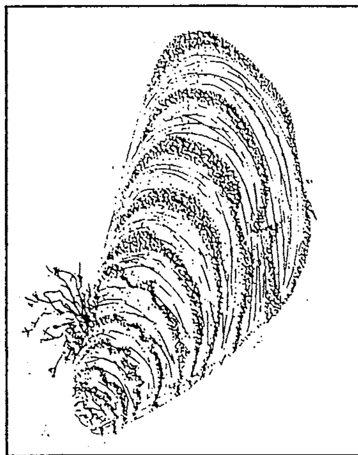
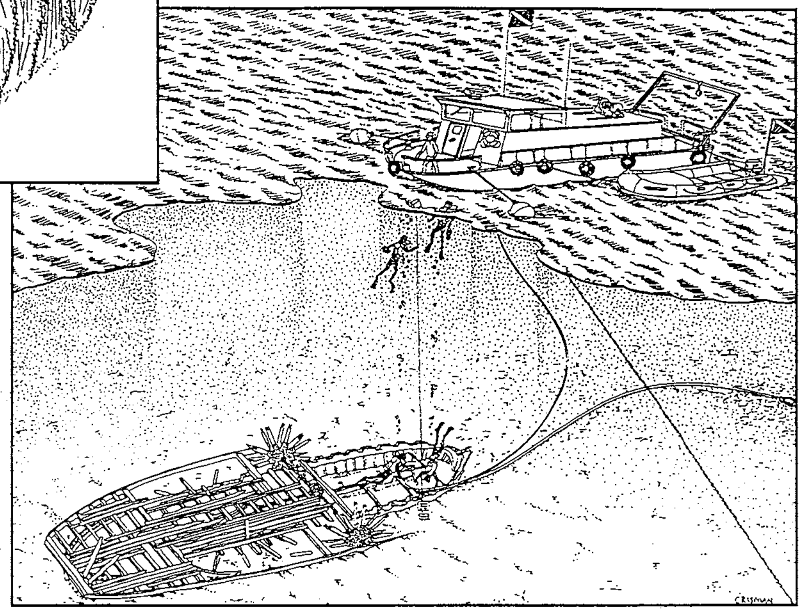
Lake Champlain
Basin Program





Zebra Mussels and Their Impact on Historic Shipwrecks

Prepared by the
Lake Champlain Maritime Museum

Art Cohn, Project Director
with contributions by
Laurie Eddy, Lee Petty, and Erick Tichonuk

For
Lake Champlain Management Conference
January 1996

PUBLICATION SERIES

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Basin Prog. Temp.

TABLE OF CONTENTS

List of Illustrations

FIGURES

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Zebra Mussels and Their Impact On Historic Shipwrecks

EXECUTIVE SUMMARY: ARTHUR COHN, SEPTEMBER 18, 1995

Five years ago hardly anyone in this region had heard of zebra mussels. Today "zebra mussel" has become a household word, and their status in our environment is changing rapidly. Since the enclosed report was drafted, zebra mussels have appeared in siginifcant numbers on many of Lake Champlain's shallow water shipwrecks, and it is now possible to walk down to North Harbor and collect zebra mussels from rocks or native clams anytime we want to replenish our stock for our laboratory exhibit. This summer for the first time, swimmers around the lake cut their feet on zebra mussels and, as a consequence, bought protective footwear.

The Lake Champlain Maritime Museum has joined with officials from the Vermont Department of Environmental Conservation in its Veliger Monitor Program. Through grant support from the Lake Champlain Basin Program and the Lake Champlain Partnership program, five new data collecting sites have been established at shipwreck locations, and a publicly accessible veliger analysis laboratory has been established at the LCMM. A laboratory technician/educator has been funded for the season, providing a significant public outreach capability. That is the good news.

The bad news is that since 1994, veliger counts lakewide have increased exponentially and adult zebra mussels are being seen in large numbers in many places for the first time. Our analysis suggests that there is currently no cost effective technology to prevent or control the colonization of zebra mussel on shipwrecks. We do, however, make the following recommendations:

- We recommend the accelerated, systematic survey and inventory of Lake Champlain. This remains our primary action item to insure that valuable information about our submerged cultural resources is not lost. This lake-wide survey will provide baseline imaging of Lake Champlain prior to full zebra mussel infestation and track the changes in the Lake situation over time. The Maritime Museum is willing and able to be the coordinating institution for this survey, however, funding is an issue. We recommend continued funding through the Lake Champlain Basin Program, or other appropriate agencies, and expect that a number of private foundations would fund such a project. This survey would involve many partners, including the states of New York and Vermont Divisions for Historic Preservation and Geological Survey offices. We expect to work in cooperation with all research institutions in the Champlain Valley region, such as the State University of New York, University of Vermont, and Middlebury College. There are also several potential federal partners, including the National Park Service and the National Oceanic and Atmospheric Administration (NOAA). In addition to the substantial amount of irreplaceable information about history, this accelerated lake-wide survey will yield valuable information in a variety of scientific disciplines, including archaeological, geological, hydrographic and bathometric data.

•We recommend the continuation of the veliger monitoring programs, as well as programs aimed at educating the public about zebra mussel issues - particularly what can be done to slow their spread.

•We recommend that while appropriately developing a Lake Champlain approach to the problem, we continue to evaluate new control methods, and conduct experiments to explore promising options, including the feasibility of experimental encapsulation of an historic vessel in silt.

•We recommend continued efforts by the LCMM to develop a cooperative program with researchers from the Parks Canada Historic Resource Conservation Branch to determine the degree to which zebra mussels may cause the degradation of submerged cultural resources.

•We recommend the continued collection of statistical and economic data about the use of submerged cultural resources and the relationship of this use to positive economic stimulus in a community. In addition, forecasting of economic impacts related to zebra mussels should be evaluated.

Introduction

Zebra Mussels

First observed in Russia in 1770, zebra mussels *(Dreissena polymorpha)* survived the trans-oceanic journey to North America in 1987 in a new high speed vessel. Once introduced into the favorable ecosystem of the Great Lakes they have flourished, and they have continued to spread with alarming efficiency. Zebra mussels require a certain range of temperature, salinity, calcium, dissolved oxygen, water movement and pH in order to successfully colonize. Because Lake Champlain's water has these characteristics, it provides an ideal environment for the colonization.

Carol Allaire

Zebra Mussel (dreissena polymorpha) shown here with byssal fibers which allow them to attach to hard surfaces.

Zebra mussels are prolific breeders, which attach to submerged hard surfaces with "byssal threads." These threads are extraordinary in their adhesive properties. Zebra mussels are also remarkable filter feeders, and one result of their presence is clearer (though not necessarily cleaner) water. They also can move contaminants found in the water column to the sediment surface. Zebra mussels are having wide-ranging impacts on other creatures both up and down the food chain, and devastating impacts on the water intake pipes of power and water plants. This report will focus on predicting impacts on historic shipwrecks.

Shipwrecks in Lake Champlain

The Lake's long, navigable character and North-South orientation resulted in its active use as one of the vital links in the historic chain of inland transportation until the 20th century when the bulk of this through-lake activity ceased. The legacy of 18th and 19th century wooden watercraft, however, may represent the best preserved collection of shipwrecks in North America. As early as the mid 19th century, history buffs removed historic hulks from the lake for a variety of reasons. In 1935, Colonel Lorenzo Hagglund raised the Revolutionary War gunboat *Philadelphia*, which now resides in the Smithsonian Institution, as a rare survivor of this removal activity.

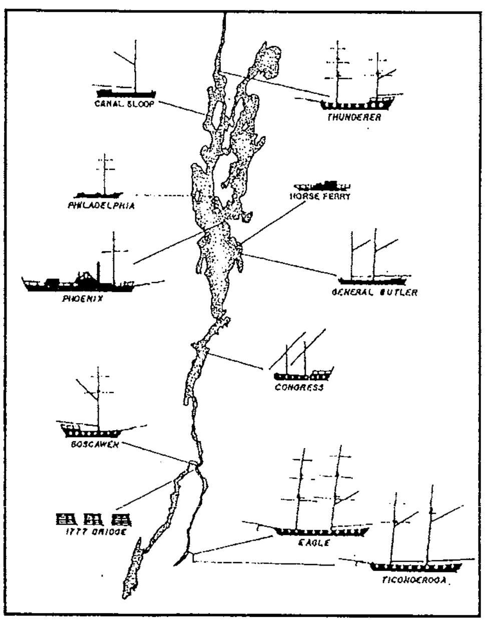
In recent times, researchers have used improved survey technology to locate, and nautical archaeology to document underwater sites in-situ.

*Raising the **Philadelphia**, 1935*

This effort has resulted in the study of a large number of exceptional submerged sites which include the British sloop, *Boscawen* (1759), The Revolutionary War Great Bridge (1777), The U.S. Brig *Eagle* (1814), the steamboat *Phoenix* (1815), the only known surviving turntable style horse-powered ferry (c.1825) and the canal schooner *General Butler* (1862). These examples are representative of only a fraction of the vast cultural wealth which lies beneath the waters of Lake Champlain. It is fair to say that, at the time of this writing, the bulk of submerged cultural sites remain unlocated and undocumented on the bottom of Lake Champlain.

FOCUSING ON ZEBRA MUSSELS AND THEIR IMPACT ON HISTORIC SHIPWRECKS

In February of 1995, the Lake Champlain Basin Program commissioned the "Zebra Mussel Impact Study and Protection Plan" and contracted the Lake Champlain Maritime Museum to implement the study. A major strategy of the study's fact-finding effort was to send a team from the Maritime Museum to Toronto, Canada to attend the Fifth International Zebra Mussel Conference:1995. This intensive immersion into the world of zebra mussel research, along with reviews of relevant literature, and follow-up phone conferences with literally dozens of principal investigators, is the basis of this report. The report is divided into three sections: **The Invasion of the Zebra Mussel, Impacts of Zebra Mussels On Historic Shipwrecks, and Control of Zebra Mussels.**



Kevin Crisman

Lake Champlain shipwrecks.

SECTION 1

The Invasion of the Zebra Mussels in Lake Champlain

HOW FAR HAVE ZEBRA MUSSELS INVADED LAKE CHAMPLAIN?

Dreissenid mussels, Dreissena polymorpha (zebra mussels) and Dreissena bugensis (quagga mussels) are among the 10% of about 1,400 invading exotic species that have successfully established themselves in North America (Leach, 1995). Based on the proliferation rate of zebra mussels and the rapid spread from their point of introduction in 1987 in Lake St. Clair, throughout the Great Lakes, to the St. Lawrence, Mississippi, Illinois, Ohio, Cumberland, Tennessee, Monongahela, and Hudson River systems, and an increasing number of inland lakes, they are perhaps the most successful of all invading species. (Figure 1)

First discovered in the southern portion of Lake Champlain in the summer of 1993, adult mussels expanded their range to locations throughout the entire length of the Lake by November 1994. While adult densities remained highest south of West Addison, VT, adult zebra mussels have been identified as far north as Windmill Point near Alburg, and in numerous locations in bays and harbors on both the Vermont and New York shores. No adults were reported in 1994 in the northeastern arm of the Lake or in Malletts, St. Albans or Missisquoi Bays (Kamman, 1994). In July 1995, the VT DEC reported larval densities south of Crown Point ranging from 60,000-109,000 veligers/cubic meter compared to 1,500-3,900 veligers/cubic meter in the same area the previous year. Adult zebra mussel colonies south of Crown Point were reported "quite dense" as evidenced by the single layer of 10 mm size adults covering 80% of the Crown Point Monument dock (Stickney, 1995).

WHY ARE THE DREISSENID SPECIES SUCH SUCCESSFUL INVADERS?

First, the zebra mussels veliger larvae are microscopic in size and passively spread by wind, water currents, and other animals including humans. They can also travel by "rafting" on flotsam, macrophytes, and boats, and by "bubble flotation" (Claudi and Mackie, 1994). Even after initial settlement, the juveniles can release their byssal attachments and "drift" by gliding on surfaces or by floating attached by a single long byssal thread ("thread drifting") (Claudi and Mackie, 1994). Adult zebra mussels have also occassionally been observed translocating, especially during the fall and winter. This variety of effective dispersal mechanisms assures continuous rapid spread of zebra mussels to new areas. Dispersal potentials coupled with the variable length of larval development (up to 5 weeks in water column) can account for a range extension rate of 250 km/year (Claudi and Mackie, 1994).

Adult Dreissenid body design gives maximum protection from predators. The shape of the zebra mussel's hard shell with its convex ventral edge enables it to attach tightly against firm substrates. Its laterally placed umbow gives maximum upright stability; its dorsally tapered shell and strong attachment by hundreds of byssal threads make it difficult for predators to pry the adults loose.

Adult zebra mussels are not only tenacious, they are also prolific. A female may produce a million eggs in her two-year life span. Metamorphosis from fertilized egg to adult can take from 8-240 days depending on water temperature (Nichols, 1995). The average growth rate of adults is 0.10-0.15 mm/day (15-20 mm/year) (Claudi and Mackie, 1994). Once a mussel has grown to a 5-6 mm shell size, it is considered to be sexually mature (Nichols, 1995). Zebra mussels can reproduce in their first year if they settle early enough and conditions are optimal. Spawning may last from 3-5 months each year in temperate latitudes. Provided environmental requirements are met, small populations of adult zebra mussels can expand into huge colonies (up to 1,000,000/m^2) in a few year's time (Claudi and Mackie, 1994).

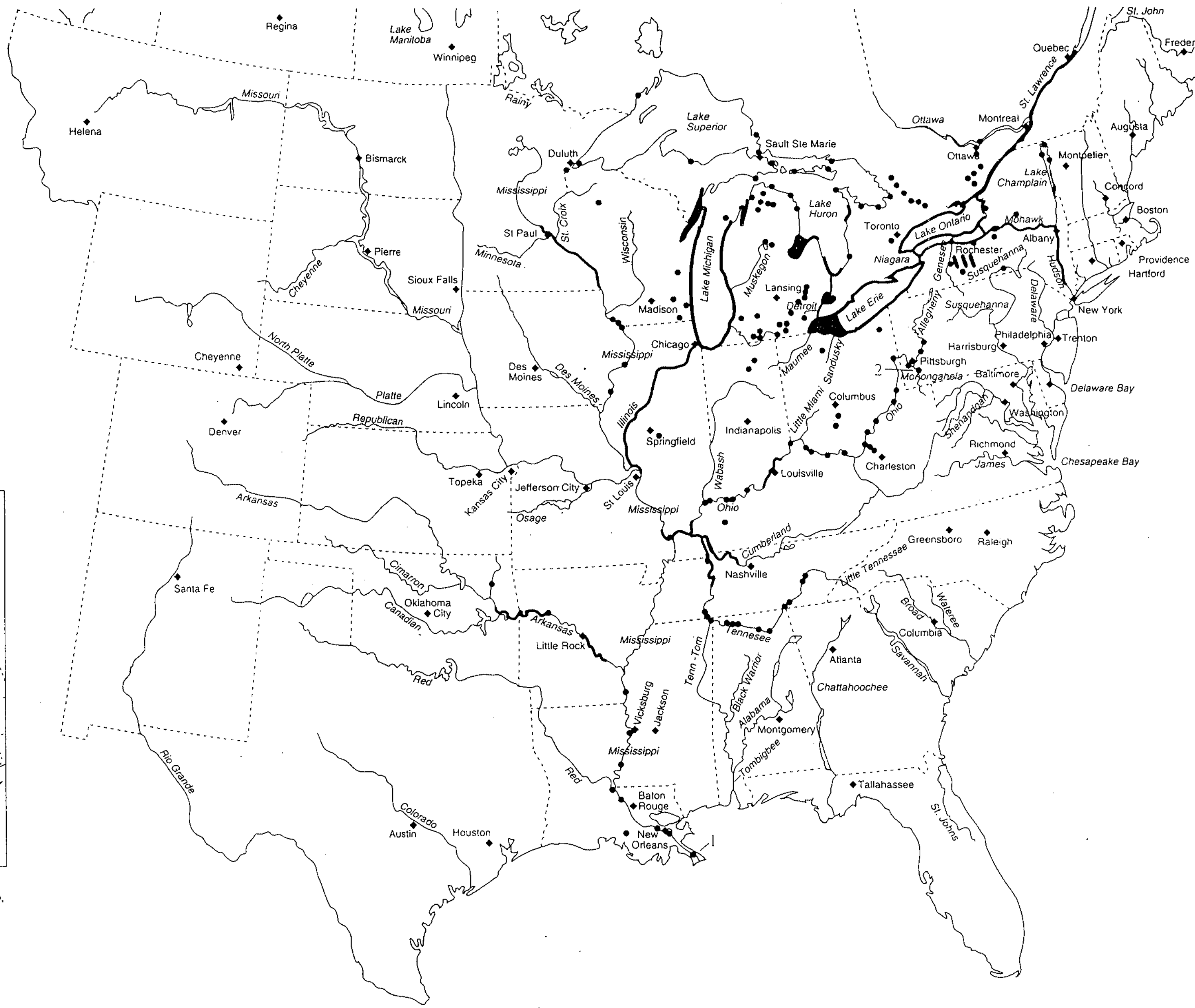
Zebra mussels are adapted physiologically for accessing both pelagic and benthic food sources. They can siphon feed by filtering water at a rate of 10-100 ml/individual/hour, removing particles as small as .07 micrometers (Claudi and Mackie, 1994). They are able to utilize bacteria for nutrients as well as pelagic phyto- and zooplankton.

SIGHTINGS

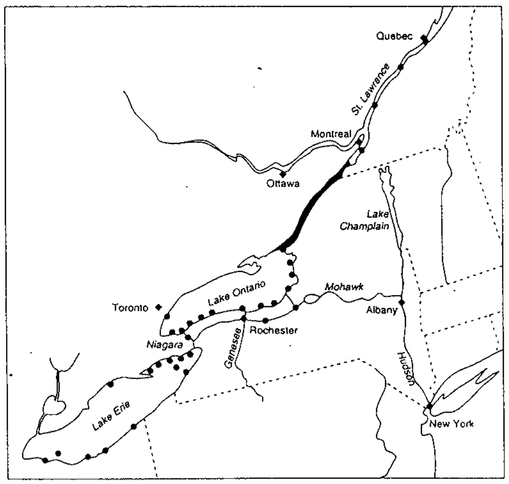
North American Range of the Zebra Mussel
as of 15 May 1995

Compiled by New York Sea Grant with information from: Empire State Electric Energy Research Corp., Fisheries and Oceans Canada, Great Lakes Sea Grant Network, Illinois Natural History Survey, Ontario Hydro, Ontario Ministry of Natural Resources, Tennessee Valley Authority, US Army Corps of Engineers, US Fish & Wildlife Service, and Utilities and others throughout North America.

Sightings:
1. Grande Pass, Mississippi River, Venice, LA
2. Monongahela River Mile 11.2, Braddock, PA



North American Range of the Quagga Mussel
as of 30 September 1994



Sightings:
Quagga mussels have been confirmed in the Mississsippi River between St. Louis, MO, and Alton, IL.

Figure 1

Figure 2

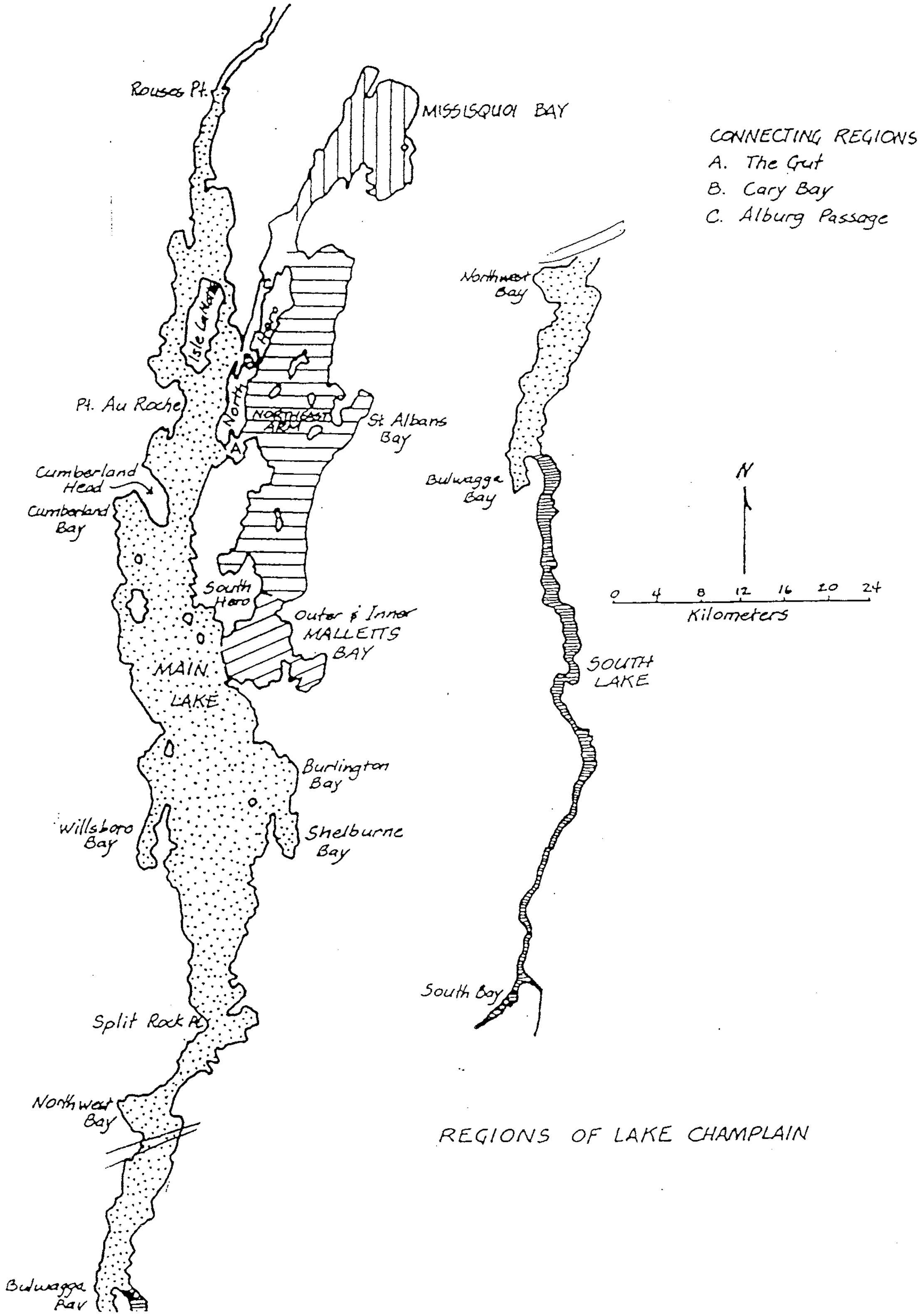


Figure 2. The five major basins of Lake Champlain (from Myer and Gruendling 1979)

From: Watzin, M.C. 1992. "A research and monitoring agenda for Lake Champlain: proceedings of a workshop", December 17-19, 1991, Burlington, VT. Lake Champlain Basin Program Report No. 1.

Nichols reports that recent studies indicate that zebra mussels can also feed directly from the benthos through their mantle opening (1995).

Zebra mussels are highly adaptable. They can acclimate to and tolerate a wide range of conditions. While zebra mussels will attach to any non-toxic hard substrate, Paul Berkman (1995) reports that they have also been found to be "fairly extensively distributed on soft substrates" in the western basin of Lake Erie by building their own substrate of sand grains and byssal threads. Adults are known to tolerate starvation, dessication, hypoxia, and freezing (Chase, Matthews, McMahon, Payne, et.al.). Peter Fong (1995) has observed that zebra mussels gradually build a tolerance to salinity, as indicated by their appearance in river estuaries, perhaps in response to rapid genetic selection .

Taken together, Dreissena's unique structural and physiological characteristics enable this species of mollusk to successfully invade and dominate new ecosystems.

How vulnerable is Lake Champlain to invasion by zebra mussels ?

In any body of fresh water, the magnitude of a Dreissenid invasion will be largely determined by the physical and chemical condition of the water supply. To assess the ability of zebra mussels to survive or flourish in Lake Champlain, one must compare the threshold tolerance factors of zebra mussels with annual variations of the same factors in the Lake. A good historical data base of chemical and physical characteristics of the Lake of 2-5 years is desirable. The findings of the Vermont Lay Monitoring Program (1979- present), the Lake Champlain Diagnostic Study (1990-1991) and the Lake Champlain Lakewide Monitoring Project (1992-present), which employ co-located stations and standard methods provide statistically valid data to draw upon.

Even so, such a comparison in Lake Champlain is complex. Lake Champlain is a diverse body of water composed of five major basins (South Lake, Main Lake, Malletts Bay, Northeast Arm, and Missisquoi Bay) each of which has its own distinct chemical and physical features and seasonal fluctuations. Whenever possible, each area should be considered separately on the basis of its own unique data. (Figure 2)

As previously mentioned, Dreissenids as a group are highly adaptable and changeable. Although they have very well-defined environmental needs and preferences, they are capable of tolerating a wide range of conditions outside those norms. They have a proven ability to gradually acclimate to conditions beyond their normal range of tolerance or to temporarily shut down. Claudi and Mackie (1994) observed that when presented with acute adverse conditions, "the animal will close its shell and remain closed to up to two weeks...before opening". It is quite possible that zebra mussels will defy our best predictions.

Environmental Requirements of Zebra Mussels

The three most crucial environmental requirements of Dreissenids for successful colonization of a body of water are temperature, calcium and pH. Of lesser importance, but still significant, are nutrient levels, turbidity, dissolved oxygen, and pollutants. Zebra mussels also require access to suitable substrate materials for attachment and sufficient water circulation. (Figure 3)

Temperature

Survival of Dreissenids is limited by extremely high and extremely low temperatures. Zebra mussels are rarely found in areas where water temperatures exceed 86°-95° F (30°-35° C). for an extended period of time; they cannot survive in air temperatures below 26° F (-2° C) (Claudi and Mackie, 1994). Between these extremes, growth performance improves as temperatures move toward optimal levels. Temperatures between 50°-54° F (10°-12° C). are needed for the release of eggs and sperm into the water column; spawning occurs between 54°-61° F (12°-16° C) (Claudi and Mackie, 1994). Peak veliger densities are reached between 64°-72° F (18°-22° C). Temperature is so critical for veliger development that settlement events may be long delayed or prevented if water temperatures fail to rise to needed threshold levels (Nichols, 1995).

The main body of Lake Champlain is a deep, narrow basin with a relatively small surface to volume ratio. Extending to a maximum depth of 400 feet (122 m), a large portion of its water remains very cold year-round. Periods of thermal stratification in summer and winter alternate with periods of thermal mixing in spring and

Figure 3

Table 1 Comparison of Zebra Mussel Colonization Potential with Environmental Tolerances				
Variable	Colonization Potential			
	High	Moderate	Low	Very Low
Salinity, ppt	0-1	1-4	4-10	10-35
Calcium, ppt	25-125	20-25	12-20	<12
pH	7.4-8.5	7.0-7.4 8.5-9.0	6.5-7.0	<6.5 >9.0
Water temperature, °C	17-25	25-27	15-17	<15 >27
Turbidity, cm (Secchi disk)	40-200	20-30	10-20 200-250	<10 >250
Dissolved oxygen, ppm	8-10	6-8	4-6	<4
Water velocity, ft/sec	1.6-2.3	0.3-1.6 2.3-3.3	3.3-6.6	>6.6

From: Miller, AC and Tippit,R <u>Evaluating the Susceptibility of Structures to Zebra Mussel Infestation</u>, Technical Note ZMR-1-11, USArmy Coprs of Engineers, August 1993

Figure 4

Approximate Growth Performance of Zebra Mussels in Relation to Alkalinity, Calcium, Total Hardness, Conductivity, and pH.

	No survival		Poor growth		Mod. growth		Good growth		Best
Criteria	From	To	From	To	From	To	From	To	growth
Alkalinity ($mg\ CaCO_3/l$)	0	17	18	35	36	87	88	122	>122
Calcium (mg/l)	5	6	10	11	25	26	35	>35	
Total hardness ($mg\ CaCO_3/l$)	0	22	23	41	43	90	91	125	>125
Conductivity (µSiemens)	0	21	22	36	37	82	83	110	>110
pH	0	6.8	6.9	7.4	7.5	7.8	7.9	8.0	>8.0
Temperature (°C)[a]	<-2	>40	0–8	28–30	9–12	25–27	13–17	21–24	18–20

Note: Use only for a "first guestimate" and verify with a monitoring program. Values are based on geometric summer means.

[a] Temperature should be interpreted with caution here because it affects mussels at both high and low values. For example, there is no survival at temperatures below -2 or above 40°C but there is survival between these temperatures; there is poor growth both between 0–8°C and 28–30°C but moderate to best growth between these extremes; etc. The values should be used only for "guestimates"; they are NOT hard and fast predictors.

FROM: Claudi, R. and Mackie, G., Practical Manual for Zebra Mussel Monitoring and Control, Lewis Press, 1994

fall. In summer, the temperature of the 33 foot (10 m) deep upper layer, the epilimnion, can warm to 77° F (25° C). Shallow bays and shoreline areas, as well as the river-like South Lake, are often warmer than the Main Lake, but rarely reach the upper limits for zebra mussel survival and, then, not for an extended period of time. In winter, reverse thermal stratification results in the colder, less dense, 32° F (0° C) water at the surface and the warmer 39°F (4° C) water at the bottom.

Adult zebra mussels would appear to be able to successfully overwinter in Lake Champlain, adding to population expansion from year to year. The spring turnover results in a uniform water temperature of 41° F (5° C) which gradually warms to 46°-50° F (8°-10° C), the threshold for zebra mussel reproduction. With continued warming, temperatures suitable for spawning and optimal veliger and adult growth are reached and sustained through the summer and fall, providing a spawning period of three to four months and adequate time for several settlement events.

Depth

Depth, in as much as it requires zebra mussels to tolerate extremely cold temperatures and sometimes depleted dissolved oxygen levels, slowing reproduction and growth, may be considered a factor that limits their invasion. Zebra mussels are found in greatest abundance in depths of 6-50 feet (2-15 m). In stratified lakes, veligers and adults will be distributed throughout the epilimnion to a depth just above the thermocline (32-50 feet/10-15 m). In unstratified areas, vertical distribution of veligers peaks at 6-20 feet (2-6 m) (Claudi and Mackie, 1994). Quagga mussels *(Dreissena bugensis)*, a relative of the zebra mussel which has been found in the Great Lakes, St. Lawrence and Mississippi Rivers, are known to grow and reproduce at significantly lower temperatures than zebra mussels, and are commonly found at depths of up to 98 feet (30 m). The maximum depth at which a quagga mussel has been found is 351 feet (107 m) (Snyder, Helgendorf, and Garton, 1994).

While temperature and depth taken alone are not absolute predictors of Dreissenid colonization, one can speculate (all other necessary factors present) that zebra and quagga mussels have the ability to colonize not only Lake Champlain's shallow bays and shoreline areas, but also deeper areas up to 98 feet (30 m) where suitable substrates are plentiful.

CALCIUM

The presence of calcium in certain threshold quantities is also an important prerequisite for invasion and proliferation of the Dreissenids. Claudi and Mackie (1994) report that growth performance can be predicted based on the number of mg/l of total calcium in the water source: There is no survival in water with 5 mg/l calcium or less; survival with poor growth from 10-11 mg/l; moderate growth at 25-26 mg/l; and good growth at 30 mg/l or greater. (Figure 4) Zebra mussels need 7-8 mg/l of calcium for shell growth, 12-14 mg/l for reproduction and 25-30 mg/l for massive infestation (Snyder, Helgendorf, and Garton) (1994).

Calcium, along with sodium, magnesium and potassium, is one of the four major cations found in the waters of Lake Champlain. It is the most highly concentrated of the four in all areas of the lake. 1992-1994 annual averages of calcium measured by the Lake Champlain Lakewide Monitoring Network show levels to be highest in the South Lake (30.49 mg/l). Concentrations lessen as the lake flows northward, dropping to 17.83 mg/l in the Main Lake, and to even lower levels in Mallett's Bay (13.76 mg/l) and Mississquoi Bay (13.48 mg/l) (Stickney 1995).

It seems safe to conclude that total calcium levels in Lake Champlain are sufficient for zebra mussel survival and reproduction. Growth performance potentials based on total calcium levels present range from poor to moderate throughout the Lake, except in southern portions where values reach levels required for massive infestation. It is important to note that recent studies suggest zebra mussels may also be able to access calcium directly from substrates to which they attach (Nichols, 1995). If this is the case, the basin of Lake Champlain, could provide enough calcium to support massive infestation where its substrate is comprised of calcium carbonate based dolostone.

pH

A pH of 6.5 or higher is required for adult zebra mussel survival and a pH of 6.9 or higher for veliger survival. Reproduction requires a pH threshold level of 7.4. A pH of 8.0 or greater is necessary for massive infestation (Claudi and Mackie, 1994).

Lake Champlain is an alkaline lake with a pH range of 7.0-8.5. Hydrogen ion concentrations in the Lake at any given time, correlate closely with calcium levels. Calcium ions in the water

bond with hydroxyl ions, lowering concentrations and raising the pH. This buffering capacity, which has saved Lake Champlain from the ill effects of acid rain, will also be responsible for maintaining pH conditions ideal for zebra mussel growth and development. 1992-1994 annual average values of pH as reported by the Lake Champlain Lakewide Monitoring Network range from a low of 7.67 near Cole Bay, south of Westport, NY, to a high of 8.39 in St. Albans Bay. Averages of 7.89 were found in the Main Lake west of Burlington; 7.99 at Crown Point; and 8.10 in Burlington Harbor. Values such as these (all other necessary factors present) could support best growth performance levels of zebra mussels throughout the Lake.

Food Sources

Zebra mussel growth and development requires a sufficient preferred food supply. Dreissenids filter plankton and bacteria from the water column and may also ingest particles from benthic substrates via the mantle opening. One can assess plankton availability by measuring chlorophyll-a or total phosphorus values in a body of water. Greatest mean densities of zebra mussels are achieved where chlorophyll-a concentrations range from 10 - 40 ug/l, or total phosphorus measures 100-300 ug/l. Zebra mussels are found in waters with total phosphate concentrations as low as 20 ug/l (Claudi and Mackie, 1994).

The Lake Champlain Lay Monitoring Program data for 1979-1993 indicate chlorophyll-a concentrations ranging from 2.7-25 ug/l with the highest amounts in the South Lake. Chlorophyll-a levels above 9 ug/l are also found at the mouth of Otter Creek (11 ug/l) and in St. Albans (11 ug/l) and Missisquoi Bays (12 ug/l). (Figure 5) Mean summer levels of total phosphorus in Lake Champlain range from 14-55 ug/l. Levels greater than 40 ug/l were recorded south of Crown Point and in Missisquoi and St. Albans Bays. (Figure 6)

Food is available in sufficient quantities in Lake Champlain to allow zebra mussel presence in all areas of the Lake. The ability of zebra mussels to supplement filtered planktonic food sources by ingesting nutrients from the benthos greatly increases the potential for a massive infestation in all areas of Lake Champlain.

LAKE CHAMPLAIN CHLOROPHYLL-A CONCENTRATION

1979 - 1993

(LAY MONITORING PROGRAM)

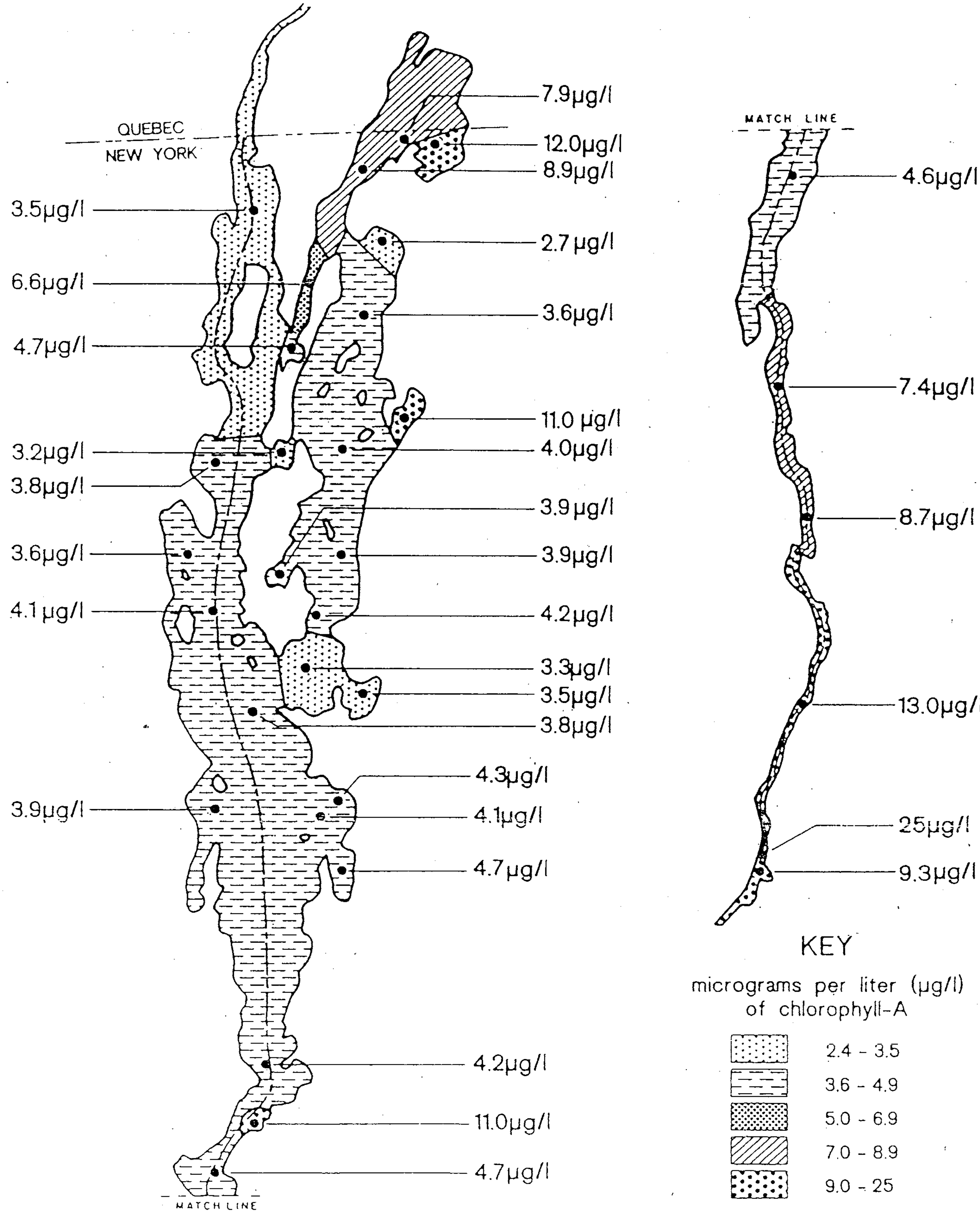


Figure 5 Picotte, A. (1993) "Lake Champlain Lay Monitoring Report"
Agency of Natural Resources
[illegible]

LAKE CHAMPLAIN TOTAL PHOSPHORUS CONCENTRATION

1979 - 1993

(LAY MONITORING PROGRAM)

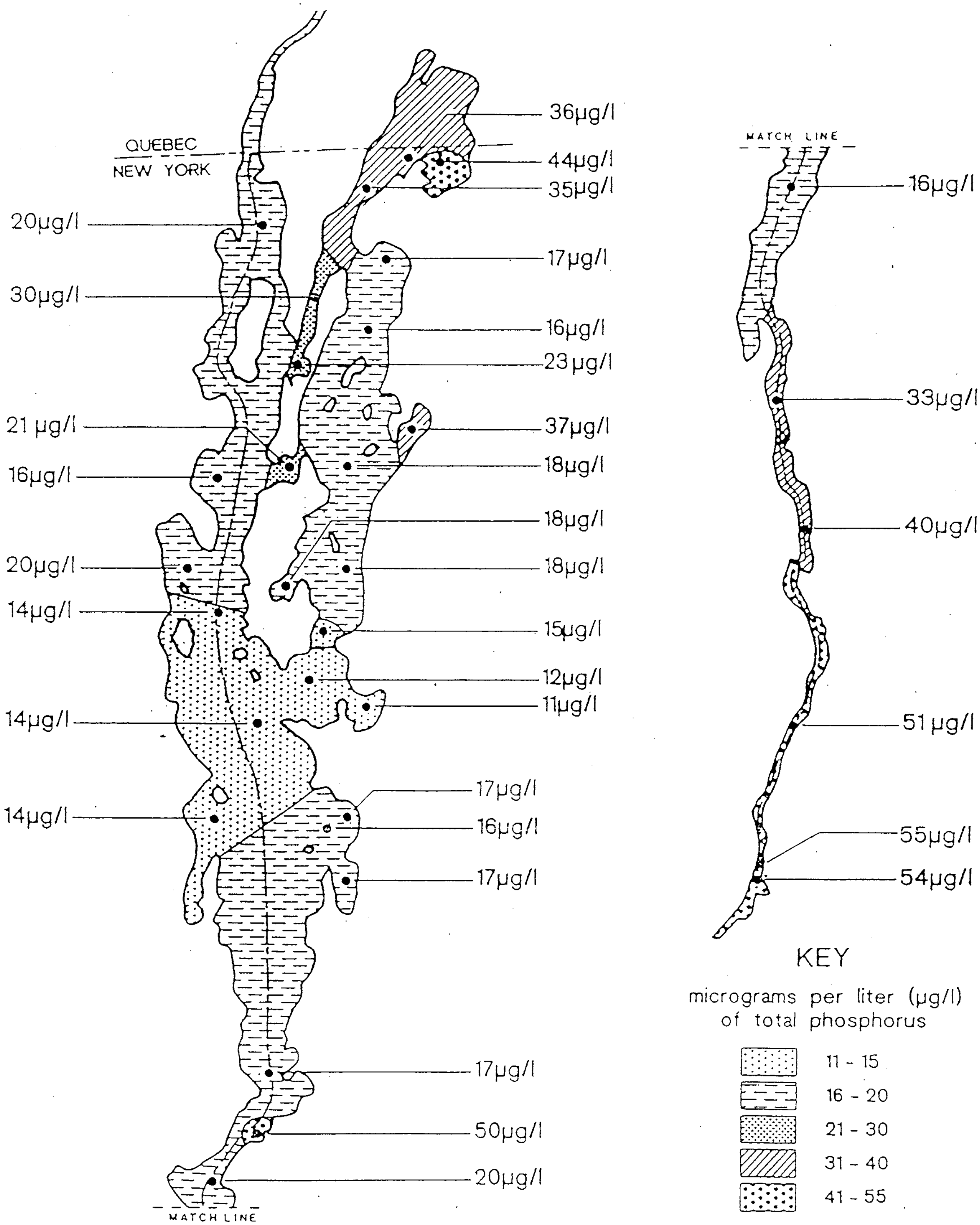


Figure 6 Picotte, A. (1993) "Lake Champlain Lay Monitoring Report"
Agency of Natural Resources

Transparency

As the transparency of water decreases, the ability of zebra mussels to filter it decreases. Threshold tolerance levels for transparency have not been well defined, though zebra mussel colonization potential is highest where Secchi readings range from 40-200 cm. Below 10 cm and above 250 cm there is very low growth. (Figure 3) Variations in light intensity, as a consequence of changes in transparency, have no known effect on adult zebra mussels (Snyder, Helgendorf, and Garton, 1994), though veligers are found to settle most frequently on shaded substrates.

In Lake Champlain, Secchi disk transparency varies from a long-term mean low of 0.4 m (40cm) in the South Lake to a high of 5.9 m (590 cm) in the Inland Sea. (Figure 7) Typically most turbid are the waters of the South Lake, and other shallow bays, shoreline areas, and river mouths where bottom sediments are constantly mixed into the water column by wind, waves, and currents.

Dissolved Oxygen (DO)

Percent dissolved oxygen is also a limiting factor for invading zebra mussels. DO ranges of 4-6 ppm sustain low colonization, 6-8 ppm moderate, and 8-10 ppm high. (Figure 3) Though zebra mussels are severely limited by low dissolved oxygen concentrations, adults can, provided temperatures are low enough, survive oxygen deprivation for up to two weeks.

In the benthos of Lake Champlain, in areas of deep sediments, biochemical demands may reduce or deplete dissolved oxygen to the point that zebra mussels can no longer survive. Such periodic depletion may limit the extent to which zebra mussels are able to colonize the deeper areas of Lake Champlain.

LAKE CHAMPLAIN SECCHI DISK TRANSPARENCY
1979 - 1993
(LAY MONITORING PROGRAM)

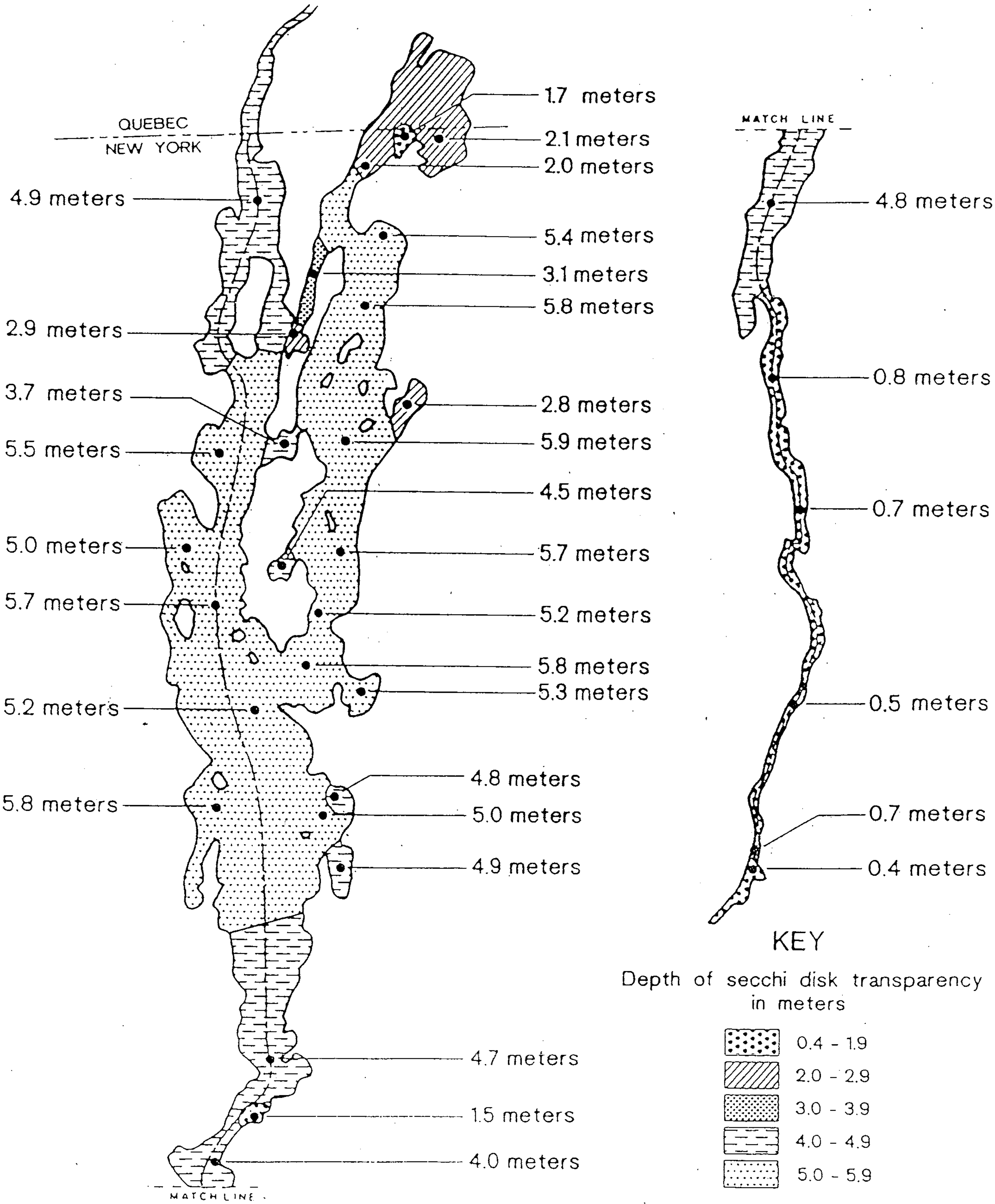


Figure 7 Picotte, A. (1993) "Lake Champlain Lay Monitoring Report"
Agency of Natural Resources
Department of Environmental Conservation, Water Quality Division, Waterbury, VT

Lake Champlain's Risk of Zebra Mussel Infestation

Taken together, the water quality and physical characteristics of Lake Champlain, as well as rapid population growth and spread of Dreissenids, suggest that waters throughout the Lake are capable of supporting a large zebra mussel invasion. The greatest threat of intense colonization appears to be in the riverine portion of the Lake south of Crown Point. There, temperature ranges are tolerable, calcium levels and pH values are the highest of any area of the Lake, and nutrients are abundant. The rocky shorelines and stems of numerous wetland macrophytes provide substrates for settlement and attachment. High turbidity levels may play a limiting role there, but the degree of limitation is unclear. While massive infestations, such as those which occurred in Western Lake Erie, appear likely for the South Lake, they are also possible in other areas of Lake Champlain. The zebra mussels' uncanny ability to tolerate and adapt to conditions outside expected levels and their flexibility in adopting alternate feeding methods and nutrient sources, puts Lake Champlain at great risk for large-scale infestation.

What is the Timeline for the Spread of Zebra Mussels into Lake Champlain?

"The problem with the future is that it keeps turning into the present."
-Hobbes
(quoted by Joe Leach, 1995 International Zebra Mussel Conference, Toronto)

The time clock is ticking in Lake Champlain. It has been two years since the first adult zebra mussel was discovered in the South Lake in the summer of 1993. Over the course of the 1994 breeding season, adult mussels appeared in numerous other locations throughout the Lake. Billions of microscopic veliger larvae, floating northward with Lake currents and the wind-driven summer seiche, proceeded those adults and will contribute to total population growth this season. In 1994, adult numbers remained highest in the South Lake. No adult zebra mussels were reported in the Northeast Arm or in Malletts, St. Albans, and Missisquoi Bays. Veliger counts in spring and early summer 1995 average about 30 times greater than in 1994.

What will happen in Lake Champlain during the 1995-1996 breeding seasons?

How fast will mussel populations grow and spread?

In the first five years following the introduction of zebra mussels in the Great Lakes, population growth was rapid during years one to three, then leveled off and the population growth stabilized during years four and five (Nalepa, 1995). In Lake St. Clair, where physical variables influencing zebra mussel survival, reproduction and growth were optimal (T= 32°-86° F (0°-30° C), Ca= 35-40 mg/l, pH=7.9-8.6, chlorophyll-a = 0.6-4.2 ug/l and turbidity varied 5- 200 NTU), average densities five years after introduction neared 100,000/sq m, with areas up to 1,000,000/sq m. After that point, infestations declined, but rose again to levels below the initial infestation rate (Claudi and Mackie, 1994). Population growth rates in the Great Lakes parallel those recorded in Europe.

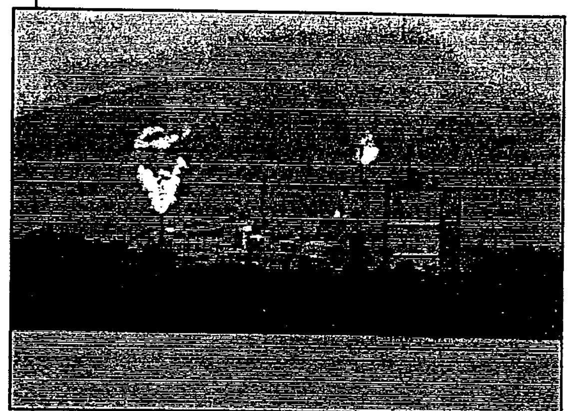
Conditions are favorable for continued zebra mussel expansion in Lake Champlain. Year number three of the zebra mussel invasion in Lake Champlain is under way! With a veliger population explosion already taking place, the growth of adult populations will be painfully apparent in the next 12-24 months.

Zebra mussels in Lake Champlain will have significant impacts. Zebra mussels will clog water intakes of power generating and water treatment plants and shut down fire hydrants that draw water from the lake. Adult mussels will foul pipes of residential water systems along the Lake and clog freshwater cooling systems in boats. They will attach to docks, moorings, boat bottoms, beaches and often concentrate on the shells of native mollusks, which is expected to devastate the native mussel populations. They will remove nutrient particles from the water column and deposit them in the benthos, changing energy flow in the Lake Champlain food chain. They will transfer contaminantsto bottom communities and change contaminant dynamics. Active prevention and controls have the potential to alleviate impacts in many of these areas.

There is one other impact of the zebra mussel invasion in Lake Champlain for which no prevention or control is known at the present time-- the impact of zebra mussels on the irreplaceable historic wooden shipwrecks and other submerged cultural resources beneath Lake Champlain's waters.

SECTION 2

Zebra Mussels and Their Impact On Historic Shipwrecks



A. Cohn

As in the Great Lakes, Lake Champlain's first priority is protecting water intake pipes on industrial and municipal water facilities and fish hatcheries.

Although zebra mussels are having a profound effect on a vast number of historic shipwrecks in the United States and Canada, surprisingly little investigation has been initiated on the issue. The primary focus of research on zebra mussels has been centered on understanding the invading mollusks' impact on water intake systems for power plants and municipal water facilities. Another major area of research attempts to understand the impact of zebra mussels on the other creatures within the ecosystem. Currently, we have been able to find few studies directed specifically at understanding zebra mussel's impact on shipwrecks. This has been explained by one respondent this way: "In relation to the implications of zebra mussels to the big industrial plants, shipwrecks are pretty far down on the list." Another researcher explained, "It is believed that much of the information gained from our basic research efforts can be "transferred" to other areas, and shipwrecks is one of those areas."

SHIPWRECKS AND THE GREAT LAKES EXPERIENCE

It is a sad coincidence that most of the aquatic environments into which zebra mussels have spread are also the resting places of a vast quantity of submerged cultural resources. These fresh water, inland corridors were the transportation highways for Native American, colonial empires, and 18th and 19th century military and commercial navigators. This same aquatic highway is now facilitating the spread and colonization of zebra mussels. Within these newly colonized ecosystems are literally hundreds of known historic shipwrecks and an undetermined number of undiscovered ones. In many areas of the Great Lakes, the older wooden sailing ships and more modern steam-powered vessels with iron machinery are completely encrusted by zebra mussel colonies. One interviewee shared the observation that this past summer, he was part of a team which located a two-masted wooden schooner completely covered in quagga mussels in 180 feet (55 m) of water.

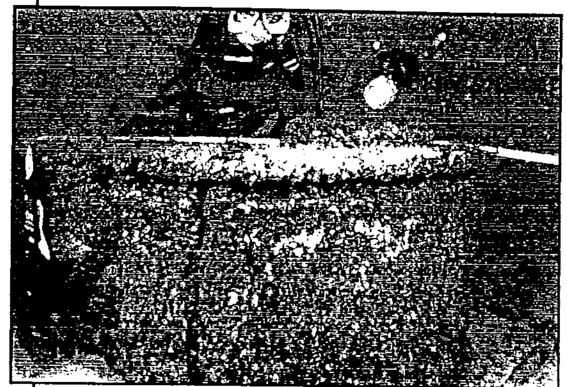
State Sea Grant offices, the Army Corps of Engineers and the National Oceanographic and Atmospheric Administration's Great Lake Environmental Research Laboratory (NOAA GLERL) have been in the forefront of the information gathering and dissemination. In Michigan, the Sea Grant office works with the Michigan's Bottomland Preserve System, a recreational program aimed at attracting sport divers to the various regions of Lake Michigan. The program, which has a recreational and historic interpretive mission, is also an economic stimulation program for the various regions in which they are located. To date, Michigan has adopted no formal approach to zebra mussels.

The explanation for this reaction, or lack of reaction to zebra mussels and shipwrecks, has been explained in different ways. In Michigan, the preserves are scattered over a wide geographic area, and each is experiencing zebra mussel's presence differently. While some of the southern preserves are experiencing significant zebra mussel infestation, the preserves located further north are having little or no adverse effects. Perhaps the most significant explanation given for the apparent lack of concern by the diving community is a perception that the zebra mussel invasion has both negative and positive aspects. When asked to characterize, anecdotally, the attitude of the diving community, most respondents replied: "Most divers are certainly sorry to see the wrecks impacted by zebra mussels, but many are pleased with the dramatic increase in visibility, and therefore, on balance, don't see zebra mussels as a negative."

The increase in visibility is dramatic. In Lake Erie, it is reported that visibility has increased from 4'-5' (1m-1 1/2m) to 40'-50' (12m-15m). One charter captain from Lake Erie expressed it this way, "We would rather be able to see a large area of zebra coated shipwrecks than small areas of clean ones." This confusion over the net effect on their underwater activities may account for why the sport diving community has not been more vocal in their reaction to the zebra mussel invasion. Indeed, when zebra mussels spread to an inland quarry in Ohio which is utilized as an active sport diving location, speculation centered around whether the infestation was accidental or intentional.

The Underwater Archaeological Society of Chicago

In 1991, the Underwater Archaeological Society of Chicago [UASC], a group of dedicated sport divers with an avocational interest in historic shipwrecks, became alarmed at the potential adverse effects of zebra mussels on shipwreck sites in their region. After consultation with a number of agencies, they proposed a pilot "Photographic Survey of Zebra Mussel Colonization in Illinois Waters of Lake Michigan." This survey was approved and funded by Illinois Sea Grant and resulted in "zebra mussel colonies [being] found on various underwater substrate; photographed, measured, counted and collected for further investigation. Patterns of colonization [were] noted and described in a detailed manner" (Childs, 1993).



Chet Childs

*The wreck of **Lady Elgin**, Great Lakes.*

The goal of the project was to develop techniques for photographing zebra mussels on shipwrecks over time and to quantify the data produced from these images. Although this project has produced promising results, the study has not been repeated. Chet Childs, the project's coordinator, sent the results of their study with the following cover letter to Art Cohn, Director of the Lake Champlain Maritime Museum (LCMM),

> "I hope that these materials will be of benefit to you. Our shipwrecks are now completely covered with mussels down to a depth of 60'. Only cold water prevents their migration to greater depth. Even then, the critters will somehow find new ways to feed at greater depth.
> Art, my bottom line to you is this- you have approximately two years until the mussels cover over your shipwrecks. Then underwater photo/video survey and detailed drawings will no longer be possible!" (Childs, 1995).

Great Lakes Environmental Research Laboratory/National Oceanic and Atmospheric Administration/Thunder Bay Project, Lake Huron

Thunder Bay, Lake Huron, is one of several sites in the Great Lakes region being evaluated for inclusion in the NOAA Marine Sanctuaries program. Thunder Bay has already been designated a State of Michigan Bottomland Preserve where researchers estimate that in the past 125 years over 100 ships have gone to the bottom in and around these waters. The NOAA proposal states "There is a rising interest and concern among the coastal management, underwater archaeological, and underwater historic preservation communities over this matter" (Vrana). "In addition to possible destruction of historic artifacts, zebra mussel infestation on popular diving wrecks could diminish or eliminate the interest of the diving public in visiting these wrecks, resulting in economic impact in the local area through the loss of

tourism." (McCormick, et al, 1995).
As of this writing, few programs focus specifically on zebra mussels and shipwrecks. The NOAA GLERL has proposed a project entitled "Factors Affecting the Infestation of Zebra Mussels on Thunder Bay Recreational Diving Wrecks" (McCormic, et al, 1995). At first glance, the Thunder Bay proposal appears to focus on the issue of zebra mussels' impact on historic shipwrecks. However, a complete reading of the proposal suggests that while selected shipwreck locations in Thunder Bay will be utilized as focus sites to examine the spread and colonization of zebra mussels, this study's primary objectives will be environmental and biological. The scattered shipwrecks simply provide a conveniently distributed venue for the examination of zebra mussel colonization. This study may ultimately generated information which will help in a wider understanding of how and why zebra mussels colonize shipwrecks the way they do, but no specific issues regarding site degradation or economic impact are raised in the study's proposal.

Parks Canada, Historic Resource Conservation Branch

In recent years, the Parks Canada, Historic Resource Conservation Branch has implemented "A Monitoring Program for Shipwrecks at Fathom Five National Marine Park." Lorne Murdock and John Stewart delivered a paper on this program at the 1995 Conference on Underwater Archaeology (CUA). Perhaps the most sophisticated shipwreck impact analysis in either Canada or the United States, the program was initially developed to address issues relating to diver impacts on historic shipwrecks. Zebra mussels, however, are mentioned briefly near the end of the report: "In recent years zebra mussels have been introduced into the Great Lakes system and in some lakes have covered entire shipwrecks. During the last two years, these have been observed on two of the wreck sites in the park. Further studies are planned to develop a counting/distribution technique and to determine the possible impact these species could have on the wrecks" (Murdock and Stewart, 1995).

In a series of recent communications with Mr. Murdock, he repeatedly characterized the presence of zebra mussels on shipwrecks at Fathom Five National Marine Park as having gone from "none, to a few you could look for, to an amazing explosion, increasing perhaps 100 fold from the previous year." Murdock also indicated they were in the planning stage, in conjunction with the Province of Ontario, for developing a program to determine if zebra mussel colonization has an adverse effect on the physical stability of the shipwrecks for 1996.
The Lake Champlain Maritime Museum has established a

collaborative relationship with these parties for future studies. Lake Champlain could benefit the study design by adding another environment to the zebra mussel analysis base. The excellent facilities of the Parks Canada laboratory could, in turn, provide the Lake Champlain region with the necessary technical analysis capability. The current plan is to develop a program that will provide information to help answer the following questions about zebra mussels and their impact on historic shipwrecks:

- Are zebra mussels causing damage to the resources i.e. dothey increase the degradation of wood or the corrosion rate of metal that they adhere to (realizing that almost all industrial literature will deal with modern uncorroded metal and undecayed wood while underwater cultural resources are usually in states of advanced decay or corrosion)?

- Is it wise to remove unique artifacts from shipwrecks (or other small cultural resources) and give them conservation treatment if they become coated with zebra mussels?

- What techniques are available to remove zebra mussels from shipwrecks and other underwater cultural resources without damage to the resource?

- Given that divers are requesting advice on removing these mussels from shipwrecks, what damage is done (or not done) by such techniques as scraping the mussels off, removal with water jets or using chlorine bleach to kill them?

- What is influencing the spread of zebra mussels?

- What is the loading density (i.e. Kg per cubic meter) of zebra mussels underwater and what effect does this have on the structural stability of the wrecks covered by them?

- How can the results of this work form a protocol for dealing with zebra mussel infestation on underwater historic sites and how can this protocol be shared with the multitude of sports divers presently enjoying these resources? (Murdock, 1995)

The Wisconsin Underwater Program

In 1994, State Underwater Archaeologist, David Cooper, executed an extensive field examination of several submerged cultural sites in Lake Michigan and Lake Superior (Cooper, 1994). Objectives of the survey were to inventory and document these sites as part of Wisconsin's on going underwater resource management program. While observing the presence or absence of zebra mussels was secondary, the observations made during the survey are indicative of the issues and problems which we can anticipate in future documentation projects on Lake Champlain.

One of the survey's primary objectives was the documentation of the steamer, *Francis Hinton*. Located in Lake Michigan, the *Hinton* was a steambarge built of wood in 1889 and lost in a gale in 1909. The hull is 152 feet in length, 30.9 feet in beam, and she was powered by a 385 horsepower steeple compound engine. The wreckage is located in a maximum of nineteen feet of water, with only seven feet of water over the boilers. The survey report well describes the problems associated with documenting shipwrecks which are colonized by zebra mussels.

> Another unfavorable environmental factor on the *Francis Hinton* is the presence of heavy concentrations of zebra mussels. The shallow depth, ambient light, extensive metal and wood structure, and relatively warm water have all combined to create an ideal environment for the invaders. Concentrated principally on the ship's iron boiler and machinery, the mussels have also obscured much of the vessel's wooden structure, greatly adding to the difficulty of documenting the wreck. Diver reports indicate that the mussels first appeared on the wreck in 1993, rapidly colonizing the wreck from 1993 to 1994 (Jenson, Cooper, Cantelas & Beard, 1995).

In another observation, the report details some of the specific problems associated with extracting archaeological information from a zebra mussel encrusted site.

> An interesting (but frustrating) by-product of the *Hinton* survey was the opportunity to examine the process by which zebra mussels colonize a shipwreck site. As observed earlier, the engine, boiler, and machinery were heavily encrusted with the organisms, as were the upper elements of the ships wooden

> structure such as frametops, sides, and the keelson. The mussels were strongly adhered in these areas, and could only be removed with vigorous scraping. Areas of mussels had to be forcibly removed with dive knives and recording slates in order to obtain measurements of the underlying structure and machinery (Jenson, Cooper, Cantelas & Beard, 1995).

The researchers' experience on the *Hinton* can be contrasted to their experience, also in Lake Michigan, on the steamer *Niagara.*

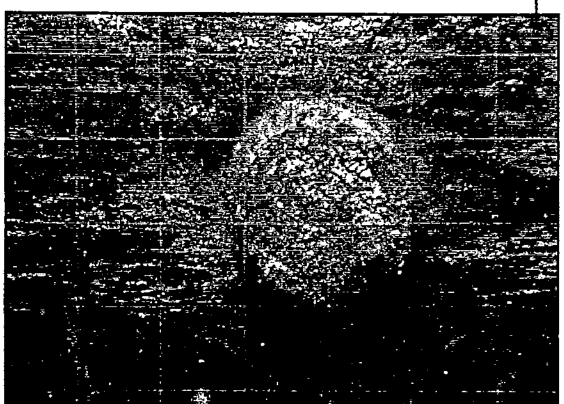
> Archaeologists did note the presence of a few zebra mussels adhering to the machinery and around the paddlewheels. These were first noted on the site in 1993, but have not noticeably increased between 1993 and 1994. In any case they were not present in anything like the density as on the *Francis Hinton,* nor were the mussels as tightly adhered to the *Niagara.* Apparently due to the *Niagara's* greater depth (45-55 feet), low light levels, colder water and (presumably) lower levels of nutrients for filter feeders, the site was obviously at the margin of being habitable for zebra mussels (Jenson, Cooper, Cantelas & Beard, 1995).

Clearly, different environments experience different rates and densities of colonization. Cooper's survey team found no zebra mussels on the next four shipwrecks they examined in Lake Superior. In attempting to explain why some areas of the Great Lakes ecosystem have been relatively unaffected by zebra mussels, researchers suggest that low levels of available calcium may be a decisive factor in limiting zebra mussel populations in Lake Superior and other northern Canadian lakes.

Do Zebra Mussels Damage Shipwrecks?

While many cultural resource managers expressed concern about the short and long term effects of zebra mussels on the structural integrity of historic shipwrecks, to date, no formal study has been initiated to examine this issue. One respondent expressed concern that the sheer weight of a zebra mussel colony could crush a fragile ship's structure. Another respondent speculated that zebra mussels may produce carbon and actually help to preserve shipwrecks. Another observed that when zebra mussels are scraped off the wood or iron of a shipwreck, a small amount of wood or iron goes with them. There is a strong consensus among respondents that physical removal of zebra mussels is not a practical idea. It was reported, however, that a diving instructor in the Chicago area offers an "Eco-Diver" specialty course which involves removing zebra mussels from shipwrecks.

One observation based on research examining the effect of zebra mussels on steel intake pipes, does raise a serious concern about zebra mussel's potential to degrade iron. MIE Consulting Engineers of Toronto, Ontario, observed that zebra mussel colonies in steel intake pipes had accelerated the "rate of corrosion of steel substrates" (Simkins, 1995). Upon reinspection three years later, MIE confirmed that the rate of corrosion beneath a layer of zebra mussels is "substantially greater than in their absence" (Simkins, 1995). Through special photogrammetric techniques they were able to quantify the degradation at "a rate approximately 30 times that normally anticipated in fresh water" (Simkins, 1995).



Chet Childs

One of the crucial questions is whether zebra mussels will degrade the iron fastenings of shipwrecks, like this iron spike ina wooden crib in the Great Lakes.

In an interview with MIE's Lisa Simkins, she suggested that a bacteria which thrives in the environment beneath the zebra mussel colony may be the cause of the pitting observed under zebra mussel colonies on steel pipes. When asked if she would expect the same phenomenon to occur on the iron components of old ships, she was unsure, but thought the same chemical reactions could be at play. She did note that this same corrosive action was not observed on wood. Ms. Simkins also raised the possibility that zebra mussel feces and pseudo-feces could corrode the shipwrecks (1995).

The possibility that zebra mussels will degrade iron components and iron fastenings on historic shipwrecks is particularly troubling. The iron fastenings are what hold most of these structures together, and their integrity is one of the main factors in determining the potential "life-span"" of an intact ship. During his survey of the *Francis Hinton*, Cooper observed, "The heads of many of these spikes are also clustered with zebra mussels, highlighting the iron bilge fastenings" (1994). Also troubling is the possibility that the corrosive action will continue to penetrate and degrade metal over time. This issue of degradation of iron on historic shipwrecks is a critical one, and should be studied in a scientific way. The proposed 1996 Parks Canada monitoring program could provide an important opportunity for such analysis.

FEASIBILITY OF CURRENTLY AVAILABLE CONTROL TECHNIQUES

Are controls an option? As described in section 3 of this report, current research focuses primarily on the control of zebra mussels in industrial power and water intake plants. We should continue to monitor this research and look for strategies which can be adapted to protect shipwrecks. There may be some repellents or other barrier strategies, such as covering the vessel with silt, which may prevent zebra mussel attachment, but, at the present time, the state of the product, the extreme costs and sheer number of underwater sites make this strategy impractical.

It is the consensus that zebra mussels *will* attach to Lake Champlain shipwrecks. The method of zebra attachment does not lend itself to their removal, and anecdotal information available at this time seems to suggests that removal of mussels from shipwrecks may cause more damage than allowing them to remain.

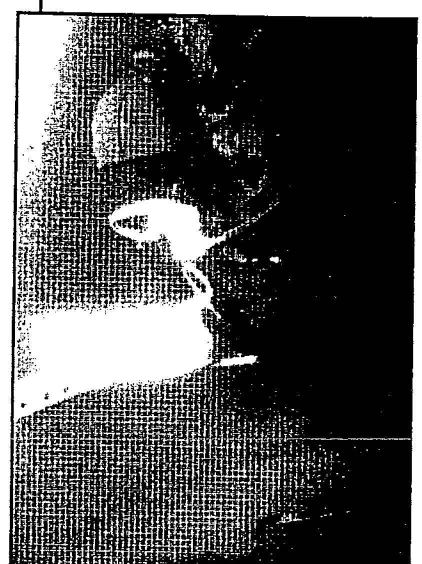
A. Cohn

Modern remote sensing and navigation control systems make possible the systematic examination of the Lake bottom.

WHAT CAN WE DO?

SYSTEMATIC LAKE-WIDE INVENTORY AND DOCUMENTATION PROJECT

While the information presented above does not bode well for the recreational use or archaeological potential of our shipwrecks, there is one positive, proactive strategy which we suggest: an accelerated effort to survey the lake's bottomland and inventory and document submerged cultural sites prior to infestation. Utilizing modern remote sensing equipment and navigational control systems, it is now possible to methodically image the entire lake bottom.



Documenting the Horse Ferry wreck in Burlington Harbor, Lake Champlain.

Documentation of all cultural targets located would be another primary component of the project. Utilizing archaeological trained divers for shallow water and remote operated vehicles (ROV) to reach deeper sites, this strategy would provide an opportunity for some level of site documentation before zebra/quagga mussels destroy these cultural resources. Collateral benefits of this survey would be its gathering of important geological, hydrological, and bathymetric information, as well as its documentation of a pre-zebra mussel portrait of the lake bottom.

If predictions about zebra mussel colonization in Lake Champlain prove to be true, then in a short time shipwrecks located in shallow water (6'-60') will be covered with zebra mussels. We have already seen this process begin in 1995, and in the next year or two, many sites will be completely covered. We would also expect to see colonization migrating to deeper depth over time. As stated in Section I of this report, if quagga mussels establish themselves in this ecosystem, we can expect colonization in the 98' range, but also in over 200 feet of water. The strategy we propose is locating and documenting shipwrecks before this infestation so as to preserve an important body of information which will otherwise be lost.

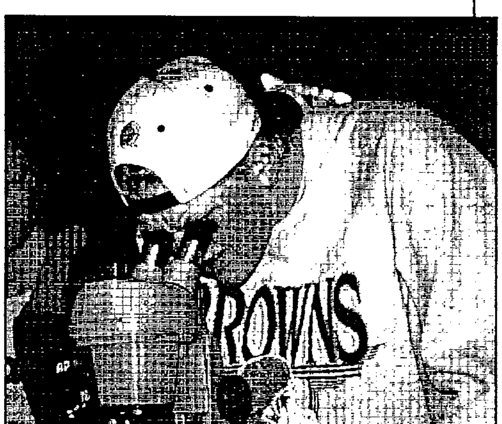
In 1995 the Diamond Island Stone Boat, a shollow water shipwreck in Lake Champlain, was settled by adult mussels on roughly 10 % of the exposed wooden surfaces.

Researchers are working to discover a means to control zebra mussels in our environment, a solution which may be around the corner or generations away. However, the technology to locate and document submerged cultural resources exists and is available to us now. Time is of the essence.

EDUCATION

Education is the key to gaining public understanding of the issues surrounding zebra mussels and, specifically, what can be done to slow the mussels' spread. During the 1995 season, the Maritime Museum worked with all appropriate governmental parties and the Lake Champlain Basin Program to design the most effective informational public exhibit. Seed money from this project grant was added to other funds to develop a new public education exhibit within the LCMM's new Nautical Archaeology Center. This exhibit was developed in conjunction with DEC education specialist, Michael Hauser, to instruct the public about the wide ranging issues surrounding zebra mussels.

M. McDevitt



An 8th grade student from Camel's Hump Middle School views microscopic zebra mussel larvae in LCMM's lab.

In addition to informational video presentations and graphic information, the LCMM provided a truly effective component to the program, a working laboratory staffed with a lab technician educator. The additional water samples taken at shipwreck sites were brought back to the LCMM lab, where, as part of the zebra mussel exhibit, the technician processed the samples, explained the procedure to visitors and gave them an opportunity to look through a microscope at veligers. A special educational curriculum component about zebra mussels has been added to our summer and fall school programs.

MONITORING

Vermont and New York Departments of Environmental Conservation (DEC) currently have eleven off-shore monitoring stations to evaluate the presence and density of zebra mussel veligers. In conjunction with DEC the LCMM added all five shipwrecks in the State of Vermont Underwater Preserve Program to the water sampling sites in 1995. Procedures for the collection and analysis of these samples were executed in conformance with standards developed by the DEC. Underwater Preserve Monitors were trained to collect the samples as part of their regular duties.

In addition zebra mussel settling plates were established at two of these sites, the steamer *Phoenix* and the canal boat off Diamond Island. The stations are deployed at the beginning of the season and recovered in the fall. The plates are then analyzed to determine the amount of settling occurring in the vicinity of the shipwreck. It is our hope that the three additional underwater preserve sites will be added in the future.

SECTION 3

Zebra Mussel Control Methods

CONTROLLING THE SPREAD OF ZEBRA MUSSELS

Due to the potential for significant financial loss that industries and municipalities face as a result of zebra mussels' proliferation, much emphasis has been placed on controlling the spread of zebra mussels. Specifically, this negative economic impact is the direct result of zebra mussels' dense presence in water intake systems. These enclosed intakes, most often pipelines, are an ideal habitat for the mussels. The pipelines provide a solid substrate for attachment, and the increased water flow supplies more food than an open water environment. Due to the zebra mussels' prolific reproduction, they quickly become so dense that they significantly decrease water flow and eventually fill the pipeline, causing the flow to cease altogether. Municipalities can find themselves without a drinking water supply if control measures are not taken. Industries which use water intake systems can experience days or even weeks of costly shutdown. A lack of water becomes particularly dangerous in the case of nuclear power plants which pump in water for cooling purposes. Even facilities which don't use water intake systems but instead use the water as it flows by, such as hydroelectric plants and navigational locks, can experience crises as the mussels clog sensitive areas. Because of the significant economic impact, many types of control methods have been researched, developed, and implemented. Our objective was to assess which, if any, of these current techniques could be practically applied or modified to help protect Lake Champlain's submerged cultural resources. Cost estimates for these control methods were beyond the scope of this project, and will not be included in this report.

STRATEGIES FOR PREVENTING SETTLEMENT AND METHODS OF REMOVAL

Two basic strategies have been employed to control zebra mussels. The first is a **reactive** strategy in which the method is implemented after the zebra mussels have been allowed to settle and grow to adults. The second is a **proactive** strategy in which the method is enacted prior to mussel settlement on a substrate (Claudi, 1995).

The control methods fall into three general types: **chemical, non-chemical,** and **biological** (Claudi, 1995). Thus far, researchers have explored chemical and non-chemical means more than biological. Unfortunately, however, these chemical and non-chemical methods have been applied almost solely in the confined area of an industrial or municipal setting. Adapting chemical and non-chemical control methods to an open water environment so as to study their applicability to submerged cultural resources is often impractical, costly, and environmentally unfriendly. As mentioned above, relatively little research has been committed to biological control methods, as this approach appears impractical. To date no control method has proved to be the "silver bullet" which will solve this problem. On the contrary, researchers continue to stress the remarkable capabilities of these tiny organisms to adapt to and overcome even the most established control methods.

CHEMICAL CONTROL

OXIDIZING CHEMICALS

Proactive chemical control strategies include the use of oxidizing chemicals such as chlorine or bromine. In higher concentrations, oxidizing chemicals become toxic to most biological organisms, making these chemicals useful as virus and bacteria killers. Oxidizing chemicals are most often used by facilities such as municipal water districts, which do not return the treated water to the lake, river, or reservoir. To prevent zebra mussel colonization, these facilities move the chemical application point to the intake end of the water pipeline. Because of their damaging effects on the environment, however, oxidizing chemicals applied in open water is impractical and illegal.

Deoxidizing Chemicals

Deoxidizing chemicals known as molluscicides are being used as a reactive strategy. These toxic chemicals are also applied in a confined, controlled area due to their fatal effect on many biological organisms. Molluscicides result in adult mussel mortalities over a given period of time. Once the mussels die off, they are removed from the site and disposed of. The chemical is released into open water after the molluscicides have been diluted with water to within acceptable parameters (Piccirillo, 1995). These concentrations can be easily monitored and regulated in the confines of a water-using facility.

Use of deoxidizing chemicals in open water environments, such as shipwreck sites, has potential, but there are many legal, political, and environmental considerations. Research is being conducted on the use of certain deoxidizing chemicals in a bottom formulation, which is accomplished by coating grains of sand with the chemical. In order for this type of treatment to be effective in a shipwreck area, the use of a curtain around the site would be needed to minimize effects on other organisms and to justify environmental safety (Cope, 1995). There would also be site specific considerations due to the local water flow. Side effects, such as degradation of wood, or iron, from deoxidizing chemicals on historic shipwrecks is unknown, and the process is probably not reversible. Application of deoxidizing chemicals in open water shipwreck environments is currently impractical.

Dissolved Gases

New research investigating zebra mussel tolerance to various environmental changes is underway. Researchers speculate that altering an environment by increasing or decreasing its natural content of dissolved gases to a point could cause zebra mussel fatality. As stated in section I of this report, zebra mussels are not tolerant of low oxygen (O_2) levels. Using this information, companies could make their pipelines airtight for a period of time to produce an anoxic environment (O'Neill, 1995). High carbon dioxide (CO_2) levels also appear detrimental to the zebra mussel. Since industrial facilities often produce CO_2 as a waste product, researchers are examining the possibility of recycling the waste into the water within the facility (McMahon, 1995). Unfortunately, this process, which works in an enclosed controlled area, is likely inapplicable to an open water environment.

Non-Chemical Control

The most wide ranging and diverse forms of control methods are non-chemical. Non-chemical control methods are appealing due to their environmentally friendly nature. A number of proactive and reactive strategies have been studied, and several have been used effectively. **Proactive measures** include the use of surface coatings, electrolytic protection, acoustics, filtration, and UV light. **Reactive strategies** include mechanical removal, thermal shock, and freezing.

Proactive Measures: Can We Prevent Zebra Mussels from Settling?

Coatings

Coatings are extremely popular for solid surfaces where zebra mussels attach. The idea behind coatings is to inhibit settlement by producing an undesirable surface. A common example is copper or tin based paint which slowly releases low levels of toxins, inhibiting zebra mussel attachment. Even if attachment occurs, coatings ease the removal of the tenacious byssal thread attachments. All coatings are applied to the surface when it is dry, but due to the residual moisture in a recently drained water system, it is often in a high humidity environment (Meyer, 1995). These coatings are typically effective for two to seven years with some claims of ten years (Rosslee, 1995). Using such products in the case of submerged objects is a problem because they must be applied on dry surfaces. Only one manufacturer of coatings said it had attempted controlled experiments on underwater application. This silicone based coating on which the experiments were done is called EXSIL 2200 Series and is produced by General Electric (GE). A GE representative, Thomas O'Shaughnessy, indicated that tests were preliminary and could in no way suggest that the product could be applied successfully underwater on shipwrecks (O'Shaughnessy, 1995). Even if the EXSIL 2200 coating can be applied underwater and prevent zebra mussel attachment, the cost effectiveness of this approach is seriously in question. Also, once the coating is applied, one must question if the resource has been done any service in being covered with another foreign substance which may be harder to remove than the initial nuisance. It's reversibility at this time is unknown and needs to be investigated. The possibility exists for limited application to specific spots on wrecks such as metal fastenings where the presence of mussels will result in the deterioration of the metal. Since limited field testing of the product is cost effective and can be done on wood and iron substrates other than submerged cultural resources without negatively affecting the resource, coatings such as EXSIL 2200 may warrant further investigation.

Electrolytic protection

Electrolytic protection has been used successfully in non-confined areas, such as sluice gates, trash or intake grates, and piers (Vigneault, 1995). The principle of electrolytic protection is to set up an electric field between a cathode (negative charge) and an anode (positive charge) which will stun free-floating veligers and prevent settlement (Pawson, 1995). The field voltages can be either AC, DC, or DC pulse (Smythe, 1995). The problems with applying this technology to submerged cultural resources are numerous. First, the size of the shipwreck sites to be protected are exceedingly large. In addition, the proximity of available power supplies and the danger of having that power activated while divers are present poses serious doubts as to any possible application of this technology.

Acoustic control

Acoustic control methods have been tested for the most part in laboratory settings. Acoustics do, however, pose some interesting possibilities for submerged cultural resources. Acoustics energy can be broken down into three basic categories: cavitation, sound treatment, and vibrations. Both high and low frequency sound treatments have captured most of the attention of researchers simply because vibration and cavitation are too damaging to surrounding structures. Recent studies in low frequency sound (less than 200HZ) have shown that veliger mortality and adult translocation (forced movement) are possible. The method is simple, relatively inexpensive, and does not appear to affect other organisms adversely. A reasonably low power expenditure of one hundred watts can treat up to one hundred thousand square feet. By fluctuating the hertz, structurally destructive resonance can be avoided (Donsky, 1995). The problem for shipwreck application again lies with the fact that this technology is designed for use in confined facilities. To use this technology on shipwrecks would require a readily available power source. Acoustics may prove useful for translocating zebra mussels off a site for a limited time for archaeological documentation purposes.

Filtration systems

Filtration systems must have a fine enough mesh to stop the passage of microscopic veligers. In-line fine mesh (40 microns or smaller) filtration systems have proven effective at stopping zebra mussel eggs, which are even smaller than the veligers (Smythe, 1995). Though most filtration systems have been designed for use inside of a pipeline, it is possible that a fine mesh could be placed over a shipwreck to prevent settlement on the object itself. The problem is that mussels could settle on the mesh, still incurring weight on the underlying object. We have considered experimenting with barriers, such as tarps, but if water can flow through to the vessel at all, veligers will be part of that system. Also, deploying a covering over an entire vessel is logistically impractical. We do not see this as a feasible alternative. Other filters have been developed which use a sand substrate at the intake of water pipelines. These filters are effective because byssal thread attachment is nearly impossible on objects as small as sand or silt, however, as stated in Section 1, the highly adaptable zebra mussels have been found building their own substrate of sand grains and byssal threads in Lake Erie.

Encapsulation

It is theoretically possible to cover a submerged cultural resource with sand or silt, as is already naturally the case with many vessels in southern Lake Champlain. During past underwater archaeological projects on Lake Champlain, shipwrecks have be excavated and then recovered with silt upon completetion of studies. An experimental program that would completely cover a currently exposed vessel with silt could be explored to determine the economic viability or practicality of this strategy. Two major considerations would be the potential negative impacts to the vessel by altering the stability of its environment and to the surrounding natural environment as the silt is redistributed on the bottom. The vast number of submerged cultural resources, both known and unknown, make lake wide application of coverings questionable.

Ultra violet Light

Ultra violet (UV) light is currently being used successfully to destroy pathogenic organisms such as bacteria and viruses in wastewater facilities. Large doses of UV light reorganizes genetic material making survival impossible. This same technology has been applied to the destruction of zebra mussel veligers prior to their settlement in other industrial settings (McKenna, 1995). This proactive measure can be effective in an enclosed facility with a large power source, but is not apparently applicable for the protection of submerged cultural resources.

REACTIVE STRATEGIES: CAN WE GET RID OF ZEBRA MUSSELS ONCE THEY SETTLE?

THERMAL SHOCK AND FREEZING

The **non-chemical reactive strategies** are more labor intensive than the proactive, and often result in temporary shut down of facilities. As shown in section 1 of this report, survival of zebra mussels is limited by extremely high and extremely low temperatures. Research has been done utilizing steam, hot water, and even freezing. The latter's effectiveness has proven limited due to the difficulty of dropping the temperature in an expansive area to the point of freezing. Hot water or steam, however, present a technique for killing and removing the mussels. At temperatures greater than 105°F, mortality is eminent for the mussels. Flushing systems with hot water has proven to be an effective, but costly means to eliminate the infestations (Tsou, 1995). Lake Champlain does not nauturally exceed the thermal limits for zebra mussel survival, and there seems to be no practical means to apply this technology to submerged cultural resources in the open water of the Lake.

MECHANICAL REMOVAL

Another technique is to mechanically remove the zebra mussels. Divers and robots are two means to implement mechanical cleaning techniques. Divers are restricted by the size of an area they can fit in, air and temperature considerations, and physiological pressure limitations. Robots are able to get into smaller spaces and are not restricted by human limitations. Practical use of robots is limited due to high cost and their specialized nature. For example, some are specifically designed for certain diameter pipe, or they are designed for the floors but not walls of a structure (Kotler, 1995).

Numerous devices have been utilized by both divers and robots for the process of mechanical cleaning. A popular means to remove the mussels is by using hard bristle scrub brushes on a rapidly rotating disc (Hobbs, 1995). These power brushes literally rip the byssal threads from their point of attachment. Other techniques include high power hoses to blast the mussels off or shovels to scrape them off.

It may be necessary to remove large quantities of zebra mussels from wrecks or other submerged cultural resources in the future to prevent structural collapse from the weight of zebra mussels, or create exposure for archaeological documentation. Techniques should be explored to minimize the impact on the shipwrecks during this procedure. Many of the methods used at facilities today, such as hard bristle brushes, would severely damage fragile wooden structures. As described in section 2 of this report, there is a strong consensus that physical removal of zebra mussels is not a practical idea. The other issue is how to dispose of the large quantites of mussels which would result from the cleaning. The answer could be as simple as leaving them adjacent to the site, or as involved as developing a technique for the lifting and removal of the zebra mussels for disposal at a landfill.

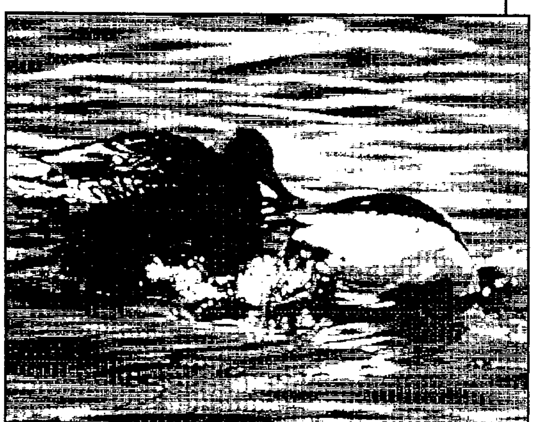
All of these techniques require the removal and disposal of vast quantities of zebra mussels once the technique is completed. Currently the truck loads of zebra mussel remains are disposed of in land fills. Unfortunately, because zebra mussels accumulate toxins in their tissues, the remains cannot be used for more useful purposes such as fertilizers. The mussels are not so toxic, however, as to pose special landfill considerations for toxic waste (Kreis, 1995).

Biological Control
Are There Any Natural Predators?

Biological control is an interesting area of research, but no practical control techniques have been discovered, or are even close to being developed. On a microscopic scale, both parasites and bacteria that live in zebra mussels have been examined, but to date none have had a serious detrimental impact on them (Molloy, Gu, 1995).

The freshwater drum and crayfish

Bottom feeding fish, like the freshwater drum commonly known as sheepshead, and crayfish have adapted their diet to include the zebra mussel (Roehrs, Perry, Richardson, 1995). No increase in population of these predators has been noted. (French, 1995).



Diving ducks feed on shallow water zebra mussels, but offer little promise for control at shipwreck sites.

Diving ducks

Some diving ducks feed on the shallow water mussels, but many scientists are quick to point out that if there were enough ducks to eat all the mussels, we would have a duck population problem. "In some parts of Europe, large populations of diving ducks have actually changed their migration patterns in order to forage on beds of zebra mussels." (Snyder, 1990) During the winter of 1991 the Ohio Department of Natural Resources counted record numbers of diving ducks on Lake Erie. However, these waterfowl do not hold much promise for zebra mussel control in the Great Lakes or Lake Champlain due to depressed duck populations and ice covered bays in the winter when the diving ducks would be present.

The Freshwater Sponge

Some freshwater sponges that inhabit the same solid substrates as zebra mussels have been seen covering zebra mussel colonies, thus producing a suffocating effect. Fred Snyder of the Ohio Sea Grant College Program found sponges on the Lorain Artifical Reef and described the zebra mussels as encased in the sponge "like chocolate chips in a cookie". (Snyder, 1995) Zebra mussels do not colonize on sponges, nor have zebra mussels or quagga mussels been found to byssally attach to the sponges. Since the mussel invasion on the Great Lakes, these sponge overgrowths have had little impact on zebra mussels. Although sponge overgrowth has been shown to kill zebra mussels, and they do compete for space, it is doubtful that they will slow the spread of zebra mussels. Current expansion rates of these sponges suggests that the sponges have adapted to the invaders, but since they don't feed on them they will have very little overall effect on mussel populations (Ricciardi, Miner, Snyder, 1995).

Control Options for the Future of Our Submerged Cultural Resources

Water-using facilities have struggled for years and spent millions of dollars to understand and respond to the zebra mussel problem. The industrial and municipal interests have created enclosed, controlled environments to develop and test preventative and control methodologies. Despite all of the research, practical treatment is confounded because of the zebra mussels' amazing ability to adapt. As was expected, in regards to submerged cultural resources specifically, no easily applicable cure can be applied, but possibilities for some control do exist. These control techniques would be experimental, may prove difficult to implement, and would potentially be costly. Despite these drawbacks, experiments with control techniques such as acoustics, coverings, or coatings should not be overlooked. Unfortunately, in the near future no control techniques can be applied on a wide scale to protect all submerged cultural resources.

CONCLUSION

Predictions for the Future of Our Submerged Cultural Resources

Lake Champlain contains one of the best preserved collection of wooden shipwrecks in North America. These submerged cultural resources have been protected for hundreds of years by the preserving qualities of Lake Champlain's cold, fresh water. We were confident that these pieces of our past would quietly wait for us to find them on the Lake bottom, and reveal the secrets that they hold about the people, customs, and technology that came before us.

These same preserving qualities that have protected our shipwrecks, are also an ideal environment for the colonization of zebra mussels. Taken together, the water quality and physical characteristics of Lake Champlain, as well as rapid population growth and spread of Dreissenids, suggests that waters throughout the Lake are capable of supporting a large-scale zebra mussel invasion.

It is the consensus that within the next 12-48 months, zebra mussels will attach to Lake Champlain's shipwrecks, and there is currently no cost effective technology to prevent or control their colonization on these submerged cultural resources.

WHICH SUBMERGED CULTURAL RESOURCES ARE MOST LIKELY TO BE NEGATIVELY IMPACTED?

Although more monitoring is needed, and the final 1995 data is still being compiled, we can use visual analysis and veliger sampling at the VT Underwater Historic Preserve sites to predict impacts on these sites in the next 12-24 months.

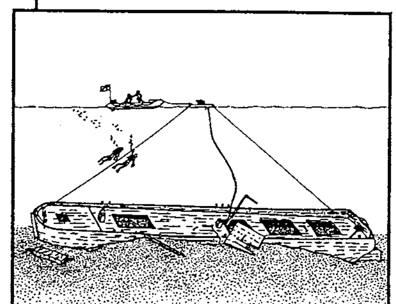
PRESENCE OF VELIGERS

Analysis of water samples collected in July and August of this year revealed the presence of veligers at all five VT Underwater Historic Preserve locations.

PRESENCE OF ADULTS
Adult zebra mussels were reported on both the Diamond Island Stone Boat, and the *General Butler*. No adults were reported on the other three sites.

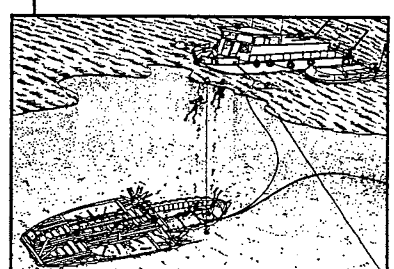
PREDICTIONS FOR THESE FIVE VESSELS INCLUDE:

The Stone Boat - located in 12-20 feet of water just south of Diamond Island near the mouth of the Otter Creek. Roughly 10% of the exposed wooden surfaces were settled by adult zebra mussels in 1995. In addition to adult settlement, high veliger counts were found in this area, which leads us to expect significant colonization in 1996.



Kevin Crisman

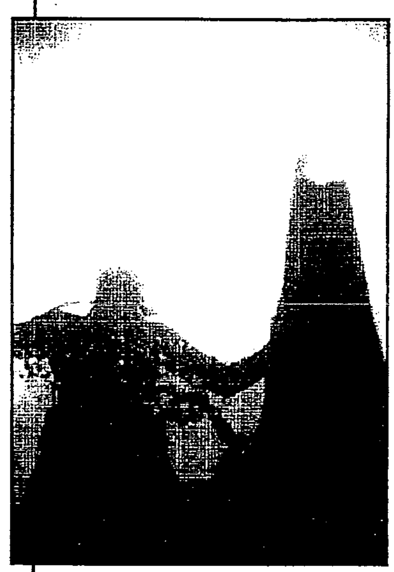
The *General Butler* - located in 35-40 feet of water in Burlington Harbor. While less than a handful of adult zebra mussels were found on the mooring pads in 1994, a significant number were found on the vessel in 1995. Each season will see a higher degree of colonization, and within the next few years this popular dive site will be completely encrusted.



Kevin Crisman

The Horse Ferry - located in Burlington Harbor in 40-45 feet of water. No reports of visible adult zebra mussels in 1995, but veliger counts suggest that zebra mussels will settle on this vessel in the 1996 season.

The Coal Barge - located in the greater Burlington Harbor is in 60-70 feet of water. Although there were veligers present in water samples, no adults were reported in 1995. The depth of this vessel may increase the time-table for settlement. We do not expect impacts on this site in 1996, but anticipate colonization by zebra mussels as they migrate to greater depth over time. Quagga Mussels could also become a factor with this site.



The *Phoenix* - located in 60-110 feet of water off the northern end of Colchester Shoals. This site showed relatively low veliger counts in 1995, and no reports of adult zebra mussels. We do not expect impacts on this site in 1996, but as colonization of zebra mussels migrates to deeper depth over time, and quagga mussels appear in Lake Champlain, this site will be negatively affected.

Using these vessels as a gauge, we can estimate that any submerged cultural resource in similar environmental conditions (depth, temperature, nutrients, etc) are in danger. It is, however, important to remember that zebra mussels have a proven ability to gradually acclimate to conditions beyond their normal range of tolerance. It is quite possible that zebra mussels will defy our best predictions.

How many shipwrecks are at the bottom of Lake Champlain?

The truth is we do not know. There has never been a systematic lake-wide survey of the lake's bottomland. Less than 10% of the Lake has been surveyed and we can predict that there are a vast number of undiscovered shipwrecks hidden beneath the water of Lake Champlain. Prior to the zebra mussel invasion, time was not a factor in locating and documenting other submerged cultural resources. With approximately 50% of Lake Champlain lying above the depth of 64 feet, we can predict that the majority of these unlocated and undocumented vessels will be victims of zebra mussel colonization.

The recommendations outlined in the Executive Summary of this report are a strategy to continue our effort to preserve an important body of information, which will otherwise be lost. Time is of the essence.

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