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18-19 April 1997
Burlington, Vermont

Sea Grant
Connecticut

Proceedings of the Second Northeast Conference on Nonindigenous Aquatic Nuisance Species

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Proceedings Editor
Nancy C. Balcom

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Preface

A lot has happened since the first Northeast Conference on Nonindigenous Aquatic Nuisance Species was held on 25 January 1995 in Cromwell, Connecticut. Zebra mussels have spread throughout Lake Champlain, but have not been found anywhere else in New England to date. Hydrilla was discovered in a small pond in southeastern Connecticut in 1996. Efforts are on-going to completely eradicate it from the pond. Unfortunately, it was just found in another larger water body in the same area in July 1997.

My conference co-coordinator, Mike Hauser of the Vermont Department of Environmental Conservation, was named to the national Aquatic Nuisance Species Task Force, which meets regularly to discuss aquatic nuisance species (ANS) on a national scope. One of their on-going discussions is the feasibility of establishing regional ANS panels, following the successful example of the Great Lakes. Perhaps we'll see the establishment of a Northeast regional panel within a year or so. Congress passed the National Invasive Species Act of 1996, A reauthorization and expansion of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990. It includes additional research dollars for a broader range of ANS, and establishes a national ballast water management program, which will become mandatory after three years if voluntary compliance is poor.

Interest in nonindigenous species continues to grow among researchers in the Northeast, as evidenced by the number and breadth of abstracts and papers contained in this proceedings volume for the Second Northeast Conference on Nonindigenous Aquatic Nuisance Species, held in Burlington, Vermont on 18-19 April 1997. The Northeast is developing a strong cadre of researchers, agency personnel, educators, and lake managers interested in sharing information, and working together to address the ANS already in the waters of the Northeast, as well as those that may arrive in the future.

It is equally important to draw on the experiences and expertise of researchers from outside the Northeast, and so I was pleased to be able to support the travel of several experts from California, Minnesota, and Florida, so that they could share in and add to our discussions during this conference. We were equally pleased to be joined by colleagues from Quebec, Canada and Belarus, former Soviet Union, making the conference truly an international one.

I would also like to take this opportunity to thank my co-sponsors from the Water Quality Division of the Vermont Department of Environmental Conservation: Mike Hauser, Ann Bove and Holly Crosson. They certainly worked hard to ensure that this conference was an interesting and worthwhile experience.

I hope that this proceedings volume will aid in the sharing of information on ANS, both within the Northeast and nationally. Any errors or omissions are strictly my responsibility. I urge you to contact the authors directly for additional information.

The momentum for future conferences on freshwater and marine invasions exists. Connecticut Sea Grant is proud to have sponsored the first two conferences, and we look forward to participating in more ANS conferences in the future.

Nancy C. Balcom
Conference Coordinator
July 25, 1997

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Plenary Session

An Overview of Nonindigenous Aquatic Organisms

Amy Benson U.S. Geological Survey, Biological Resources Division, 7920 NW 71 Street, Gainesville, Florida 32653-3071

With the arrival of the zebra mussel, the issue of nonindigenous aquatic species finally received some of the attention of the masses it deserves. Since the 1970s, Department of the Interior bureaus have recognized the need for research on various issues and problems presented by the introduction of nonindigenous aquatic species. Federal legislation, old and new, seems inadequate as introductions continue to occur. The nonindigenous aquatic species data base, now with the U.S. Geological Survey, offers researchers, natural resource managers, and legislators the opportunity to examine the status and distribution of many nonindigenous aquatic organisms. To facilitate information transfer, these data are continually being compiled and entered into a geographic information system (GIS). The GIS currently contains more than 34,000 records of over 620 species of freshwater fishes, mammals, reptiles, amphibians, mollusks, crustaceans, bryozoans, coelenterates, plants, diseases, and parasites.

(Editor's Note: This paper was first presented at the Seventh International Zebra Mussel and Aquatic Nuisance Species Conference in New Orleans, LA, 28-31 January 1997.)

The Role of Ballast Water in Transporting Nonindigenous Species to U.S. Waters

David Smith[1], Marjorie Wonham[2], Linda McCann[3], Gregory Ruiz[3], James Carlton[4], Diann Lavoie[1]
[1]Marine Science Center & Department of Biology, Northeastern University, Nahant, Massachusetts 01908; [2]Department of Zoology, University of Washington, Seattle, Washington 98195; [3]Smithsonian Environmental Research Center, P.O. Box 28, Edgewater, Maryland 21037; [4]Williams College-Mystic Seaport, P.O. Box 6000, Mystic, Connecticut 06355

The introduction of nonindigenous aquatic species into coastal waters worldwide is having profound ecological and economic impact upon recipient communities. In recent years, a principal mechanism for transport of exotic species is their movement in ballast water of ocean-going ships. Used to maintain stability during a voyage, ballast water is actively pumped or gravitated into dedicated tanks and cargo holds at one port and released at other ports when receiving or delivering cargo. The volumes of water being released into U.S. waters are immense (> 57 million metric tons in 1991). Most ships carry a diverse assemblage of organisms in their ballast water, and a number of devastating invasions are now linked to ballast transport (e.g., zebra mussel in the Great Lakes; comb jelly in the Black Sea).

The potential for ballasted organisms to invade depends on a host of factors, including species-specific characteristics, inoculum density and frequency, and physical/chemical similarity between source and recipient waters. We have recently completed a study characterizing the amounts and sources of ballast water and the composition of plankton arriving to Chesapeake Bay. Our data show that Chesapeake Bay is being inoculated on a massive and frequent basis by a diverse assemblage of live organisms transported from around the world. The vast majority of the water released into Chesapeake Bay came from the Northeast Atlantic Ocean, the Mediterranean, and the Western Central Atlantic Ocean. We found at least 221 species of protist, animal and plant taxa in 60 vessels sampled. Densities of organisms in the ballast water were extraordinarily variable from ship to ship (0 to 18,000 organisms/m^3) and reflect the stochastic nature of ballast transport. Significantly, the transit times for most bulk cargo carriers arriving to Chesapeake Bay were sufficiently short as to allow survival of planktonic organisms entrained in the ballast water. In addition, sampling of recently deballasted cargo holds revealed the presence of post-settlement, and in some cases, gravid, benthic organisms.

As the major gateway to New England, Boston and the Gulf of Maine are potentially at significant risk to ballast-mediated invasions not only from foreign ports, but also from domestic ports with established populations of exotic species. We currently have a study underway that examines the ballast water assemblage in coastal bulk cargo traffic traveling between Massachusetts and Chesapeake Bay.

Nonindigenous Aquatic Angiosperms in New England

Donald H. Les and Leslie J. Mehrhoff Department of Ecology & Evolutionary Biology, University of Connecticut, U-42, Storrs, Connecticut 06269-3042

The northeastern states possess a rich native aquatic flora with a level of diversity that not only rivals but surpasses that found in tropical aquatic ecosystems. This richness has been seriously threatened by introductions of nonindigenous aquatic plants which can quickly displace native species. Although several invasive helophytic (i.e. wetland) species also occur in our region (e.g. purple loosestrife) only the truly hydrophytic (aquatic) species are considered here. Among the list of nonindigenous, aquatic, invasive species are: *Butomus umbellatus, Callitriche stagnalis, Egeria densa, Hydrilla verticillata, Hydrocharis morsus-ranae, Marsilea quadrifolia, Myriophyllum aquaticum, Myriophyllum quitense, Myriophyllum spicatum, Najas minor, Nasturtium officinale, Nymphoides peltata, Potamogeton crispus, Trapa natans*, and *Veronica beccabunga*. A number of nonindigenous aquatic species (e.g. *Eichhornia crassipes, Pistia stratiotes*) are highly aggressive elsewhere, but do not normally persist in northeastern climates. Several regionally indigenous species (e.g. *Myriophyllum heterophyllum, Cabomba caroliniana*) are spreading aggressively in New England.

It is difficult to manage introductions of nonindigenous aquatic plants for several reasons: 1) A lack of survey information precludes an adequate assessment of the occurrences and migration of invasive water plants, 2) insufficient taxonomic expertise has hindered the detection of new plant introductions, and 3) sources of potentially dangerous nonindigenous aquatic plants remain because of inadequate federal and state regulations or the lack of enforcement for existing statutes. Once populations of nonindigenous aquatic plants have spread successfully throughout a region, they become difficult if not impossible to control. It is imperative that further introductions of noxious aquatic plants be thwarted by increased surveillance and monitoring, improved methods of species identification, and adoption of restrictions for potentially invasive plants. Public education should also be an important part of efforts to control the spread of nonindigenous invasive species.

Aquatic Plants

Hydrilla: It's Not Just in Dixie Anymore

Greg Jubinsky Bureau of Invasive Exotic Plant Management, Florida Dept. of Environmental Protection, 3915 Commonwealth Blvd., Tallahassee, Florida 32399

Since its discovery in 1960, *Hydrilla* has spread rapidly throughout Florida. By the early 1970s, it was established in all major watersheds in the state, with acreage estimates approximating the weed in excess of 50,000 acres (not counting 20,000 acres that were being actively managed). *Hydrilla* is now found in the western states of California, and Arizona, Tennessee, and all the Gulf and Atlantic coast states as far north as Maryland and Delaware, and most recently, Connecticut.

While it is believed that the strain of *Hydrilla* present in Connecticut is the non-seeding variety, that is probably of minor importance in terms of eradication or long-term management of the weed, when compared to its success at vegetative reproduction. Research demonstrated that 50% of *Hydrilla* fragments having a single whorl of leaves can sprout a new plant, and, coupled with production of tubers and turions (densities of 5,000 per square meter), and its ability to utilize lower light levels for photosynthesis than native plants (less than 1% full sunlight) add up to rank *Hydrilla* as one of the most invasive aquatic weeds in the world.

Discussion will include the biology and physiology of *Hydrilla*, economic impacts, and pros and cons of various mechanical, herbicidal, biological, and integrated management options.

Hydrilla Management and Eradication: Left Coast Approach

Lars W.J. Anderson USDA-Agricultural Research Service, Aquatic Weed Science Program, Room 124, Robbins Hall, University of California, Davis, California 95616

Since the first correct identification of *Hydrilla verticillata* in California in 1976, state, local and federal agencies have agreed that total eradication of this exotic pest was not only in the best interests of agriculture, but also the most cost-effective long-term strategy. Following the initial consensus-building workshops, *Hydrilla* was listed as an "A" rated pest thereby directing the California Department of Food and Agriculture to eradicate the plant whenever and wherever it appears.

Over the past twenty years, *Hydrilla* has been discovered in 16 counties and has been eradicated in most at a cost of about $1 million per year. Both the monoecious and dioecious types have entered state waters, but the eradication approaches have been similar. These have included dredging, sediment sterilization, chemical (contact herbicides and systemic herbicides), and biological control using the triploid grass carp. Since *Hydrilla* forms a tuber in the sediment that can last several years, eradication requires annual monitoring of the infested sites to remove newly sprouted plants. In California, all parts of the plants must be absent for three years before the site is declared eradicated.

The most recent discoveries of monoecious *Hydrilla* were in two interconnected lakes in Washington: Pipe and Lucern Lakes. Fortunately, Washington state officials had become aware of the detrimental impacts of *Hydrilla* and were able to move relatively quickly to implement an eradication plan in the two lakes. Applications of Sonar herbicide have resulted in nearly complete removal of the *Hydrilla*. Regrowth will be monitored in the spring/summer of 1997 and further applications of Sonar may be made.

The aggressive, zero-tolerance position taken for *Hydrilla* in California and Washington has no doubt prevented this weed from becoming established in thousands of miles of waterways in the Sacramento / San Joaquin Delta in California and will greatly diminish the likelihood of further spread in Washington and Oregon waters. The success of these programs is directly due to a cooperative relationship among several research and regulatory agencies as well as public-interest groups. This cooperative spirit has also enabled developing the necessary funding base to implement the long-term programs.

Biological Control of Purple Loosestrife

Luke Skinner Minnesota Department of Natural Resources, 500 Lafayette Road, Box 25, St. Paul, Minnesota 55155-4025

Purple loosestrife *(Lythrum salicaria* L.) is an exotic perennial plant of European origin that is invading and degrading wetland habitats all across North America. Purple loosestrife can form dense monotypic stands in a variety of wetland and lakeshore habitats replacing native plant species, thus, degrading food, shelter and nesting sites for wildlife. Control efforts such as cutting, burning and herbicide applications have been attempted with limited success. Armed with new knowledge of the biology of purple loosestrife and the emergence of biological control, new integrated strategies have been developed to manage purple loosestrife.

Biological control, the use of natural enemies to control a pest, shows promise as a long-term method of reducing impact of purple loosestrife on our native wetland environments. Since 1992, four species of European insects, one root-mining weevil, one flower-feeding weevil and two leaf-feeding beetles, have been released in North America to control purple loosestrife. The introduction of these four insects will not eradicate purple loosestrife, but if successful, will significantly reduce its abundance within wetland habitats. Encouraging results are now being seen at several sites in Canada and the United States.

Water Chestnut: An Exotic Plant Invasion in Lake Champlain

Ann Bove and Tim Hunt VT Dept. of Environmental Conservation, Water Quality Division, 103 S. Main Street, 10N, Waterbury, Vermont 05401-0408

Water chestnut (*Trapa natans*) is an annual aquatic plant introduced from Eurasia to the northeastern United States in the late 1800s. Due to aggressive growth habits and the ability to form extensive surface mats, water chestnut, once established, restricts recreational and commercial uses of the water it invades. Water chestnut was first reported in southern Lake Champlain in the 1940s. Since 1982, the Vermont Department of Environmental Conservation has been involved in water chestnut management, implementing a program to control growth and prevent further advancement. While early efforts were successful in significantly controlling the plant's northward spread, limited funding during the past six years has significantly reduced the control effort and water chestnut has spread dangerously northward both in and outside of the lake. Areas in Lake Champlain where water chestnuts were once controlled have become reinfested in recent years; recreational use of many areas of the southern portion of the lake are restricted. Water chestnut's range now extends over 52 miles in Lake Champlain and populations of the plant have been identified in an additional four Vermont waterbodies.

Determining the Relative Importance of Biotic and Abiotic Factors in the Establishment and Spread of an Invasive Grass, *Phalaris arundinacea*

Shannon L. Morrison and Jane Molofsky Dept. of Botany, University of Vermont, Burlington, Vermont 05405

Phalaris arundinacea (reed canary grass) is an aggressive, invasive plant that shows an affinity for wet areas. We conducted a multifactorial experiment with moisture, location, and genotype as the main effects in order to determine the relative importance of each in the establishment of reed canary grass. Three genotypes of *P. arundinacea* were transplanted into wet and dry plots, in a pasture in Vermont. Environmental factors, as well as neighbor identity and percent cover were assessed for each transplant. Moisture and location within the field explained most of the variation seen in both above and belowground biomass of the transplant, but there was no significant effect of genotype. Plants grown under higher moisture conditions produced greater above and belowground biomass and more tillers. Therefore, results demonstrate that regions with high soil moisture are susceptible to successful invasion by *Phalaris arundinacea*.

Losing Loosestrife by Fire

Terry Bastian Waterflowers Ecological Design, 50 Main Street, North Reading, Massachusetts 01864

Waterflowers has had some success in managing purple loosestrife in a wetland meadow by returning to fire management as a technique for weed control. Over the last 9,000 years fire has been used to control succession of a wet meadow, first by Indians, then farmers to improve grazing and prevent tree growth in the Ipswich River corridor, as well as elsewhere in New England.

The Sagamore Spring Golf Course in Lynnfield has returned to this age old management technique in a section of the golf course that was succeeding from open meadow to alder and poison sumac swamp. This was restricting airflow on the 15th green. The fire was successful and the golf green returned to health, requiring less fertilizers and fungicides. The tussoc sedge meadow also rebounded with a suprising result, less loosestrife.

This paper/poster explores the potential of non-toxic management techniques for this alien invader.

Post Island Marsh Restoration and Reclamation

Michael C. Wheelwright, Landscape Architect City of Quincy Department of Public Works, 55 Sea Street, Quincy, Massachusetts USA

Abstract

The restoration of this once impounded 10 acre (coastal) marine marsh helped to rebuild its estuarine ecosystem. By reestablishing the tidal flow, the soil salinity was increased, thus encouraging indigenous animal, fish, shellfish and birds to reestablish themselves. To date, the action of drowning the *Phragmites* (common reed) roots together with vigorous mowing has stunted the common reed, reduced fuel for spot fires, and eradicated mosquito larvae beds. Interplanting of smooth cord grass (*Spartina alterniflora*) helped to complete the restoration.

The subject marsh had been cut off from regular incursions of sea water for nearly six decades, resulting in an overgrowth of nuisance freshwater reeds that posed a serious fire hazard. Further, existing drainage ditches had become clogged, and intermediate bogs developed, becoming mosquito breeding habitats (Marsh 1932).

By reestablishing tidal action and increasing the soil salinity of the marsh, the common reed was stressed and subsequent crops were stunted. In its place, the growth of indigenous plant material was encouraged (e.g. *Spartina alterniflora*), which in turn promoted a habitat in which flora and fauna could begin to reestablish themselves.

Reintroducing tidal flow to restricted marshes does not produce vegetative changes overnight, but the process is effective over time. All parties involved are encouraged by the results to date. The self- regulating tidegate, in tandem with intensive plant community modification and long-term estuarine management, has been successful to date.

Prologue

We at Public Works are not preservationists by profession, our interest in Post Island did not, at first, focus on a program, the site, or a piece of legislature, as important as they are. Instead, the project evolved through all the permitting, funding and fabrication functions, and metamorphosed into a reality motivated by instinct. Preservation has to do with looking at the past, in a rigorous, not reverential way. We go to the past for the tools or models that we need to deal with our present. Marsh preservation, (the more we are involved), seems to be quite simply about place. What makes a certain place beautiful, functional, livable, ecologically viable, or sacred? Marsh restoration is "as much an art (instinct) as it is a science (preservation)" stated Lisa Vandergaard, regional biologist for The Trustees of Reservations.

Introduction

Salt marshes range in our sphere of interest, and evoke powerful images and emotion to the casual observer and the trained scientist as well. To some, marshes are mysterious, forbidding places, to be avoided at all costs. To many novelists, poets and artists, they have been a source of inspiration. John Steinbeck revered the tide pools of the Pacific Coast, (Rickets & Collin 1948). Water and wetlands have been immortalized by artists of both the European and American schools, but no one has done it better than James Russell Lowell:

> "In spring they lie one broad expanse of green,
> O'er which the light-winds-run with glimmering feet
> Here, yellower stripes track-out the creek unseen,
> There, darker growth o'er hidden ditches meet."

The ominous image of wetlands and marshes was perpetuated in the mid 1800s with the passage of the Swamp Wetlands Act by the U.S. Congress (Errington 1996). This law gave the states 65 million acres of Federal land for 'reclamation'. This obviously meant draining the wetlands so that they could be used for more 'constructive' purposes. Nonetheless, a new image of this habitat has since emerged. These areas have finally been recognized as a vital part of our landscape.

Massachusetts is blessed with over 1,500 miles of coastline, with stretches of rocky shore and sandy beaches, estuaries, salt marshes, bustling sea ports and harbors, tidal flats and islands. According to information gathered in 1990, 38 percent of the coastline (360 miles) is owned by the local, state, or federal government, or by regional nonprofit conservation organizations. Most of this open space is available for public use and enjoyment, while the rest is set aside for wildlife protection, water quality, and other purposes (MA CZM 1995).

Throughout history, the Massachusetts Bay colony has followed a doctrine that states that all rights, in tideland and the water itself, are held 'in trust' for the benefit of the public, (David 1950). There is wide latitude in determining this. However, it is clear today that all intertidal land is reserved for one of three purposes in the Commonwealth: fishing, fowling, and navigation. In fact, Quincy, Massachusetts, through its Conservation Commission, has drafted a local wetlands protection policy, under the home rule amendment of the Massachusetts Constitution and Home Rule status, (MA CZM 1995).

Quincy is an urban community, seventh in population (88,500) in the Commonwealth, with 27 miles of coastal shoreline and in excess of 2,000 acres of marsh wetland. Some of these wetlands are freshwater, though almost all were formerly salt marshes, which is of intrinsic, as well as pragmatic interest in the preservation and restoration of all of Quincy's wetland land use areas. The mayor's office, the City Council and the Commissioner of Public Works, and the aforementioned Conservation Commission, all agree that salt marsh restoration is environmentally correct and in the best interest of the citizens. The residents who live in or near the coastal environs understand the wetlands, if only from their own perspective. They understand nature affects them, and they are experts on the subject, as it affects them. After years of observation, and enlightened self-interest they are quick to embrace most programs which enhance their micro-environment and are beneficial to their common good.

Project Description

Salt marsh restoration is an idea that the citizens of Quincy could and did embrace, when the Massachusetts Trust Fund identified Post Island Marsh as the recipient of a $100,000 grant. Simultaneously it became the mission of the Department of Public Works to be the steward of the wetland restoration efforts in Quincy, since its defined responsibility for infrastructures includes head walls, tidegates and outfalls (Hardsheep and Murry 1994). The Massachusetts Trust Fund allocated the monies for water-related reconstruction of Post Island Marsh (HGD 1993).

The attempt to restore the marsh ecosystem began with the hypothesis that if the marsh were reconnected to its former salt water source, Quincy Bay, then the salt marsh ecosystem, including its characteristic vegetation, would be restored. The benefits would not be limited to the salt marsh habitat in general. Particularly important for those residents living near the marsh, the salt water flow would enable the return of saltmarsh hay, and cause the gradual die-off of the freshwater common reed, *Phragmites*. The 10-acre salt marsh was once part of a larger salt marsh ecosystem, but development over the last two decades has led to increased freshwater input to the ailing wetland. As a result, the Post Island Marsh ecosystem supported both freshwater and saltwater species. Chief among them were salt hay grass, cordgrass, black grass, purple loosestrife, sumac and an inordinate amount of the opportunistic common reed.

Method

The heart of the proposed restoration lay in the engineered tidegate system and its appurtenances which was designed by LEA Group, Inc. (Boston, Massachusetts). The tidegate would be used to increase the salinity of the marsh waters and soils, thereby severely stressing the root system of the common reed. The total tidegate configuration consists of a 42' outfall pipe to Quincy Bay which leads into a tidegate chamber with a mercury-actuated float switch which regulates the tidegate. Water is routed at a pre-set elevation through two 30" pipes into an inlet structure at the marsh edge of Post Island, to throughly saturate the marsh without flooding the surrounding property. This inlet structure (the Head wall) contains sluice gates to compensate for the lag in time involved with water entering the marsh past high tide and again on the outflow beyond low tide, while also functioning as a trash rack to filter both incoming and outgoing tides. Presently the overflow or maximum design level is augmented with an overage factor of 0.5 feet for surge storm action set at 7.9 feet in the interior of the marsh (local datum). Saturating the marsh while protecting the surrounding properties from storm surge has proven to be a valid criterion, and succeeding storm damage has been avoided, to date.

The restoration goal was to convert the existing freshwater marsh—with its problems of unchecked mosquito populations and fire hazards caused by the common reed overgrowth—back into a salt water marsh. Ideally, this marsh would have a whole range of saltwater-based flora and fauna. The restoration procedure outlined by the LEA Group, Inc. was to create optimal saturation of the marsh to include the periphery and inland areas via the reestablishment of the ditching system dug in the 1920s. This would provide mosquito control to the expanding salt panne developing in the interior of the marsh. The main component of the engineering solution—in which the tidegate and appurtenances would mechanically promote thorough saturation of the entire surface of the marsh—would in turn stress and stunt the growth of the common reed.

The firm of Lelito Environmental Consultants (Peabody, Massachusetts) participated in the next phase of the project. From the beginning, they cited studies indicating that saltwater inundation of the root zone of common reed, coupled with limited oxygen availability, was a reasonably effective method, over time, to eradicate common reed. Further they suggested that the duration of inundation, rather than the specific water salinity was a crucial factor in the process, a premise which was substantiated by a concurrent study by the Harvard Graduate School of Design Landscape Ecology Study team (1993). The Lelito Environmental Group suggested periods of up to 4-7 hours daily had been successful in other projects, although considerable experimentation is required to determine the optimal daily inundation period for a given marsh ecosystem. This proved to be an understatement.

The common reed eradication program began with two small, light Bobcat loaders with tank type tracks connecting the drive wheels, which effectively distributed the weight, allowing the vehicles optimal operation throughout the marsh and vastly enhancing their maneuverability in the tall common reed stand. A brush cutter with a mower blade sufficient to cut the mature common reed stalks was mounted on the bucket forward of the driver. Ultimately this arrangement, with minor modifications, served throughout the growing season and four successive cuttings.

Results

During the first summer when the common reed stand was six foot high or more, the cutting operation was an arduous task. By the third summer, work-study crews could use hand-held equipment, because the reeds were much shorter. Air circulation in the middle of the marsh was renewed. This method proved feasible and most effective. Over the following three summers, work crews reduced the large volume of common reed already stunted by saltwater inundation provided by the tidegate design.

Lelito Environmental Consultants produced a Guidance Manual and Maintenance Schedule in 1993, which we have been using in a modified form. In the text, field observations document a notable decrease in average height and stem density that has occurred since the initiation of the increased tidal flooding and the vegetation management programs. Areas within the marsh were characterized by varying heights and densities of common reed which were the result of the aforementioned management techniques. Historic data reveals that prior to these practices, mature common reed stands were located throughout the entire marsh and at significantly greater heights (Lelito 1993).

The principal colonies were found at the periphery which was rarely inundated with salt water, probably not even in severe storm conditions. Direct observation suggests that low lying areas generally retain standing water after tidal waters have receded, thus forming pools which slowly drain on their own or by way of ditching, via a salt creek. Specifically some areas are characterized by scattered depressions (pannes) that hold in excess of three inches of standing water, which is retained for a significant period of time beyond high tide. This standing water results in an anoxic environment, and the resulting high salinity stresses the panne areas.

Conclusion

The Department of Public Works has employed variations of the above-mentioned Guidance Manual and Maintenance Schedule, with the key word being "guidance". The Department has taken the long view. Pragmatically recognizing the myriad of duties involved in maintaining the City's infrastructure, the most prudent course for ongoing marsh maintenance for the near future is to mow and continue the total saltwater immersion. Time consuming as it may be, it is effective and environmentally the best strategy. Ultimately, history as it has alongshore since pre-colonial days, will prove if paying attention and being motivated by our best instinct, is the best course to stay. We know that our action is better than the instant gratification of chemical pesticide applications, or massive earth movement and dredging.

Literature Cited

Amos, W. and S. Amos. 1994. *Atlantic & Gulf Coast*. The Audubon Society, Kopf, New York.

Anon. 1910. The Tidemarsh. *Atlantic Monthly*. Boston, Massachusetts. Pp. 745-753.

Brower, D. 1996. *Let the Mountains Talk, Let the Rivers Run*. Harper, San Francisco.

Clark, J. 1977. *Coastal Ecosystem Management*. Wiley New York.

Dano, R. 1950. Metro Boston Access

Engellener, C. S. 1975. The Boston South Shore Area, Some Problems and Conflicts. MIT Sea Grant Program, Cambridge, Massachusetts.

Errington, P. 1996. *Of Men & Marshes*. The Iowa University Press, Ames, Iowa.

Hardshdeep & Murry. 1994. Post Island Marsh Restoration: A Salinity Analysis. Harvard Graduate School of Design, Cambridge, Massachusetts.

HGD. 1993. Salinity Studies. Harvard Graduate School of Design Landscape Ecology Study, Cambridge, Massachusetts

Jahod, J. 1975. The Tidal Wetlands of the City of Quincy. Quincy, Massachusetts.

Kusler. 1984. *Our National Wetland Heritage, a Protection Guidebook*. Environ. Law Institute, Washington D. C.

MA CZM. 1995. *The Massachusetts Coast Guide, Access to the Open Space Along the Shoreline*. Massachusetts Coastal Zone Management, Boston, Massachusetts.

Marks, Lapin & Randall. 1986. *Phragmites*. The Nature Conservency, Arlington, Virginia.

Marsh, A.H. 1932. Annals of Post Island, Quincy, Massachusetts.

Niering, W.A. 1966. *The Life of the Marsh, the North American Wetland*. McGraw-Hill, New York.

Rickets & Collin. 1948. *Between Pacific Tides*. Stanford University Press, Menlo Park, California.

Stilgoe, J.R. 1995. *Alongside*. Yale University Press, New Haven, Connecticut.

Teal, J. and M. Teal. 1971. *Life & Death of a Saltmarsh*. Ballantine Books, New York.

Aquatic Herbicides: Long-term Management Tool for Invasive Exotic Aquatic Plants

Lee Lyman Lycott Environmental, Inc 600 Charlton Street, Southbridge, Massachusetts 01550

Aquatic herbicides have been used to effectively manage water bodies in the United States for more than fifty years (Bennett 1970). Many publications and reports, including the Environmental Protection Agency's (EPA) 1988 publication, *The Lake and Reservoir Restoration Guidance Manual*, states that herbicides " . . . can be an effective short-term management procedure to produce a rapid reduction of vegetation for periods of weeks to months . . .".

Since the US EPA began reviewing and registering herbicides in the 1960s, the aquatic herbicides that threatened the environment are no longer in use. These herbicides contained compounds such as sodium arsenate and Silvex (2,4-5TP). Additionally, the use of compounds that had the ability to infiltrate the groundwater and translocate has been discontinued by the professional lake manager. The four properties that made the compounds environmentally incompatible were their: (1) persistence, (2) breakdown products, (3) bio-accumulation in the food chain and environment, and (4) lack of target specificity. The herbicides used today do not contain the properties of the organochlorine pesticides that prompted the environmental movement in the 1960s.

Currently there are only a small number of registered and permitted herbicides. These are categorized as either contact or systemic herbicides based upon their mode of action. A contact herbicide, such as Diquat, is fast acting, non-specific, and provides shorter term management than its counterpart. Since the root systems do not come in "contact" with the herbicide, the plant will regrow in the future (Nichols 1991; Sculthorpe 1985; Westerdahl and Getsinger 1988; Gangstad 1986). The trend in herbicide manufacturing is toward the development of target-specific, systemic herbicides like Sonar. These are absorbed, then translocated throughout the plant allowing for management of the entire organism (Nichols 1991; Sculthorpe 1991; Westerdahl and Getsinger 1988; Gangstad 1986). These herbicides are slow-acting, do not impact much of the native vegetation, and provide management that may last for a number of years.

Of all the techniques available for the management of aquatic plant growth today, the most widely-used method is aquatic herbicides (Ross and Lembi 1985). In the Northeast, hundreds of lakes, ponds, and reservoirs are treated with herbicides and algaecides on an annual basis. In many instances these compounds are combined with other management techniques such as lake-level drawdown, hand-pulling, or suction harvesting, to effectively manage the growth of aquatic plants (Nichols 1991).

Lake managers—both professionals and lake residents—realize that watershed management is crucial to the long-term reduction of nutrients which can encourage accelerated plant growth. In a N-enrichment experiment with *Myriophyllum spicatum* (Eurasian milfoil), Anderson and Kalff (1985) found a 30-40% increase in biomass over controls. Although, the reduction of external nutrient inputs may only reduce the rate of growth of macrophytes as they can obtain nutrients from both the ambient water and the sediments (Sculthorpe 1985). Since many of the water bodies in New England were once fields and wetland areas, the sediments are already nutrient-rich and macrophyte growth will probably not be limited (Nichols 1991).

A major problem lake managers face today is the translocation and infestation of non-native plant species into a water body, such as Eurasian milfoil and fanwort *(Cabomba caroliniana)*. These invasive plants can spread rapidly through vegetative colonization and fragmentation, and inundate large sections of water bodies within a few years (Smith and Barko 1990; Nichols 1991; Sculthorpe 1985). Many plants are introduced by boats and boat trailers, but the majority of the plants are transported by water fowl (Sculthorpe 1985; Warrington 1985)

Contrary to published literature concerning lake and pond management, herbicides can provide long-term management by effectively reducing and/or eliminating certain plant species. New infestations of the aquatic plant milfoil have been precluded in several water bodies in New England with one herbicide application. In

Sturbridge and Brimfield, Massachusetts, two water bodies experienced infestations of milfoil which began to flourish near the state launching ramps.

In Big Alum Lake, Sturbridge, Massachusetts, Eurasian milfoil (*Myriophyllum heterophyllum*) was identified by lake association members in the summer of 1990. After its discovery, benthic screens were installed in a 1/4-acre section of the lake as a management tool. The lake association determined that this method was not only cumbersome, but it did little to preclude the spread of milfoil. The association contracted with Lycott to obtain the necessary permits to conduct an herbicide treatment. On June 18, 1993 Lycott applied 25 pounds of 2,4-D pellets (Aqua-Kleen) with an airboat and an application spreader. The milfoil was affected within two weeks after the treatment, and a biological survey conducted approximately four weeks later revealed no signs of milfoil. This, and other areas of Big Alum Lake have been monitored annually by Lycott and the association; no signs of milfoil re-infestation have been reported.

Similarly, Little Alum Lake in Brimfield, Massachusetts experienced the introduction and infestation of milfoil (*Myriophyllum heterophyllum*) in 1986. In 1990, the lake association contacted Lycott to prepare and submit the necessary permit applications. After numerous telephone calls and meetings, approval was acquired from the local conservation commission and a permit was received from the DEP, Division of Water Pollution Control. On May 19, 1992 Lycott applied 300 pounds of 2,4-D pellets (Aqua-Kleen) to a four-acre area of milfoil. There have not been any signs of milfoil re-infestation since that time.

These are only two of several water bodies for which herbicides have provided long-term management. Other water bodies with similar success stories with which Lycott has been associated, include: Bear Pond in Canton, Connecticut for milfoil (*Myriophyllum heterophyllum*); Echo Lake in Barrington, Rhode Island for *Cabomba* and lilies; Crescent Lake in Enfield, Connecticut for lilies; Lyman Pond in Southbridge, Massachusetts for duckweed; and Metacomet Lake in Belchertown, Massachusetts for *Cabomba*, and Swiacki Pond in Sturbridge, Massachusetts for lilies.

Although eradication of a particular plant species is not always attainable or desirable, herbicides can be viewed as a valuable tool in reducing the spread of invasive plant species (Nichols 1991). New infestations of non-indigenous species can be effectively managed with prompt herbicide applications as the Big Alum Lake example is testament. In lakes inundated with nuisance vegetation, herbicides may reduce the target vegetation up to 100%. In many cases, localized follow-up treatments or use of other techniques is required to fully manage the nuisance plants species (Gangstad 1986).

Typically, lake managers and lake residents endeavor to manage aquatic plants to reestablish their lake's recreational resources, to improve the quality and diversity of wildlife habitat, and to restore the water quality. As one of the least disruptive of all the management techniques on non-target organisms and the ecosystem, herbicides can enhance all of these characteristics (Nichols 1991; Westerdahl and Getsinger 1988; Gangstad 1986). Additionally, herbicides do not cause the fragmentation of plants which provides a means of re-infestation in new areas.

Herbicides have been used to manage water bodies for many years. With responsible regulations and permitting, these compounds can continue to effectively manage and preserve our valuable water bodies.

Literature Cited

Anderson, R.A. and J. Kalff. 1985. Nutrient limitation of *Myriophyllum spicatum* growth in situ. Pp. 95-103 IN: L. Anderson (Editor), *Proceedings of the First International Syposium on Watermilfoil (Myriophyllum spicatum) and Related Haloragaceae Species*. Victoria, B.C., Canada, Aquatic Plant Management Society.

Bennett, G.W. 1970. *Management of Lakes and Ponds*. Von Nostrand, New York. P. 375

Gangstad, E.O. 1986. *Freshwater Vegetation Management*. Thomas Publication, Fresno, California. 377 pp.

Nichols, S A. 1991 *The Interaction between Biology and the Management of Aquatic Macrophytes* Elsevier Science Publishers B.V., Amsterdam. Pp 225-252.

Ross, M. and C.A. Lembi. 1985 *Applied Weed Science*. Burgess, Minneapolis. P. 340

Sculthorpe, C.D. 1985. *The Biology of Aquatic Vascular Plants*. Edward Arnold Ltd., London. 610 pp

Smith, C.S. and J.W. Barko. 1990. Ecology of Eurasian watermilfoil. *Journal of Aquatic Plant Management*. 28: 55. A publication of the Aquatic Plant Management Society, Inc. Washington, D.C

Warrington, P.D. 1985. Factors associated with the distribution of *Myriophyllum* in British Columbia. In: L.W.J. Anderson (ed.), *Proceedings of the First International Symposium on watermilfoil (Myriophyllum spicatum) and related Haloragaceae species*. Aquatic Plant Management Society, Inc. Washington, D.C. Pp.79-94.

Westerdahl, H.E. and K.D. Getsinger (Editors). 1988. *Aquatic Plant Identification and Herbicide Use Guide. Volume I: Aquatic Herbicides and Application Equipment*. Tech. Rep A-88-9, U.S. Army Eng Waterways Exp. Stn., Vicksburg, MS. P. 146.

Lake-level Drawdown as a Management Tool for Indigenous and Nonindigenous Species

Lee Lyman Lycott Environmental Inc. 600 Charlton Street, Southbridge, Massachusetts 01550

For decades lake and pond managers throughout the United States have used lake-level drawdown as a method for managing aquatic vegetation. Many water bodies in the Northeast have employed this technique successfully for the management of native and exotic macrophyte species. Lake-level drawdown is an effective way to manage nuisance aquatic plants. As the name implies, the technique involves lowering the water level in the pond to expose the sediments to the harsh conditions of the winter months. The disruption of the sediments and rhizomes, as the result of ice action and other weather-related activities, is the key aspect to successful aquatic plant management. Proper timing of the drawdown and subsequent refilling is essential to enable aquatic animals time to adjust to the water level changes, and to maximize the efficacy of the technique. Drawbacks associated with this technique are the "doughnut effect", proliferation of drawdown resistant hydrophytes, and potential adverse impacts on the adjacent wells.

Aquatic Animals

The Discovery of Blueback Herring, *Alosa aestivalis*, in Lake Ontario with Some Theoretical Implications for Trophic Interactions with Land-locked Populations of the Alewife, *Alosa pseudoharengus*, in the Great Lakes

David B. MacNeill[1], Randall Owens[2], Robert O'Gorman[2], Edward Mills[3], Lars Rudstam[3], John Hasse[4], and Brandon Kulik[5] [1]New York Sea Grant Extension Program, Morgan III, SUNY, Brockport, New York 14420-2928; [2]U.S.G.S. Biological Resource Division, Oswego, New York; [3]Cornell University Field Station, Bridgeport, New York; [4]New York State Department of Environmental Conservation, Utica, New York; [5]Kleinschmidt Associates, Pittsfield, Maine

Blueback herring, *Alosa aestivalis*, and alewives, *Alosa pseudoharengus*, are sibling species whose ranges are broadly sympatric from the Carolinas to the Canadian Maritimes. Because these species overlap partially in a spatial and ecological context, the potential for interspecific interactions exists. Two immature specimens of *A. aestivalis* (151 mm and 154 mm TL) were collected from bottom trawls in Lake Ontario during the fall of 1995, representing the first record of this species in the Great Lakes basin. The invasion route was likely via the Erie Canal linking the Hudson and Mohawk systems, to Oneida Lake and the Oswego River system—the same invasion route taken previously by the sea lamprey (1820s), alewives (1870s) and white perch (1950s).

Prior to this sighting, a westward movement of *A. aestivalis* in the Upper Mohawk River has been observed over the last two decades, presumably the result of improving water quality. In one impingement study conducted in the Oswego River (Minetto, NY), over 9,000 blueback herring, apparently from at least two, possibly more, cohorts, were captured during 1994-1995. Minetto is only 12 km upstream from the Oswego River's confluence with Lake Ontario. A few individuals of the smaller cohort were captured as late as March in the Oswego River. Size cohort 1 ranged in size from 75 mm to 175 mm TL with a modal peak at 125 mm; and cohort 2 ranged from 275 mm to 325 mm, with a modal peak around 300 mm TL. Although no ages were determined, these sizes correspond roughly to at least three age classes as reported in the literature; possibly age 0 (YOY), age 1, age 2 (and age 2+ ?) fish. This suggests that a small, resident population of *A. aestivalis* may exist in the Oswego-Mohawk River corridor or in Lake Ontario.

Tributaries of the canal at its highest elevation, near Rome, NY, that support spawning runs of *A. aestivalis*, may also be a source of downstream inoculation in both directions of the corridor. YOY of *A. aestivalis* spend but a few months in freshwater before moving downstream to the ocean during the fall, yearlings and other sub-adults are otherwise encountered only in the ocean, with adults (age 2+) migrating upstream to spawn in the spring and typically outmigrating by July in anadromous populations. The colonization potential of *A. aestivalis* in the Great Lakes is unknown because of the paucity of thermal tolerance data, assuming temperatures may be a limiting factor. The presence of possible yearling fish in the Oswego River suggests, however, that some YOY fish may successfully overwinter in freshwater.

In Lake Ontario, the land-locked population of *A. pseudoharengus* has been destabilized by declining productivity of the lake ecosystem and predation by stocked salmonine predators, suggesting the availability of a niche for *A. aestivalis*. Comparisons of known feeding behaviors and feeding morphologies of these two species were also used to predict interspecific trophic interactions. This presentation will also summarize the morphological and ecological characteristics of each species and provide some theoretical perspectives on potential trophic interactions between land-locked populations of these species in the Great Lakes, should *A. aestivalis* become established.

The Relationship Between Nonindigenous Fish and the Native Fish Fauna in Massachusetts Lakes: Forty Years of Change

Mark Chandler New England Aquarium, Central Wharf, Boston, Massachusetts 02110-3399

The introduction of exotic fishes in freshwaters is commonplace, yet the effects of introduced species on native fauna has received little attention. Over the past 130 years, lakes in the Northeast region of the U.S. have been stocked with largemouth bass, bluegill sunfish, and several species of trout, while the "accidental" release of other species has resulted in the doubling of the number of species found in some states (e.g. Massachusetts).

A survey of the fish community in littoral zones of over 70 lakes across Massachusetts was undertaken to compare the current fish species composition with that documented in surveys done 40 years ago. The results indicate that the current community is now codominated by exotic and native fish, bluegill sunfish are now the most abundant littoral zone fish, and no lakes could be found without exotic species of fish. Moreover, a native minnow has disappeared from over 70% of the historic locations it formerly occurred in. Hypotheses relating the loss of this species to predation by largemouth bass, competition with bluegill sunfish, loss of littoral habitat, and acidification are examined. None of the hypotheses by themselves can adequately account for the pattern of species loss observed.

The results suggest that multiple factors are acting in concert to impact fish community structure in Massachusetts. The proportion of exotics in communities of freshwater fishes is almost without parallel in other "natural" communities. The consequence of introductions needs to be understood in conjunction with other impacts to the environment.

Effects of Round Gobies in the Great Lakes—and Beyond?

J. Ellen Marsden School of Natural Resources, Aiken Center, University of Vermont, Burlington, Vermont 05405

The round goby (*Neogobius melanostomus*) was accidentally introduced from eastern Europe to Lake St. Clair in 1990. In 1993 they began to spread along the southern shoreline of Lake Erie, and by late 1993 they were found in southern Lake Michigan. Round gobies are now found in all five of the Great Lakes, and have begun to make their way into the Mississippi River drainage via the Chicago Canal. Goby densities as high as $50/m^2$ (adults and juveniles) have been noted on rocky and sandy substrata.

To date, the most visible impacts of gobies in the Great Lakes ecosystem have been on sculpins and fishermen. Gobies appear to compete with native sculpins for interstitial foraging and spawning habitat. In areas where round gobies are abundant, slimy sculpins have declined in number. Round gobies will aggressively take or steal bait from shoreline anglers.

As interstitial predators, gobies are likely to have negative impacts on benthic food resources such as invertebrates and fish eggs. Gobies are natural predators of zebra mussels, but may also consume fingernail clams and native snails. Laboratory data indicate that gobies can acquire and consume lake trout eggs in rocky cobble substrates. To date, only local changes in benthic species populations have been connected with the arrival of gobies; their eventual effect on Great Lakes and riverine ecosystems remains to be seen.

Sea Lamprey Control Project on Lake Champlain

John Gersmehl U.S. Fish & Wildlife Service, Lake Champlain FWRO, Winston Prouty Building, 11 Lincoln Street, Essex Junction, Vermont 05452

The negative impacts of sea lamprey parasitism on lake trout and landlocked Atlantic salmon have been clearly documented in Lake Champlain, where an experimental sea lamprey control program has been in effect for more than seven years. Surveys conducted during the 1980s on Lake Champlain showed sea lamprey larvae were abundant in 14 tributaries and five delta areas. In order to effect a rapid and dramatic reduction in parasitic phase sea lampreys in Lake Champlain, an eight-year experimental sea lamprey control program utilizing the lampricides TFM and Bayer 73 was implemented on 13 Lake Champlain streams and the five delta areas during the period 1990-96. The Pike River in Quebec, a substantial producer of sea lampreys, was not included in the experimental control program. With several exceptions, two applications of chemical lampricides were made to each stream or delta during the first seven years of the program. Agencies involved in the program include the New York Department of Environmental Conservation, the Vermont Department of Fish and Wildlife, and the U.S. Fish and Wildlife Service.

Assessments associated with the sea lamprey control project are being done to provide information for determining the desirability of continuing control long-term. Assessment by the U.S. Fish and Wildlife Service include monitoring changes in sea lamprey larval and adult abundance and the analysis of lamprey attack data. Assessments of salmonid host fish abundance, growth and survival rates are being conducted by New York and Vermont.

Abundance of sea lampreys in Lake Champlain peaked during the late 1980s and then declined dramatically in 1992, following the first round of control. Initiation of the second round of sea lamprey control was begun in 1994 and completed in 1996. In the nine streams treated since 1994, the densities of sea lamprey larvae decreased by an average of 93 percent following control. On a lakewide basis, the abundance of spawning adult sea lampreys, as indicated by nest count surveys conducted in ten index streams, declined by 79 percent in 1996 from the average levels recorded during the peak years of 1988-91.

Sea lamprey wounding rates on lake trout declined substantially following completion of the first round of treatments in 1992. A slight increase in sea lamprey attack rates has been recorded on lake trout since 1992. This development may be related to the increasing population of sea lampreys in Quebec's Pike River, where improvements in water quality have provided more favorable environmental conditions for lamprey survival.

A feasibility study considering the use of lampricides, physical or electric barriers, and sterile males is presently underway to determine what lamprey control methodologies may best be utilized in reducing the sea lamprey population in the Quebec waters of Lake Champlain at a future date.

A Test of the Potential Spread of Zebra and Quagga Mussels From the St. Lawrence River to Inland Waters of Northern New York

Brad Baldwin, Paul Filippetti, and Shelby Sanderson Biology Department, St. Lawrence University, Canton, New York 13617

In laboratory experiments we examined the ability of zebra and quagga mussels collected from the St. Lawrence River (SLR) to survive and reproduce in currently uncolonized rivers and lakes in northern New York: (1) a major tributary called the Raquette River (RR), (2) a nearby and popular fishing lake called Black Lake (BL), (3) two important Adirondack Lakes; Upper Saranac Lake (SL), and Upper St. Regis Lake (RL). While the St. Lawrence River and Black Lake have similar water quality (SLR: pH ~7.5, $[Ca^{+2}]$ ~30 mg/L; BL: pH ~7.3, $[Ca^{+2}]$ ~22 mg/L), the other sites appear to be unsuitable water quality for zebra mussel colonization (RR: pH ~6.3, $[Ca^{+2}]$ ~3 mg/L; SL: pH ~7, $[Ca^{+2}]$ ~4 mg/L; RL: pH ~7, $[Ca^{+2}]$ ~4 mg/L).

Using laboratory simulation experiments, we tested 3 possible invasion scenarios. First, could juvenile (5 mm shell length) and adult (15 mm) zebra mussels from populations in the St. Lawrence River (control site) be transported into and survive in the other test waters? Based on experiments lasting 5 weeks, overall mussel survivorship was comparable in SLR, BL, SL, and RL (≥ 90%), but it was low (≤ 30%) in RR. Moreover, mussels reared in BL actually grew more than in SLR. Secondly, could transported adult zebra or quagga mussels from SLR reproduce in the above test waters? Here, embryonic development to the shelled veliger stage was successful and comparable in SLR and BL, but development always failed RR, SL, RL. Finally, could veliger larvae of zebra and quagga mussels from SLR survive in test waters? In 14 d experiments, living veligers (taken from the above SLR development trials) survived well in both SLR and BL (≥ 60%), but they always died in RR, SL, and RL.

Together, these results suggest that juvenile and adult zebra mussels from SLR may survive well (at least for short periods of time) in BL, SL, and RL but not in RR. (The ability of surviving mussels to persist and possibly adapt to tested waters has not been addressed.) However, it appears that only BL will support embryonic and larval stages of SLR mussels. Thus, BL is most at risk of invasion and colonization by mussels, while RR, SL, and RL may support at least temporary—but nonreproductive—populations of juvenile and adult mussels.

Veligers of Zebra Mussels in the Richelieu River: An Intrusion from Lake Champlain?

Yves de Lafontaine and Brigitte Cusson Environnement Canada, Centre Saint-Laurent, 105 McGill St., Suite 700, Montréal, Québec, Canada H2Y 2E7

Abstract

The possible input of zebra mussels (*Dreissena polymorpha*) to the Richelieu River from Lake Champlain was assessed by means of veliger and juvenile mussel sampling programs. During summer 1996, veliger densities were estimated from plankton samples collected at two sites along the Richelieu River and at one reference station in the St. Lawrence River. The seasonal cycle of veliger occurrence and abundance was different in the Richelieu River as compared to the St. Lawrence River. Veliger densities exhibited large seasonal variability, with maximum values in July. Peak densities of veligers in the Richelieu River did not exceed 10 larvae/L. These were analogous to densities found in the northern part of Lake Champlain during summer 1996, but much lower than those measured in southern Lake Champlain or in the St. Lawrence River, where adult zebra mussel populations are established. There was no evidence of annual recruitment of zebra mussels in the lower Richelieu River. The existence of a downstream gradient in densities and seasonal occurrence of veligers within the Lake Champlain-Richelieu River system suggests that larvae are mainly drifting from spawning populations in the lake and that local production in the river is very low.

Introduction

Some studies have indicated that the abundance of zebra mussels tends to be lower in rivers than in upstream lacustrine environments (Stanczykowska 1977; Strayer 1991; Hunter *et al.* 1997). It has also been suggested that a local *Dreissena* population cannot recruit by itself nor self-sustain in riverine environments and must depend on the reproduction of populations located further upstream in lentic systems (Neumann *et al.* 1992). In the lower Rhine River, the origin of recruiting larvae was estimated to be between 190 and 480 km upstream and located in Lake Constance (Kern *et al.* 1994). In the St. Lawrence River, it has been postulated that zebra mussel larvae may originate from parent populations located as far as Lake Ontario (de Lafontaine *et al.* 1995). Presumably, water currents and substrate types would control the colonization and distribution of zebra mussels in rivers.

In the province of Quebec, Canada, zebra mussels have, so far, only been found in the St. Lawrence River, downstream of the Great Lakes. First reported in 1989 in Lake St.Francis, upstream of the Montreal area, zebra mussels were distributed throughout the freshwater part of the river by 1990 (Lapierre *et al.* 1994). Both zebra (*D. polymorpha*) and quagga (*D. bugensis*) mussels are now common in the river. Zebra mussels were first reported in the southern part of Lake Champlain in 1993, and were found in all parts of the lake during summer 1996 (Eliopoulos and Stengel 1997). At its northern end, Lake Champlain empties into the Richelieu River, which flows northward to the St. Lawrence River. During the summertime, the Richelieu River is a major waterway for recreational boating between Lake Champlain and the St. Lawrence River. Consequently, the Richelieu River is potentially at risk of being colonized by zebra mussels via larval drift from Lake Champlain and/or transport by boats and other human aquatic activities along the river. Zebra mussels have not been previously reported in the Richelieu River.

The goal of our study was to investigate the occurrence of zebra mussels in the Richelieu River and to determine whether Lake Champlain is a major source of zebra mussels to the river. Our specific objectives were to 1) monitor the presence and density of zebra mussel larvae in the Richelieu River; 2) determine the seasonal variation in the density of zebra mussel veligers in the river; 3) evaluate the transport of zebra mussel veligers along the river; and 4) estimate the levels of annual recruitment of zebra mussels in the Richelieu River. The study consisted of a veliger sampling program, from mid-spring to mid-autumn, and a juvenile mussel sampling program in the fall.

Materials and Methods

Veliger sampling

Veliger sampling was conducted at two sites, Fort Lennox and St-Ours in the Richelieu River (RR), located 25 km and 110 km downstream of Lake Champlain respectively (Fig. 1). Fort Lennox is representative of the upper Richelieu River while St-Ours corresponds to the lower Richelieu River. Sampling was also carried out at a third station in the Lachine Canal, near Montreal, in the St. Lawrence River (SLR), which was used as a reference site for comparison. Sampling was conducted from May 22 to October 15, 1996, at a frequency of three, but sometimes two, times per week. Each sample consisted of a volume of 50 liters of surface water collected with a bucket and filtered on a 53 mm mesh sieve. The content of the sieve was preserved in a 85% v/v ethanol solution. The total number of samples collected was 59 at Fort Lennox, 46 at St-Ours and 47 at Lachine. Water temperature was monitored continuously (four times per day) using Aquamate multisensor probes moored at the Fort Lennox and Lachine stations.

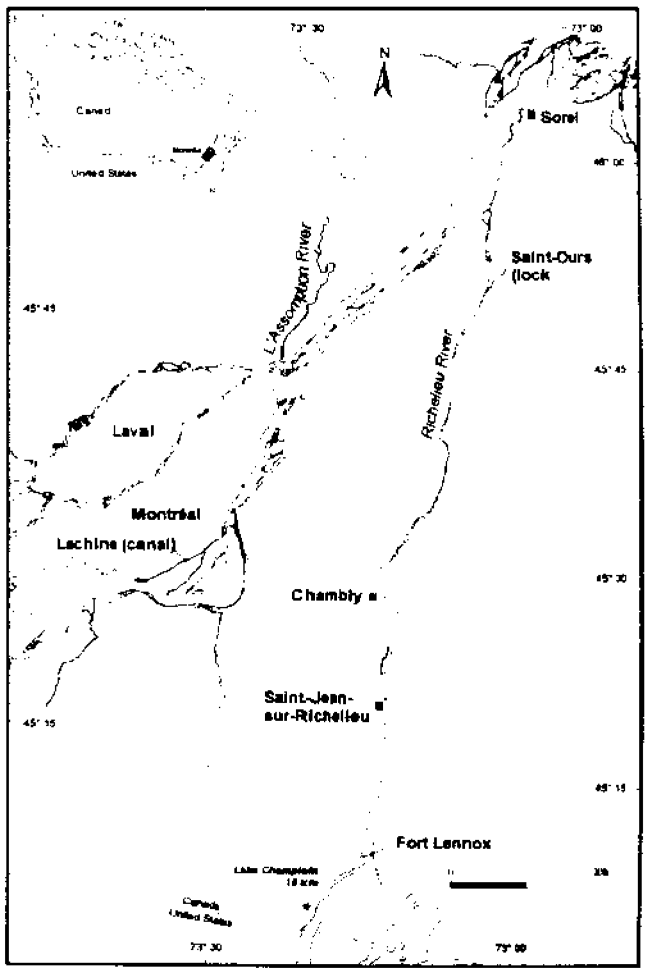

Figure 1. Location of sampling sites.

In the laboratory, samples were concentrated to 40 ml and veligers were counted using a stereomicroscope at 50X magnification. If veligers were estimated to be > 100, two or more subsamples of 1 ml were examined. Veligers of both zebra and quagga mussels were identified according to morphological characteristics defined by Nichols and Black (1994). Four developmental stages were identified: the D-shelled veliger, the umbonal (or veliconcha), the pediveliger and the plantigrade. Veliger densities were expressed in numbers per liter.

Juvenile sampling

During fall 1995 and fall 1996, a total of 33 navigation buoys moored between Chambly and Sorel in the lower RR (Fig. 1) were examined at the time of their retrieval from the water. Zebra mussels attached to external surface of each buoy were collected and counted and abundance was expressed as number of mussels per m^2. This technique provides estimates of annual recruitment of zebra mussels since clean buoys are moored each spring and are therefore colonized by new mussels every year.

Results

Water characteristics

Seasonal variation in water temperature was nearly identical in both rivers (Fig. 2). In late-May, water temperature had already reached 12°C in the RR (Fort Lennox) and 14-15°C in the SLR (Lachine). It reached a maximum of 25°C in early August and decreased to 9-11°C in mid-October. Overall, water temperature at Lachine was 0.46°C warmer than at Fort Lennox (paired T-test, $p<0.001$). Such a small difference, although statistically significant, was probably due to sensor or calibration variability in recording apparatus and has little biological importance. The strong synchrony in the short-term variability exhibited at the two sites indicates a strong influence of large-scale climatic events on water temperature in both rivers. Considering that temperature > 12°C is required for zebra mussel reproduction and spawning (Borcherding 1991,1995; McMahon 1996), the theoretical reproductive season for zebra mussels would extend from mid-May to early-October, in both the RR and the SLR. Moreover, the effect of temperature on development and growth of larval populations in each river should be similar.

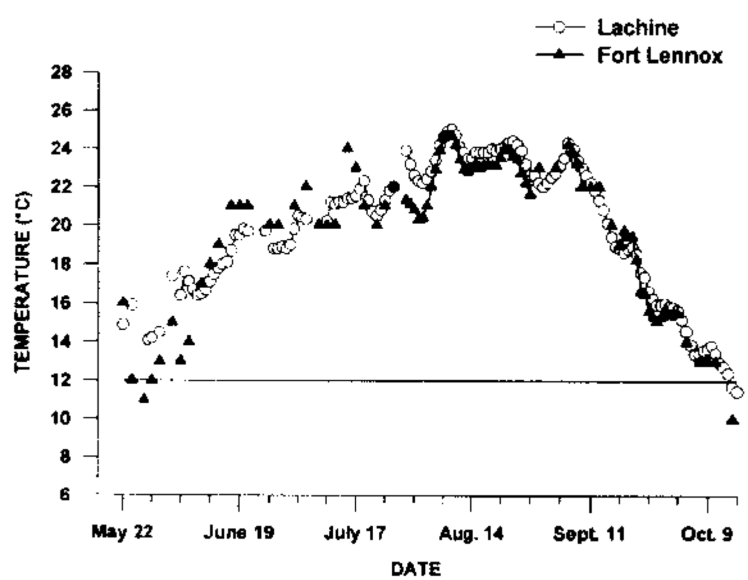

Figure 2. Seasonal variation in water temperature in the Richelieu River (Fort Lennox) and in the St. Lawrence River (Lachine) during 1996.

Available data in the literature revealed that the water characteristics of the RR differ slightly from those of the SLR, but would not be limiting for zebra mussel development or survival (Table 1). For each parameter, values were above the threshold or tolerance limits for survival or minimal growth. Calcium levels in the RR are low and less than optimal (> 30 mg/L - McMahon 1996), but would not preclude veliger or adult viability. Consequently, the water quality of the RR is considered to be suitable for the growth and survival of zebra mussel populations once established.

Table 1. Water characteristics in the Richelieu River and the St. Lawrence River as compiled from literature data.

Parameter	St. Lawrence River [a]	Lachine Canal [b]	Richelieu River [c]		Tolerance limits for zebra mussels [d,e]	
			Fort Lennox	St-Ours	No survival	Best growth
Conductivity (µS/cm)	298	229	152	171	< 21	> 110
Calcium (mg/L)	35.9		16.2	17.7	< 6	> 35
Dissolved Oxygen (mg/L)	10.5	9.0	10.8	11.6	< 4	8 - 10
pH	8.2	7.8	7.8	7.7	< 6.8	7.5 - 8.7
Suspended Solids (mg/L)	3.9	3.7	1.0	5.8		
Chlorophyll-a (µg/L)	1.30		1.96	0.86		

[a] Rondeau, 1993; C. Hudon (Environment Canada, pers. comm.).
[b] CUM, 1990.
[c] Simoneau, 1993.
[d] Claudi and Mackie, 1994.
[e] O'Neill, 1996.

Veliger abundance

The total abundance of veligers summed over the entire sampling season was 51.3/L at Fort Lennox (upstream station) and only 0.66/L at St-Ours (downstream station) (Table 2). The mean density in the upper RR was 90 times higher than in the lower RR. The total abundance at Lachine (SLR) was 2039.3/L. The mean density in the SLR was thus approximately 50 and 4000 times higher than that measured in the upper and lower RR respectively.

According to the identification criteria used, most veligers (> 98%) were zebra mussels (*D. polymorpha*) and only a small proportion of larvae were identified as quagga (*D. bugensis*) (Table 2). The relatively high proportion (30.3%) of quagga mussels at the St-Ours station is probably strongly biased by the very low number of larvae collected at that site.

Veligers appeared first at Fort Lennox during the last week of June (June 28) and about ten days later (July 8) at St-Ours (Fig. 3). Maximum densities were 8/L and 0.14/L at Fort Lennox and St-Ours respectively, and peaked almost at the same time of the year (July 19 at Fort Lennox, July 22 at St-Ours). At Fort Lennox, veligers occurred at densities > 0.1/L until the third week of September and were virtually absent afterward.

At St-Ours, the period of occurrence was relatively shorter (< 1 month) and larvae were only sporadically collected after the first week of August. By comparison, densities at Lachine in the SLR were significantly higher and larval occurrence was longer, extending from late-May to late-September (Fig. 3). Maximum densities (~250/L) at Lachine were also observed earlier (June 17, July 3-5 and July 19) than in the RR. It is worth noting that although the date of first larval appearance and first peak of abundance was delayed by one month in the RR relative to that in the SLR, the sharp larval decline in the fall was almost synchronous (1 week apart) in both rivers.

The difference in the timing of first larval appearance and peak density between the two rivers may be due to delayed larval production in the RR relative to the SLR or to the lengthy drift time of veligers from Lake Champlain. The second hypothesis would assume that local production contributes little to larval abundance in the RR. In

Table 2. Total abundance and species composition of zebra mussel veligers in the St. Lawrence River and the Richelieu River in 1996.

	St. Lawrence River	Richelieu River	
	Lachine	Fort Lennox	St-Ours
Number of samples	47	59	46
Total density (#/L)	2039.3	51.3	0.66
Mean density (±c.i.)	43.4 ± 19.4	0.9 ± 0.4	0.01 ± 0.01
Larvae examined	7001	1087	33
% zebra (*D. polymorpha*)	98.5 %	98.5 %	69.7 %
% quagga (*D. bugensis*)	1.5 %	1.5 %	30.3 %

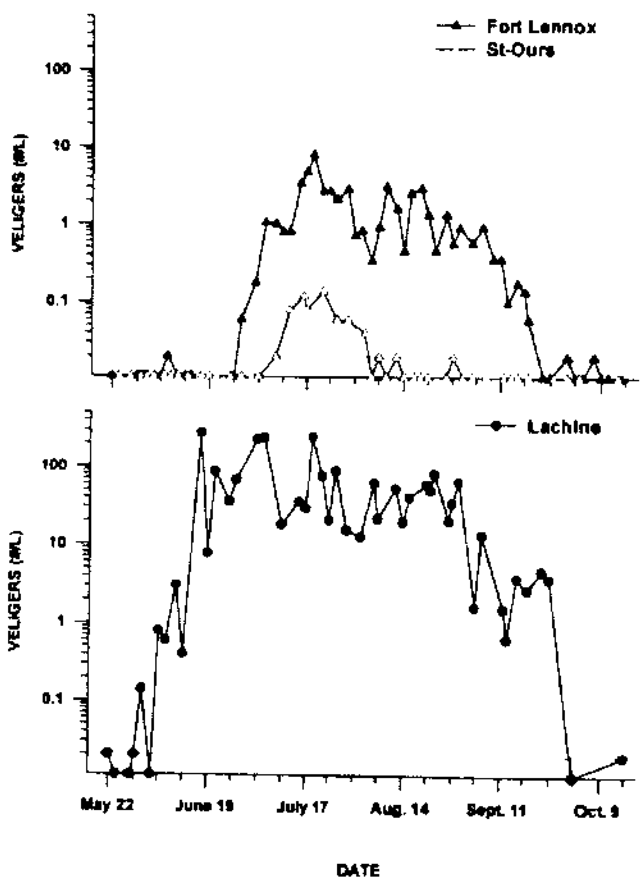

Figure 3. Veliger densities at the three sampling sites during the 1996 sampling season.

order to disprove these hypotheses, we compared our Richelieu abundance results with those measured at three stations in Lake Champlain as part of the 1996 Lake Champlain Zebra Mussel Monitoring Program (Eliopoulos and Stangel 1997). We selected the two stations (STA-46 and SH-11) in northwestern Lake Champlain which were closest to our Fort Lennox sampling site (about 25 and 30 km away). The third selected station (SH-03) was in southern Lake Champlain, approximately 125 km south of Fort Lennox. Because the sampling frequency at these three stations was bi-weekly, we decided to calculate the weekly geometric mean in larval densities at our two Richelieu stations for easier comparison.

The seasonal occurrence and the densities of zebra mussel veligers at the two northern stations in Lake Champlain were very similar to those observed at Fort Lennox (Fig. 4). By contrast, veligers at the southern Lake Champlain station (SH-03) were more abundant (by over one order of magnitude) than at the two northern sites from mid-June to mid-August. Although the time of first larval appearance is not precisely known for the Lake Champlain stations, the seasonal variation in larval density would indicate that larvae appeared earlier in plankton at the southern station relative to the northern sites and Fort Lennox. In early June, veliger densities varied from 1-10 larvae/L and were indeed comparable to those measured at Lachine in the SLR at the same time period (Fig. 3). Maximum densities were observed in early July at the southern station.

Larval development

The relative proportion of the various developmental stages varied between sites. The proportion of D-shelled veligers was lower (59.7%) at Fort Lennox than at the St-Ours (97%) and Lachine (93.9%) stations (Table 3). Alternatively, the proportion of umbonals and pediveligers was higher at Fort Lennox. Plantigrade larvae were never observed in our samples. Overall, the percent ratio of the overall abundance of pediveligers relative to that of D-shelled larvae was much higher (8.2%) at Fort Lennox than at the two other stations (Table 3). This ratio represents the numbers of larvae that develop and survive to the pediveliger stage and may be used as a crude index of larval survival during the planktonic life.

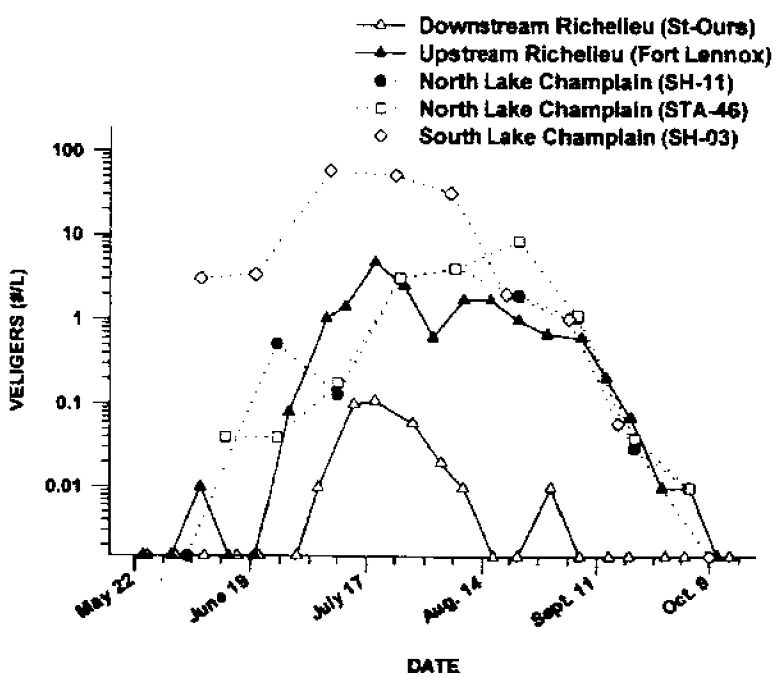

Figure 4. Comparison of veliger densities between different sites in the Richelieu River and Lake Champlain.

Table 3. Proportion of the different developmental stages of zebra mussels in the Richelieu and St. Lawrence Rivers in 1996.

	St. Lawrence River		Richelieu River			
	Lachine		Fort Lennox		St-Ours	
Total density (#/L)	2039.3		51.3		0.66	
D-shelled	1915.8	(93.9%)	30.6	(59.7%)	0.64	(97%)
Umbonal	123.1	(6.0%)	18.2	(35.4%)	0.02	(3%)
Pediveliger	0.4	(0.02%)	2.5	(4.9%)	0	
Plantigrade	0		0		0	
Pediveliger/D-shelled ratio	0.02%		8.2 %		0 %	

The temporal distribution of each larval stage at Fort Lennox was assessed by plotting the cumulative frequency distribution of abundance as a function of time (Fig. 5). The three developmental stages did not overlap in time and exhibited a successive pattern of occurrence as expected from larval growth. The duration of occurrence of each larval stage was estimated graphically from the 5% and 95% quartiles of the cumulative distribution (i.e. date at which 5 and 95% of all larvae were collected) and the median date of occurrence was taken as the date at which 50% of larvae were collected. The time lags between the occurrence of the various stages can provide estimates of larval developmental time and growth. According to our results from Fort Lennox, the average duration of the D-shelled larvae was 10 days and the umbonal stage lasted 13-17 days.

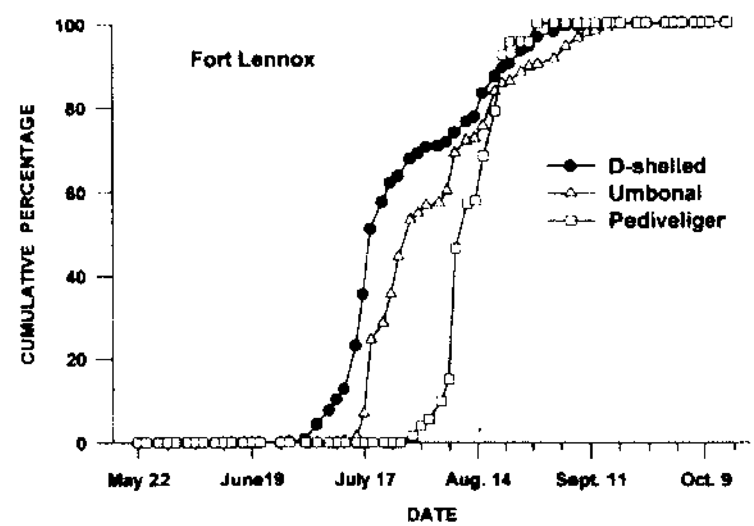

Figure 5. Cumulative frequency distribution of three developmental stages of zebra mussel veligers collected at Fort Lennox (RR) in 1996.

Juveniles

No juvenile or adult zebra mussels were found attached to navigation buoys in the lower RR in 1995 and 1996. Because juvenile mussels have been collected on similar buoys in the SLR every year since 1990 (de Lafontaine, in prep.), we conclude that the level of zebra mussel recruitment in the lower RR over the last two years has remained very low and practically unquantifiable.

Discussion

The finding of zebra mussel veligers in the Richelieu River is the first report of zebra mussels in Quebec waters outside the St. Lawrence River. The absence of zebra mussels in other lakes or streams in southern Quebec may, in part, be due to the lack of appropriate monitoring and surveillance programs. Information on the presence of zebra mussels at certain locations in Quebec in the past was anecdotal and has remained unverified. In 1993 and 1994, occasional samplings at a few municipal water intakes in southern Quebec rivers (including the Richelieu River) reported no veligers, suggesting no zebra mussel intrusion at that time (Riopel 1995). Given the potential risk of invasion and distribution of zebra mussels in southern Quebec (Biorex 1995) and given the actual evidence of zebra mussels in the RR (this study), it would be recommended that the spread and colonization of zebra mussels be followed and, possibly mitigated, by establishing specific monitoring and management programs in southern Quebec waters.

Both zebra and quagga veligers were tentatively identified in our samples. Although adults of both species have been collected in the SLR, the presence of quagga mussels has not been reported yet in Lake Champlain. The relative proportion of quagga veligers was low (1.5%) but identical in both the SLR and the RR, where densities were sufficiently high to allow comparison. Such a similitude is rather intriguing and may reflect some identification problems. Most of our identified quaggas were at the D-shelled stage and only five specimens (all from SLR) were at the umbonal stage. According to Nichols and Black (1994), separating veligers of zebra and quagga mussels on the basis of morphometric criteria may be problematic for very early stages and becomes easier at the pediveliger stage. Based on laboratory-reared larvae, there is very little difference in shell shape between zebra and quagga larvae and the morphological distinction would not be possible at the pre-pediveliger stages (Brad Baldwin, St. Lawrence Univ., Canton, New York; pers. comm.). It is thus conceivable that the identification criteria that we used may not be precise or sensitive enough for identifying and separating zebra and quagga veligers in our samples. The total numbers of pediveligers examined in our samples (45) was obviously too low for detecting the presence of quagga larvae, if present at a low proportion (< 10%). Consequently, the presence of quagga mussels in the RR cannot be confirmed with certainty. Given the taxonomic difficulty at the larval stages, the presence and eventually the relative proportion of quagga mussels in the RR and Lake Champlain should be validated by looking for adult or juvenile mussels (May and Marsden 1992).

Veliger densities in the RR during 1996 were much lower than those measured in SLR (Fig. 3) at the same time or in previous years (de Lafontaine *et al.* 1995). Usually, densities > 100 larvae/L are found in lakes and rivers where adult populations have become established over a certain period of time, such as Lake Erie (Garton and Haag 1993; Fraleigh *et al.* 1993; Riessen *et al.* 1993), Lake Huron (Nalepa *et al.* 1995), Niagara River (Knepper *et al.* 1997), lower Mississipi (Nichols 1996), Hudson River (Strayer *et al.* 1996), and Rhine River (Borcherding *et al.* 1992). Given that the water quality of the RR is considered adequate for the colonization and establishment of zebra mussel populations (Table 1), the very low abundance of veligers was probably not the result of poor water quality on larval survival, but rather suggests that the RR is still at an initial stage of colonization.

The densities and the seasonal distribution of veligers varied within the Lake Champlain-Richelieu River system and showed a gradual downstream decline in abundance and duration of occurrence. Both the very large decline in larval densities between Fort Lennox and St-Ours and the lack of annual recruitment on navigation buoys in the lower RR suggest that larval transport is relatively weak along the RR. The average current speed in the RR was not measured during the course of our study, but should vary between 5 and 15 cm/s during the summertime, when the discharge rate is 100-300 m^3/s (Environment Canada, Hydrological Service, Montreal). The distance between the two sampling sites being approximately 85 km, the calculated drifting time for larvae between the two sites varied from 7 to 21 days. Assuming that the larvae would be drifting passively with the water mass, the peak of larval abundance at St-Ours would be delayed by one to three weeks relative to abundance measured at Fort Lennox. Our results indicate that the time of first appearance at each site lagged by one week, but peaks in abundance occurred during the same week. As a result of transport, one would expect to collect larvae at older stages of development at the downstream sites. Borcherding *et al* (1992) showed that larval size increased during downstream transport in the Rhine River. However, such a pattern was not evident in our study, where the proportion of younger larvae was relatively higher at the downstream station (St-Ours, Table 3). In fact, the calculated drifting times for larvae along the RR were within the range of the developmental times of veligers derived from the cumulative frequency distribution of abundance at Fort Lennox (Fig. 5). These estimates of developmental times are very close to previously reported values for zebra mussel veligers (see review by Ackerman *et al.* 1994). It is therefore possible that the majority of larvae develop and settle between Fort Lennox and St-Ours and that only a very small fraction of the early larval stages got advected downstream and eventually reached St-Ours. This also assumes that larvae were still alive at the time of collection in St-Ours. Further sampling in future years will make it possible to verify some of these hypotheses.

Several lines of evidence concur to support the hypothesis that zebra mussel veligers in the RR were mainly originating in Lake Champlain spawning populations and that local production was very low. First, the larval densities in the upper RR (Fort Lennox) during 1996 were similar to those observed in northern Lake Champlain, but lower than in southern Lake Champlain (Fig 4). Larval production was between one and two orders of magnitude higher in the southern part of the lake and can represent a major larval supply to the northern sector and the RR. Second, the timing of first larval appearance and of peak abundance gradually shifted in time from south to north in Lake Champlain and in the RR. Although the start and the duration of larval production for zebra mussels are highly variable between regions (Nichols 1996), it has been hypothesized that, within a region, zebra mussel spawning can be controlled by specific environmental cues inducing synchronous production (Sprung 1993; Ram *et al.* 1996). The small temporal variability in larval occurrence observed within Lake Champlain and the RR suggests the existence of a large common population with a reproductive cycle characterized by a unimodal larval production. In our interpretation, the shorter duration in larval occurrence at the downstream RR sites was associated to lower densities, reflecting a sampling artifact rather than some biological or adaptative response. Finally, the relatively high proportion of umbonals and pediveligers at Fort Lennox (relative to that observed in the SLR) would suggest that larvae at Fort Lennox were already in advanced stages of development and were not spawned locally. As pointed out by Nichols (1996), separating locally produced larvae from larvae drifting in from other areas is often problematic and, in the case of the RR, would eventually require spawning adult surveys.

The presence of veligers in the Richelieu River is viewed as the beginning of an irreversible process of colonization, of the spread and growth of zebra mussel adult populations throughout the river. Mitigation and control programs to minimize the impact of these nuisance species at local sites along the river will have to take into account that larvae from Lake Champlain may always represent a major supply for recruitment of the riverine stock.

Acknowledgements

We wish to express our sincere gratitude to the following people and colleagues who facilitated our work during the course of this study : Michel Arseneau for his technical skill, the staff at Parks Canada and Canadian Coast Guard for sampling help, Laboratoires SAB (especially Bernadette Jacquaz and France Mongeau) for veliger identification and sorting, and finally, Cathi Eliopoulos and Peter Stangel from Vermont Department of Environmental Conservation for sharing their data and enthusiasm.

Literature Cited

Ackerman, J.D., B. Sim, S.J. Nichols, and R. Claudi. 1994. A review of the early life history of zebra mussels (*Dreissena polymorpha*): comparisons with marine bivalves. *Can. J. Zool.* 72 : 1169-1179.

Biorex Inc. 1995. Exigences écologiques de *Dreissena polymorpha* et *Dreissena bugensis* et prévisions relatives à leur occurrence dans les lacs et rivières du Québec - Rapport final, vol. 1. Ministère de l'Environnement et de la Faune du Québec, Direction de la recherche et des technologies environnementales. 171 p.

Borcherding, J 1991. The annual reproductive cycle of the freshwater mussel *Dreissena polymorpha* Pallas in lakes *Oecologia* 87 : 208-218.

Borcherding, J. 1995. Laboratory experiments on the influence of food availability, temperature and photopenod on gonad development in the freshwater mussel *Dreissena polymorpha*. *Malacologia* 36 : 15-27.

Borcherding, J. and E.D. De Ruyter van Steveninck. 1992 Abundance and growth of *Dreissena polymorpha* larvae in the water column of the River Rhine during downstream transportation. In : D. Neumann and H.A. Jenner (eds.), *The Zebra Mussel Dreissena polymorpha*. Gustav Fischer Verlag, Stuttgart, Germany, pp. 29-44.

Claudi, R. and G.L. Mackie. 1994. *Practical Manual for Zebra Mussel Monitoring and Control*. Lewis Publ., Boca Raton, Fl., USA. 227 p.

CUM 1990. Résultats d'analyses de l'eau : 5 stations dans le canal (1990-05-29, 1990-06-18, 1990-07-16, 1990-08-21, 1990-09-16) incluant des informations sur les effluents industriels et pluviaux. Letter from Montreal Urban Community (CUM) to Parks Canada, Dec 18, 1991.

de Lafontaine, Y., L. Lapierre, M. Henry, et Y. Grégoire. 1995. Abondance des larves de Moule zébrée (*Dreissena polymorpha*) et de quagga (*Dreissena bugensis*) aux abords des centrales hydroélectriques de Beauharnois, Les Cèdres et Rivière-des-Prairies. Environnement-Canada - Québec region, Centre Saint-Laurent, *Rapp. Sci. & Tech. ST-14*. 52p.

Eliopoulos, C., and P Stangel. 1997. Lake Champlain 1996 Zebra Mussel Monitoring Program. Vermont Department of Environmental Conservation, Waterbury, Vermont. 42 p

Fraleigh, P.C., P.L. Klerks, G. Gubanich, G. Matisoff, and R.C. Stevenson. 1993. Abundance and Settling of Zebra Mussel (*Dreissena polymorpha*) Veligers in Western and Central Lake Erie. In : Nalepa, T.F., and D.W. Schloesser (eds.), *Zebra mussels : biology, impacts and control*. Lewis Publ., Boca Raton, Fl., USA, pp. 129-142.

Garton, D.W. et W.R. Haag. 1993 Seasonal Reproductive Cycles and Settlement Patterns of *Dreissena polymorpha* in Western Lake Erie. In : Nalepa, T.F., and D.W. Schloesser (eds.), *Zebra mussels : biology, impacts and control*. Lewis Publ., Boca Raton, Fl., USA, pp. 111-128.

Hunter, R.D., S.A. Toczylowski, and M.G. Janech. 1997. Zebra mussels in a small river : impact on Unionids. In : F.M. D'Itri (ed.), *Zebra mussels and aquatic nuisance species*. Ann Arbor Press, Chelsea, Mi., USA, pp. 161-186.

Kern, R., J. Borcherding, and D. Neumann. 1994. Recruitment of a freshwater mussel with a planktonic life-stage in running waters - Studies on *Dreissena polymorpha* in the River Rhine. *Arch. Hydrobiol.* 131 (4) : 385-400.

Keppner, H.T., D.J. Adrian, and T.A. Ferro. 1997. Seasonal Variations in Dreissenid Veliger Density in the Niagara, Mississippi, and Other Selected Rivers. In : F.M. D'Itri (ed.), *Zebra mussels and aquatic nuisance species*. Ann Arbor Press, Chelsea, Mi., USA, pp. 117-123.

Lapierre, L., J. Fontaine, B. Cusson, et C. Ménard. 1994. Distribution spatiale des larves et stades fixés de la Moule zébrée, *Dreissena polymorpha*, dans le Saint-Laurent au cours de 1991. Environnement Canada - Québec region, Conservation de l'Environnement, Centre Saint-Laurent, 66p.

May, B. and J.E. Marsden. 1992. Genetic identification and implications of another invasive species of dreissenid mussel in the Great Lakes. *Can. J. Fish. Aquat. Sci.* 49 : 1501-1506.

McMahon, R.F. 1996. The Physiological Ecology of the Zebra Mussel, *Dreissena polymorpha*, in North America and Europe. *Am. Zool.* 36 : 339-363.

Nalepa, T.F., J.A. Wojcik, D.L. Fanslow, and G.A. Lang. 1995. Initial colonization of the zebra mussel (*Dreissena polymorpha*) in Saginaw Bay, Lake Huron: Population recruitment, density, and size structure. *J. Great Lakes Res.* 21: 417-434.

Neumann, D., J. Borcherding, and B. Jantz. 1992. Growth and seasonal reproduction of *Dreissena polymorpha* in Rhine River and adjacent waters. In : Nalepa, T.F., and D.W. Schloesser (eds.), *Zebra mussels : biology, impacts and control*. Lewis Publ., Boca Raton, Fl., USA, pp. 95-109.

Nichols, S.J. 1996. Variations in the reproductive cycle of *Dreissena polymorpha* in Europe, Russia, and North America. *Amer. Zool.* 36: 311-325.

Nichols, S.J. and M.G. Black. 1994. Identification of larvae : the zebra mussel (*Dreissena polymorpha*), quagga mussel (*Dreissena rosteriformis bugensis*), and Asian clam (*Corbicula fluminea*). *Can. J. Zool.* 72 : 406-417.

O'Neill, C.R. 1996. Colonization. In : *Dreissena !*, Zebra Mussel Clearinghouse, New York Sea Grant, 6(5): 9.

Ram, J.L., P.P. Fong, and D.W. Garton. 1996. Physiological aspects of Zebra mussel reproduction: Maturation, spawning and fertilization. *Amer. Zool.* 36 : 326-338.

Riessen, H.P., T.A. Ferro, and R.A. Kamman. 1993. Distribution of Zebra Mussel (*Dreissena polymorpha*) Veligers in Eastern Lake Erie during the First Year of Colonization. In : Nalepa, T.F., and D.W. Schloesser (eds.), *Zebra mussels : biology, impacts and control*. Lewis Publ., Boca Raton, Fl., USA, pp. 143-152.

Riopel, A. 1995. La moule zébrée: statut de la situation et surveillance des véligères dans l'eau brute de 21 municipalités du Québec. Ministère de l'Environnement et de la Faune du Québec, Dir. des Politiques du Secteur Municipal, Serv. Assainissement des eaux et Traitement des eaux de consommation. 32p. + vi.

Rondeau, B. 1993. Qualité des eaux du fleuve Saint-Laurent 1985-1990 - Tronçon Cornwall-Québec. Environnement Canada - région du Québec, Centre Saint-Laurent, 240 p.

Simoneau, M. 1993. Qualité des eaux du bassin de la rivière Richelieu, 1979 à 1992. Ministère de l'Environnement du Québec, Direction de la qualité des cours d'eau, 141 p.

Stanczykowska, A. 1977. The ecology of *Dreissena polymorpha* (Pall.) in the food web of lake ecosystems. *Polskie Archiwum Hydrobiologii.* 24 : 461-530.

Sprung, M. 1993. The Other Life : An Account of Present Knowledge of the Larval Phase of *Dreissena polymorpha*. In : Nalepa, T.F., and D.W. Schloesser (eds.), *Zebra mussels : biology, impacts and control*. Lewis Publ., Boca Raton, Fl., USA, pp. 39-53.

Strayer, D.L. 1991. Projected distribution of the zebra mussel, *Dreissena polymorpha*, in North America. *Can. J. Fish. Aquat. Sci.* 48 : 1389-1395.

Strayer, D.L., J. Powell, P. Ambrose, L.C. Smith, M.L. Pace, and D.T. Fischer. 1996. Arrival, spread, and early dynamics of a zebra mussel (*Dreissena polymorpha*) population in the Hudson River estuary. *Can. J. Fish. Aquat. Sci.* 53: 1143-1149.

In-situ Determination of Metabolic Rates of Zebra Mussel Individuals and Populations Using the Electron Transport System (ETS) Enzyme Assay

Sharook P. Madon[1], Daniel W. Schneider[2], James A. Stoeckel[3] and Richard S. Sparks[3] [1]Department of Biological Sciences, Pace University, 861 Bedford Road, Pleasantville, New York 10570. [2]Urban and Regional Planning, University of Illinois, 907 1/2 W. Nevada, Urbana, Illinois 60801; [3]Illinois Natural History Survey, Forbes Biological Station, P.O. Box 590, Havana, Illinois 62644

We used the ETS enzyme assay to determine in-situ oxygen consumption rates by zebra mussel individuals and populations. The ETS assay relies on the fact that the process of oxygen consumption in organisms is accomplished via the electron transport system; therefore, ETS enzyme activity is strongly correlated with oxygen consumption. In-situ metabolic rates can be predicted from the ETS-oxygen consumption relationship if ETS levels are measured in organisms collected from natural systems. The ETS assay is particularly advantageous because it is insensitive to immediate stress associated with capture and collection of organisms from natural systems

We used the ETS assay to estimate ETS enzyme activity in zebra mussels ranging in size from 10-30 mm (28.0-551 mg soft-tissue wet mass). We also measured respiration rates of the mussels via the Winkler method. ETS enzyme activity and respiration rates were both strongly and similarly related to soft-tissue wet mass (r^2 >0.92, $p<0.001$; homogeneity of slopes test = $p>0.05$). Our results revealed a strong linear relationship between respiration rates and ETS enzyme activity ($r^2=0.93$, $p<0.0001$; $n=26$) across all sizes of mussels tested. Another test also revealed that a strong linear relationship existed between respiration rates and ETS enzyme activity in mussels of similar body mass (280-295 mg wet weight). Our results indicated that the calibrated ETS-respiration rate relationship could be used to derive in-situ respiration rates from ETS activity measured in mussels collected from the field. Independent statistical tests revealed that the ETS-respiration rate relationship provided accurate estimates of oxygen consumption rates in zebra mussel individuals and populations in the laboratory.

We also used the ETS-respiration rate relationship to estimate in-situ oxygen demand by zebra mussel populations in the Mississippi River. There was a strong relationship between oxygen demand (mg $O_2/m^2/h$) and zebra mussel density per square meter ($r^2 = 0.93$, $p<0.0001$). A zebra mussel density of 1,000 individuals/m^2 is estimated to have used 66 mg $O_2/m^2/h$, whereas a zebra mussel population at a density of 25,000 individuals/m^2 is estimated to have used 419 mg $O_2/m^2/h$. Dense populations of zebra mussels are expected to exert a strong demand upon the oxygen resources of a water body.

Natural Enemies of Zebra Mussels

Daniel P. Molloy[1], Alexander Y. Karatayev[2], Lyubov E. Burlakova[2], Dina P. Kurandina[3], and Franck Laruelle[1] [1]Biological Survey, New York State Museum, The State Education Department, Cultural Education Center, Albany, New York 12230; [2]Lakes Research Laboratory, Belarusian State University, F. Skoryna Ave. 4, Minsk, 220050, Republic of Belarus; [3]Institute of Hydrobiology, Ukrainian Academy of Sciences, 12 Prospect Geroyev Stalingrada, Kiev - 210 254655, Ukraine

The absence of the vast majority of the zebra mussel's natural enemies has contributed to their rapid population growth in North America, but to what degree is open to debate. This presentation discusses the biology and ecology of European and North American organisms known to be involved in their predation (176 species), parasitism (34 species), and competitive exclusion (10 species). Research on natural enemies, both in Eurasia and North America, has focused on predators, particularly birds (36 species) and fish (38 and 15 species eating veligers and attached mussels, respectively). Other field-documented predation includes consumption of pelagic larvae by copepods and coelenterates, and consumption of attached mussels by leeches, crabs, crayfish, and rodents. Cannibalism of veligers by adult zebra mussels has also been reported. Ciliates and trematodes are the most commonly reported obligate parasites, with occasional records of suspected bacterial or ascetosporan infection. Mites, nematodes, leeches, chironomids, and oligochaetes have been observed to be associated symbiotically within the mantle cavity, but with little to no adverse effect. Organisms capable of competitively displacing zebra mussels from hard substrates include sponges, amphipods, algae, bryozoans, hydrozoan coelenterates, and other bivalve species (including interspecific competition among *Dreissena* spp.).

While the vast majority of organisms that are natural enemies in Europe are not present in North America, ecologically similar species do exist on this continent, and zebra mussels represent a novel and abundant organism for these predators, parasites, and ecological competitors—the new natural enemies of *Dreissena*. The idea that these organisms might eliminate zebra mussel populations, even in limited areas of North America, however, is far more hopeful than realistic. As in Europe, there will likely be isolated reports of major impacts by natural enemies, but on the whole we will likely see a cumulative effect of a suite of enemies having a constant, but limited, role in suppressing zebra mussel populations.

History and Current Geographic Pattern and Rate of Spread of *Dreissena polymorpha* in Belarus, Former Soviet Union

Alexander Karatayev and Lyubov E. Burlakova Belarusian State University, Skoring 4, Minsk 220050 Belarus

Zebra mussels appeared in Belarus about 190 years ago with the opening of Dneprovsko-Nemansky channel that connected the basins of the Black and Baltic Seas (1803). The first study of the spread of zebra mussels in Belarus was in 1929 by I.F. Ovchinnikov. He found *Dreissena* in four lakes and some rivers of Belarus. The degree of spread of zebra mussels in Belarus increased after World War II and was correlated with the joining of Eastern and Western Belarus (1939) and with the increasing of intensity of commercial fisheries.

The majority of Belarusian lakes are drainage lakes with low water exchange. They are usually isolated, and large lake systems are rather rare. Navigation is not possible among most lakes. Small paddle and motor boats, used in lakes, are rarely transported to other lakes. Therefore commercial fishing is the main vector spreading zebra mussels to other new lake systems during the last three decades.

At present zebra mussels populate 100 lakes and reservoirs of over 600 waterbodies studied. Most frequently zebra mussels populate mesotrophic lakes (56%), where they reach the highest densities. They are more rare in meso-oligotrophic lakes (25%) and in eutrophic lakes (16%). *Dreissena* is absent from dystrophic lakes.

The rate of zebra mussel spread across Belarus has especially increased during the last few decades and is correlated with increasing human economic activity, which is usually higher in the largest lakes. The proportion of lakes populated by zebra mussels increases with increasing area of the lake, from 10% in lakes with an area of 0.1-0.25 km^2 to 40% in the larger lakes (>15 km^2).

Lakes populated with *Dreissena* differ significantly from the lakes without mussels, by a number of factors such as pH, mineralization, and hydrocarbonated calcium, which can limit the spread of zebra mussels.

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Distribution of *Dreissena polymorpha* Within and Among Rivers, Lakes and Reservoirs with Different Abiotic Conditions

Lyubov E. Burlakova and Alexander Karatayev Belarusian State University, Skoring 4, Minsk 220050 Belarus

We studied the distribution of zebra mussels in Belarus in mesotrophic Naroch Lake, eutrophic Myastro Lake and highly eutrophic Batorina Lake, Svisloch River, and two reservoirs within the boundaries of Minsk (the capital of Belarus)—Drozdy and Chizhovskoe, with different levels of pollution.

The average density of zebra mussels greater than 1 mm in Naroch Lake in 1990 (approximately five years after initial invasion) was 7.2±0.5 ind.m^{-2} and average biomass was 1.4±0.5 gm^{-2}. By 1993, the density of *Dreissena* in this lake increased over 100 times and biomass increased 68 times. In 1995 the average density of zebra mussels in mesotrophic Naroch Lake was 794±249 ind.m^{-2}; in eutrophic Myastro Lake—579±135 ind.m^{-2} and in highly eutrophic Batorina Lake, 269±103 ind.m^{-2}. The average density of zebra mussels in lakes decreases with increasing degree of eutrophication. The highest average biomass was found in Myastro Lake, 224±82 gm^{-2}. The zone of maximum density of *Dreissena* shifts to shallower depths with increasing eutrophication.

We also found that distribution of zebra mussels can be limited by pollution. Drozdy Reservoir is above city and characterized by low levels of industrial and metropolitan pollution. In 1995 the average density of zebra mussels in Drozdy Reservoir was 840±285 ind.m^{-2} and biomass was 349+105 gm^{-2}, while in the heavily polluted lower Chizhovskoe Reservoir, the average density of *Dreissena* was only 82+67 ind.m^{-2} and biomass was 33+17 gm^{-2}.

The Svisloch River has the highest average density (1,797+864 ind.m^{-2}) of zebra mussels among studied waterbodies. Absolute maximum density of zebra mussels in this river was more than 20,000 ind.m^{-2} and biomass was more than 7,500 gm^{-2}. Within rivers, the distribution of zebra mussels can be limited by waterfowl, which can consume up to 90% of the zebra mussels in shallow areas.

(Editor's Note: This paper was first presented at the Seventh International Zebra Mussel and Aquatic Nuisance Species Conference in New Orleans, LA, 28-31 January 1997.)

Dispersal Vectors of the Zebra Mussel: Myths, Reality, and Common Sense

Ladd E. Johnson[1] **and James T. Carlton** Maritime Studies Program, Mystic Seaport Museum - Williams College, Mystic, Connecticut 06355 [1] Mailing address: Département de biologie, Université Laval, Québec, QC G1K 7P4

The zebra mussel, *Dreissena polymorpha*, has spread rapidly throughout the Great Lakes and its connecting navigable waterways including the Mississippi, St. Lawrence, and Hudson Rivers. The speed of this spread appears due to the downstream dispersal of the larval stage and the attachment of the adult stage to the exterior surfaces of boats and ships, especially commercial equipment. However, the continued expansion of the geographic range of this invasive species will depend on its ability to disperse overland into other watersheds. Prevention of such range expansion requires knowledge of the means by which zebra mussels disperse overland and establish new populations

Fortunately, unlike many other aquatic organisms (e.g., cladocerans) there is no stage of the zebra mussel life cycle specifically adapted for overland dispersal. However, there are many activities of humans or wildlife that have the potential to transport either adult or larval stages overland. The efficacy of these potential vectors to transport enough zebra mussels to establish new populations remains poorly understood, and much of our policy directed at preventing or delaying the spread of zebra mussels relies on a dispersal mythology that may be largely incorrect.

One such myth is that the fouling of the exterior surfaces of recreational boats is a common vector of dispersal However, our research in Michigan demonstrates that zebra mussels are almost never found on the exterior surfaces of recreational boats due to the boat's short period in the water (i.e., a transient boat). Instead, zebra mussels were more commonly found as adults on macrophytes entangled on the boat's motor or trailer (adults) or as larvae (veligers) in the water contained in the live well of fishing boats. Although boats left for longer periods in infested waters (i.e., a resident boat) are not commonly moved to other waters, such rare events may be nevertheless quite important for establishing new populations and thus should be specifically targeted by educational efforts. Another myth is the importance of waterfowl in the dispersal of zebra mussels. Experiments using mallard ducks demonstrated that they are capable of transporting both larval and juvenile stages but in trivial numbers compared with recreational boating.

Observations such as these emphasize the need for a scientific basis for the assessment of the risk posed by different dispersal vectors of exotic species. Not only do different vectors need to be ranked in terms of their probability of transporting exotic species, but also in terms of the survival during transport and the demographic conditions needed for establishment of new populations (i.e., the number, life history stage, and distribution of the founding population). In terms of the zebra mussel, a dioecious species with external fertilization, we suggest that only introductions of large numbers of adults are likely to remain sufficiently aggregated to achieve the high rates of fertilization needed to establish the population.

The Dispersal of Zebra Mussels to Inland Lakes: The Michigan/Indiana Experience

Paul Marangelo[1] **and Ladd Johnson**[2] [1]University of Michigan/Williams College - Mystic Seaport Maritime Studies Program, Mystic, Connecticut 06355; [2]Département de biologie, Université Laval, Québec, QC G1K 7P4

Patterns and rates of the overland dispersal of the zebra mussel *(Dreissena polymorpha)* to inland lakes in the Great Lakes region may yield insights into probable patterns and mechanisms of dispersal in frontier areas of *Dreissena* range expansion. A systematic, large-scale inland lake sampling program has been investigating the movement of zebra mussels from the Great Lakes to inland lakes in the lower peninsula of Michigan (since 1993) and northeastern Indiana (since 1995). Data from early-detection veliger sampling and confirmed incidental inland lake detections show that Michigan progressed from one known inland lake population in 1992 to 32 lakes in 1996. Inland lake invasions in Indiana progressed from one lake in 1992 to 10 lakes in 1996.

Inferences from dispersal patterns suggest that primary dispersal (boat-mediated, from the Great Lakes overland to inland lakes), secondary dispersal (boat-mediated, from inland lakes overland to inland lakes), and waterborne (inland lake to inland lake via connected water channels) dispersal pathways all influence patterns and rates of inland lake invasion. Emerging regional inland lake invasion "hotspots" in northeast Indiana, Jackson County, Michigan, and suburban Detroit appear to differ in terms of the relative importance of these three dispersal pathways to existing invasion patterns. Annual rates of new detections have varied substantially from year-to-year. Forty percent of the Michigan infestations were detected in 1994, 18% in 1995, and 12% were detected in 1996. This decrease in new inland lake zebra mussel detections is contrary to expected trends of increasing invasion rates. Such expectations are based on the potential "snowball" effect from the recent increase in numbers of new potential inland lake source populations of zebra mussels capable of exporting zebra mussels to un-infested lakes.

Zebra Mussel Colonization of Lake Champlain

Cathi Eliopoulos and Peter Stangel Vermont Department of Environmental Conservation. Water Quality Division, 103 S. Main Street, 10N, Waterbury, Vermont 05401

Zebra mussels (*Dreissena polymorpha*) were first discovered in southern Lake Champlain in July of 1993. The Vermont Department of Environmental Conservation, in cooperation with the LakeChamplain Basin Program, initiated the Lake Champlain Zebra Mussel Monitoring Program in 1994 to track the zebra mussel's progression through the lake.

A Wisconsin plankton net was used to collect veliger samples at 12 open water lake stations and 11 nearshore stations. Samples were collected biweekly and were examined for occurrence and density of veligers using cross-polarized light following methods described by Marsden (1992). Peak veliger densities were 3,272/m^3 in 1994, 34,491/m^3 in 1995, and 93,798/m^3 in 1996. Occurrence and density of settled juveniles were determined at 11 nearshore sites using an array of three, 15 X 15 cm (225 cm^2) dark-colored PVC settling plates suspended horizontally in the water column from docks at marinas, bridge abutments, or floats in bays. The top plate was left submerged for the entire sampling season to estimate seasonal accumulation, while the bottom two plates were collected on a rotational basis allowing each plate to be available to settled juveniles for approximately 4 weeks. Peak juvenile densities reached 5,600/m^2 in 1994; 876,000/m^2 in 1995; and 3,676,000/m^2 in 1996 for the four week rotating plates. However, density estimates in 1996 were estimated based on a different plate orientation and are therefore not directly comparable with estimates from previous years.

In 1996 zebra mussel adult surveys were conducted at 23 sites by either mask and snorkel or shoreline observations. Most of these sites were concentrated in areas with no previously known infestations. Thirteen of the sites were found to have zebra mussels and relative abundance estimates were recorded and will be used for future comparative purposes. Quantitative information on the density of adult zebra mussels colonizing native mussels was obtained at one site in southern Lake Champlain using a transect method. Three replicate 10 meter transects were surveyed at each site using SCUBA. Native mussels were collected within 10 cm of the transect line, and species and number of live or recently dead (determined by shell condition) individuals were recorded before returning native mussels to the lake. Recently dead native mussels encountered were assumed to have succumbed to the stress caused by attached zebra mussels. All of the 178 native mussels collected during the survey had an estimated 100 - 200 attached adult zebra mussels and approximately 25% were dead. Also, in 1996, ten inland lakes with high boating activity and close proximity to Lake Champlain were sampled for veligers at public access areas or lake outlets using a plankton net. No veligers were found in any of the ten inland lakes sampled. Eight tributaries to Lake Champlain were sampled for all life stages of zebra mussel using a scouring pad attached to a 15 X 15 cm (225 cm^2) PVC plate (Martel 1992). The plate was submerged in the water current approximately 400-800 meters upstream from the river mouth for approximately two weeks. Veligers and settled juveniles were found in one of the eight tributaries sampled and no density estimates were made.

In 1996, water chemistry data including; total phosphorus, chlorophyll concentrations and Secchi disk depths, collected before and after zebra mussel colonization, were analyzed from four southern open water Lake Champlain stations to determine whether water quality changes have occurred in the area that is most heavily infested with zebra mussels. Increases in Secchi disk transparency of 17-51% and reductions in total phosphorus of 12-21% were recorded at all four southern lake stations. These changes were statistically significant at three of the four stations. Chlorophyll-a reductions of 4-24% were seen at the two stations for which data were available, but these changes were not statistically significant. No significant changes in transparency or total phosphorus were recorded at the two control stations. These results suggest that zebra mussels may be having an effect on water quality in the southern region of Lake Champlain but additional data will need to be analyzed in order to determine the role of zebra mussels in these changes.

The zebra mussel colonization of Lake Champlain is at a critical stage where the mussel's range is expanding and densities are increasing rapidly. Zebra mussel spread and abundance information is essential to determine their effect on water quality, native mussel populations and potential threats to water treatment facilities. Future monitoring efforts will continue to track the colonization of zebra mussels in the Lake Champlain, its tributaries and inland lakes within its basin. *(A copy of the report with data from 1994-1996 is available from the authors.)*

A Substrate to Which Zebra Mussels Will Not Attach

Patrice M. Charlebois[1] and J. Ellen Marsden[2] [1]Illinois Natural History Survey; [2]School of Natural Resources, Aiken Center, University of Vermont, Burlington, Vermont 05405

Studies by several investigators indicate that zebra mussels attach to a wide variety of substrates; mussels will even attach in low numbers to noxious materials such as copper. We noted that zebra mussels held in fiberglass mesh containers attached only to each other, and not to the fiberglass. We hypothesized that zebra mussels were deterred from attaching by the mesh size rather than by the material of the screening. To test this hypothesis, we conducted an experiment using flow- through trays with wooden frames and four types of substrates including: (1) wood, (2) fiberglass screening on top of wood (screen + wood), (3) fiberglass material, and (4) fiberglass screening. Each substrate treatment was replicated five times. Ten mussels in each of four size classes were placed in each substrate type. After 20 days, numbers and sizes of mussels attached to each substrate were recorded. No zebra mussels attached to the fiberglass screening, but 13.5%, 18.5%, and 16% of the mussels attached to the fabric, wood, and screen + wood, respectively. Preliminary results suggest that attachment to these substrates is size-specific. This experiment demonstrates the existence of a material resistant to zebra mussel attachment. Further exploration of the uses of this material could prove rewarding.

Ecological Studies on the Recently Introduced Japanese Shore Crab (*Hemigrapsus sanguineus*), in Eastern Long Island Sound

Andrew M. Lohrer[1] and Robert B. Whitlatch[2] [1]Department of Ecology and Evolutionary Biology, University of Connecticut, Box U-42, Storrs, Connecticut 06269, [2]Department of Marine Sciences, University of Connecticut, Groton, Connecticut 06340

Abstract

Hemigrapsus sanguineus, an intertidal crab indigenous to Japan and other western Pacific regions, has recently established breeding populations in Long Island Sound, and continues to expand its range along the northeast United States coastline. Basic ecological parameters of this species have been largely undescribed both in its new and native habitats. Therefore, assessing the ecological impact of *Hemigrapsus* is difficult, and the factors contributing to its successful invasion are unclear. This study presents preliminary information on the general ecology of *Hemigrapsus* at several intertidal localities in eastern Long Island Sound, and examines differences in its intertidal distribution and feeding ecology relative to other crab species. *Hemigrapsus* is now frequently the most abundant crab in rocky intertidal habitats throughout southern New England. Although reported to have a high intertidal distribution, *Hemigrapsus* was more predominant in the lower half of the intertidal zone at all sites sampled. Green crabs (*Carcinus maenus*) and mud crabs (*Eurypanopeus depressus*) were common in the intertidal zone at some locations, but other sites had in essence monospecific populations of *Hemigrapsus*. Contrary to previous literature reports, *Hemigrapsus* does not appear to be strictly herbivorous in eastern Long Island Sound, and preys upon indigenous littorines (e.g., *Littorina saxatilis*, *L. obtusata*), newly recruited blue mussels (*Mytilus edulis*), and other invertebrate taxa, in addition to a wide variety of macroalgae. We conclude *Hemigrapsus* has the potential to substantially alter the abundance and distribution of the resident species in rocky intertidal habitats of southern New England.

Introduction

In recent years, a number of nonindigenous species have become established in Long Island Sound (Osman and Whitlatch 1995; J. Carlton, personal communication; personal observations), including the area's first rocky intertidal grapsid crab, *Hemigrapsus sanguineus* (Williams and McDermott 1990; McDermott 1991, McDermott 1994). While there is considerable speculation regarding the potential impact of *Hemigrapsus* in its new habitat, there is little ecological information to support it. The introduction of nonindigenous organisms clearly can cause economic and ecological harm (Elton 1958; Nichols *et al.* 1990; Hebert *et al.* 1991; Harbison and Volovick 1994). Many of New England's coastal habitats have been structurally and functionally altered by marine biological invasions in the past 200 years (e.g., decrease in soft shell clam populations by green crabs, alteration of salt marshes by littorine snails). The recent invasion of *Hemigrapsus* may also significantly impact the resident flora and fauna along the east coast of North America.

Hemigrapsus sanguineus (de Haan), a shore crab indigenous to Japan and other western Pacific regions, was first recorded in North America in September 1988, in Cape May Harbor, New Jersey (Williams and McDermott 1990). *Hemigrapsus* has rapidly spread north and south along the eastern United States seaboard in the last 9 years (Grosholz 1996; J. Carlton, personal communication). It is now established throughout Long Island Sound (personal observations), and currently ranges from North Carolina to the north shore of Cape Cod, Massachusetts (A. Hines and N. O'Connor, personal communications). It is commonly found on rocky shores, usually under the rocks at low tide (Depledge 1984, personal observations). In southern New England, *Hemigrapsus* frequently co-occurs with native mud crabs (primarily *Eurypanopeus depressus*, also *Panopeus herbstii*) and the previously introduced green crab (*Carcinus maenus*). Small rock and Jonah crabs (*Cancer irroratus*, *Cancer borealis*) also occur in the rocky intertidal but are relatively rare in this region of New England. *Hemigrapsus* has the potential to interact with a number of resident invertebrate taxa, and may affect natural and economically important resources in southern New England. While some investigators (e.g. McDermott 1992; Lafferty and Kuris 1996) have suggested

Hemigrapsus will not have much impact on resident fauna due to its "upper intertidal" distribution, this assessment is premature. For example, many invaders do not begin causing significant ecological or economic damage until 5 to 10 years after their first appearance (Williamson 1996), basic ecological parameters of *Hemigrapsus* are largely undescribed in its native and new habitats, and preliminary observations indicate the crab is a predator of a wide variety of resident species in Long Island Sound rocky intertidal habitats.

The goals of this article are fourfold: Firstly, to quantify the abundance of *Hemigrapsus* in a variety of rocky intertidal habitats in eastern Long Island Sound. How abundant is *Hemigrapsus* relative to the other crab species in the region? How does its relative abundance vary with environmental or geographic parameters? Secondly, to determine the vertical distribution of crabs residing in the intertidal zone at low tide. Do different crab species partition space according to tidal height? Is *Hemigrapsus* characterized by an upper intertidal distribution, as reported in the literature? Thirdly, to examine the population size structure of crabs inhabiting the intertidal zone. Size is a very important consideration in crab-crab interactions, and often dictates predator foraging behavior (e.g., Eggleston 1990; Kaiser *et. al.* 1990; Lee and Seed 1992; Beck 1995). Fourthly, to analyze the diet of *Hemigrapsus*, *Carcinus*, and *Eurypanopeus*. How similar are the diets of the three co-occurring species? Is the diet of *Hemigrapsus* consistent with previous literature reports?

Materials and Methods

Study sites

Five sampling sites were chosen in eastern Long Island Sound (Fig. 1). To allow proper replication, a relatively long, rocky shore was required at each site. The five sites spanned more than 160 km from the westernmost site (New Haven, CT) to the easternmost site (Point Judith, RI), and varied in tidal amplitude, wave exposure, substrate type, and dominant co-occurring species (Table 1).

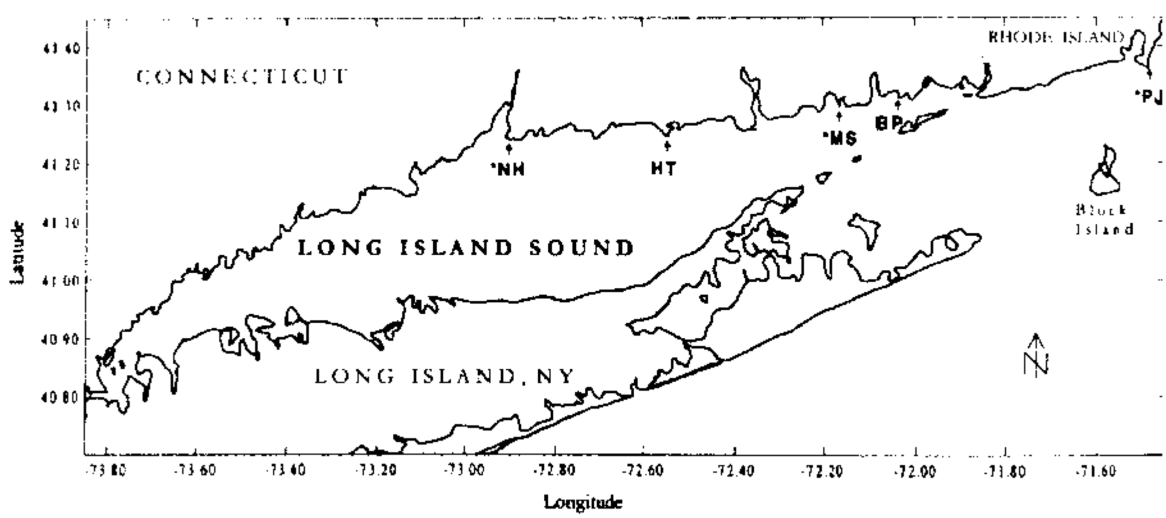

Figure 1. The five sites quantitatively sampled from June to December, 1996 (NH=New Haven,CT; HT=Hammonasset, CT; MS=Millstone Point, CT; BP=Bluff Point, CT; PJ=Point Judith, RI). PJ,MS and NH were repeatedly sampled (*), whereas HT and BP were sampled once in the early summer.

Table 1. Characteristics of the three sampling sites which were monitored from June to December, 1996. There appears to be a gradient along the length of the Sound in terms of substrate composition, exposure level, and tidal amplitude.

	New Haven, CT (NH)	Millstone, CT (MS)	Point Judith, RI (PJ)
Substrate	small rocks, with sand and mud patches	rocks and cobbles, some patches of course sand	rocky shore, cobbles and boulders, gravel underneath
Exposure	rocky headland, but protected by an outer breakwater and Long Island, NY	intermediate exposure level, on the edge of Niantic Bay	exposed, occasionally receives high wave action
Tidal range	6.20 ft. mean tidal range	2.7 ft. mean tidal range	3.1 ft. mean tidal range
Dominant organisms	filamentous, ephemeral green algae many soft-shell clams (*Mya arenaria*) small littorines (*L. saxatilis*) and polychaetes (mostly nereids) seagulls common in intertidal	lower intertidal with thick *Fucus* zone *Zostera* litter piles at upper tide mark fewer clams, fewer worms large littorine snails (*L. littorea*) blue mussels (*Mytilus edulis*) - small	occasional *Ascophyllum* patches, not much algal cover high *L. littorea* abundances blue mussels present small rock crabs (*Cancer*), and *Asterias* are occasionally found

Field sampling protocol: crab abundance, vertical distribution, and size

A sampling regime similar to Batie (1982) was undertaken at each of the 5 sites. Up to 10 replicated transects at each study site, spanning from the mean low water of spring tides (MLWS) to the mean high water of spring tides (MHWS), were subdivided into four equal intervals. Two of these tidal height intervals were above the mid-tide mark, and two below it. One quadrat (1 m^2 was randomly selected from within each height in each transect, and sampled at low water on spring tides (Fig. 2). All crabs within the quadrats were caught by hand and placed in buckets. Any sandy sediment under rocks was probed and/or sieved (with a 2.0 mm mesh screen) to account for any buried, small, or cryptic crabs. Crabs were identified, counted, measured across the maximum width of the carapace, and eventually returned to the plots. Three of the five sites (New Haven, CT, Millstone, CT, and Point Judith, RI), were sampled repeatedly from June to December, 1996.

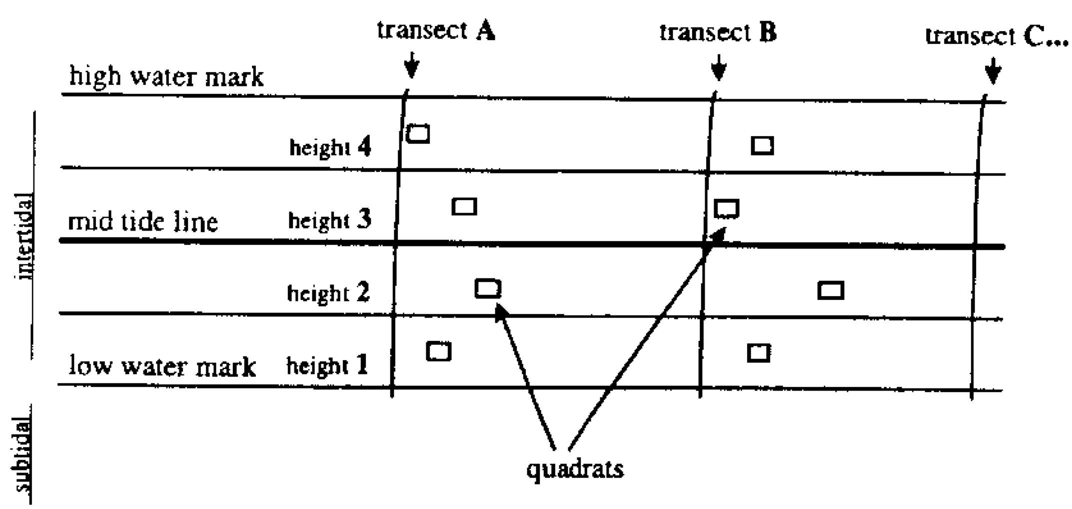

Figure 2. Representation of intertidal sampling scheme. For each vertical transect line, one 1 m^2 quadrat was randomly selected and sampled at each tidal height. Between 5 and 10 transect lines were sampled per site. Crabs were enumerated based on species and size.

Analysis of stomach contents

Crabs were collected haphazardly from the intertidal zone at Bluff Point and New Haven, CT. Personal observations indicated crabs are more active at night, and probably feed when covered by water. In order to capture crabs soon after feeding, collections were made on retreating tides and during darkness. Crabs were immediately put on ice, and were placed in freezers in the laboratory. Methods used for gut analysis are described in Ropes (1989) and the data were analyzed according to Hines (1982). In brief, crab stomachs were removed under a dissecting microscope, and the percent gut fullness was estimated. Stomach contents were then identified, and the percent contribution of each item was recorded. The guts of 42 *Hemigrapsus* (both sexes, and a variety of sizes) were analyzed, along with 28 *Carcinus* and 16 *Eurypanopeus*.

Results

Crab abundance

At each site and during every sampling period, *Hemigrapsus* was a conspicuous member of the crab community (i.e., more than 30% of the crabs found were *Hemigrapsus*). Green and mud crabs were sometimes absent or uncommon. Analyses of 10 of 12 sampling dates revealed *Hemigrapsus* was greater than or equal to the combined number of other resident crab species (Table 2). Two of the sites (Hammonasset, CT and Point Judith, RI) had nearly monospecific crab populations of *Hemigrapsus*, with densities in the lower portion of the intertidal zone often exceeding 30 crabs/m^2. *Cancer irroratus* and *C. borealis* were found at Point Judith in the lower intertidal zone, and recruits of these species were observed at New Haven, but they were in very low abundances (e.g., < 0.35 per m^2), if present at all.

Crab vertical distributions

There were significant differences in abundance of *Hemigrapsus* (>8 mm carapace width) with respect to tidal height at five sites sampled in Long Island Sound (10 of 12 dates, $p < .05$, Kruskal-Wallis tests). While McDermott (1992) described *Hemigrapsus* as an "upper intertidal" species, this species was almost always more common in the lower half of the intertidal zone in the southern New England sampling sites (8 of 12 dates, $p < .05$, Mann-Whitney U tests). The vertical distribution of *Hemigrapsus* was similar to that of the other resident crab species, showing substantial overlap in a number of instances (Fig. 3). The lower intertidal distribution of *Hemigrapsus* was most obvious in August and December. Regardless of the season, however, there was a general pattern for all three crab species; while found throughout the entire intertidal zone at low tide, more crabs are concentrated in the lower half of this habitat.

Population size structure

At each of the sampling locations, a number of *Hemigrapsus* had attained large sizes (i.e., > 30 mm cw). The proportion of *Hemigrapsus* in discrete size categories significantly varied through time (Chi square analysis, $p < .025$, all 3 sites), as was expected of crabs during a growing season. The mean size of *Hemigrapsus* was between roughly 15 mm cw and 22 mm cw in the 12 sampling dates. There was some degree of variability in the size of *Hemigrapsus* (>8 mm cw) with sampling location. For example, crabs in New Haven were significantly larger than those at Millstone, which were significantly larger than those at Point Judith, during the first sampling period (ANOVA $p < .0001$, Scheffé test $p < .0001$).

Green crabs can attain a maximum carapace width of over 80 mm, while *Hemigrapsus* and *Eurypanopeus* are much smaller at maximum size (40 mm cw and 25 mm cw, respectively) (Weiss 1996; Fukui 1988). Mean sizes of these three species collected in the field reflected the same general pattern (*Carcinus* > *Hemigrapsus* > *Eurypanopeus*). Most of the green crabs found in the rocky intertidal zone at low tide were relatively small; more than 95% of the *Carcinus* collected (n=536) were less than 40 mm cw.

Analysis of stomach contents

Gut content analyses of wild-caught crabs revealed a diversity of plant and animal food items were present (Table 3). The four food items with the highest proportional contribution to the diet of *Hemigrapsus* were brown algae (e.g., *Fucus*, *Ascophyllum*), barnacles, red algae (e.g., *Chondrus*, *Anfeltia*), and blue mussels (*Mytilus edulis*), reflecting an omnivorous diet. *Hemigrapsus* also consumed a number of gastropod species (*Lacuna vincta*, *Littorina saxatilis*, *L. obtusata*, small *L. littorea*) and polychaete worms (primarily nereids). The four food

Table 2: Crab abundance data for the 5 sites quantitatively sampled (PJ= Point Judith, BP= Bluff Point, MS= Millstone, HT= Hammonasset, NH=New Haven). DATE = beginning of sampling period (sampling took 2-4 days at each site). TOTAL# = total number of crabs found; broken down by the 3 most common species, # = total number of a species found, % = percent of a species relative to the total number of crabs found, and AVE = overall mean abundance (+/- 1 standard error) of a species. The symbol ** denotes that *Hemigrapsus* is significantly more abundant than all other crabs (paired sign test, p<.01), the symbol NS signifies that *Hemigrapsus* is not significantly different in abundance than all other crabs (paired sign test, p>.05), and a "+" indicates that *Hemigrapsus* was less abundant than all other crabs. Abundance data are paired because they compare numbers found in the same quadrat, and the paired sign test, rather than a Wilcoxon, was used because the data were not evenly spread about the median.

SITE	DATE	TOTAL #	*HEMIGRAPSUS* > 8 mm cw			*CARCINUS* > 10 mm cw			MUD CRABS > 6 mm cw			
			#	%	AVE	#	%	AVE	#	%	AVE	
PJ	June 28	505	477	94	11.925+-1.489	21	4	.525+-.148	7	2	.175+-.087	**
PJ	Aug 25	725	706	97	19.08+-2.663	8	1	.216+-.165	11	2	.297+-.128	**
PJ	Oct 26	407	398	98	19.9+-3.080	4	1	2.0 +-1.0	5	1	2.5 +-1.5	**
PJ	Dec 11	185	178	96	8.9+-2.642	7	4	.35+-.209	0	0	0+-0	**
BP	July 15	232	147	63	7.350+-1.679	82	36	4.1+-2.38	3	1	.15+-.10	NS
MS	July 3	441	203	46	5.075+-1.058	207	47	5.175+-.885	31	7	.775+-.317	NS
MS	Aug 13	319	171	54	6.017+-1.54	133	42	4.750+-1.266	15	4	.536+-.221	+
MS	Oct 12	142	53	37	2.65+-.634	72	51	3.6+-.755	17	12	.85+-.365	NS
HT	Aug 1	384	358	93	17.9+-5.328	0	0	0+-0	26	7	1.3+-.603	**
NH	July 30	289	93	32	4.65+-1.179	0	0	0+-0	196	68	9.8+-13.59	NS
NH	Aug 30	390	158	41	5.643+-1.595	60	15	2.143+-.524	172	44	6.143+-1.4	+
NH	Dec 14	105	52	50	2.6+-2.193	0	0	0+-0	53	50	2.65+-7.16	NS

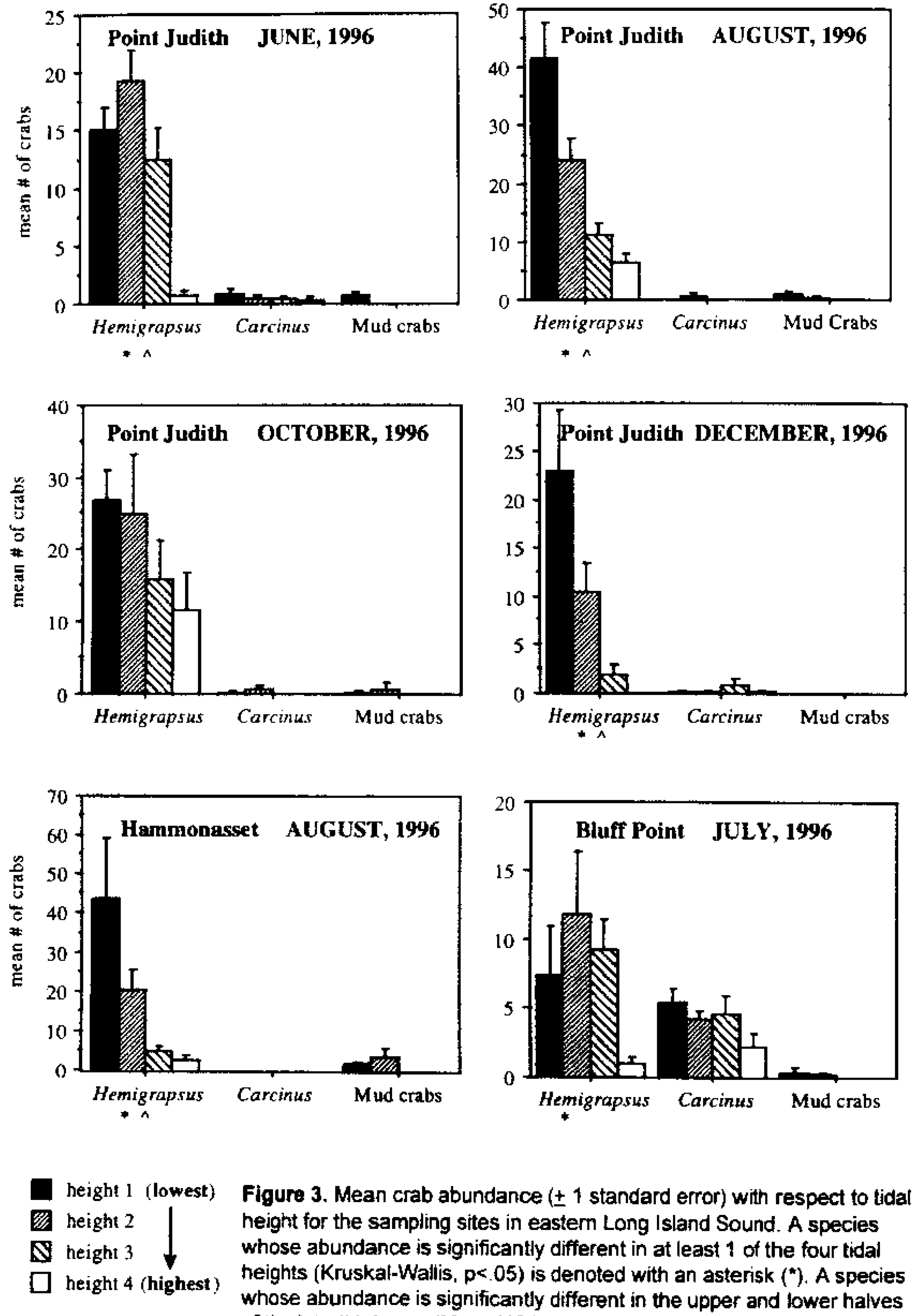

Figure 3. Mean crab abundance (± 1 standard error) with respect to tidal height for the sampling sites in eastern Long Island Sound. A species whose abundance is significantly different in at least 1 of the four tidal heights (Kruskal-Wallis, $p<.05$) is denoted with an asterisk (*). A species whose abundance is significantly different in the upper and lower halves of the intertidal zone (Mann-Whitney U, $p<.05$) is denoted with a carrot(^).

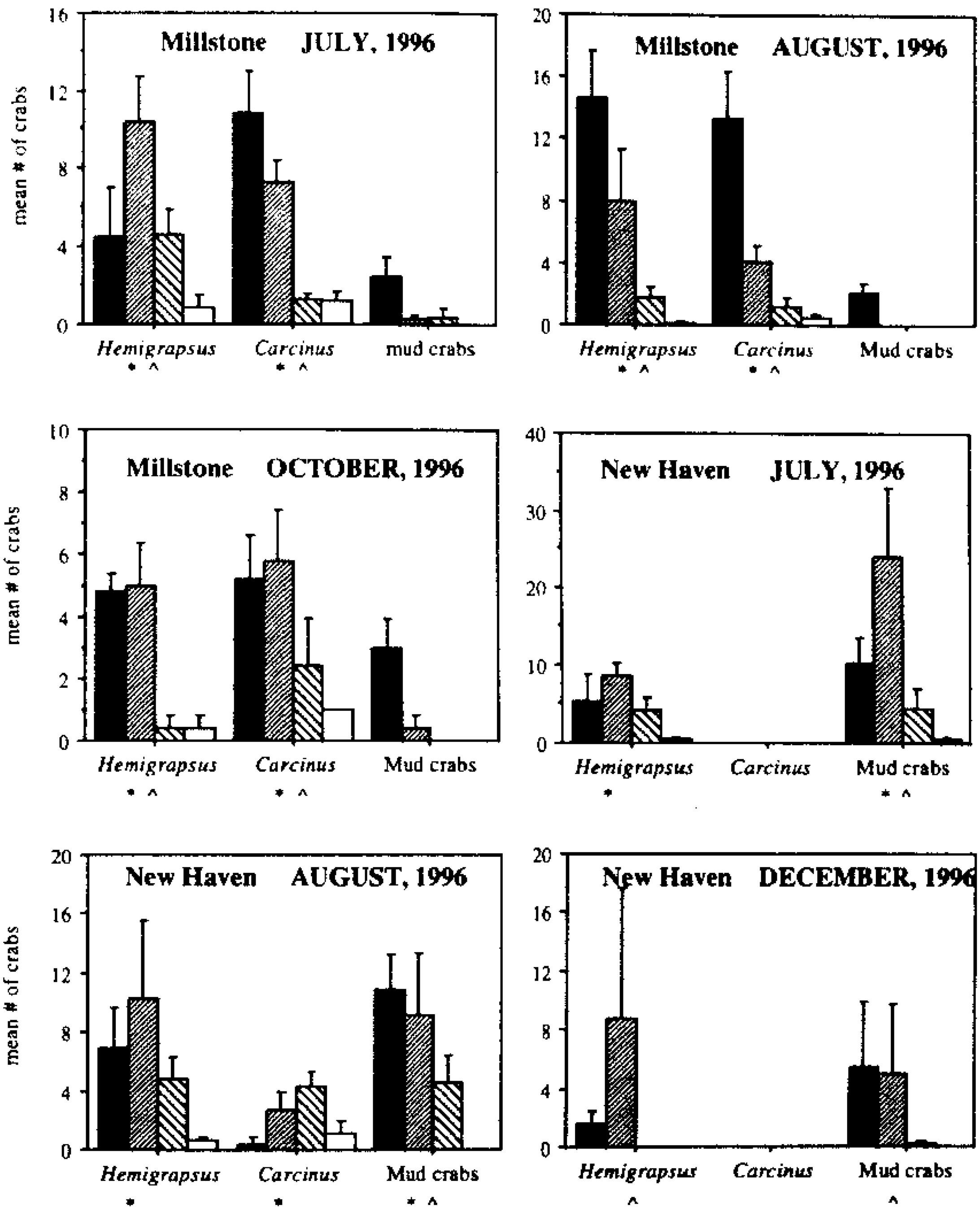

Figure 3. (Continued, see previous figure legend.)

Table 3. Results of gut content analysis on crabs caught in the intertidal zone in eastern Long Island Sound (Millstone and Bluff Point). Percent occurrence refers to the percent of the crab stomachs containing the item. The proportional contribution is the mean proportion of a food category in the diet as calculated by Hines (1982). Asterisk (*) denotes non-filamentous algae. NP = not present.

FOOD ITEM	*HEMIGRAPSUS*		*CARCINUS*		*EURYPANOPEUS*	
	percent occurrence	proportional contribution	percent occurrence	proportional contribution	percent occurrence	proportional contribution
Detritus	11.9	.019	NP		62.5	.229
Unidentified animal	11.9	.016	3.6	.007	18.8	.032
Eggs	2.4	.011	7.1	.004	NP	
Zostera marina	33.3	.051	3.6	.001	12.5	.023
Red fil. algae	16.7	.022	3.6	.002	12.5	.012
Red algae *	11.9	.128	3.6	.002	6.2	.006
Brown fil. algae	21.4	.041	17.9	.032	31.2	.013
Brown algae *	40.5	.287	NP		18.8	.045
Green fil algae	4.8	.006	NP		81.2	.247
Green sheet algae	2.4	.001	3.6	.062	NP	
Barnacles	28.6	.222	21.4	.154	18.8	.071
Crabs	4.8	.008	10.7	.199	NP	
Other arthropods	4.8	.013	10.7	.147	6.2	.020
Gastropods	21.4	.051	46.4	.303	NP	
Bivalves (*M.edulis*)	21.4	.122	10.7	.088	18.8	.080
Polychaetes	2.4	.055	7.1	.034	37.5	.224
	n=42, mean % fulness of stomach = 33.024+-5.598		n=28, mean % fullness of stomach = 21.393+-5.385		n=16, mean % fullness of stomach = 43.750+-8.690	

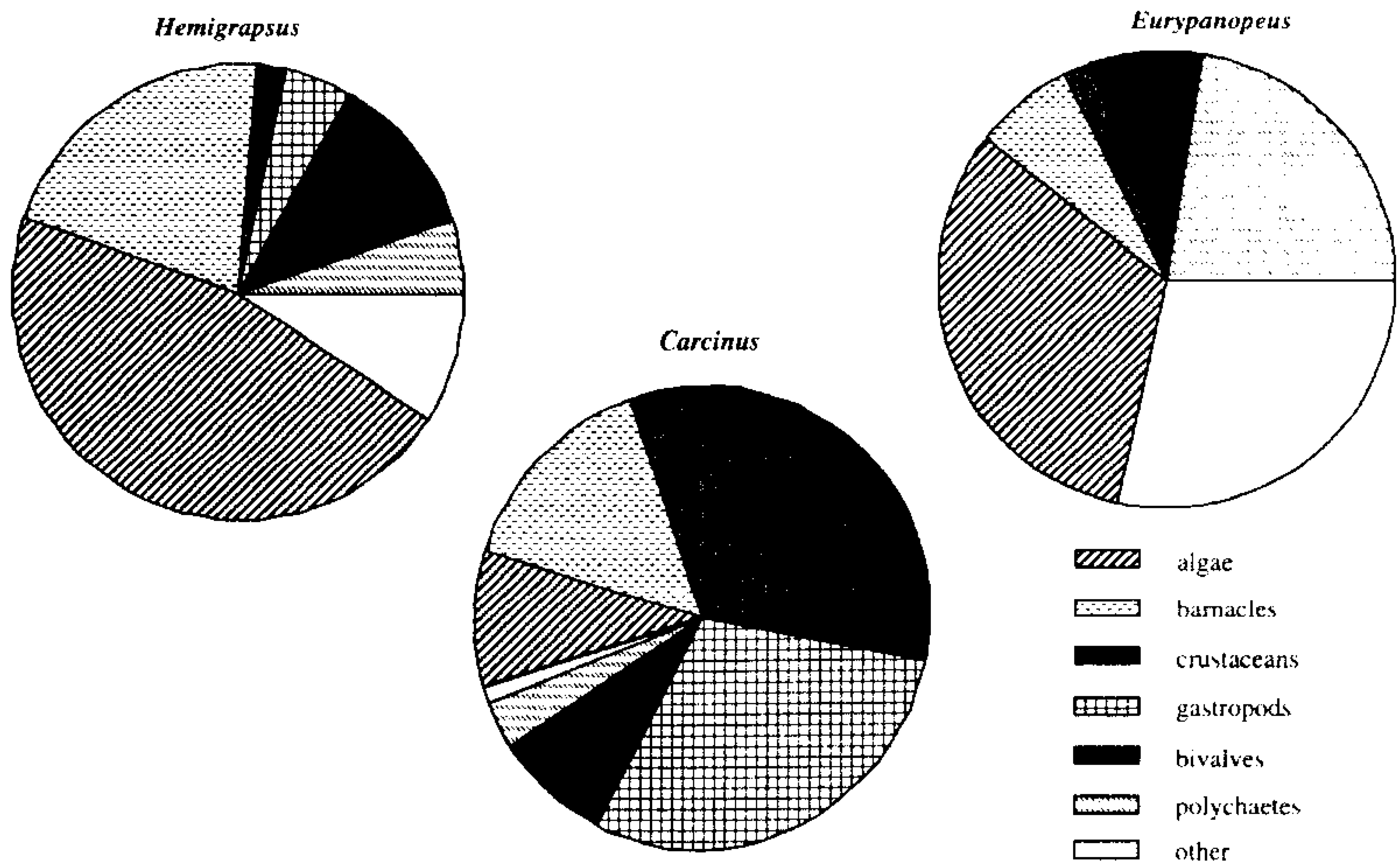

Figure 4. A pie diagram representing the percent contribution of seven broad food categories for *Hemigrapsus sanguineus*, *Carcinus maenus*, and *Eurypanopeus depressus*. The 16 food categories listed in Table 3 were combined into 7 groups (algae = all macroalgal species regardless of color or thallus form, crustaceans = all crustaceans excluding barnacles, other = detritus + unidentified animal tissue + eggs + *Zostera marina*).

categories contributing most to the diet of *Carcinus* were gastropods, crabs, barnacles, and other arthropods (e.g., amphipods, isopods). *Eurypanopeus* appears to be more of a detritovore, but commonly consumed filamentous green algae and polychaete worms (Table 3).

Discussion

Hemigrapsus was frequently found to be the most abundant brachyuran crab along rocky and cobble shores throughout eastern Long Island Sound, and was common on all of the five rocky intertidal habitats surveyed from New Haven, CT to Point Judith, RI. At two sampling locations where other crab species were nearly absent (Hammonasset, CT and Point Judith, RI), *Hemigrapsus* was very abundant (up to 98 crabs per m^2 in one quadrat). These two sites had similar characteristics, both being exposed to waves on rugged, rocky headlands. Green crabs, while broadly distributed, are not commonly found on heavily wave-washed areas along eastern North American coastlines (Grosholz and Ruiz 1996). Perhaps, a high abundance of *Hemigrapsus* contributed to the reduced numbers of green and mud crabs in these areas. The high densities of *Hemigrapsus* in exposed areas could also influence other taxa as well. Predation levels are thought to be lower on exposed shores (Peterson 1991), but the emergence of an abundant, wave-tolerant crustacean predator may have an impact on resident flora and fauna.

The crabs inhabiting the southern New England rocky intertidal zone do not appear to be partitioning space according to tidal height. All three species showed a high degree of overlap, residing predominantly in the lower half of the intertidal zone. The lack of spatial separation among the different crab species, may result in competitive and/or predator-prey interactions among them. In previous literature reports, *Hemigrapsus* had been described as an upper intertidal species (McDermott 1992; Takada and Kikuchi 1991), but this was not true of the crabs sampled in various habitats in southern New England. *Hemigrapsus* has also been collected in shallow subtidal habitats (personal observations, M. Syslo, T. Furota), though no quantitative sampling has been conducted. *Hemigrapsus* may have shifted its distribution downward after a release from competition in its native habitat. New England has a lower diversity of intertidal crabs than Japan, where *Hemigrapsus* co-occurs with up to 6 other grapsids, including the congener *Hemigrapsus penicillatus* (Fukui 1988).

For crabs, as with other intertidal organisms, subtidal regions are thought to be more benign (in terms of physical stress) than intertidal areas (Peterson 1991). *Hemigrapsus* was more concentrated in the lower intertidal during hot weather in August and cold weather in December. By moving lower down on the shore to increase submergence time, *Hemigrapsus* may avoid heat-stress and desiccation in the summer, and cold-stress and freezing in the winter. In contrast, the intertidal may be advantageous over the subtidal zone in terms of reduced competition and predation. Due to its small size, *Hemigrapsus* may avoid deleterious biological interactions by remaining in the intertidal zone. Similarly, *Carcinus* recruits and juveniles appear to use the intertidal as a refuge; after attaining 35 mm carapace width, *Carcinus* can escape most subtidal predators and move offshore (Warman *et al.* 1993; see also Fernandez *et al.* 1993 for *Cancer magister*).

In the two years after settlement, *Hemigrapsus* can reach roughly 19 mm cw, and female crabs that have overwintered just once can produce eggs (Fukui 1988). Ovigerous *Hemigrapsus* were found from June to September in eastern Long Island Sound, with sexual maturity occurring at approximately 12 mm carapace width (personal observations, 1996). We hypothesize that one year old *Hemigrapsus* are able to reproduce in southern New England. Although *Hemigrapsus* is relatively small at maximum size, it was the largest species present at some sites (New Haven, CT; Hammonasset, CT), and *Hemigrapsus* > 30 mm cw were present at all sites.

The natural diet of *Hemigrapsus* in eastern Long Island Sound is omnivorous. Calcified remnants of blue mussels, barnacles, snails, worms, and other crustaceans were found in *Hemigrapsus* stomachs, in addition to a variety of macroalgal species. The ratio of animal to plant food items for *Hemigrapsus* was roughly 50:50 (Fig. 4). *Carcinus, Eurypanopeus*, and *Hemigrapsus* ate similar food items, but apparently ate the food items in different proportions (e.g., *Carcinus* focused almost exclusively on the animal food items, while *Eurypanopeus* consumed a relatively large amount of detritus). It is clear that *Hemigrapsus* acts as a predator on a variety of invertebrates in the intertidal zone. Due to direct effects on commercial shellfish populations (e.g., blue mussels) and/or interactions with another known shellfish predator (the green crab), *Hemigrapsus* appears to have the potential to cause substantial ecological and economic impacts along the coastline of New England.

Conclusions

The Japanese shore crab (*Hemigrapsus sanguineus*) has successfully invaded the southern New England coastal zone Our studies indicate it is often the most abundant crustacean predator of rocky intertidal habitats throughout the north shore of Long Island Sound The crab feeds upon a variety of resident organisms (both invertebrates and macroalgae) It also may be directly competing with and/or preying upon other crabs, particularly green (*Carcinus maenus*) and mud (*Eurypanopeus depressus*) crabs, thereby altering the distribution and abundance of these species The management of natural and harvestable resources in Long Island Sound is an important goal of both the public and private sector (e.g , Long Island Sound Study 1994), and the introduction of *Hemigrapsus sanguineus* potentially threatens this goal

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Literature Cited

Batie, R E. 1982. Population structure of the crab *Hemigrapsus oregonensis* (Brachyura, Grapsidae) in Yaquina Bay Estuary, Oregon II. Vertical distribution, biomass, and production. *Northwest Sci* 56(3) 241-249

Beck, M.W 1995 Size-specific shelter limitation in stone crabs a test of the demographic bottleneck hypothesis *Ecology* 76(3): 968-980.

Depledge, M. H., 1984. Cardiac activity in the intertidal crab *Hemigrapsus sanguineus* (de Haan). *Asian Mar. Biol.* 1. 115-123.

Eggleston, D B. 1990. Functional responses of blue crabs *Callinectes sapidus* (Rathbun) feeding on juvenile oysters *Crassostrea virginica* (Gmelin): effects of predator size, and prey size. *J. Exp Mar. Biol. Ecol* 143: 73-90.

Elton, C.S. 1958. *The Ecology of Invasions by Animals and Plants* Methuen and Co., Ltd., London. 181 pp.

Fernandez, M., Iribarne, O., and D. Armstrong. 1993. Habitat selection by young-of-the-year Dungeness crab *Cancer magister* and predation risk in intertidal habitats. *Mar. Ecol. Prog. Ser.* 92(1,2). 171-177.

Fukui, Y. 1988. Comparative studies on the life history of the grapsid crabs (Crustacea, Brachyura) inhabiting intertidal cobble and boulder shores. *Publ. Seto Mar. Biol. Lab.* 33: 121-162.

Grosholz, E.D. 1996. Contrasting rates of spread for introduced species in terrestrial and marine systems. *Ecology* 77: 1680-1686.

Groshotz, E.D., and G.M. Ruiz. 1996. Predicting the impact of introduced marine species. Lessons from the multiple invasions of the European green crab *Carcinus maenus*. *Biol. Conserv.* 78: 59-66.

Harbison, G.R., and S.P. Volovik. 1994. The ctenophore, *Mnemiopsis leidyi*, in the Black Sea: a holoplanktonic organism transported in the ballast water of ships. In *Nonindigenous and Introduced Marine Species*. US Dept. of Commerce. Government Printing Office, Washington, D.C. pp 25-29.

Hebert, P.D.N., Wilson, C.C., Murdoch, M.H., and R. Lazar. 1991. Demography and ecological impacts of the invading mollusc *Dreissena polymorpha*. *Can. J. of Zool.* 69: 405-409

Hines, A.H. 1982. Coexistence in a kelp forest: size, population dynamics, and resource partitioning in a guild of spider crabs (Brachyura, Majidae). *Ecol. Monog.* 52: 179-198.

Kaiser, M.J., Hughes, R.N., and D.G. Reid. 1990. Chela morphometry, prey-size selection and aggressive competition in green and red forms of *Carcinus maenus* (L.). *J. Exp. Mar. Biol. Ecol.* 140: 121-134.

Lafferty, K.D and A. M. Kuris. 1996. Biological control of marine pests. *Ecology* 77: 1989-200.

Lee, S.Y., and R. Seed. 1992. Ecological implications of cheliped size in crabs: some data from *Carcinus maenus* and *Liocarcinus holsatus*. *Mar. Ecol. Prog. Ser.* 84: 151-160.

Long Island Sound Study. 1994. The comprehensive conservation and management plan. Office of Long Island Sound Programs, Hartford, CT.

McDermott, J. J. 1991. A breeding population of the Western Pacific crab *Hemigrapsus sanguineus* Crustacea: Decapoda: Grapsidae) established on the Atlantic coast of North America. *Biol. Bull.* 181:195-198.

McDermott, J. J. 1992. Biology of the Western Pacific crab, *Hemigrapsus sanguineus*, living along the mid-Atlantic coast of the United States. *Amer. Zool.* 32: 73A

McDermott, J. J. 1994. Geographical distribution of a Western Pacific brachyuran crab, *Hemigrapsus sanguineus*, along the east coast of the United States. In *Toward a Sustainable Coastal Watershed: The Chesapeake Experiment. Proceedings of a conference*. Chesapeake Res. Cons. Pub. No. 149.

Nichols, F.H., Thompson, J.K., and L.E. Shemel. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. II. Displacement of a former community. *Mar. Ecol. Prog. Ser.* 66: 95-101

Osman, R.W. and R.B. Whitlatch. 1995d. Ecological factors controlling the successful invasion of three species of ascideans into marine subtidal habitats of New England. pp. 49-60. In *Proceedings of the Northeast Conference on Nonindigenous Aquatic Nuisance Species*. N. Balcom,ed. Connecticut Sea Grant College Program

Peterson, C.H. 1991. Intertidal zonation of marine invertebrates in sand and mud. *Amer. Sci.* 79:236-249

Ropes, J.W. 1989. The food habits of five crab species at Pettaquamscutt River, Rhode Island. U.S. Nat. Marine Fisheries Serv., *Fish. Bull.* 87(1):197-204.

Takada, Y. and T. Kikuchi. 1991. Seasonal and vertical variation of the boulder shore fauna in Amakusa. *Publ. Amakusa Mar. Biol. Lab* 11: 1-17.

Warman, C.G., D.G. Reid and E. Naylor. 1993. Variation in the tidal migratory behaviour and rhythmic light responsiveness in the shore crab, *Carcinus Maenus*. *J. Mar Biol. Ass.* U.K. 73: 355-364.

Weiss, H.M. 1995. *Marine Animals of Southern New England and New York*. State Geological and Natural History Survey of Connecticut. CT Department of Environmental Protection. U.S.A.

Williams, A. B., and J. J. McDermott. 1990. An Eastern United States Record for the Western Indo-Pacific Crab, *Hemigrapsus sanguineus* (Crustacea: Decapoda : Grapsidae). *Proc. Biol. Soc. Wash.* 103: 108-109.

Williamson, M. 1996. *Biological Invasions*. Chapman and Hall. 256 pp.

Aquatic Policy

Developing a State Aquatic Nuisance Species Management Plan

Timothy J. Sinnott New York State Department of Environmental Conservation, Room 576, 50 Wolf Road, Albany, New York 12233-4756

Zebra mussels first appeared in the New York waters of Lake Erie in the Fall of 1989 Immediate concern was expressed by the recreational boating community of Eastern Lake Erie, and by power generating stations that drew cooling water from Lake Erie, and from the Niagara River

The New York State Department of Environmental Conservation is a single agency charged with the dual missions of environmental quality and natural resource protection Environmental Quality issues are managed by the Division of Air, Division of Water, Division of Solid and Hazardous Materials, and the Division of Environmental Remediation Natural Resources are managed by the Division of Lands and Forest, Division of Mineral Resources, and the Division of Fish, Wildlife and Marine Resources. The initial responsibility for responding to the invasion of New York waters by zebra mussels was shared between the Division of Water (DoW) and the Division of Fish, Wildlife and Marine Resources (DFWMR)

The immediate issue for the DFWMR was responding to the concerns raised by boaters Within the DFWMR, the Bureau of Fisheries responded immediately by developing a "Tip Strip" brochure. This one page handout told boaters how to protect their boats and engines from zebra mussel impacts, and perhaps more importantly, what boaters can do to keep from spreading zebra mussels inland.

The immediate issue for the DoW was managing a potentially large influx of emergency requests for SPDES permit modifications that would allow for the discharge of chemicals used to protect cooling water systems, service water systems, and industrial processes using raw water from zebra mussel colonization The Bureau of Environmental Protection (BEP) is also a bureau within the DFWMR. Originally charged with fish and wildlife habitat protection, the mission of BEP has expanded to encompass standards and criteria development, risk assessment, and review of any activity that could potentially impact fish, wildlife, or ecosystems of the state BEP worked with DoW to develop the "Generic SPDES Permit Modification for Zebra Mussel Control Treatments" procedure. Three chemical treatment programs were intensively studied: chlorine; bromine; and surfactants For each treatment, environmentally protective parameters such as: chemical concentration in treated effluent water, how frequently treatments could occur; how long treatments could last; size of mixing zones; etc , were developed If a permit applicant would abide by all of the recommended treatment parameters, the applicant could receive a SPDES permit modification to allow for zebra mussel control treatments almost immediately One treatment required that a caged fish study be conducted at least once. A protocol for conducting the caged fish study as well as statistical analysis procedures were provided. In addition to this procedure, BEP worked closely with industry and power generators alike to encourage experimentation with new treatment processes while still providing for comprehensive protection of aquatic ecosystems.

In 1990, Congress passed Public Law 101-646, the "Aquatic Nuisance Prevention and Control Act of 1990." This law, among many other things, established that the federal government would fund 75% of the activities conducted by states to prevent and control the introduction of nonindigenous aquatic nuisance species (ANS) and to mitigate the adverse impacts of those already introduced, providing that the state had a federally-approved state management plan. In July 1991, the New York State legislature passed Chapter 456 of the Laws of 1991, which tasked the Department of Environmental Conservation to develop the "state management plan" as described in the Aquatic Nuisance Prevention and Control Act of 1990.

The responsibility for addressing nonindigenous aquatic nuisance species did not clearly "fit" into the mission of any particular bureau within the Department of Environmental Conservation. However, because BEP had developed expertise with zebra mussels when working on the Generic SPDES Permit Modification for Zebra Mussel Control Treatments procedure, the mission of writing the state ANS management plan fell to the BEP.

At about the same time, there was a great deal of concern within the DFWMR about the skills and training of the staff outside of the typical areas of biology and ecology. Primarily at the instigation of the Assistant Division Director, Gerald A. Barnhart, DFWMR had begun a staff training program with concentrations in three areas: Comprehensive Management; Communications and Citizen Participation; and Negotiation and Litigation. As a result of having just completed this training, BEP staff utilized a comprehensive management approach to the project, and decided that a full slate of citizen participation was required to develop an effective, meaningful plan.

Because BEP staff had no clear idea of how to address nonindigenous ANS management, an ad hoc committee was created. The ad hoc committee was drawn from different groups, agencies, and organizations that had interest or experience with, or had otherwise been impacted by zebra mussels. Members of the committee represented the following groups: Great Lakes Research Consortium; Monroe County Water Authority; Rochester Water Bureau; New York State Power Pool; U.S. Fish & Wildlife Service; New York State Department of Health; Great Lakes United; New York Sea Grant; New York City Bureau of Water Supply; New York State Museum Science Service; and the NYSDEC Bureau of Fisheries Public Access Section. This committee met and laid out the basic goals and objectives that the plan should achieve. A draft was prepared and submitted to the ad hoc committee for review. The draft was revised based on comments received, and re-submitted both to the ad hoc committee and to a larger group of primarily state agencies. After recommendations by this review group were accommodated, the availability of the draft plan was announced to the public and copies were sent out as requested. Fifty-one comments were received during the public review period. Those comments were recorded and appended to the document in a responsiveness summary. The final plan was submitted to the Federal Aquatic Nuisance Species Task Force where it was approved in March 1994.

The plan identified four goals:

I. Reduce the potential for future introductions of nonindigenous aquatic species into New York Waters;

II. Reduce the potential for nonindigenous aquatic species that have been introduced into New York waters to spread into uncolonized waters;

III. Minimize harmful ecological, economic, and social impacts resulting from nonindigenous aquatic organisms that have already been introduced or are proposed for introduction into the waters of New York State;

IV. Educate the public on the importance of preventing nonindigenous aquatic species introductions, and how the harmful impacts of nonindigenous aquatic species can be reduced or mitigated.

For each goal, several related objectives are identified along with problems related to accomplishing the goals and objectives, and actions to overcome the problems. The plan also describes the role of federal, state, and municipal governments in accomplishing the goals and objectives. As required by P.L. 101-646, the plan also described annual objectives for a three-year program along with the staff and budget required to implement the plan.

Although the plan was approved, and federal funding was authorized for approved state plans, very little money to actually do this had been appropriated by the federal government. However, $68,000 was given to New York State to begin implementation of the state Nonindigenous Aquatic Species Comprehensive Management Plan. As of May 1997, approximately 2/3rds of the grant money has been expended. Projects undertaken include purchasing videos for staff use, providing brochures and warning signs for distribution to the public, and studies of the ecosystem impacts of zebra mussels in inland lakes. An ambitious project currently in progress is funding a high quality aquatic nuisance species display in the New York State Museum. Although the money provided fell short of the budget requirements in the plan, it has provided an excellent start for implementing the New York State ANS management program.

Decontamination Procedures for Sampling Equipment: Preventing the Spread of the Zebra Mussel

Jeffrey Schloss Cooperative Extension System, University of New Hampshire 108 Pettee Hall, Durham, New Hampshire 03824

The zebra mussel, a non-native freshwater mollusk that has successfully invaded a host of lakes and rivers throughout northeastern and central North America, continues its expansion towards New Hampshire. These tenacious little shellfish have caused millions of dollars worth of trouble in the Great Lakes region of the US and Canada and in the central states. More recently, they have impacted water suppliers and a federal fish hatchery on Lake Champlain in neighboring Vermont. With this nuisance aquatic species approaching our borders it has become increasingly important that we take great care to prevent the inadvertent spread of these and other non-native species by following the proper decontamination protocols as we conduct our field sampling and surveys throughout the state and region. The information compiled below can be used as a guide to design decontamination protocols appropriate for the specifics of how you sample and the particular sampling equipment you use.

Developing a Proactive Strategy

While we may not yet have any confirmed infestations of the zebra mussel in New Hampshire, we have made a preliminary estimate of the most susceptible water bodies in the state (see the UNH Cooperative Extension fact sheet "The Zebra Mussel Threat to New Hampshire"). While working on these waters, the highest degree of precautions are taken before and after we sample. Areas that receive a high amount of boat launchings, or are known to attract boaters from known infested areas in other states, are also be prioritized as susceptible and handled accordingly. For these situations as well, a more intense effort in decontamination is made. For other waters not thought to be at risk, decontamination procedures are followed but less effective alternatives can be considered to be adequate. Even if we perceive little danger of zebra mussel transfer or infestation, decontamination of field equipment and vehicles is still warranted as it may prevent the next non-native nuisance aquatic species from taking hold.

When possible, we sample the least likely sites to be infested before the most likely sites to reduce the risk of accidental infestation or facilitating the spread of non-native species. If sampling is being performed to determine whether zebra mussels are present at a given site (as a response to a potential siting) we assume that they are present and use the most rigorous decontamination protocol practical.

Field Equipment Decontamination

Typical field equipment that may be fouled by adult or larval forms of non-native species include nets, traps, boats, marker buoys, grab samplers, corers, water samplers, lines, cables and anchors. Other, less obvious items include wet and dry suits, diving gear, fishing gear, life jackets, waders, boots and clothing that contacts the water. In all cases decontamination before moving to another location is preferred.

Try to remove any stray lines, pads or bumpers, carpets and other materials from boats and trailers that could trap tiny mussels and larvae before you go into suspected waters. All field equipment should be visually surveyed with particular attention to cracks and crevices, hinges, compartments (live-wells, bilge) and the treads of boots and waders. All visible mussels and plant materials should be removed and destroyed. Bilges, live-wells and other containers should be emptied before leaving the site.

Field equipment should then be cleaned by soaking in, dipping in, or scrubbing with one of the disinfectant solutions listed in Table 1 below, following the protocols described. Compartment areas, inboard/outboard cooling systems and containers should be filled, flushed or wiped with disinfectants. If none of the disinfectants listed are compatible with the material to be cleaned (refer to Table 2 for compatabilities), or if disinfection is not practical or possible, one of the other treatments (heat, freezing, pressure washing, mechanical removal or dessication) listed and described in the order of preference as an alternative in the protocol section that follows should be employed. When decontaminating in the field, take care not to release any wash or disinfectant where it may re-enter into the water body. Bring along any containers needed for collecting this wash material and dispose of properly upon return.

Decontamination Protocols

Chemical Disinfectants

Chemical disinfectants should be used away from the water body so as not to impact other organisms. Table 1 represents a summary of the current state of knowledge pertaining to zebra mussel control. Considerations as to the practicality of the use of a certain chemical will be primarily dependent on the material characteristics of the equipment (see Table 2) and the time / location practicality of the sampling situation.

Table 1. A summary of the chemical disinfectants effective for zebra mussel control.

CHEMICAL	NOTES/TRADE NAME	CONCENTRATION	MINIMUM EXPOSURE TIME*
Salt Solution (NaCl)	use iodized salt only	saturated	30 minutes
	for transporting fish	1.0% (10,000 mg/L)	24 hours
Ethanol		> 50%	3 minutes dip w/ agitation
Phenol-based products	Lysol	full strength	3 minutes dip w/ agitation
Sodium Hypochlorite > 5% solution	CLOROX or other "full strength" household bleach	500 ml to make 10 liters OR 3 fl. oz. for 5 gallons	1 hour
		1 liter to make 10 liters OR 6 fl. oz. for 5 gallons	30 minutes
Potassium Chloride**		0.02% (200 mg/L)	3 hours
	for transporting fish	0.25% (2,500 mg/L)	24 hours
Benzalkonium Chloride**		0.001% (10 mg/L)	24 hours
		0.01% (100 mg/L)	3 hours
		0.025% (250 mg/L)	15 minutes

* Times for treatments at 25 °C; use longer times for cooler conditions.
** Chemicals already used and approved for aquaculture.

Heat

Autoclaving or steam cleaning of heat resistant contact surfaces is the preferred method when possible and practical. At least three minutes of application time should be maintained unless visible signs of mussel clusters are present, in which case 10 minutes of contact time at full heat is recommended.

Hot water washing / soaking at 110 ° F (44 °C) for at least five minutes under constant water spray, or 10 minutes if soaking, is the next best treatment to destroy larval zebra mussel forms. For adult infestations, the temperature should be at least 140 °F (60 °C). Allow surfaces to dry after treatment.

Freezing

At 0 to 10 °F (or -10 to -15 °C), larval and adult mussels will be destroyed within two (larval) to four (adult clusters) after target temperature is reached.

High Pressure Washing

Hot (best) or cold water pressure washing of hard surfaces can be effective at removing and destroying attached mussels.

Mechanical Crushing / Removal

Scrubbing surfaces, cables, and lines is recommended in conjunction with other treatments to ensure success. Alone, it may not be effective for the microscopic larvae.

Desiccation

Air drying should only be used as a last resort. Success will be dependent on temperature, humidity, and the available protective "nooks and crannies" that the zebra mussels can hide in. Under optimal conditions (warm temperatures, sunny weather, low humidity), two days of drying may be sufficient for hard surfaces, three to four days for nets and seines. Five to seven days are generally recommended for greater confidence of mortality, but up to two weeks may be required under less than optimal conditions.

Table 2. Resistance properties of various materials to zebra mussel decontamination methods.

TREATMENT	SS/Al	LEX	PG	PVCs	PVCt	FG	NYL	PP	PC	Si	NP
Salt Solution (NaCl)	*	*	*	*	*	*	*	*	*	*	*
Ethanol	*	+	N	N	N	N	N	+	+	*	N
Phenol-based Products	*	N	N	–	~	N	N	N	N	*	N
Sodium Hypochlorite	*	~	N	+	~	N	N	~	~	N	N
Potassium Chloride	*	*	*	*	*	*	*	*	*	*	*
Benzalkonium Chloride	*	*	N	*	*	*	*	*	*	*	*
Heat-Steam/Autoclave	*	*/N	N/N	N/N	N/N	N/N	N/N	*/*	*/N	*/*	N/N
Heat - Hot Water	*	*	~	*	*	~	*	*	*	*	*
Freezing	*	*	*	*	*	*	N	N	*	*	*

* = High Tolerance / No effect
+ = Little or no damage, dependent on contact time / conditions
~ = May cause stress / weakening, dependent on contact time / conditions
N = Not recommended, will damage

SS/Al = Stainless Steel; LEX = Lexan (Polycarbonate); PG = Plexiglas (Polymethyl-acrylate); PVCs - solid PVC (Polyvinyl chloride); PVCt = PVC tubing; FG = Fiberglass; NYL = Nylon polyester; PP = Polypropylene; PC = Polycarbonate; Si = Silicone; NP = Neoprene