postveliger having a long and powerful foot. The foot has a deep slit-like pit on the sole, which helps the mollusc to be firmly attached to the substratum and to glide even on the water surface tension film. The postveligers are from 250 to 700 microns in size. The growth and development of postveligers are manifested externally in changes of the shell shape and size. The settling veliger has a symmetric round shell. Then the shell begins to elongate and grow asymmetrically, acquiring a triangular shape. The branchial and anal syphons appear (syphon forming stage, Kirpichenko, 1965). After some time, the mollusc excretes from the foot sole thin threads of mucus, which, on solidifying in water, form the so-called bissus, firmly attaching the mollusc to the substratum (definitive stage).

During conversion of the larva from the veliger to the definitive stage, about four lines of growth are formed on the Dreissena shell. Further formation of the growth lines and rings on the shell is conditioned by various other causes: wintering, episodic deterioration of environmental conditions (oxygen deficiency, sudden drop in temperature, etc.), when the animal's growth temporarily ceases or slows down. It has been noted that a distinct growth line is formed even if the animal slightly dries up. In this case, the shell becomes teratic with a sharp line. A rather distinct line on the shell is also formed after egg laying, since the mollusc does not grow during spawning, accumulating nutrient substances for sexual products.

The maximal size of the adult mollusc may reach 40mm. The Caspian and Aral Dreissenas are significantly smaller than the river and lake forms. Large Dreissenas are almost incapable of moving by themselves. Only extremely adverse conditions make adult Dreissenas leave their bissus and move slowly from one place to another. It is the pelagic larva, which may be carried over great distances by the current, and the bissus, which helps the mollusc to attach itself to ships, rafts, water fowl, fishing gear, and some aquatic organisms, that secure successful spreading of Dreissena over water systems.

Spawning is very much prolonged due to gradual ripening of the sexual products and occurs at a temperature of 15-17° C (Kirpichenko, 1965; Spiridonov, 1971; Karataev, 1983). It ends at 11° C. During spawning, two peaks of veliger abundance are clearly seen in July and August, which may shift in time depending on conditions.

Under favorable conditions, the veligers play a dominant role in the number and production of the zooplankton (Karataev, 1983). During the great peak, the number of larvae in the water may reach 40 to 400 thousand individuals per cubic meter (Kirpichenko, 1965; Spiridonov, 1971).

Growth of Dreissena after wintering starts at 10-11° C. With increases in temperature, the specific growth rate of postveligers increases. Some observations on cooler waters, where the temperature in the littoral is four degrees and in the profundal 1-2 degrees higher than in naturally heated waters, are of interest (Karataev, 1983). The density of larvae has been shown to be higher in a zone with a natural thermal regime. Thus in Lake Lukomlskoe (B.S.S.R.), the mean seasonal number was 2.5 times and biomass was three times as great as that in the unheated zone of the lake. The larvae develop better in the upper layers of water to a depth of 10m. Diurnal migrations of the larvae also occur. The maximal concentration of the larvae is observed near the surface at night, and at a depth of 3m in the daytime. The Dreissena veligers have been shown to be more resistant to adverse environmental conditions than the adult organisms. It was found, that the adults were absent in the zone polluted by waste waters of food and metallurgical industry, while the larvae numbered more than 1,000 individuals per cubic meter in the plankton (Dyga, 1966).

Being very resistant to unfavorable environmental conditions, the Dreissena larvae are at the same time very sensitive even to the slightest changes in environmental conditions, which is manifested in its development, growth and abundance. This sensitivity is one of the essential features of its adaptation and allows the organism to prepare to withstand more adverse oncoming conditions.

Fluctuations of the water level play a great role in the life of the veligers, since in winter they influence mortality in the littoral Dreissena populations due to freezing, and in summer, they determine the character of the relationship between populations of the protected inshore zone and of the open water, which facilitates enriching of the genofund and leads to flourishing of the species (Skalskaya, 1987).

Some authors have shown that natural fluctuations of the abundance occur. In the Dnepropetrovsk reservoir each third year was a bad harvest (Dyga, 1966). In the Kyibyshevsk reservoir it was bad each fourth year (Kirpichenko, 1964). The periodicity in Dreissena reproduction is a regularity, not the same for different waters.

During the first stages after settling in new areas, Dreissena occurs at all depths, then it forms aggregations in places rich in suspended food and having a favorable hydrochemical regime. Dreissena inhabits mostly eutrophic and mesotrophic lakes. In lakes, it prefers silted sands and occurs in least numbers on liquid muds of the profundal zone.

In reservoirs, very high numbers are observed on stony substrates, and insignificant numbers are found on muds, silted sand and clay. The quality of the substrate influences the number of mollusks if the colonies settle directly on that substrate. Dreissena does not inhabit pure sandy substrates and places with a great amount of mud and no current. It is especially numerous on flooded forest, bushes, stumps and snags.

For Dreissena, the oxygen demand of the water and its hardness are very important. It is known from observations in nature that Dreissenas do not occur in waters rich in organic matter of humic character (with high oxygen demand).

It is also known that it does not live in low salt (soft) waters. There is no Dreissena, for instance, in Lake Ladoga having very low water hardness, in spite of a possibility of Dreissena immigration from Lake Ilmen. This mollusc resists high salt content in the water much better. Dreissenas resist well low sodium and chloride content, but not low calcium and magnesium sulfates. The main reason for this is the salt content of the Caspian water, from which Dreissena originated.

Both the larvae and adult organisms are filter feeders. They deal with a great amount of suspension and sort out the seston into edible and non-edible fractions. The branchial and anal syphons take an active part in this. The branchial syphon serves as a filter in preliminary purification of water from coarse suspension. Fine suspension particles pass freely through the net of tentacles of the branchial syphon. Then in the posterior part of the mantle cavity one more sorting of the suspension into edible and non-edible components takes place. The unusable part of the suspension is removed from the mantle cavity in the form of agglutinates.

By the character of feeding Dreissena is a clear detritivore (Mikheev, 1966, 1967). Detritus makes up more than 90% of the total food; the remaining 10% is plankton represented by small phyto and zooplankton.

Food consumption increases with increase in the mollusc size. In the Kuibyshevsk reservoir detritus is the sole food for Dreissena less than 1mm in size. The mollusks 2-3mm long feed on the protococc and diatom algae in addition to detritus. In Dreissenas of average size, the phytoplankton food is represented by the blue-green, diatom, green and peridinium algae. They do not feed on zooplankton, however. Only large individuals are capable of feeding on zooplankton, mostly rotifers and Dreissena veligers. An increase in the food diversity during Dreissena growth is associated with the increase in the water filtration rate.

The water temperature from 15-17 to 23-24° C is optimal for feeding of Dreissena, and therefore, for its living activity. At 30° C., Dreissenas filter water very unevenly. This temperature is very close to the upper temperature limit equal to 32-33° C. Temperature below 3° C is unfavorable for Dreissena.

The filtration rate depends on seston concentration in the water. The mollusks filter most effectively at a low suspension concentration. With an increase in suspension content in the water almost the same amount of suspension is consumed for feeding as at low content, but the ability of the mollusks to flocculate seston greatly increases.

Oxygen regime in the water-body greatly influences the feeding rate. An oxygen saturation of 80-85% is optimal. At a decrease in oxygen content, Dreissena excretes 3-5 times smaller amounts of metabolites than under optimal conditions.

Current velocities from 0.1 to 1 m/sec are favorable for the living activity of Dreissena. At velocities greater than 1-1.5 m/sec feeding decreases even though food is abundant. Very fast water flow deforms the mollusc's syphon protruded from the shell, and if the seston concentration is low, the mollusks suffer from hunger.

It is clear from the above that when great masses of Dreissena accumulate in reservoirs, these mollusks perform a great work of filtering the water and accumulating metabolites. In the Volgogradskoe reservoir Dreissenas filter on the average two fifths of the total water volume daily during the summer (Mikheev, 1966). At the same time the process of sedimentation is accelerated due to formation of agglutinates and feces in places inhabited by Dreissena.

The water which passed through the filtering apparatus of Dreissena is almost free of suspension. Therefore, the food resources for zooplankton filtrators are reduced, and for benthic pelophillic species are improved. Developing on different substrata, the Dreissena accretions create favorable conditions for phyto-detritovore filtrators, which make up 90% of the total benthos biomass (without Dreissena), and for phyto-detritovore filtrators + scavengers (1.6-5.2%). An insignificant role is played in the Dreissena community by omnivorous scavenger-swallowers and predatory invertebrates.

Thus, at high population levels Dreissena acts as an environment-forming element, as a biotic factor changing essentially the living conditions for other species. This results in changes of the trophic structure of aquatic ecosystems.

Ecological, physiological and morphological features of Dreissena are of great interest. It is well-known that species populating wide areas and adapted to diverse environmental conditions are able to rather rapidly produce some local, clearly distinct forms (populations, ecotypes, races). Dreissena is a good example of this. Being one of the most numerous components of benthic communities and spreading easily along the Volga channel, which seems to mix up its populations and level them, it has formed populations different significantly in ecological, physiological and morphological characteristics. This has been shown in studies of resistance of the mollusc to changes in temperature and salinity on the whole organism and on the cell level (thermo- and osmoresistance of the cilated gill epithelium) (Shkorbatov, 1986). The Tybinsk, Kostroma, Kuibyshev, Samara, Chapaev and Astrahan populations were studied.

Evidenced by the heat resistance of the whole organism, the Astrahan and Kostroma populations are clearly the most resistant, those of the Rybinsk and

Kuibyshev area are the least resistant. These differences correspond to environmental conditions of the compared groups: the Astrahan is the most southern, the Kostroma inhabits a zone influenced by discharge of heated waste waters from the thermal power station.

The salt resistance of the mollusc differs even more distinctly. The Astrahan group, living near the marine part of the species' distribution area, has been shown to be the most resistant; the least resistant is the Rybinsk group, most distant from the Caspian sea.

Survival of the ciliated epithelial cells under increased salinity conditions (25 per mille) is highest in the Astrahan group and lowest in the Rybinsk group.

Oxygen consumption at different salinities differs distinctly, which confirms the data on general and cell salt resistance.

The characteristics presented here illustrate well the ecological and physiological differentiation of the species. The differences in the investigated characters appear quite stable (adaptation to the same conditions has not leveled then down), and correspond to climatic and environmental conditions of the habitats of the compared groups.

In addition to ecological and physiological peculiarities some statistically significant differences have been established in morphology of the compared groups.

The materials provided here show how the symptoms of interspecific differentiation of Dreissena are diverse and significant within the Volga part of the species' distribution area, where isolation of separate groups is quite relative. It is natural that the populations of this species from different more isolated parts of the distribution area differ to a much greater extent.

Analysis of polymorphism of color and pattern on the Dreissena shells taken from various parts of the European USSR has revealed four main varieties: dark stripeless, light stripeless, radial stripped and dentated striped. Distribution of the occurrence frequency of the varieties of Dreissena distinguishes four main groups: the Aralo-Caspian, Ponto-Caspian, Middle-Russian, Baltic and the Northeast. They differ in both the number of the varieties and the ratio of these varieties (phenes). The maximum number of varieties (all four) and the greatest differences in the ratio of these phenes are found in the Aralo-Caspian group, which is indicative of its unique position in the system of the inter-specific differentiation of Dreissenas (Biochino, Slynko, 1988; Biochino, 1990). Since all the groups, in addition to their phenotypical peculiarities, are bound to certain geographical regions differing in the time of colonization by Dreissena (Morduhai-Boltovskoi, 1960) and coincide with zoogeographical division of the Eurasian mammal fauna (Starobogatov, 1970), one may propose that these groups possess the status of geographical races (Mayer, 1974).

Studies of the geographical variability have shown that the polymorphism decreases with approach to boundaries of the species distribution area.

To explain the obtained data on ecological, physiological and morphological peculiarities of Dreissena one should consider the history of its origin, which was first described by A.I. Andrusov as early as in 1897. The contemporary family of Dreissenas is represented in the world fauna by only two genera, Dreissena and Congeria. The most ancient representatives of Dreissena belong to the genus Congeria, which appeared in the early Eocene. The greatest development of this genus occurred during the epoch of the 1st and 2nd Pontic tier. In the Pliocene Congeria almost completely disappeared from Europe replaced by the genus Dreissena. The maximum development of Dreissena occurred during the Khvalynsk time of the Quartionary period. During this period, it became widely spread over the Volga and its tributaries, occupied Northern areas of Eastern Europe, penetrated into Western Europe and also settled in the Aral sea.

In the Upper Pliocene Dreissena penetrated into the area of Slavonia and at the beginning of the Quartionary time into Albania. It is worth mentioning that looking at the map of distribution of the family of Dreissenids, presented by Andrusev (1897) and supplemented by Zhadin (1946), it is easy to understand why Dreissena polymorpha was absent in America till recent time.

As has been said already, the time when the genus Congeria appeared in Europe is ancient Eocene. At that time, according to Wegener's theory (1925) of continental drift, Europe and Africa were in contact with the American continent and could have a common fauna or could exchange their faunas. Later, in Pliocene, when the genus Dreissena differentiated in Europe, Europe had already separated from America and penetration of a new species there became impossible.

During the Quartionary glacial epoch Dreissena was rapidly displaced from that huge distribution area which it had occupied in the Khvalynsk time. It was not only because of climatic conditions; the erosion by glaciers probably affected Dreissena much more strongly. The waters of the glacial time were saturated with coarse suspensions, which had an adverse effect on both the adult and larval mollusks. The disastrous effect of turbid glacial flows could be traced far beyond the glaciers themselves. On the other hand, favorable oases of clean water might be preserved in some places, where Dreissena could have survived the glacial time.

Thus, Dreissena survived the glacial epochs not only in the brackish waters of the Caspian and Aral, in the freshened parts of the Azov and Black sea, but also in some water-bodies of the Balkan peninsula and Near Asia and, probably, directly in the area of glaciers. This is confirmed by Dreissena findings in intraglacial deposits in both East and West Europe. After the glacial phenomena receded and the water in rivers became clear, Dreissena started to conquer the lost habitats.

At the present time, owing to peculiarities of its biology and to a great physiological durability, Dreissena rapidly spreads to new areas suitable for its life.

REFERENCES NOT AVAILABLE

ECOLOGY AND USE OF ZEBRA MUSSELS IN THE NETHERLANDS (EUROPE).

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The zebra mussel is an indigenous species in Europe, since it was present here before the last glacial era. Recolonization took place about 160 years ago by merchant vessels and through the inland waterways.

In the Netherlands, the embankment and subsequent freshening of former estuaries has created several suitable zebra mussel habitats. From a study in Lake Volkerak, it is concluded that also in The Netherlands zebra mussels are very rapid colonizers. A population is gradually built up in two successive years. Release of oöcytes and spermatozoids starts in spring as soon as the water temperature rises above 12° C. A second release of reproductive materials takes place during summer at a temperature range of 16-21° C. The veliger larvae settle after 2-3 weeks on solid substrates. The young mussels may reach maturity the same summer, if environmental conditions are suitable. A reproduction peak in September is probably attributable to the young mussels. This means that the zebra mussels may have two generations annually. Low temperatures during winter induce gonad development. From the reproductive cycle it can be deduced that zebra mussels are restricted to water bodies with summer temperatures above 12° C and low water temperatures during winter.

Zebra mussels tolerate chloride concentrations up to about 600 mg/l. In the Netherlands, shell growth is positively related to average summer temperatures. Growth in the River Rhine nearly always exceeded that in the connected lakes, in spite of lower chlorophyll-a concentrations. Water movement is probably essential to zebra mussel growth.

In small and shallow Lake Veluwe eutrophication has led to the disappearance of zebra mussels. Large phytoplankton concentrations enhanced the amount of sedimented organic matter that covered the solid substrates. In the closed off Rhine-Meuse estuary sediment transport limits the establishment of a permanent zebra mussel population. In terms of biomass, zebra mussels are dominant invertebrate species in the River Rhine and the connected lakes with a surface exceeding 50 km^2.

Its role in the aquatic ecosystem is therefore important. In zebra mussel colonies, an interesting ecological community may develop, consisting of very high densities of worms, midge larvae and leeches. Diving ducks (e.g. Tufted duck, Pochard and Scaup) are important regulators of zebra mussel densities. They overwinter on the Dutch lakes that freeze only occasionally. Their population level has increased steadily over the last 150 years. Several fish species (e.g. Eel and Roach) also consume zebra mussels. Their impact on the zebra mussel population level is not known. The possibility of using zebra mussels in water management is now being studied. Its filtering capacity can be used to decrease phytoplankton concentrations by increasing the zebra mussel density. Experiments in two connected ponds at Roggebotsluis revealed that 370 mussels/m^2 were able to increase water clarity from 40 to 80 cm on average during summer. Hanging cultures of zebra mussels can serve as a 'biological filter' to remove contaminated suspended matter from the water phase. Mucus sticks the rejected particles together as pseudofaeces that sediments faster than the original suspended material. In this way, the pollution load can be concentrated on a small surface. A biological filter is now being developed to prevent the intrusion of polluted suspended matter in Lake Volkerak.

Zebra mussels are very suitable for several biomonitoring purposes. Since they accumulate micropollutants, they can serve as bioindicators when concentrations in the water phase are below the detection limit. Histopathological analyses of the body tissues give good insight into the effects of environmental stress on the health of the organism. Its suitability as an effect indicator of micropollutants in routine monitoring is still being studied. Valve movements respond to very low concentrations of some toxic chemicals and can be used as an early warning system for accidental pollution. An operational pollution monitoring system is commercially explored in the Netherlands.

If the spread of zebra mussels through the Great Lakes cannot be stopped, it would be advisable to use them for water management purposes.

ZEBRA MUSSEL BIOLOGY AND ECOLOGY IN NORTH AMERICA

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Standing crops of zebra mussels in the Great Lakes are currently increasing by an order of magnitude annually. Zebra mussels already outnumber native species of unionid bivalves by three to four orders of magnitude. They are strongly byssate and with their epifaunal mode of life are colonizing all hard substrates, a habitat that has not been previously exploited by any benthic organism. The species is exhibiting life history features which not only explain why zebra mussels are already the dominant mollusc but indicate that some native species of bivalves may even be eliminated from the Great Lakes. Compared to native species of bivalves, these features include: external fertilization which allows for greater reproduction than internal fertilization; a free-swimming larval stage for more effective and faster dispersal rates (>250 km/yr in Lake Erie); a longer (June to October) birth period; up to four orders of magnitude greater recruitment and standing crops; and a faster growth rate. The population of D. polymorpha in Lake St. Clair has a different growth rate and life span than European populations. The Lake St. Clair population is short-lived (2 years), fast-growing (about 2 cm/yr) and small in adult shell length (less than 3 cm maximum size). Massive encrustations of zebra mussels are hypothesized to have one or more of the following effects on native unionid clams: (i) impairment of normal locomotion and burrowing activities; (ii) prevention of valve closure by invasive growth of zebra mussels thus exposing the unionid to predation, parasitism and environmental extremes; (iii) prevention or limitation of valve gaping to affect normal metabolic functions for feeding, growth, respiration, excretion and/or reproduction; (iv) interference with normal functioning of the siphons and processes associated with them (e.g. respiration and feeding); (v) stripping the water of food and nutrients making little or none available to the unionid host which may ultimately starve to death; (vi) causing shell deformities that may ultimately result in premature death of the unionid; (vii) smothering by complete occlusion of the siphon region.

SPECIES INVASIONS IN THE GREAT LAKES: HISTORICAL TRENDS AND ENTRY VECTORS.

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Scientists have been concerned for many decades about risks associated with non-indigenous species in the Great Lakes ecosystem. The impact of exotic species in the Great Lakes has been highly variable, ranging from those which have simply supplemented existing communities to those which have posed a threat to the integrity of the Great Lakes resource. The objective of this study has been to document known non-indigenous flora and fauna in the Great Lakes since the early 1800s and to ascertain the most probable vector each organism used to enter the lakes. For purposes of this study, we defined a non-indigenous organism as a successfully reproducing non-native species transported by human activity into the Great Lakes watershed and an entry vector as the most probable means by which a species was introduced by humans into the Great Lakes watershed. Our results clearly indicate that exotic species have been successfully invading the Great Lakes since the early 1800s. To date, 115 different organisms have been identified as successfully reproducing non-indigenous species in the Great Lakes. The bulk of these organisms have been represented by aquatic plants (28%), fish (19%), algae (23%), oligochaetes (10%), and mollusks (9%). While exotic species have been entering the Great Lakes for at least two centuries, 46% have been identified in the Great Lakes during the last 30 years. This recent surge also coincides with the opening of the St. Lawrence Seaway in 1959.

Non-indigenous Great Lakes species have entered the Great Lakes though a variety of vectors. We have grouped entry vectors into five categories. These include accidental release (e.g. bait, escape from fish culture, escape from cultivation, release with infected fish, etc.), deliberate release (e.g. stocking or planting), waterfowl, ships (e.g. solid ballast, ballast water, fouling), and migration through canals. Thirty-five percent (40) of the exotic species identified for the Great Lakes have entered through ship activities, and of these, 28% have entered through ballast water. The second most common vector has been identified as accidental release (23%). Canals have represented a small percentage (5%) of the entry vectors but species such as the lamprey, alewife, and white perch, which have all entered the Great Lakes through this vector, have had significant ecological and economic impact. Currently, vectors for 25% of Great Lakes exotic species are unknown.

Non-indigenous species have had both significant positive and negative impacts in the Great Lakes ecosystem. We have identified 15 out of 115 non-indigenous species, or 10% of the successful invaders, which have had a significant ecological and/or economic impact in the Great Lakes. This list includes the alewife, sea lamprey, purple loosestrife, brown trout, chinook salmon, furunculosis, white perch, the spiny water flea, ruffe and zebra mussel.

PREVENTING INTRODUCTIONS OF SPECIES INTO THE GREAT LAKES VIA SHIPPING.

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Introduction. The issue of exotic species introduced by discharges of ship ballast water into the waters of the U.S. first came to national attention in 1988. Ballast water has now been widely recognized as an important factor in the accidental transport and discharge of exotic plants and animals. The question remains, how to prevent further introductions of exotic plants and animals into U.S. waters.

Coast Guard Authorization. The Coast Guard Authorization Act (P.L. 101-225) enacted in December 1989, required the Secretary of Transportation to submit to Congress a report on the options to control the infestation of the waters of the United States, including the Great Lakes, by exotic species from ships' ballast water. An interim report was transmitted to Congress in August, 1990 which identified those options. We indicated further research must be conducted on those options that appear both practically and economically feasible. A final report will be submitted by the end of 1991.

Options Study. The content of the interim report was not the result of my ideas alone. It was the culmination of several brainstorming sessions at international conferences such as this. Participants from Canadian provincial and state governments, academia, industry, U.S. federal and state agencies, the Great Lakes Fishery Commission, the International Joint Commission, and other organizations provided significant input. However, in my opinion, the majority of credit must go to Dr. Jim Carlton, author of the Paper on "Preventative Option for the Management and Control of Accidental Intercontinental Transfers of Exotic Organisms by Ballast Water." His paper provided the basis for the interim report.

During the many deliberations we did not look at the practicality, feasibility, or associated costs of a particular control option because we felt that would limit the brainstorming process. Additionally, our concentration was on commercial vessels since they are suspected of being the major vector for transferring exotic species by ballast water from overseas ports. Pleasure boats were not studied in depth; however, we recognize that they are a major transportation vector for spreading exotic species (e.g., zebra mussels) after they are introduced into the ecosystem. Pleasure boats will be the topic of future studies.

There are several control options that require additional research into their feasibility and practicality for shipboard use. They include ballast water exchange; electrical current; heating ballast water; treatment facilities; use of screens and filters; high velocity water flow; addition of biocidal agents; ultraviolet light; and ultrasound. I will briefly discuss some of these options.

Ballast Water Exchange. The most attractive option, at this point, is ballast water exchange. Therefore, I will spend the most time addressing this control option. Ballast water exchange appears to be the most attractive option because it requires the least amount of change (i.e., modification to the vessel) and the process is currently being done by vessels entering the Great Lakes in order to comply with the Canadian voluntary guidelines. However, before we can make a final determination regarding the feasibility of this option, there are two major concerns that must be addressed; 1) ship safety and 2) biological effectiveness.

Some of the ship safety factors include:

* The safety and stability concerns for an unladen vessel to exchange ballast at sea. Shifting of ballast during a voyage can be extremely hazardous due to the potentially large free surface effects and rise in the vertical center of gravity. In addition, the stress to the vessel's hull must be evaluated.

* The costs associated with delays, if any, when conducting at-sea ballast exchange.

* Vessel manning needs and crew fatigue issues as a result of the extra work load.

* The impact of coastwise voyages. Would this requirement force vessels to proceed to open seas for ballast water exchange? Is it economically feasible?

The biological and ecological effectiveness of ballast water exchange also needs to be determined. Rarely is there 100 percent exchange of water when vessels exchange ballast water at sea. It is possible, for example, for several million gallons of original water to remain at the bottom of ballast tanks and in various compartments even after an "exchange" has been made. A study has been ongoing since June 1990 which is focusing on sampling "exchanged" water and determining the species and numbers of residual organisms, if any, remaining in inbound vessels in transit on the Great Lakes.

Heating Ballast Water. This also seems to be a feasible option. Questions include 1) how hot does the water have to be in order to kill organisms, and 2) what effects does heating ballast water have on the ships' hull?

Treatment Facilities. Treatment facilities would be used to off-load contaminated water to the facility and, when necessary, to load treated water. Some liquid bulk facilities may already have treatment facilities in place. While this option would provide the needed protection against accidental discharges, it may be cost prohibitive for dry cargo facilities to construct such a facility.

Screens and Filters. The use of screens and filters has merit. Questions such as 1) the strength of the mesh, and 2) the size of the mesh needed to filter the smaller organisms must be resolved. A problem with this option is that filters and screens small enough to capture and retain smaller organisms become clogged so quickly that they would need to be constantly monitored and changed.

High Velocity Water Flow. It has been reported that very high velocity water flow during pumping has been used in industrial water systems in an attempt to increase the mortality of entrained organisms. Ships ballast pumps are high volume but low pressure, and are not designed to achieve such velocities. Additional research must be conducted to determine if such a pump can be modified for shipboard use.

Biocidal Agents. The use of biocidal agents in industrial applications has reportedly been effective in controlling zebra mussels. I understand that several industries in the State of New York have received approval to use chlorine in clearing intake pipes of zebra mussels. For shipboard use, however, there are several concerns or difficulties that must be addressed. First, the amount of poison required to kill many species is unknown. Second, the total quantities necessary for various species and the associated expense must be determined. Third, the method of application, including access to the many separate ballast tanks while at the same time achieving good mixing, needs to be considered. One application method might be to access most tanks by sounding tubes or manhole covers; mixing could be achieved by adding the biocide during ballasting. Fourth, potential human health hazards must be considered. Fifth, subsequent disposal of the contaminated ballast water must be dealt with. Sixth, highly trained personnel are required to apply the biocidal agent.

With any control option that is considered, it must be effective against organisms in the upper, middle, and lower levels of the ballast tank.

Legislation. At this time there are over seven pieces of legislation currently before congress that address this issue. However, I will discuss the two major pieces of legislation, S. 2244 and H.R. 5390. Both the House and Senate versions, although somewhat different, both mandate that the Coast Guard issue voluntary guidelines for the Great Lakes within 12 months after enactment, and publish regulations for the Great Lakes within 24 months after enactment. I anticipate that the final version will be passed before the end of this Congress. The International Maritime Organization's Marine Environment Protection Committee determined during last year's (1989) meeting that exotic species are an international problem which requires an international approach. As a result, a working group is planned for the meeting in November of 1990 to begin work on developing international standards for preventing the discharge of exotic species by ships' ballast.

Conclusion. According to U.S. Customs figures, there were over 67,000 port calls in the U.S. in 1989 by commercial vessels. As you can see, we have a formidable task ahead. We will continue to work with the International Maritime Organization, Canada, Mexico, and other organizations to develop the best possible national program.

SHIP BALLAST WATER DESIGNS TO KILL ORGANISMS BEFORE DISCHARGE.

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Opening reference is made to papers presented at the workshop "Exotic Species and the Shipping Industry," March 1-2, 1990. Possible options to eliminate ship ballast water as a vector for migrating organisms, as discussed in those papers, are listed here. They are:

Coat tank walls with biocide
Load pre-treated ballast from shore
Treat ballast with ultrasound
Treat ballast with electrical currents
Dilute sea water with fresh water
Discharge ballast to shore facility
Pump water at high velocity
Remove organisms by screening/filtering
Treat ballast with ultraviolet radiation
Dilute fresh water with sea water
Exchange ballast offshore

Brief comments are made on each of these, with the general tenor of comments being that the effectiveness and even feasibilities of these options are virtually unknown.

The ballasting requirements (i.e. tonnages of ballast, and times allowed for ballasting and deballasting) of several disparate ship types are presented. It is seen that for some ships, especially bulk carriers, the tonnages are large and the times are short, circumstances that may make treatments during ballasting/deballasting difficult if not completely infeasible.

Speculative quantitative analysis is done for two possible on-board ballast treatment methods. One is heating ballast to a lethal temperature through use of exhaust heat from a ship's propulsion engine. Back-of-envelope calculations show that if the temperature is low enough (120° F) and the time available long enough (six days), such a thing might be accomplished. It is noted, however, that the concept might require heavy insulation of ballast tanks, and might usurp a heat source that is often fully exploited for other purposes.

The other speculative analysis concerns use of sand filters, similar to those commonly used in municipal water treatment, for on-board cleansing of ballast water. The figures show that such a concept may be feasible, but major uncertainties are obvious (e.g. would ship motion disturb the filter, would sufficient space be available aboard ship for the filters?).

In closing, a reminder is given that the Great Lakes are often spoken of, especially in Michigan, as a world-unique resource to the people who live in their watershed. If such beliefs are as strong as their proponents allege, then the "unthinkable solution", namely closing the Lakes to marine intercourse with the outside world, should be considered.

STRATEGY FOR CONTROLLING THE DREISSENA POPULATION IN NORTH AMERICA.

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Essence of the Problem. In the summer of 1988, a new type of mollusk not native to the Great Lakes was discovered in Lake St. Clair in the Great Lakes system. The American press began to call this newcomer the "zebra mussel". In the course of a single year (1988/89) in several regions of Lake St. Clair the population of this mussel grew a thousand fold, from 0.5 mussels/m^2 to 4,500 mussels/m^2.

This explosive growth of the new type of mollusk is a phenomenon typical of the introduction of a species into a new habitat and may have a major negative economic effect. It turned out that larvae of the zebra mussel (from here on we will call it by its scientific name, Dreissena) were brought to the Great Lakes by ships discharging ballast water taken aboard in Europe at the mouths of the Elbe and Rhine rivers.

Even now, in just one year, the drastic increase in this mussel population is creating complex economic problems for hydroengineering and water intake installations. For example in Monroe, Michigan repair of damaged water supply lines was estimated to cost fifty million dollars; in Cleveland, Ohio one-hundred million dollars. The repair of a water intake cooling system at a thermal power station in Detroit, Michigan is estimated at one-hundred and fifty million dollars, and one to two years after these repairs, similar amounts will be needed for new repairs, etc.

We must consider that the mussel intrusion has just begun and that it will embrace all the fresh waters of the United States and Canada, despite the control measures taken. Control has come too late; there is a high probability that this mussel has penetrated the Mississippi basin.

It is quite natural that administrators and scientists in the United States and Canada, faced with this complex ecological problem that has caused such economic losses, would raise the problem of developing a strategy for bringing the problem under control. It is clear, however, that the right strategy can be developed only if we correctly understand the essence of the situation that has arisen in the Great Lakes, or, more accurately, on the North American continent, that is, if we arrive at the proper diagnosis. Are we on the threshold of an ecological crisis for which there are parallels in Europe, or are we on the threshold of a unique ecological disaster? The answer to this important question will also determine the strategy for action.

The Ecological Crisis. The mussel *Dreissena polymorpha* evolved as a species millions of years ago in the huge saline waterbasin which includes the present Aral, Caspian, Azov, and Black seas. It was in the mouths of the rivers that flowed into these seas, such as the Volga, Don, Dnieper, and Danube, that there were stable ecological communities in which the Dreissena population was in equilibrium with its natural enemies.

About 200 years ago, evidently in connection with the construction of canals and increased eutrophication of the water basins, *Dreissena* began to penetrate the North European rivers that emptied into the Baltic Sea. Every time *Dreissena* entered a new region approximately the same situation developed as now in the Great Lakes - damage to water intake equipment, water supply lines, and other hydroengineering installations.

About 40-50 years ago the *Dreissena* mussel problem arose again in the USSR because that mollusk began to move quickly northward along rivers (Volga, Don, Dnieper), the mouths of which were the "motherland" of this mussel. The reason for the abrupt growth of the *Dreissena* population in this case was the sharp increase in the contamination of these rivers by biogenic and organic elements in connection with the flooding of large regions caused by the construction of a series of hydroelectric station reservoirs.

In this case, we can see a clear example of the main reason for population explosion of *Dreissena*, namely water pollution; the increase of the biomass of microplankton, the food of the filtrator mollusk *Dreissena*, in these polluted waters. I prefer to call this phenomenon an *ecological crisis* (by analogy with the human recovery after a serious illness), since as a result of this process a more powerful system of biological self-purification of the water basin takes place, in which the mollusk-filtrators (including *Dreissena*) play a decisive role.

The crisis process itself - the establishment in the reservoir of a new, greater degree of contamination of the system of self-purification - takes about 20-30 years, depending on the features of the specific water basin. This corresponds in its general features to what takes place in a number of reservoirs in the European part of the USSR. When the biomass of *Dreissena* increases, the biomass of the river roach (*Rutilus rutilus*), one of the most widespread types of fish in the rivers of the European USSR, also increases. In such water basins the roach, reaching a length of 13-15 cm, feeds on *Dreissena*. Its growth rate increases and it becomes larger and fatter.

When we first heard of the intrusion of *Dreissena* into the Great Lakes, we presumed that North America was on the threshold of a major ecological crisis in its freshwater basins, which would gradually spread from one water basin to another and, therefore, the general continuing crisis would be somewhat greater than was generally the case for Europe. The process may last from 30 to 50 years.

Strategy for a Crisis Situation. The cost of repair of hydroengineering installations, including repair of water supply and water intake systems for that period (30-50 years) over a vast territory may amount to 200 to 500 billion dollars. The natural inclination to reduce these expenses should result in the introduction into North America of a number of European methods of protecting hydroengineering installations from Dreissena and the introduction of new methods based on more extensive research into the biology and ecology of this mussel.

However, the application of these protective methods should be strictly local and controlled. They should be limited, for example, to physical and biological (ecological) methods. The uncontrolled use of chemical compounds (biocides, molluscicides) supposedly specific only to mollusks, should be avoided.

Our research has established that the high resistance of the mussels to contamination of the medium and the effects of toxic chemical is connected with the presence in their cells of high concentrations of carotinoids that participate in the formation of energy producing intracellular organoids which we have called cartionoxisomes. A similar type of organoid ensures the resistance of the cells (particularly of the brain and heart) of middle-aged and old humans. Therefore, toxic chemicals specific for mollusks may also be specific for middle-aged and elderly humans.

Instead of using chemical methods to reduce the population density of the mussels, one should use ecological methods of control. One of these methods consists of industrial removal of some of the mussels from the water basins and converting them into protein fodder. In the process a technology may be developed for using the water basin substrates for cultivation of the mussels. When appropriate laws have been made, and probably tax breaks, this method may yield annually millions of tons of valuable protein fodder rich in vitamins and microelements and thus reduce the general losses involved in the introduction of Dreissena into water basins. The biomass of Dreissena may also be used as raw material for the pharmaceutical industry.

The proposed method of reducing the population density of Dreissena will reduce their total burden on water intake and hydroengineering installations. Besides, such systems of basin substrates for cultivating mussels may be located in the immediate vicinity of hydroengineering installations for local protection from their encrustation with Dreissena.

This, in its general outlines, should be the strategy for control of the Dreissena population in North America, if what is now happening is the initial stage of the ecological crisis of the water basins.

The Possibility of an Ecological Disaster. Unfortunately, the information we have does not exclude the possibility that the events taking place in the Great Lakes are the beginning of an ecological disaster, the likes of which have not been experienced in Europe or the USSR. I have in mind the results of laboratory research, conducted by Paul Hebert at Windsor University, reproducing the growth rate of the Dreissena population of Lake St. Clair. This growth rate greatly exceeded that usually observed in Europe in the first years of the intrusion of this mussel into a water basin new to it.

These results put us on guard and we attempted to use a mathematical model for analysis of the reasons for such a high rate of population growth of these mussels. The results appeared paradoxical at first glance. The anomalously high growth rate of the mussel population in Lake St. Clair could occur only if there were no (or almost no) fish in the Great Lakes able to eat the mussels.

Analysis of the literature showed that this conclusion seems paradoxical only at first glance. In Europe, carp are the principal predators of Dreissena, including the aforementioned roach (Rutilus rutilus). In all, there are about 1,500 species of carp, including about 50 species that inhabit the Great Lakes. However, carp can be divided into two groups:

1) those with weak pharyngeal teeth that are not capable of feeding on mussels;
2) those with two or three rows of strong pharyngeal teeth easily capable of crushing mussel shells.

In Europe and especially in the mouths of the rivers of the Azov-Caspian basin, there are a considerable number of fish belonging to group 2, for which mollusks, and especially Dreissena, are the main source (70-80%) of their food. These are principally subspecies of the roach such as the Caspian roach (Rutilus caspicus) and the Azov-Black Sea carp (Rutilus heckeli), which, perhaps, came into being at the same time as Dreissena. These species of fish form a considerable part of the commercial catch of fish in the lower course of the Volga, Don, and Dnieper.

Among other molluscivorous fish in this basin are the roaches Rutilus frisii, Rutilus frisii cutum, the gustera (Blicta bioerkna), the Aral barbel (Barbus brachycephalus), and sturgeons (Acipensetidae).

In contrast to this, in the rivers of North America most of the carps belong to group 1, these with weak pharyngeal teeth evidently incapable of feeding on mussels. There appear to be few fish capable of feeding on mussels. This is the reason (the lack of molluscivorous fish in the North American water basins) that may lead to an ecological crisis of disastrous proportions in these waters. The scenarios for the development of this ecological crisis may differ depending on the characteristics of specific water basins.

In the most favorable scenario of an ecological disaster, the biomass (population) of the Dreissena mussel will grow much faster and reach the maximum sooner with a total population of mussels several times that of European water basins. In contract to crises in European water basins, the biomass of fish in the case of a disaster will decrease because the filtrator mollusk Dreissena with its gigantic biomass will be a strong competitor with the fry and larvae of fish for microplankton, and with small crustacea that serve as food for fish fingerlings.

In the first stages, this should lead to a reduction of the fry and fingerlings of native fish. As of August, 1990 we do not have direct data to confirm this hypothesis. However, the laboratory data of Paul Hebert of August, 1989 showed a reduction of the fat content of native species of double-walled, filtrator mollusks (Unionides) as a result of the competition for food (microplankton) by Dreissena.

The filtering action of Dreissena reduces the population (biomass) of microplankton and has reduced the turbidity of the Detroit River. The increased transparency of the water of the Great Lakes has been noted in other work as well. Perhaps by the fall of 1990 there will be direct data on the change in population of the larvae and fingerlings of native species of fish.

Thus, the maximum Dreissena population in the Great Lakes will be determined solely by the supplies of biogenic elements and organic substances capable of transforming into microplankton. When the Dreissena population reaches its maximum, it will begin to fall to a level determined by the entry rate of biogenic elements and organic substances into the water basins and the rate of their transformation into microplankton.

In a less favorable scenario for disaster, after the maximum population of Dreissena has been reached the system will convert into an unstable regime whereby most of the mussels will perish because of a still unknown disease that is highly probable with such a large Dreissena population density. This means that in the waters of the Great Lakes there may be millions of tons of decaying biomass which will lead to a sharp drop in the oxygen content of the water and complete destruction of the fish. The quality of the drinking water will become very low.

In the best case, the diatomic microplankton in the waters of the lakes will increase rapidly, a normal level of oxygen will be reached, and the explosion of the Dreissena population will occur again. In the worst case, the oxygen-deprived waters of the Great Lakes will capture blue-green autotrophic-heterotrophic microorganisms capable of precipitating toxins into the surrounding medium. Then the water will become unsuitable for drinking.

Disaster Strategy. The possibility of a disaster is associated with the absence of molluscivorous fish in North America. Under these circumstances the creation of an industry to extract and process the Dreissena mussel into protein fodder is the only possibility for controlling the Dreissena population in North America that would not have adverse ecological side-effects. However, this measure may not be sufficient or realizable in time and it may be necessary to introduce molluscivorous fish into North America in large numbers.

What Should Be Done in the Immediate Future? Inasmuch as events develop rapidly, it may be necessary to create an Emergency Dreissena Ecological Program in no more than 2-3 years. The aim of this program would be to concentrate efforts to learn as quickly as possible what it is that threatens North America - an ecological crisis or an ecological disaster - and to prepare for the worst case scenario.

It is probable that the following would be the basic directions taken by this program:

1) Sharply increase research on the changes in the ecological communities of the Great Lakes, and first of all in Lake St. Clair, to find the answer to the question posed here; are the developing events the beginning of a crisis or a disaster?

2) In parallel, arrange for American and Canadian scientists to conduct research on the ecological communities of Dreissena in its "native land," the Aral-Caspian-Azov-Black Sea basin, where this mussel has natural enemies and competitors. This is necessary to help determine whether molluscivorous fish should be introduced into North American waters if the situation reaches disaster proportions.

3) To urgently undertake experiments on creating a mussel extraction industry for conversion into protein fodder. At the same time the legal aspects of such an industry must be explored, including, probably, tax breaks.

4) Create the conditions and mechanisms for joint action of European countries and the USSR in developing and applying methods of protecting hydroengineering installations from encrustation by Dreissena and testing these methods in the Great Lakes.

5) Sharply expand research on the biology and ecology of Dreissena to develop new methods for their control and for preventing their encrustation of hydroengineering installations, employing the scientific potential of various countries and creating, if possible, regional information centers and an infrastructure of scientific research.

THE ZEBRA MUSSEL: CHEMICAL AND PHYSICAL CONTROL METHODS FOR INDUSTRY

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The introduction of the zebra mussel (Dreissena polymorpha) to the Great Lakes in 1985/1986 has had a dramatic impact on water users located on these lakes, connecting waterways, and associated tributaries.

Aquatic Sciences has been helping industry cope with the zebra mussel phenomenon since 1988, initially in a monitoring role and then as a consultant designing and implementing zebra mussel control programs for industry and undertaking research on alternate control methods.

This paper provided a review of the mussel's biology as it relates to mussel control and then provided a survey of chemicals that have been used or proposed for control of the zebra mussel in municipal and industrial settings.

The majority of chemical control programs recommended in European literature focused on the use of chlorine which led to initial attempts in North America using chlorine at levels between 0.5 ppm and 2 ppm for durations of 7 to 21 days. The potential usefulness of other oxidants (bromine, potassium permanganate, hydrogen peroxide, ozone) as well as molluscides and toxic coatings was discussed. The importance of pH and temperature of incoming water was emphasized for all chemical control programs.

The use of physical controls such as heat, hydrosonics, and electricity was reviewed as potentially useful methods of reducing chemical use. Research efforts in these areas were reviewed.

SUCCESSFUL MANAGEMENT OF AN INTRODUCED SPECIES. SEA LAMPREY: PAST, PRESENT AND FUTURE CONTROL STRATEGIES.

Terry J. Morse, U.S. Fish and Wildlife Service, Marquette Biological Station, Marquette, Michigan.

The Sea Lamprey, Petromyzon marinus, is a species that parasitizes other fish and is endemic to the North Atlantic. Lampreys migrated through the St. Lawrence Seaway into Lake Ontario and became common there in the 1800's. Niagara Falls, a natural barrier to the migration of lampreys into the other Great Lakes, was bypassed by the Welland Canal in 1829 which provided lampreys a direct invasion route to the other Lakes. By the late 1930's sea lampreys had spread throughout the Lakes and targeted lake trout (Salvelinus namaycush), the dominant fish in the food chain, as a primary food source. In the absence of natural controls, the sea lamprey population expanded and quickly devastated the lake trout populations in Lakes Michigan and Huron and in much of Lake Superior.

As a result of the total collapse of the fisheries in the Great Lakes, the Great Lakes Fishery Commission was created by convention between the United States and Canada to improve fishery resources and manage the sea lamprey. Early control efforts centered on blocking spawning migrations with physical and electrical barriers. These efforts were ineffective as the barriers were easily negotiated during periods of high water, which were typical during spring spawning migrations. The search for a better control technique led to testing of over 6,000 chemicals by scientists at the Hammond Bay Research Laboratory. Finally, a larvicide, TFM (3-triflouromethyl-4-nitrophenol), was found to selectively kill sea lampreys while having minimal effects on most non-target organisms, and proved to be non-toxic to humans and other mammals. Since the advent of chemical control in the Great Lakes in 1960, sea lamprey populations were reduced by 95%. Today, the fisheries in the Lakes have rebounded to a value in excess of $4 billion annually, due largely to the success of the Sea Lamprey Management Program, which returns over $400 for every dollar spent for control.

Although lampricides are currently the primary control tool, we are currently striving to implement an integrated management approach for controlling sea lampreys. This approach includes the following non-biocidal control methods which would be used concurrently to control lampreys: physical and electrical barriers with lamprey traps, and the Sterile-Male Release Technique.

Low-head barrier dams have been constructed on 28 streams in U.S. and Canada to restrict spawning migrations of sea lampreys. Lamprey traps are fished in conjunction with barriers to capture spawning-phase lampreys during spring migration. Although trapping efficiency varies with the site, efficiencies as high as 75% have been documented. Over 80,000 spawning-phase lampreys were captured during the 1989 spawning season. Experimental electrical barriers using new electronics technology have shown potential for the integrated control approach. The Michigan Department of Natural Resources tested the new electric barriers on the Pere Marquette and Jordan rivers, and a similar version was successfully tested on the Ocqeouc river by U.S. Fish and Wildlife Service personnel.

The Sterile-Male Release Technique, the most promising of the new control techniques, has been used successfully to control or eradicate insect pests. Successful execution of this technique is dependent on capturing spawning-phase lampreys, sterilizing the males and placing them back into the streams to mate with the females, which would result in unfertilized eggs. Preliminary studies have shown that spawning-phase lampreys could be effectively sterilized by an injection of Bisazir, a chemical sterilant, without adversely affecting the spawning behavior. Temporary intensification of chemical control combined with Sterile-Male Release and optimal use of barriers with traps, might reduce the sea lamprey population to a point when the release of sterile males would be all the control necessary. The Sterile-Male Release Technique is scheduled to be implemented in Lake Superior and the St. Mary's River in 1991.

The lamprey control program has successfully contributed to the recovery of the fisheries in the Great Lakes by using biocides to control lampreys. However, we are fervently working towards less dependency on biocides and more of an integrated control approach, utilizing non-biocidal techniques whenever possible.

APPENDIX B

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