41-HXA-B114

Zebra Mussels in the Quabbin Reservoir

Interactive Qualifying Project

Submitted by:

Lucas Deisadze

Project Advisor:

Professor Holly K. Ault

Date Submitted:

5/02/2012

Table of Contents

Table & Figures

i

Abstract

Abstract

Over the last few years there has been an increasing concern over the growth of invasive species. These alien species are not only affecting and endangering our agriculture and ecosystems, but also are causing damage to many cities. Zebra mussels are an aquatic invasive species infesting the water supply and recreational areas in some regions of the USA. This project addresses the following four primary objectives; the first is to ascertain the viability of the zebra mussels in the Quabbin reservoir as well as in major water supplies in the Commonwealth of Massachusetts. The second objective is to analyze the effects of zebra mussel infestation on the water, the environment and the infrastructure of these water supplies. The third objective is to consider financial aspects in the event of infestation by zebra mussels. The final objective addresses legislative approaches that may be used to limit the spread of invasive species such as the zebra mussels. In order to spread, zebra mussels must be in a habitat with specific conditions that include chemical properties, such as pH and alkalinity, as well as calcium levels of the water, which have an enormous influence on the survival of the mussel and its infestation. Quabbin Reservoir doesn't meet the required conditions for zebra mussel infestation. The chemical properties that the Quabbin exhibits are lower than the mussel comfort zone. A study also revealed that the general water bodies in Massachusetts have low vulnerability towards the mussel infestation. Therefore we predict the financial impact to be less significant than in other locations. The economic impact is determined by finding the costs associated with preventing infestation, removal of mussels from infested regions, enforcement of regulations, and public education in different mussel infected regions. The legislation of other regions found most effective to educate the public and create restrictions to diminish the spread of the mussels.

I

Introduction

Chapter 1. Introduction

Zebra mussels “dreissena polymorpha” are small freshwater shellfish about two inches or less in size. This species is native to Black, Caspian and Aral Seas of Eastern Europe. It is believed that some ships coming from European ports carried the mussel in the freshwater ballast, which was discharged into Great Lakes {{Horvath, 2008}}. The first appearance in North America of the zebra mussel was in Lake St. Clair, Michigan, in June 1988. In less than three years, the zebra mussel was found in all of the Great Lakes, later as far as New York and now in Massachusetts. One of the more significant threats by mussels in Massachusetts is the possibility of the Dreissena getting into the Quabbin Reservoir, which is the main water supply of metropolitan Boston.

The dreissena are troublesome pests that are known to spread rapidly. The mussels are known to physically attach to objects, which can cause the clogging of the pipes in water distribution systems. The latter can cause various damages, such as attachment to structures, clogging the pipes, disturbing the life cycle of other species which inhabit the ecosystem invaded by the mussel and many more. These events can have significant effects on the state’s financial affairs, well-being of the people and loss of business. In order to prevent zebra mussels from entering the Quabbin Reservoir, boats are closely monitored and cleaned.

Although, the Quabbin Reservoir is currently free of zebra mussels, {{Zhang, 2004}} the rapid spread in some parts of Massachusetts indicates the possibility of infestation. To help avoid such infestation in water supply, the Massachusetts Department of Conservation and Recreation (DCR) and the Massachusetts Water Resources Authority (MWRA) have taken precautions to prevent such threats and closely monitor the Quabbin. Since the traffic of trailered boats between water bodies is the main vector of the zebra mussels, to minimize the vulnerability of the Quabbin in 2009, the aquatic invasive species (AIS) management plan forbid the boats to enter the reservoir unless they were cleaned and started sealing the boats so that the boats don't enter other lakes and then return to the Quabbin, thus minimizing the danger of the mussel infestation. The number of workers to control illegal boating activity has been increased and with it the public, not only close to the Quabbin but also other surrounding lakes and ponds, has been educated about zebra mussels {{Worden, David.2010-10}}.

Currently, there is no effective way to permanently eliminate infestations. Even though chemicals have been effective against the mussels, such chemicals applied have been prone to cause harm to plants and vegetation, other living species, and even the taste of the water {{Connelly, 2003}}. In smaller lakes, divers have removed mussels by physical labor which has helped control population of the mussel, but for larger lakes, which provide public water supply and recreation, physical labor alone is not enough to eradicate the mussels. By studying the biology and ecology of zebra mussels, closely examining the Quabbin and its waters, solutions can be found to minimize and control the impact of the zebra mussels from public water supply. Thus researching and studying biology and the ecology of the mussel we can shed some light on the problem of the zebra mussels, the possible avoidance of infestation, and provide suggestions for controlling and limiting the damage inflicted by these mussels when and if they infest the Quabbin or other water supply systems in Massachusetts.

II Zebra Mussels

Chapter 2. Zebra Mussels

2.1 Description of the Zebra Mussel

Zebra mussels (dreissena polymorpha) are considered to be semi-sessile[1], filter-feeding bivalve of several centimeters in length {{Stewart, 2004}}. The mussels have resided in lakes and reservoirs in North America since the 1980s. There are three major types of lakes (see fig 2.1), classified based on the amount of available nutrients for organisms. The first category is Oligothropic Lake, which contains very few nutrients. The second type is Mesotrophic lakes, which contains a medium amount of nutrients. Finally, Eutrophic Lakes have a great amount of nutrients. Zebra mussels prefer to live in Mesotrophic waters, but they can live in Oligothropic waters, however mussel inhabitance tends to decrease in Eutrophic waters.

Generally the depth of existence of zebra mussels in most places does not exceed 6-8 meters {{Caraco, 2002}}, but the mussel can occur at depths up to 12 meters in some waters. Mussels are bio-fouling[2] organism capable of attaching to various surfaces in very high densities. Since the dreissena is an abundant benthic[3] filter feeder, it is capable of removing and destroying planktonic organisms and particles from the water column. The ability of the mussel to actively pump water makes it a filter feeder in the environmental conditions where water tends to be calm {{Lucy, 2006}}. Therefore zebra mussels remove particles from water that they filter, some of

[1] One that tends to temporarily attach to a substrate
[2] undesirable accumulation of microorganisms, plants, algae, or animals on wetted structures
[3] the ecological region at the lowest level of a body of water such as an ocean or a lake, including the sediment surface and some sub-surface layers

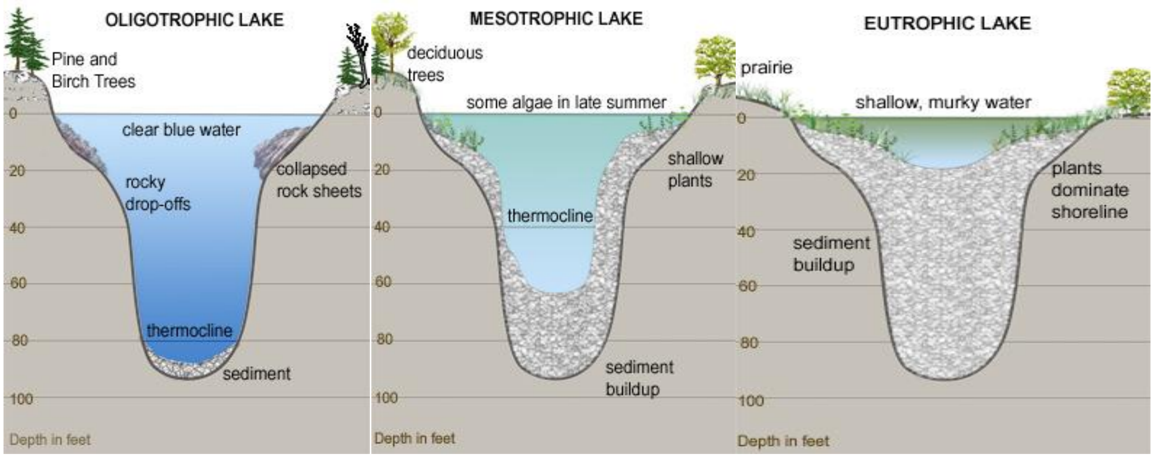

Figure 2.1 Three major Lake ecosystems (RMB Environmental Laboratories, 2002)

which they consume. Zebra mussels only spend part of their lives in water columns during the early stage of their life cycle, the planktonic larval stage. Later they settle on a surface.

2.2 The life cycle of the Zebra Mussel

Mussel life cycle consists of three main stages: veliger, juvenile, and adult (see fig 2.2). Veligers are planktonic larvae that move through the use of a ciliated organelle, known as the velum. The spawning period for zebra mussels is late spring or early summer, and a single colony of mussels is capable of producing large numbers of veligers through external fertilization. The primary natural dispersal mechanism for zebra mussel populations is translocation in the veliger state resulting from water current flow. Adult mussels have also been known to travel as a result of drifting and human vectors (e.g. recreational boating). It is the mobility of mussel veligers that gives way to rapid dispersal of mussels in a single watershed and what makes this species so successful to spread and attach to objects. The juvenile stage begins when the individual veliger settles and ends at sexual maturity, which occurs over a period roughly equal to two years. As a juvenile, the mussels develop a byssal thread, which enables them to attach to a substrate. Zebra mussels do not colonize all available areas of a habitat but instead attach themselves only to firm substrates, although it is possible for adults to detach and move elsewhere. The earliest stages of zebra mussels are the most sensitive in their life cycle. The dreissena are of separate sex, the eggs are released in enormous quantities into the water column {{MACKIE, 1999}}. One female produces over a million eggs; dreissena eggs are about 70 micro meters in diameter.

The rate of development depends upon the temperature. For successful fertilization the temperature must be higher than 10°C, usually in a range of 12-24°C. The pH (acidity of water) must be between 7.4 and 9.4, and calcium ions must be present in the water {{Voets, 2004}}. The vast number of the zebra mussels result in the uptake of many particles and competes with the life cycle and survival of other species. Soon after the larval stage the zebra mussels move towards the land or attach to various objects. The mussels are dispersed overland, through the attachment to boats, the flow of the waters and many other ways. Very often, the mussels are found attached to the aquatic plants that have been snagged by propellers or drive units. These plant fragments are easily transported between water bodies, and are a naturally moist and shaded environment in which mussels can remain alive.

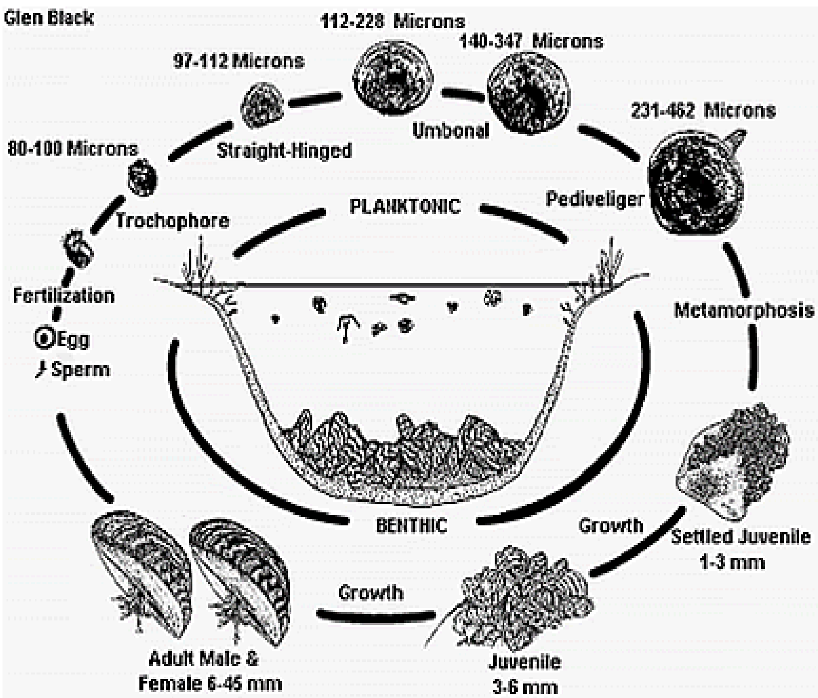

Figure 2.2 Life cycle of the zebra mussel (U.S. Fish & Wildlife Service,2000)

2.3 The History of the Zebra Mussels in the U.S.

The zebra mussels are native to Eastern Europe, specifically of Black, Aral and Caspian seas. Boats that have been in the water for more than 1 or 2 days in areas where zebra mussels are abundant, may have these mussels attached to their hulls, anchors and chains, trailers, equipment, and engine drive units. The mussel is believed to have entered the USA through transport boats coming from European ports. The boats carried the mussel in the freshwater ballast and discharged into the Great Lakes {{Horvath, 2008}}.The first appearance of the zebra mussel was in Lake St. Clair, Michigan, in June 1988 {{Strayer, 1990}}. The mussel spread rapidly by both, natural and human processes, through the east coast and Mid-Atlantic. Smaller mussels are more likely to be inadvertently transported.

Colonization of zebra mussels in North America has proceeded by long range distance leaps (see fig 2.3): including downstream through the Mississippi river and overland to Lakes Mead and George, to medium range jumps such as in Great Lakes, and short journeys between the lakes within regional lake districts. By 2003, the Great Lakes region was invaded and the mussel entered the state of Massachusetts in 2009 where it has spread regionally. The spread has decreased in recent years as the most vulnerable bodies of water have been colonized, however, the spread will not terminate, but rather continue for many years, until the entire potential range is filled {{Johnson et al, 2006}}.

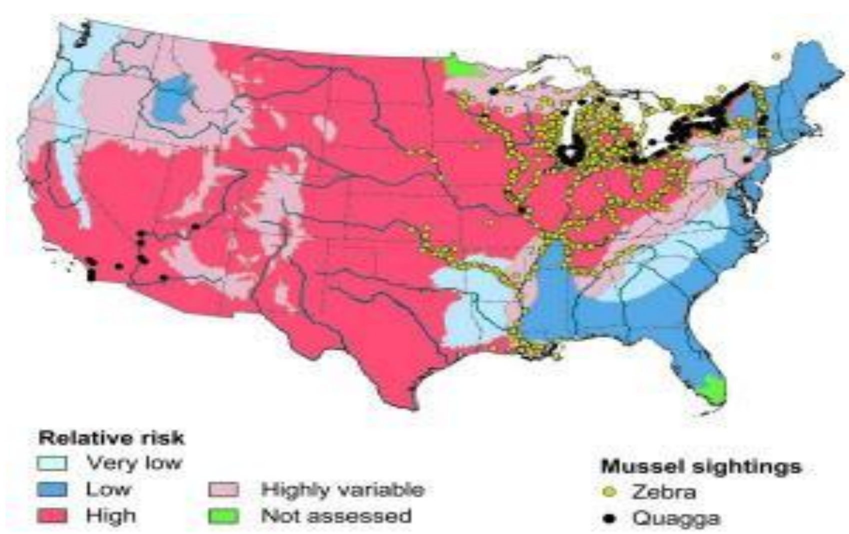

Figure 2.3 Zebra and Quagga mussel sightings distrubition (USGS),2002

2.4 Dangers of the Zebra Mussel

In spite of the zebra mussel being small in size, the mussels are invasive species and are known to spread rapidly. Zebra mussels can cause far-reaching damage to water structures and native ecosystems. The mussels attach to manmade structures and clog pipelines (see fig 2.4), hindering water movement through hydroelectric turbines and intake structures for drinking water and irrigation systems {{Nalepa, Thomas,1993}}. In 1989, in the city of Monroe, Michigan, the main water-providing power plant reservoir was shut down The city lost its water supply for two days because its intake pipes were plugged by a huge colony of zebra mussels, and Detroit Edison spent half a million dollars cleaning them from the cooling system of its Monroe power {{Welcker,Bonnie C, 1997}}.

Figure 2.4 Zebra mussels cover a current meter (right) and clogged pipes (left) in Michigan (National Oceanic and Atmospheric Administration)

Ford Motor Company was forced to close its casting plant in Windsor, Ontario, to remove a colony from the pipes which send cooling water to their furnaces. There is a significant danger of other water supply reservoirs being affected by the mussel, which can lead to substantial financial damage and impact on the infrastructure, including boating and fishing. Recreation-based industries along Lake Erie have been impacted by zebra mussels. Unprotected docks, break walls, boat bottoms, and engine outdrives were rapidly colonized beginning in 1989.

Consequently, there were numerous reports of boat engines overheating due to colonies of zebra mussels clogging cooling water inlets and mussels colonizing boat hulls.

Figure 2.5 Mussels washed up on beach, clogged up engine (GLERL)

There have been many reports about the destruction of the boat engines, boat ramps and docks causing harbor to constantly be damaged and repaired. Mussels also have caused fouling of the beaches, where swimming and relaxing are impossible because of the sharpness of the mussels, which can also cause injury to the people (see fig 2.5). Zebra mussel fecal material may also contribute to taste and odor problems in drinking water sources, which is another reason to control these invasive species, so they don't get into public recreational areas and drinking waters.

Authorities in charge of reservoirs are concerned with the spread of the mussel, and take extra precautions such as banning boating from certain areas. Before entering the water in the areas free to roam and fish, boats have to be cleaned and checked for any signs of the mussel on the boat. The strict rules on boating have caused many tourists and vacationers to avoid the troubles of precautions and thus affect the local businesses with many financial damages because of the desertion of tourist attractions.

Dreissena invasion can lead to pronounced changes in aquatic ecosystems; the severity and scope of impacts varies between ecosystems. In the Great Lakes {{Vanderploeg et al., 2002}} and some inland waters of North America {{MacIsaac, 1996}} , mussel invasion has increased water clarity and light penetration, which diverts energy from pelagic[4] to benthic pathways, meaning in the absence of large allochthonous[5] inputs, primary production determines the availability of energy to higher trophic levels in ecosystems and provides a template of overall ecosystem productivity, such as decline of other species and many plants and bacteria that benefit from these inputs.{{Idrisi et al., 2001 }}.When benthic and pelagic food webs are tightly linked, underestimates of total primary production will lead to overestimates of efficiency of energy transfer between primary producers and primary consumers. This will make secondary producers appear more efficient in oligotrophic lakes {{Vadeboncoeur, M. JVZ, Lodge. 2002}}.

The mussels are known to negatively impact aquatic ecosystems by harming native organisms {{Miehls, 2009}}. They out-compete other filter feeders in huge numbers, leading to the starvation of the other species. The mussels can adhere to all hard surfaces, including the shells of native mussels, turtles, and crustaceans making the life harder on such species. Zebra mussels indirectly impact tastes and odors through in the phytoplankton[6] community {{Makarewicz, 1995}}. Even though the mussel causes change in taste and smell, it's unable to cause problems to the overall taste of the water.

2.5 Quabbin Reservoir

Created in the 1930s, Quabbin reservoir is one of the largest built public water supplies in the United States. Before the reservoir's construction, there was a hill called Quabbin Hill as well as a lake in Greenwich called Quabbin Lake. These names originate from a Native American chief called Nani-Quaben, meaning place of many waters. The reservoir is fed by the Swift River and seasonally by the Ware River, but countless unnamed streams and brooks also feed into the reservoir. Prior to construction, four towns had to be vacated in the Swift River Valley to allow for flooding. A state highway, railroad line, hundreds of homes and businesses, and 34 cemeteries were dismantled or moved to make way for the new reservoir. Quabbin can hold up

[4] Any water in a sea or lake that is not close to the bottom or near to the shore
[5] usage: of rocks, deposits, etc.; found in a place other than where they and their constituents were formed
[6] photosynthesizing microscopic organisms that inhabit the upper sunlit layer of almost all oceans and bodies of fresh water

to 412 billion gallons of water; the reservoir covers 39 square miles, is 18 miles long and has 181 miles of shoreline {{Ahlfeld , 1982}}.

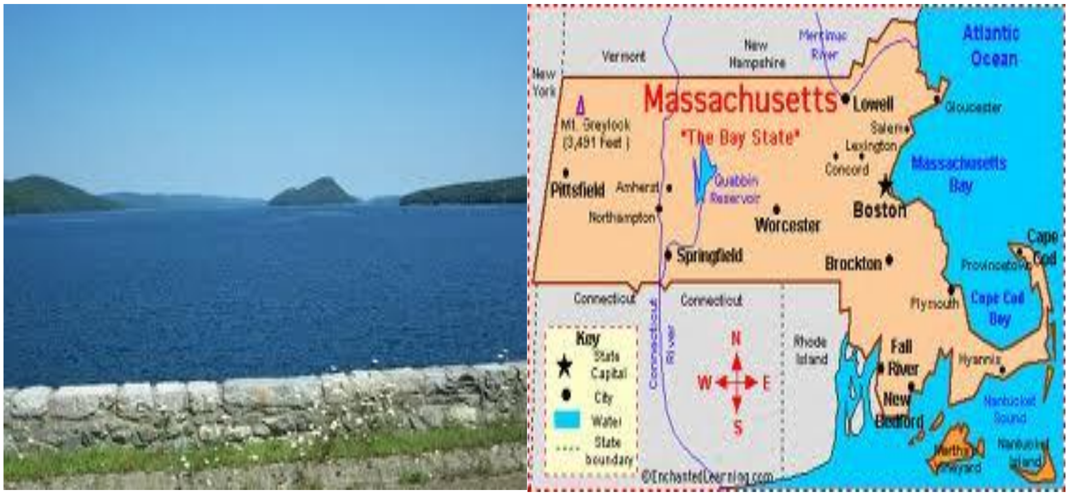

Figure 2.6 Quabbin Reservoir (MWRA)

Quabbin reservoir is the primary water supply for metropolitan Boston. Water from the Quabbin reservoir flows to the Wachusett reservoir through the Quabbin Aqueduct and the Ware River. The Quabbin watershed is managed by the Massachusetts Department of Conservation and Recreation (MDCR) and is operated by the Massachusetts Water Resources Authority (MWRA). Over the years MWRA has improved the reliability and quality of the water supply to metro Boston to meet all the stringent requirements of the federal Safe Drinking Water Act. This includes five critical areas: watershed protection, water treatment, transmission and reliability (metro west water supply tunnel), covered water storage, and distribution of pipeline rehabilitation.

Although the main purpose of the Quabbin Reservoir is to supply the public with drinking water and to protect the water supply, Quabbin Reservoir is a hot spot for recreational opportunities, offering many exciting occasions for mountain biking, fishing, hiking, and educational opportunities. Fishing in the Quabbin Reservoir is heavily restricted because it is reserved for drinking water distribution.

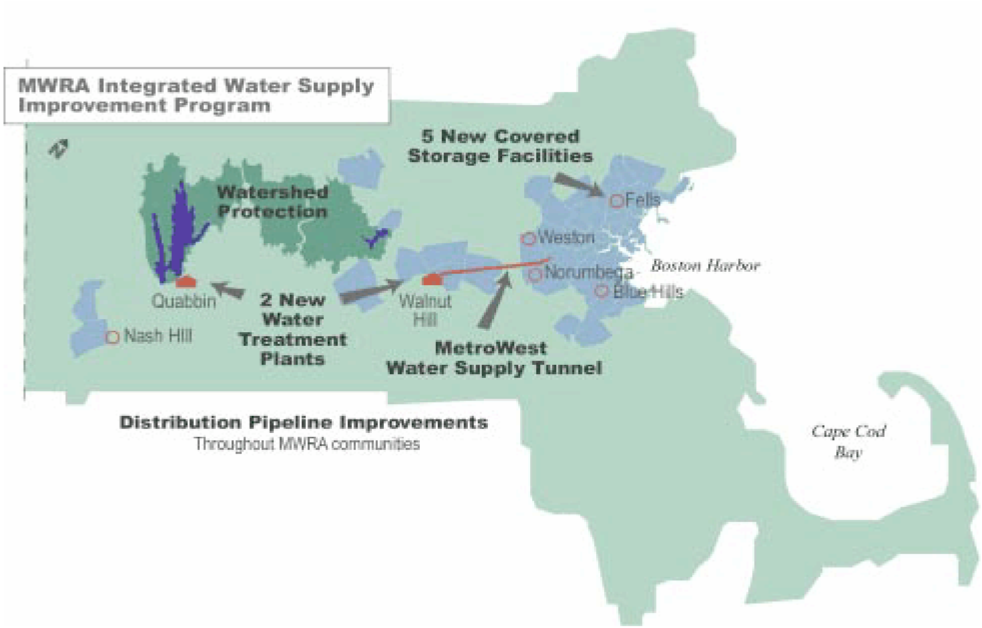

Figure 2.7 Water improvement program (MWRA,2009)

Because of its abundance of fish, boat fishing is permitted from April through October, which is the standard fishing season in Massachusetts {{Cohen, 2008}}. The Quabbin Reservoir offers three boat launches. However pontoon, inflatable and sailboats are not permitted on the reservoir, during the regular fishing season. Shore fishing is allowed on about 50% of the shoreline which is accessible only by foot, due to early legislation. MDCR feels that by limiting the access areas, it limits potential negative impacts to the water quality (Cohen). All recreational opportunities come with restrictions to maintain water quality. When venturing onto either the lands surrounding the reservoir or the waters comprising the Quabbin, it is tantamount that each person leaves no traces behind. Biking is allowed only on paved roads to prevent soil erosion and limit access to shorelines. Hiking, walking, and snow shoeing are allowed in designated areas during designated times because the MDCR must limit access to sensitive areas to protect the drinking water quality from contamination by improperly disposed of sanitary wastes(Cohen).

III Methodology

Chapter 3. Methodology

The main objective of this project was to identify the viability of the zebra mussels in the Quabbin, the effect on the water, the financial factors that must be considered in the event of infestation by zebra mussels and legislative approaches that may be used to limit the spread of invasive species such as the zebra mussels. Furthermore, this project investigates the potential impact of the zebra mussel on major water supplies in the Commonwealth of Massachusetts. This chapter describes the methods that were used to accomplish these objectives in more detail.

3.1 Zebra mussel viability

Studies were done to assess the properties of ecosystems and waters that the mussel prefers for its habitat compared to the Quabbin. The viability was assessed by comparing the pH, temperature, nutrient levels, calcium, sunlight, water flow, depth and oxidation of the lakes in which the mussel has spread to those of the reservoir. The necessary information was found through journal reports and data including research on the life cycle of the zebra mussels.

3.2 Case studies from other Lakes

To understand more about the mussel, its capability of harming and causing damage to water supply infrastructure and impact on local economies, research was done to determine the impact on other lakes that the zebra mussel had already invaded. The research identified journal reviews and lab reports such as the Lake George Invasive Species Committee report which provided a good understanding of what can be expected from the mussel and how the Lake George committee approached the infestation, thus helping to get a better sense of the viability.

3.2.1 Ecosystem changes

In order to find out what effect the zebra mussel will have on the ecosystem and other living species in the infested waters, the history of the mussel and questions were proposed through literature review, which informed us regarding the outcome impact that the mussel had on the infested areas, which other lakes and reservoirs were damaged. Some information was provided on environmental change and influence the mussel had on other species and alteration of the vegetation in the infested lakes.

3.2.2 **Removal or control methods**

The removal of zebra mussel has been implemented or at least talked about in all of the regions where mussel infestation has occurred. Thus there are methods used for removal, which are discussed in numerous sources and research reports which were used in this project. The main source for the removal technique was the Lake George Watershed Conference committee, where they have formed a community of biologists and volunteers for the removal of the mussel from the lake, articles about Lake Champlain removal methods and sources describing efforts in numerous other lakes. Another approach for the removal or control problem was literary review about exclusion and marginalization of the invasive species from any reservoir or lake infested, by not only zebra mussel but other species. Since the control of the species and removal can be expensive or difficult, there were some research and literature review done on other species that are dealt in a way that the surroundings won't be affected.

3.3 Economic impact

The economic impact of the zebra mussel is a major concern, especially in a public water supply and recreational reservoir. Therefore research was done on the financial impact that the mussel has had on other reservoirs, lakes and their surroundings. Research also included the financial damage of the local businesses and recreational areas. Discovering journal articles and reports about the economic impact of the infestation included information on the cost of prevention tactics, control or removal.

3.3.1 **Removal or control costs**

One of the major priorities of Lake George Watershed Conference was the removal cost of the mussel from Lake George. Thus, studying this committee entry and budget discussions provided estimates with the removal and control costs. Another helpful way to estimate the removal cost was done by gathering information on the remediation costs for other damages that have been caused by the mussel to various places such as power plants and industrial facilities.

3.3.2 **Damage to infrastructure**

Mussels are known to attach to a variety of objects. Therefore there is a possibility of risk for many reservoirs, because mussels can attach to the water uptake pipes, power plants and water treatment plants causing them to clog up and disturb the water distribution to the general public. The following can cause some financial damage, thus investigation was done to identify the preferential object the mussel attaches to, it provided information to conclude that the mussel can attach and damage the infrastructure. MWRA web sites provided information for the protection water uptake pipes and power plants have against large particles capable of disturbing the uptake of water.

3.4 Legislation

Since the appearance of the mussel in the US, many laws have been enacted which are intended to control the spread of invasive species. Many regulations were studied from other mussel infested states which provided information for the fight and evasion of the mussel. Local invasive species rules were studied from government websites and some suggestions were given on what rules should be adopted in order to fight and control the mussel.

IV Results

Chapter 4. Results & Analysis

This chapter covers different sources and research, comparison and factual data, which will supply significant data about zebra mussel viability and determine the probability of infestation in the Quabbin and other major water supply sources in the Commonwealth.

4.1 Comfort level of zebra mussels

Zebra mussels will spread in environments with a lower thermal tolerance of 0-8°C {{DMDS, 1996}} and upper thermal tolerance of 26-32°C (Strayer,1993), a calcium threshold for survival of 12 mg/liter {{Neary; Leach, 1996}}, and a pH and calcium threshold for growth and reproduction of 7.3 and 28.3 mg/liter, respectively {{Ramcharan, 1992}}. Although zebra mussels may survive and grow in waters with pH as low as 7.3 and calcium levels between 8 and 20 mg/liter, infestation levels of abundance probably will not occur until pH exceeds 7.5-8.0 and calcium levels exceed 15—20 mg/liter {{Mitchell 1991}}. Larval development is inhibited below pH of 7.4. Higher rates of adult survival occur at a pH of 7.0-7.5, but populations have been found in the hypo limnetic zone[7] of lakes with a pH of 6.6-8.0, and in the epilimnetic zone with a pH of 7.7-8.5 {{Miehls 1996}}. Optimal larval survival occurs at a pH of 8.4, and optimal adult growth occurs at pH 7.4-8.0 {{Cohen, 1990}}.

In European populations, calcium concentrations of 24 mg/l allow only 10% larval survival due to inhibition of shell development. Optimal calcium concentrations ranges from 40-55 mg/l, but North American populations have been found in lakes with lowers concentrations.

[7] An area of deep water away from the edge of a lake, in which plants cannot live but where phytoplankton can exist. Is the well-lit, open surface water in a lake, away from the shore. The vegetation of the littoral zone surrounds this expanse of open water and it is above the profundal zone.

North American populations require 10 mg /l to initiate shell growth and 25 mg/l to maintain shell growth {{Cohen, 1990}}.

4.2 Study and comparison of various infested Lakes

Since the appearance of the mussel in the Great Lakes, it has rapidly spread through other lakes, some of which are Lake George, Lake Champlain and Laurel Lake.

4.2.1 **Lake George**

A lake that is infested by the mussel which is of a significant interest is Lake George, because of the ecological and environmental similarities with the Quabbin reservoir. Lake George is an oligotrophic lake flowing northwards into Lake Champlain and the St. Lawrence River drainage basin located at the southeast base of the Adirondack Mountains in northern New York. The lake extends about 32.2 miles on a north-south axis, is quite deep, and varies from 1 to 3 miles in width {{Bloomfield, 2000}}. Lake George drains into Lake Champlain to its north through a short stream, the La Chute River, with many falls and rapids, dropping about 230 feet in its 3.5-mile course. Eventually the waters flow over 100 miles through long Richelieu River emptying into the St. Lawrence River downstream and northeast of Montreal and finally then into the North Atlantic Ocean above Nova Scotia {{Momen, 1993}}.

Based on the Lake George water quality report {{CSLAP 2010}}, best intended use for the lake is for potable water intake, drinking with minimal treatment, contact recreation such as swimming and bathing, non-contact recreation including boating and fishing, aquatic life, even aesthetics. The lake is used extensively by lakeside residents, visitors and tourists for swimming, boating and other recreation via shoreline properties and multiple public boat launches.
The CSLAP report states that the pH ranges from 6.92-9.22 in Lake George and averages out to 8.02. Alkalinity is around 20-25mg/l which is high compared to that of the Quabbin. Calcium range is from 9.8-14.8mg/l averaging out to 12mg/l. The temperature in Lake George can get as low as -10°C and as high as 29°C {{ECY, 2008}}.
Comparing the data between the two lakes it is clear that, even though Lake George is somewhat similar to the Quabbin ecologically and environmentally, it has higher pH, temperature, and calcium level, which plays a significant impact for the infestation of the mussel. Furthermore the

comparison of the two lakes highlights differences between the lakes that suggest that the Quabbin reservoir will not be infested like Lake George.

4.2.2 **Lake Champlain**

Another lake that is infested by the mussel and is of some point of interest is Lake Champlain. Lake Champlain is located mainly within the borders of the United States between the states of Vermont and New York but it is partially placed in Canada. Although the lake is smaller than the Great Lakes, Lake Champlain is a large body of fresh water. Approximately 490mi^2 in area, 125mi long, and 14mi across at its widest point {{Keith, 1998}}. Lake Champlain is located in the Lake Champlain Valley between the Green Mountains of Vermont and the Adirondack Mountains of New York, drained northward by the 106 miles long Richelieu River into the St. Lawrence River at Sorel-Tracy, Quebec northeast and downstream of Montreal. It also receives the waters from the Lake George, so its basin collects waters from the northwestern slopes of the Green Mountains of Vermont, the north and west slopes of the Berkshire Hills of Massachusetts, and the northern most eastern peaks of the Adirondack Mountains of New York State {{Smith, 1992}}. Like Lake George, Lake Champlain is a recreational and a public resource hot spot. This includes water intake, swimming, boating, hiking and numerous other public activities. The lake is annually examined by the Safe Drinking Water Information System (SDWIS/FED), based on the report Lake Champlain has a pH is in the neighborhood of 6.5-8.5 and averages out to 7.4. The Alkalinity range from 26 to 340 mg/l; the median was 130 mg/l. The median alkalinity of samples from bedrock wells 154 mg/l was higher than the median alkalinity of samples from sand and gravel wells. The calcium measured was 8.68-57.1 mg/l and averaged out to 45.5 mg/l. Water temperature ranged from 7.9 to 15.1°C; the median temperature was 9.7°C {{Smith, 1992}}.

Lake Champlain compares somewhat to Lake George but the data showed that Lake Champlain is more preferred destination for zebra mussel because of the high calcium range. The pH is similar to that of Lake George but higher than that of Quabbin. Lake Champlain is a very likeable place for the mussel to thrive, because of the natural generation of the alkalinity and calcium in the water by the sand, gravel and bedrocks {{Whittier, 2007}}. Natural richness of some lakes plays a significant importance in the spread of the mussel.

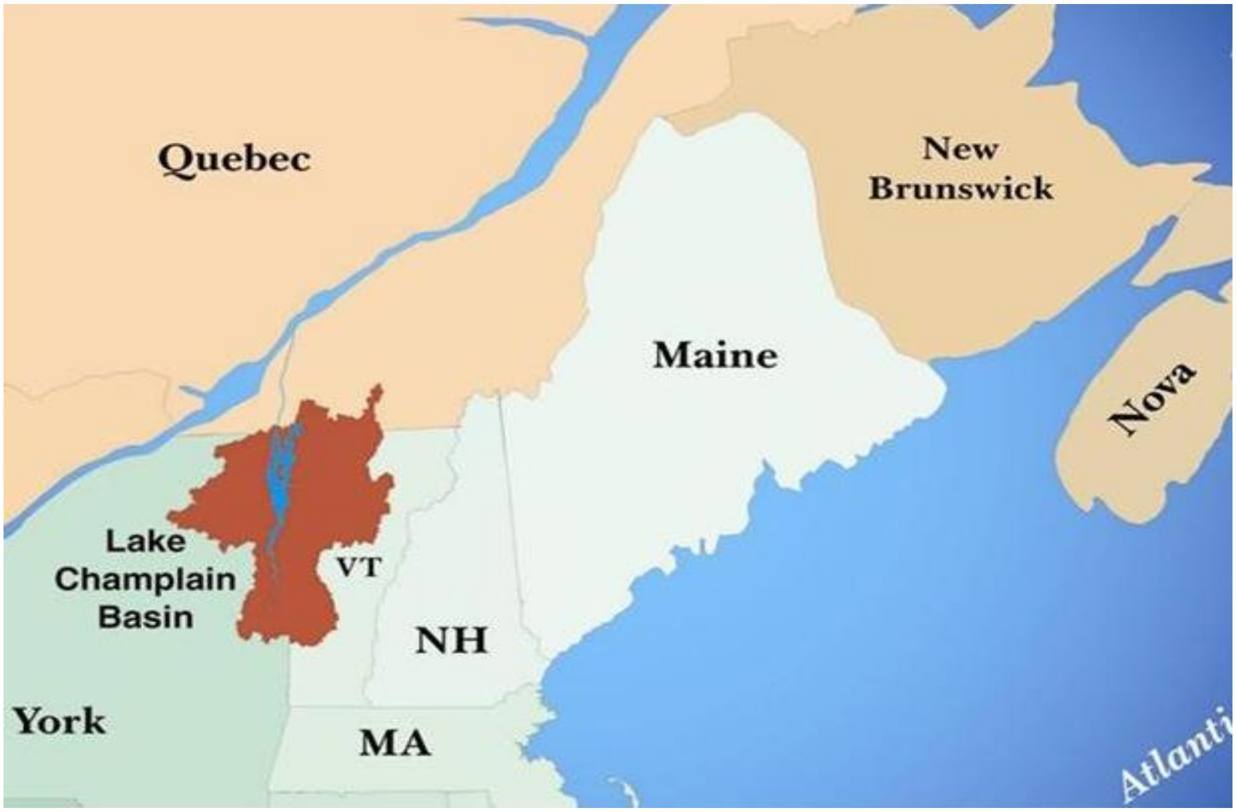

Figure 4.1 Lake Champlain Basin (LCBP,2008)

4.3 Viability of the Mussels in the Quabbin Reservoir

In European populations, calcium concentrations of 24 mg/l allow only 10% larval survival due to inhibition of shell development. Optimal calcium concentrations ranges from 40-55 mg/l, but North American populations have been found in lakes with lowers concentrations. North American populations require 10 mg /l to initiate shell growth and 25 mg/l to maintain shell growth {{Cohen, 1990}}.

According to the DCR report {{DCR,2011}} the temperature in the Quabbin varies with the season usually from 5°C to 22°C. The thermal stratification that occurs in the reservoir has a profound impact on most of the parameters monitored across the reservoir. Quabbin reservoir water is slightly acidic with a pH level that has an average of 6.66. As for the reservoir alkalinity, it is low and averages 5.22 mg/l. Alkalinity serves as a water body's principal defense by neutralizing the effects of pH. Both the alkalinity and pH have a long-term record of stability in the reservoir. The low pH and alkalinity in the Quabbin are affected by some important factors:

direct acidic inputs, including rainfall, dry deposition; biological respiration, and algal photosynthesis. Calcium concentrations in the Quabbin range from 0.863 to 6.60 mg/L.

From the comparison done for the zebra mussel viability in the Quabbin, there is sufficient data to assume that, even though the mussel can exist in the Quabbin reservoir infestation will not happen and mussel will not permeate. However this assumption does not specify the dangers of the zebra mussels harming and damaging the Quabbin reservoir and its surrounding.

4.4 Viability of the Mussels in Massachusetts water bodies

As zebra mussels continue to spread in Massachusetts, some water bodies are noteworthy to survey in order to determine the intrusion of the mussel. A reservoir that is of importance other than the Quabbin is Otis reservoir, (which supplies water to most of south-western MA) is presumed to have a low risk of the infestation because of its low pH=6.80 and calcium=6.2mg/L levels. Another reservoir that is of importance in western MA is Plunkett reservoir (located in Housatonic River Watershed), which unlike Otis reservoir is vulnerable to the mussels because of its high pH averaging around 8.0, calcium=11-13mg/L {{Biodrawversity LLC, 2009}}.

Most populated cities have several water providers which include local wells and rivers; nevertheless they each have a large body of water providing main flow. The city of Springfield's main provider reservoir is Cobble Mountain which provides most of the water to the city {{63 Karalekas,P.C. 1965}}. Cobble with a 75 million gallon capacity has low chemical properties, measured pH=6.5-6.7mg/L, alkalinity=5.5mg/L and has a very low risk of vulnerability towards the mussel (M-F Hatte, E Finn, 2010).

The city of Worcester obtains its drinking water from 10 surface water sources and reservoirs, located outside of the City (see table 4.1). The chemical properties of these watersheds are physically controlled. In order to make the water less acidic and less corrosive calcium oxide is added to the water, thus controlling pH averages out to 7.6, calcium=8.2 mg/L, Alkalinity=11.7 mg/L and Temp=14°C. Thus the following leads to a conclusion that the reservoirs are safe.

Water Bodies	Location	Million Gallons(MG)
Lynde Brook Reservoir	Leicester, MA	717.4 MG
Kettle Brook Res. #1	Leicester, MA	19.3 MG
Kettle Brook Res. #2	Leicester, MA	127.3 MG
Kettle Brook Res. #3	Leicester, Paxton, MA	152.3 MG
Kettle Brook Res. #4	Paxton, MA	513.7 MG
Holden Res # 1	Holden, MA	729.3 MG
Holden Res # 2	Holden, MA	257.4 MG
Kendal Reservoir	Holden, MA	792.2 MG
Pine Hill Reservoir	Paxton, Holden,Rutland MA	2,971.0 MG
Quinapoxet Reservoir	Holden, Princeton MA	1,100.0 MG

Table 4.1 Wocester City Water Provider Reservoirs

The city of Lowell obtains its water from the Merrimack River, which also provides water to Dracut, Tyngsboro, Lawrence, and Chelmsford and has its source in the White Mountains of New Hampshire. Merrimack River zone roughly corresponding to the Eastern Plateau and encompassing most portions of the Merrimack River drainage basin is one of the two principal areas that might support populations of the zebra mussels the other is the Connecticut River basin. The major tributaries, especially to the east, vary with respect to their alkalinity and pH values, and may be minimal habitats at best. However within the Connecticut River watershed many lakes, ponds and reservoirs will certainly not support populations of the zebra mussel due to their persistently low pH=3-4, calcium under 20mg/L {{Douglas G, Smith, 1996)}}. Merrimack River itself has a pH range of 6.5-8.3 and some place as low as 3.2 {{MRWC, 2010}}.

The city of Braintree obtains their water from Great Pond Reservoir System where water enters the reservoirs through the Farm River which is diverted into the Richardi Reservoir {{64 Soobader,M. M. 2006}}. The waters have very low chemical levels with calcium=0.04-11Mg/L, pH=6.5-8.4, Alkalinity=1-20.5 and are low level vulnerable to zebra mussel infestation {{T. Whalen, L Dutton; 2010}}.

The Saugus River is the primary source of Lynn's water supply. Water from the Saugus River is diverted to Hawkes Pond through the Saugus River diversion conduit. A concrete dam built over the Saugus River stores the water that supplies the canal through a connection equipped with stream gates. Overall water properties are very low with pH <7.1 and have a low risk {{LWSC, 2012}}.

Chicopee River is the main water supplier for the city of Chicopee. The Chicopee River watershedcovers an area of 723 square miles in Franklin, Hampshire, Hampden, and Worcester regions {{65 Randhir,Timothy T.O. 2009}}. The Chicopee River breaks down into three major parts which are: the Swift, Ware, and Quaboag river systems; they all merge to form the main stem Chicopee River. These rivers flow into the Quabbin Reservoir and are the main water providers for the reservoir. The chemical properties of the Chicopee River are low compared to other water bodies; pH ranges from 6.1-7.3, calcium 4-18 mg/L {{M. Reardon, MDEP, 2003}}. The Chicopee River is not vulnerable to the infestation of the mussel.

The city of Pittsfield gets its water from Cleveland Reservoir and Sackett Reservoir both located in the Town of Hinsdale. The chemical properties are of medium level with pH=6.5-8.3 and calcium=15-28 mg/L thus the risk level is medium for both reservoirs

Water Bodies	Location	Recreation
Otis Reservoir	Low Risk	Boating, Fishing Swimming
Plunkett Reservoir	High Risk	Boating, Fishing
Cobble Mountain Reservoir	Low Risk	Limited Fishing
Kendal Reservoir	Low Risk	Boating, Fishing
Holden Reservoir	Low Risk	Boating, Fishing
Merrimack River Basin	Low-Medium Risk	Boating, Fishing, Swimming
Great Pond Reservoir	Low Risk	Boating Fishing
Richardi Reservoir	Low Risk	Fishing
Saugus River	Low Risk	Boating, Fishing
Chicopee River	Low-Medium Risk	Boating, Fishing, Swimming
Cleveland Reservoir	Low Risk	Boating, Fishing
Sackett Reservoir	Low Risk	Boating, Fishing

Table 4.2 List of Water Bodies

4.4.1 **Laurel Lake**

As of 2012 Laurel Lake is one of the few waters in Massachusetts that is infested by the zebra mussel. Because of its clean beaches Laurel Lake is a preferred fishing and swimming area. Laurel Lake is approximately 165 acres in size. It is fed by two major branches, Sargent Brook and an unnamed tributary. Laurel Lake is primarily fed by Sargent Brook, which flows into the lake along the northeastern edge. The headwaters of Sargent Brook emanate from a forested area located approximately 1.3 miles north of the lake. The outlet from Laurel Lake is located at its southeastern end, and consists of a stone outlet structure and spillway. Water flowing over the spillway eventually empties into the Housatonic River. In the Housatonic River system, zebra mussels were found by divers working for Biodrawversity LLC, the consulting firm hired by the Department of Energy and Environmental Protection (DEEP) to survey for zebra mussels in nearby high-calcium content waters. The pH was found to be 7.7-8.9; the average was found to be about 8.2. When measured, alkalinity was from 25-169mg/l, the average alkalinity level was126 mg/L. As for the calcium it ranges from 2.1-44.0, g/l averaging out around 32 mg/l. The temperature is in the range of -5-17° C, and averages out to 4° C.

Laurel Lake ecology, unlike the Quabbin, is more vulnerable to the zebra mussel and that could be the main reason why it is infested by the mussel.

	pH Range (units)	**Alkalinity** Range (mg/l)	**Calcium** Range (mg/l)	**Temperature** Range (Celsius)
Zebra Mussel	7.3-9.4	35-200	7.3-28.3	0-32
Quabbin Reservoir	5.9-7.4	5.22	0.863-6.60	5-22
Lake George	6.92-9.22	20-25	9.8-14.8	-10-29
Lake Champlain	6.5-8.5	26-340	8.68-57.1	7.9-15.1
Laurel Lake	7.7-8.9	25-169	2.1-44.0	-5-17

Table 4.3 Zebra mussel habitat compared to various lakes

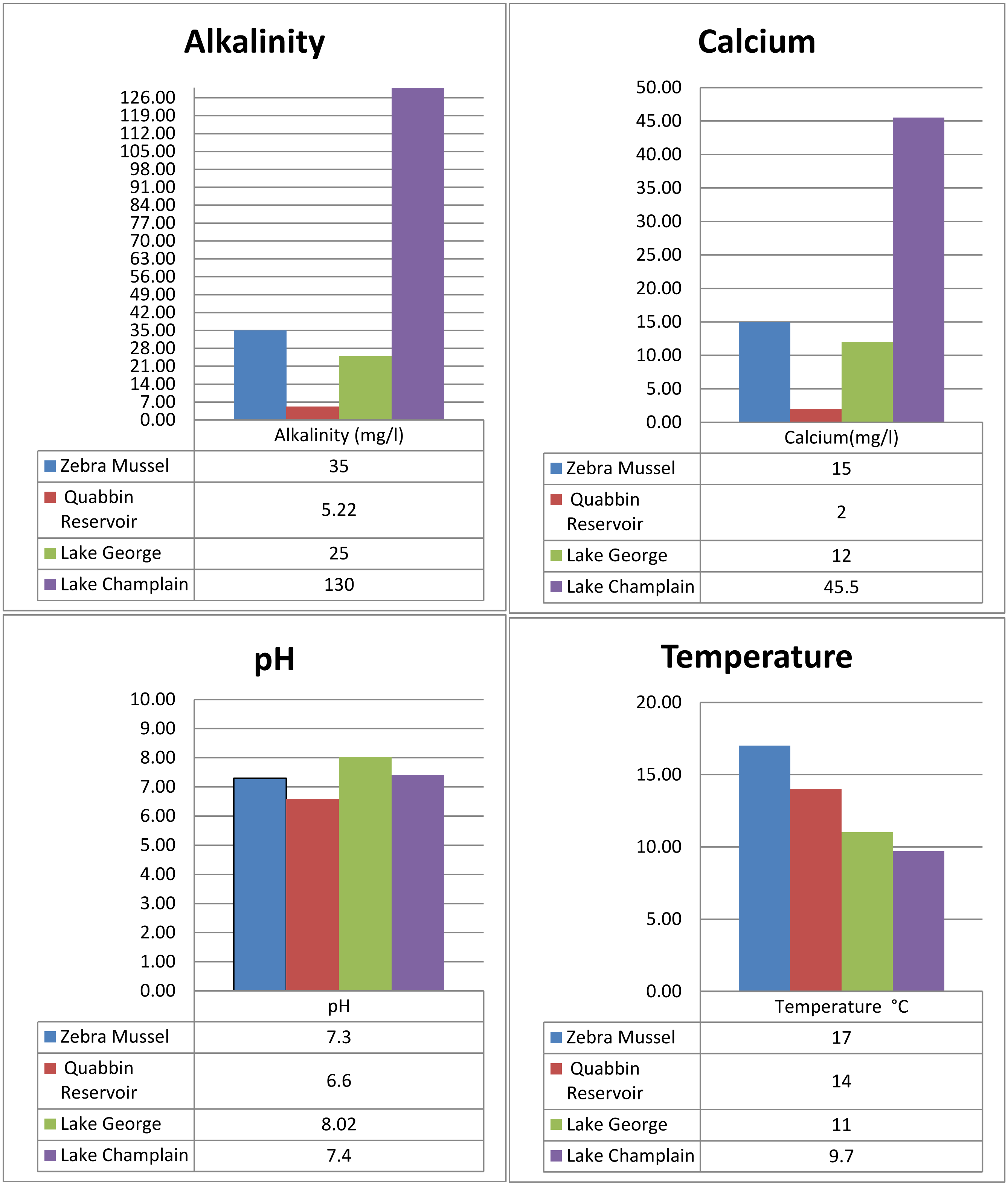

Figure 4.2 Comparison graph of zebra mussel habitats

V

Finance

Chapter 5. Economic Impact

Over the twenty plus years that the zebra mussel has been roaming the North American peninsula, it has cost significant financial losses to many cities and states. Mussels have notoriously touched the fishery, the economy, and the people of the region, and it continues to this day. The following chapter will cover the financial damages the mussel has caused throughout the US and what has been done to prevent and decrease the infestation.

5.1 **Ontario and Michigan incidents**

The zebra mussel infestation has forced large expenses on facilities that draw water from lakes damaging electric generating plants, municipal water systems, and industrial water users. In the Great Lakes region, it's been estimated that $8 billion has been spent thus far since the zebra mussel's introduction, to mitigate the damage that it has caused; with another $5 billion price tag in the next 10 years {{Pimentel, 2005}}. For instance, the largest fossil-fueled plant in the world, Detroit Edison's power plant in Monroe, Michigan had to shut down in 1989 because zebra mussels literally plugged up the water system {{Connelly, 1998}}. During 1989-1991, 24,000 residents of Monroe, Michigan experienced several water outages. The estimated cost of the infestation was $300,950 half of which went to cleaning of intake pipes, research and engineering studies. Later mussels contributed to a valve problem in the 1990s at the Nine Mile Nuclear Power plant in Lake Ontario, affected nuclear power plants averaged expenditures of $786,670 per facility {{Laruelle, 1999}}. Ford Motor Company was forced to close its casting plant in Windsor, Ontario, in order to remove a colony from the pipes which send cooling water to their furnaces {{Balogh, 1999}}. Zebra mussels were found in an impoundment of the Huron River used as the source of water for the city of Ann Arbor. Thus forcing the city to budget

$100,000 to run a pipeline to the intake and add a polymer to the inflow pipe for controlling the mussels. Just from the years 1989-1994 zebra mussel monitoring and control costs have totaled to $120 million throughout the spread regions {{40 Park,Hushak. OSU 1999}}

5.2 Financial Costs and Planning of Lake Champlain

States of Vermont and New York, and the province of Quebec, Canada share the Lake Champlain watershed. Since the discovery of the zebra mussel in Lake Champlain in 1993, the three jurisdictions work together to protect their water resources and come up with plans to rid Lake Champlain of the zebra mussel. Annually the zebra mussel in Lake Champlain maintenance costs $30,000-50,000 {{Modley, 2000}}. Since 1993 to the present day zebra mussel control efforts have cost over 2 million dollars. Because of zebra mussels and some other invasive species spread in Lake Champlain federal and local agencies developed The Lake Champlain Basin Aquatic Invasive Species Rapid Response Management Plan, which is intended to ensure and simplify the availability of appropriate protocols, trained personnel, equipment, permits, and other means to contain or potentially eliminate detected non-native aquatic plant or animal introductions as they are reported or discovered in the lake basin.

5.3 Financial Costs and Planning of Lake George

Since the discovery of the zebra mussel in 1999 at a southern part of Lake George, many different efforts were quickly launched to remove as many mussels as possible with the intent of minimizing the risk of the population reproducing and establishing a permanent presence in the lake. After the discovery of zebra mussels at the Lake George Village site (see 5.1), mussels were limited to a relatively small geographic area and that their distribution was inconsistent. Because of this the Lake George agency committee concluded that the best eradication potential was for scuba divers to remove the mussels prior to the spring when spawning was expected. Thus between 1999 and 2009 more than 25 000 (see fig 5.1) animals were removed from the site, over 90% of them shortly after the colony was discovered {{Wimbush 2010}}.

Site (year discovered)	# Removed *
LG Village (1999)	21,278
Cleverdale (2004)	1,380
Mossy Point (2004)	1,816
Sandy Bay (2006)	451
Rogers Rock (2007)	231
Yankee Marina (2007)	36
Castaway Marina (2007)	47
Treasure Cove (2008)	188
Beckley's (2008)	22
Middle Bay (2009)	26
Total	25,475

Table 5.1 Zebra Mussels removed from Lake George (LGA,2009)

In order to monitor and remove the mussel, the New York State Department of Environmental Conservation gave necessary permits to Darrin Fresh Water Institute (DFWI). The DFWI came up with a project, which in detailed description specified tasks that would be undertaken and the funding needed. The total project funding requested was $39,973 annually {{Nierzwicki-Bauer,DFWI,Bateaux Below inc.2010}}. The project was divided in three major tasks. Task I included scientific diver surveys and removal of zebra mussels at various locations. Task II included diving to establish spat traps and collect/replace collection plates at 6 different stations twice a year for a total of 2 days. Task III included collection of concentrated water samples at various locations twice in every 2 weeks.

5.4 Various power plant Control Costs

The Tennessee Valley Authority (TVA) has 30 hydropower plants, 11 fossil fueled plants, and three nuclear power plants. For the upkeep and performance of these power plants the TVA spends about $225,000 annually on zebra mussel control {{Brodie, 2005}}. At its nuclear power plants, the TVA use biocides to treat for bio fouling of their water piping through thermal control. In 2000, the TVA estimated the rental costs for thermal treatment to be $50,000 to

$70,000 per month, compared to $200,000 to $300,000 for purchasing the unit {{Kerley et al. 2001}}. Based on the TVA reports, hydropower project modification which includes cleaning condensers, raw water piping and trash racks, for zebra mussels is rare and has now become part of routine maintenance. At a nuclear facility in Oswego NY, was reported to be $467,390, plus annual operating costs of $109,058 {{Brodie 2005}}. JAF nuclear power plant in Buchanan New York uses mechanical mussel removal, which is performed every two to three years in the intake tunnel and screen house, at a cost of $150,000 to $200,000 {{Britton, 2003}}. In 1990, a NaOCl system was installed at a cost of $300,000. This system provides continuous low-level chlorination protection to all service water systems. Estimated annual operating costs for the system range from $60,000 to $80,000 {{Kahabka, 2004}}.In order to be rid of zebra mussels most of power plants both installed and used NaOCl (on-line sodium hypochlorite) control system (see fig 5.1) which cleans the pipes and prevents zebra mussels from clogging them up {{Gaspers 2003}}. NaOCl changes the taste of water giving it a chlorine salty taste and odor, but NaOCl is known to quickly dissolve and eradicate thus not effecting water taste that much. However some companies use portable water purifier device to get rid of the chlorine taste and odor before the water is dumped back in the ponds and/or rivers {{Huicochea, 2004}}.

Figure 5.1 Sodium hypochlorite control system (Ampac 2010)

Facility Type	Name, State (*Owner)*	Mitigation Strategy (year installed)	Installation Cost (Capital Cost)	Operating Cost (Annual)
Nuclear	Indian Point 3 Nuclear Power Plant, NY (*Entergy)*	NaOCl system	n/a	$60,000-$80,000
Nuclear	James A. Fitzpatrick, Nuclear Power Plant, NY (*Entergy)*	NaOCl system (1990)	Installation cost: $300,000	$60,000-$80,000
Nuclear	JAF Nuclear Power Plant	Mechanical mussel removal	n/a	$150,000-$200,000 (every
Nuclear	1)Watts Bar, TN 2)Browns Ferry, AL 3) Sequoyah, TN	Oxidizing biocide (bromine)	Unknown	Unknown
Nuclear	A.E. Kintigh, New York, (*NY State Electric and Gas)* [Source: McGraw-Hill,	Clam-trol (1990)	Unknown	$4,000-$6,000 per treatment
Hydroelectric	Various, Tennessee River Basin *(Tennessee Valley Authority)*	Thermal unit	Estimated purchase cost: $200,000-$300,000	Estimated rental cost: $50,000-$70,000
Hydroelectric	Cheatham Dam, Tennessee, Cumberland River *(Nashville District USACE)*	Automated chlorine injection (1993)	Unit only, no labor: $57,983	Estimated operating costs (estimated): $11,111-$55,556 per
Hydroelectric	Barkley Dam, Kentucky, Cumberland River *(Nashville*	Automated chlorine injection (1993)	Unit only, no labor: $70,868	Estimated operating costs: see above
Hydroelectric	SAB #1 Niagara River Ontario, Canada *(Ontario Power Generation)*	NaOCl system (1990)	$403,000	$31,200 (4-week operating period)
Hydroelectric	SAB #2 Niagara River Ontario, Canada *(Ontario Power Generation)*	NaOCl system (1990)	$805,088	$31,200 (4-week operating period)

Table 5.2 Costs for zebra mussel extenuation strategies at selected hydropower and power plants (cir.pdx. 2005)

VI Regulations

Chapter 6. Laws and Regulations control Zebra Mussels

The invasion and growing interest of zebra mussels have led the nation to some changes and strict law enforcements, since its arrival in the US. In order to fight the invasion and its harmful results, Congress in 1990 passed the Aquatic Nuisance Prevention and Control Act {{Shafland, 1991}}. This provides significant focus on aquatic invasive species by issuing rules, regulations and education of the public.

6.1 Great Lakes Region

The eight states that surround the Great Lakes region have strict laws that relate to the zebra mussels. Michigan, New York, Indiana, Ohio, Pennsylvania, and Wisconsin have laws regulating zebra mussel {{Peters 1996}}. Minnesota has both laws and regulations against mussels and Illinois has neither. Michigan and Minnesota specify civil and criminal penalties for violating laws governing zebra mussels.

6.2 Michigan

The state of Michigan recognizes zebra mussels as restricted species (Mich. Comp. Laws § 324.41301), forbids a person to have possession of a live organism unless the possession is within lawful activity to identify, eradicate, or control the species (Mich. Comp. Laws § 324.41303). The state of Michigan law establishes civil and criminal penalties for violating the laws governing restricted species (see table 6.1 in Appendix A). In addition to any other civil or criminal sanction, a person who violates the restricted species laws is liable for any damages to natural resources resulting from the violation, including costs incurred to minimize or prevent damages (Mich. Comp. Laws § 324.41309(11)). Law also demands that the departments of Natural Resources and Agriculture must deal with all fines and fees collected under the laws relating to restricted species into Michigan's Invasive Species Fund (Mich. Comp. Laws § 324.41311). They must use the funds to administer the laws relating to prohibited and restricted species and educate the public about preventing the introduction about the controlling and eradicating of non-native species {{Vasarhelyi 1997}}.

6.3 **New York**

The New York state law forbids any kind of intentional release of the zebra mussels into state waters (N.Y. Envtl. Conserv. Law § 11-0507). The state also requires anyone buying, selling, or purposely possessing or transporting zebra mussels to be licensed by the New York Department of Environmental Protection. However, the law permits a person to destroy zebra mussels at any time, except those lawfully held by license {{Thomas, 1996}}.

6.4 **Indiana**

In the state of Indiana, it is unlawful to import, possess, or release the zebra mussels and other invasive species into public or private waters. A person who takes a zebra mussel does not violate the regulation if the mussel is killed immediately upon capture {{Ind Code, 1996}}. In December of 1996, the Indiana Natural Resources Commission adopted a Zebra Mussel Containment Policy. The policy promotes precautionary steps to be taken by boaters to reduce the likelihood of zebra mussel infestation. In order to help the funding of the fight against zebra mussel the state has introduced fees which provide funding for the law enforcement division to establish additional marine enforcement patrols on Indiana lakes and rivers 1998}}. The fee is set forth by the value of the boat when new (see table 6.2 in Appendix A).

6.5 **Minnesota**

Minnesota has several state laws intended to minimize the introduction and spread of the zebra mussels. Minnesota law strictly outlaws any placement or attempt to place into state waters a watercraft, trailer, or plant harvesting equipment that has zebra mussels or other invasive species attached (Minn. Stat. § 84D.10). Minnesota requires a person leaving state waters to drain boating-related equipment by removing the drain plug before transporting the watercraft and associated equipment on to public roads (Minn. Stat. § 84D.10 and Minn. R. 6216.0500). Anyone who violates an invasive species law or illegally possesses, transports, or introduces a forbidden invasive species is guilty of a misdemeanor {{Peters, 1995}}. Also importing, purchasing, selling, or spreading of mussels is guilty of a gross misdemeanor (Szocka 208).

Civil citations and penalties are issued to anyone who violates the law (Minn. Stat. § 84D.13). Unlawful possession or transport of mussels is subject to a $250 civil fine. For the first offense of placing equipment into state waters that has a prohibited invasive species a fine of $500 is issued and $1,000 fine for each following offense. Failing of water drainage from boating related equipment is subject to a $50 fine {{Durán 1998}. Minnesota also adds a $5 surcharge on each licensed watercraft. The collected funds will be spent for control, public awareness, law enforcement, monitoring, and research of zebra mussels (Minn. Stat. § 86B.415). The received money from civil fines and license surcharges are deposited into an invasive species account, this money is used for managing invasive species (Minn. Stat. § 84D.15).

6.6 **Ohio & Pennsylvania**

Since collecting mussel is hobby to many individuals, in Ohio and Pennsylvania it is unlawful for anyone to possess, import, or sell zebra mussels. Also it is unlawful to introduce or transport zebra mussels all of which leads to fees and later misdemeanors {{Peters, 1999}}.

6.7 **Wisconsin**

Wisconsin disallows anyone from transporting, transferring, or introducing zebra mussels (Wis. Admin. Code § NR 40.05). The prohibition does not apply if the action is accidental or unknowing and not due to the person's failure to take reasonable precautions. The prohibition also does not apply if a person is licensed by the Wisconsin Department of Natural Resources to transport, transfer, or introduce the species for research, public display, or other purposes permitted by the department {{Vasarhelyi, 1997}}.

6.8 **New England**

In New England only the states of Vermont and New Hampshire have legislation against the mussel. The state of New Hampshire strictly discourages anyone from importing or possessing prohibited wildlife, which includes zebra mussels (N.H. Code Admin. R. Ann. Fis 803.04 and 804.03). However wildlife such as baitfish can be imported but only from the areas that have some monitoring program such that the area is determined to be free of zebra mussels (N.H. Code Admin. R. Ann. Fis 502.09). Fish cannot be imported from states known to have waters infested with zebra mussels {{Peters, 1999}}.

As for the state of Vermont, it prohibits any transport of zebra mussels and other aquatic nuisance species to or from any Vermont waters on the outside of a vehicle, boat, personal watercraft, trailer, or other equipment (Vt. Stat. Ann. tit. 10 § 1454) {{Peters 1999}}. However the law permits exceptions for scientific or educational purposes. The ruling does not restrict proper harvesting or other control activities undertaken to eliminate or control the growth of zebra mussels and other aquatic nuisance species {{Crawford 1998}}.

VII Conclusion

Chapter 7. Conclusion and Recomendations

Based on the results of the research and all the information gathered, helpful conclusions have been accomplished about zebra mussels spread, Quabbin Reservoir and important suggestions will be made in accordance with avoidance and financials of the mussels.

7.1 Zebra mussel Spread

Based on the inquiry done conclusion can be drawn suggesting that the mussels have specific habitat choices. Mussels prefer fresh waters with room temperature, but can survive in temperatures below freezing. The chemical properties of the water have enormous influence on the survival of the mussel; calcium threshold of 12 mg/liter and above is needed for the mussel to build the shell and protect itself from environment and a pH should be as high as 7.0-8.4. The chemical properties are very important for the growth and development of the mussel, thus if the chemical properties of the water are lower than what the mussel likes the infestation will not occur.

7.2 Quabbin Reservoir

Researching Quabbin Reservoir and comparing it with the zebra mussel comfort level of infestation, conclusion was drawn that the zebra mussel infestation will not take place. Quabbin Reservoir has very low chemical properties especially calcium and pH levels, thus the environment in the water will not be suitable for mussels to spread. However the above stated conclusion does not necessarily mean that the mussel will not survive in the Quabbin, this is because some areas of Reservoir differ in chemical properties meaning that some parts of the

Quabbin have higher chemical properties than others. Yet all the assumptions indicate that the infestation will not take place and mussels won't be a threat.

7.3 **Economics**

Most cities and states that have been infested by the mussel have spent large sums of money for eradicating and controlling it. In the state of Massachusetts water bodies (especially the Quabbin) the use of financial spending should not be as high as other places, because of the low risk of the mussel infestation. In the areas where there is no presence of the mussels most of the spending should be diverted to the education of the public and precautions taken to limit the possibility of occurrence. However the water bodies that are infested and have a potential for threat, should be dealt with by setting up some kind of proposal that will have a budget and a plan to remove and control the mussels so that the danger will be limited.

7.4 **Legislation**

The numerous places that are infected by the mussels have strict laws and regulations against possession and transport of the mussels. Most of New England does not have legislation against the mussels, thus it is important that some kind of laws be established. Once the laws are made they should be posted on city and state websites, water resource authority sites and numerous local government sites.

7.5 **Recommendations**

Zebra mussels entered the Massachusetts in 2009 and are spreading. To slow the spread down public outreach and education will be helpful to enhance understanding of the possible problems associated with zebra mussels and the measures that may help deter their expansion. Signs should be posted at all MWRA owned and managed boat ramps highlighting the potential problems associated with zebra mussels. Information should be distributed throughout the state, federal and non-governmental agency partners, sport fishing groups, ports, lake associations, Department offices and Nature Centers and other helpful places.

Proper safety measure to prevent the transfer of zebra mussels from one water body to another are needed which include inspection, treatment, and, if possible, avoidance. Carefully inspecting boats, trailers and components (boards, axles, etc.), equipment (water pumps, hatchery equipment, nets, traps) and machinery (tractors, bulldozers, etc.) for zebra mussels will help the prevention. If the mussels are found they should be removed and properly disposed of in the trash. Immediately reporting suspected occurrences of zebra mussels to the Invasive Species Controllers should suggested.

Boats should be constantly checked for mussels. Water should be drained from boats, trailers, motors, live wells, porthole wells, holding tanks and live wells, water pumps, pipes, and other equipment prior to entering or leaving a waterway. Anything entering from one water body to another should be purified (see table 7.1 and 7.2 for producers in Appendix B).

References

Ahlfeld, David P. E. "Case Study: Impact of Reservoir Stratification on Interflow Travel Time." *Journal of hydraulic engineering (New York, N.Y.)* 129.12 (2003): 966. Web.

Balogh, Steven S. J. "Transport of Mercury in Three Contrasting River Basins." *Environmental science & technology* 32.4 (1998): 456-62. Web.

Bloomfield, Jay J. A. "SURFACE RUNOFF WATER QUALITY FROM DEVELOPED AREAS SURROUNDING A RECREATIONAL LAKE." *Lake and Reservoir Management* 1.1 (1984): 40-7. Web.

Britton, D. K. "ANS." *AquaTic* 5.3 (2004)Web.

Caraco, Nina N. F. "Dissolved Oxygen Declines in the Hudson River Associated with the Invasion of the Zebra Mussel ( )." *Environmental science & technology* 34.7 (2000): 1204-10. Web.

Charlotte Vásárhelyi, Vernon G. Thomas. "Null." *full* volume 13.Issue 5 (26, Aug,2003): 417-27. Print.

Cohen, B. E. "Outdoor Recreation and the Quabbin Reservoir: An Exercise in Political Maneuvering." *Notes (Music Library Association)* (2004)Web.

Connelly, Nancy N. A. "Economic Impacts of Zebra Mussels on Drinking Water Treatment and Electric Power Generation Facilities." *Environmental management (New York)* 40.1 (2007): 105-12. Web.

---. "Economic Impacts of Zebra Mussels on Drinking Water Treatment and Electric Power Generation Facilities." *Environmental management (New York)* 40.1 (2007): 105-12. Web.

Costa, R., DC Aldridge, and GD Moggridge. "Seasonal Variation of Zebra Mussel Susceptibility to Molluscicidal Agents." *Journal of Applied Ecology* 45.6 (2008): 1712-21. Print.

Crawford, H. M. "Sea Grant and Invasive Aquatic Plants: A National Outreach Initiative." *Journal of Aquatic Plant Management* 39 (2001): 8. Web.

D., Hicks D. "Temperature Acclimation of Upper and Lower Thermal Limits and Freeze Resistance in the Nonindigenous Brown Mussel, Perna Perna (L.), from the Gulf of Mexico." *Marine Biology* 140.6 (2002): 1167-79. Web.

"Development of a Molecular Diagnostic System to Discriminate Dreissena Polymorpha (Zebra Mussel) and Dreissena Bugensis (Quagga Mussel)." *Molecular ecology resources* 10.1 (2010): 190-2. *OnlineLibrary.* Web.

Durán, Concha C. "Management Strategies for the Zebra Mussel Invasion in the Ebro Basin." *Aquatic invasions* 5.3 (2010): 309-16. Web.

Gaspers, S. "Parallel Cleaning of a Network with Brushes." *Discrete applied mathematics (Amsterdam, Netherlands : 1988)* 158.5 (2010): 467. Web.

Hallstan, Simon, Ulf Grandin, and Willem Goedkoop. "Current and Modeled Potential Distribution of the Zebra Mussel." *Biological Invasions* 12.1 (2010): 285. Print.

Horvath, Thomas T. G. "Hydrodynamic Forces Affect Larval Zebra Mussel (Dreissena Polymorpha) Mortality in a Laboratory Setting." *Aquatic invasions* 5.4 (2010): 379-85. Web.

Huicochea, A. "Portable Water Purification System Integrated to a Heat Transformer**." *Desalination* 165 (2004): 385. Web.

Johnson, L. E. "Post-Establishment Spread in Large-Scale Invasions: Dispersal Mechanisms of the Zebra Mussel Dreissena Polymorpha." *Ecology (Durham)* 77.6 (1996): 1686. Web.

Karalekas, P. C. "Recreational Activities of Springfield, Mass. Water Reservoirs, Past and Present." *Journal of the New England Water Works Association* 79 (1965): 18. Web.

Keith, A. A. "Cambrian Succession of Northwestern Vermont." *American journal of science (1880)* s5-5.26 (1923): 97-139. Web.

Laruelle, Franck F. "HISTOLOGICAL ANALYSIS OF TREMATODES IN DREISSENA POLYMORPHA: THEIR LOCATION, PATHOGENICITY, AND DISTINGUISHING MORPHOLOGICAL CHARACTERISTICS." *The Journal of parasitology* 88.5 (2002): 856-63. Web.

Leung, Brian B. "PREDICTING INVASIONS: PROPAGULE PRESSURE AND THE GRAVITY OF ALLEE EFFECTS." *Ecology (Durham)* 85.6 (2004): 1651-60. Web.

Lucy, Frances F. E. "History of the Zebra Mussel/ICAIS Conference Series." *Aquatic invasions* 5.1 (2010): 1-3. Web.

Lucy, Frances F. "Early Life Stages of Dreissena Polymorpha (Zebra Mussel): The Importance of Long-Term Datasets in Invasion Ecology." *Aquatic invasions* 1.3 (2006): 171-82. Web.

MACKIE, GERALD G. L. "Comparative Biology of Zebra Mussels in Europe and North America: An Overview." *Integrative and comparative biology* 36.3 (1996): 244-58. Web.

Marsden, J. J. E. "Exotic Species in Lake Champlain." *Journal of Great Lakes Research* 35.2 (2009): 250-65. Web.

Miehls, A. L. J. "Invasive Species Impacts on Ecosystem Structure and Function: A Comparison of the Bay of Quinte, Canada, and Oneida Lake, USA, before and After Zebra Mussel Invasion." *Ecological Modelling* 220.22 (2009): 3182. Web.

Mitchell, C. A. "Lesser Scaup Forage on Zebra Mussels at Cook Nuclear Plant, Michigan (Individuos De Aythya Affinis Se Alimentan De Mejillones En Aguas De La Planta Nuclear Cook En Michigan)." *Journal of Field Ornithology* (1993): 219. Web.

Modley, M. D. "Aquatic Invasive Species Rapid Response Planning Partnerships in the Lake Champlain Basin: Bridging International, Political, Social, and Economic Gaps." *Water S. A.* 34.4 (2008): 476. Web.

Momen, Bahram B. "RESEARCH: Are Recent Watershed Disturbances Associated with Temporal and Spatial Changes in Water Quality of Lake George, New York, USA?" *Environmental management (New York)* 21.5 (1997): 725-32. Web.

Naddafi, Rahmat R. "Physical and Chemical Properties Determine Zebra Mussel Invasion Success in Lakes." *Hydrobiologia* 669.1 (2011): 227-36. Web.

Peters, Jody J. A. "Invasive Species Policy at the Regional Level: A Multiple Weak Links Problem." *Fisheries (Bethesda)* 34.8 (2009): 373-80. Web.

"Photosynthetic Characteristics of Myriophyllum Spicatum and Six Submersed Aquatic Macrophyte Species Native to Lake George, New York." *Freshwater Biology* 26.2 (1991): 233-40. *OnlineLibrary.* Web.

Pimentel, David D. "Aquatic Nuisance Species in the New York State Canal and Hudson River Systems and the Great Lakes Basin: An Economic and Environmental Assessment." *Environmental management (New York)* 35.5 (2005): 692-702. Web.

Quaglia, Federica, et al. "Zebra Mussels in Italy: Where do they Come from?" *Biological Invasions* 10.4 (2008): 555-60. Print.

Qualls, Theresa M., et al. "Analysis of the Impacts of the Zebra Mussel, Dreissena Polymorpha, on Nutrients, Water Clarity, and the Chlorophyll-Phosphorus Relationship in Lower Green Bay." *Journal of Great Lakes Research* 33.3 (2007): 617-26. Web.

R. A. Tatara, D. R. Poe, and G. M. Lupia. "Characterization of Zebra Mussel Transport Near a Pump Intake." *Journal of Applied Science and Engineering Technology* 2 (2008): 3-8. Print.

Randhir, Timothy T. O. "Multiattribute Optimization of Restoration Options: Designing Incentives for Watershed Management." *Water Resources Research* 45.3 (2009): W03405. Web.

Shafland, Paul P. L. "Exotic Fish Assessments: An Alternative View." *Reviews in Fisheries Science* 4.2 (1996): 123-32. Web.

Smith, D. G. "A Study of the Distribution of Freshwater Mussels (Mollusca: Pelecypoda: Unionoida) of the Lake Champlain Drainage in Northwestern New England." *The American midland naturalist* (1985): 19. Web.

Smith, L. "Relating Sediment Phosphorus Mobility to Seasonal and Diel Redox Fluctuations at the sediment—Water Interface in a Eutrophic Freshwater Lake." *Limnology and Oceanography* 56.6 (2011): 2251. Web.

Soobader, M. M. "Levels of Analysis for the Study of Environmental Health Disparities." *Environmental research* 102.2 (2006): 172-80. Web.

Stewart, T. W. "Dreissena-Shell Habitat and Antipredator Behavior: Combined Effects on Survivorship of Snails Co-Occurring with Molluscivorous Fish." *Journal of the North American Benthological Society* (1999): 274. Web.

Strayer, David D. L. "Twenty Years of Zebra Mussels: Lessons from the Mollusk that made Headlines." *Frontiers in ecology and the environment* 7.3 (2009): 135-41. Web.

Szocka, A. "Impact of the Nonindigenous Zebra Mussel on the Great Lakes Region: An Ethical Analysis of Impacts and Control Strategies, the." *University of Baltimore journal of environmental law* 4 (1994): 208. Web.

Thomas, Vernon V. G. "Legislation and the Capacity for Rapid-Response Management of Nonindigenous Species of Fish in Contiguous Waters of Canada and the USA." *Aquatic conservation* 19.3 (2009): 354-64. Web.

Voets, Judith J. "Cadmium Bioavailability and Accumulation in the Presence of Humic Acid to the Zebra Mussel," *Environmental science & technology* 38.4 (2004): 1003-8. Web.

V�s�rhelyi, Charlotte C. "Analysis of Canadian and American Legislation for Controlling Exotic Species in the Great Lakes." *Aquatic conservation* 13.5 (2003): 417-27. Web.

---. "Analysis of Canadian and American Legislation for Controlling Exotic Species in the Great Lakes." *Aquatic conservation* 13.5 (2003): 417-27. Web.

---. "Analysis of Canadian and American Legislation for Controlling Exotic Species in the Great Lakes." *Aquatic conservation* 13.5 (2003): 417-27. Web.

---. "Analysis of Canadian and American Legislation for Controlling Exotic Species in the Great Lakes." *Aquatic conservation* 13.5 (2003): 417-27. Web.

---. "Analysis of Canadian and American Legislation for Controlling Exotic Species in the Great Lakes." *Aquatic conservation* 13.5 (2003): 417-27. Web.

Whittier, Thomas T. R. "A Calcium-Based Invasion Risk Assessment for Zebra and Quagga Mussels (Dreissena Spp)." *Frontiers in ecology and the environment* 6.4 (2008): 180-4. Web.

Wimbush, John J. "Eradication of Colonizing Populations of Zebra Mussels ( ) by Early Detection and SCUBA Removal: Lake George, NY." *Aquatic conservation* 19.6 (2009): 703-13. Web.

Xu, Wei, and Mohamed Faisal. "Identification of the Molecules Involved in Zebra Mussel." *Comparative Biochemistry and Physiology.Part B: Biochemistry & Molecular Biology* 154.1 (2009): 143. Print.

Zhang, Yanli Y. "Watershed Forest Management Information System (WFMIS)." *Environmental modelling & software : with environment data news* 24.4 (2009): 569-75. *SD.* Web.

VII Appendix

Appendix A: Legislation in Michigan

State of Michigan suffered the most from the invasion of the zebra mussels. Strict laws and penalties have been assembled to fight and diminish the spreading of the mussels.

Action	***Penalty***
Unlawful possession of a live restricted species	Civil fine of up to $5,000
Possession of a live restricted species that is done knowing that it is unlawful	Misdemeanor subject to a fine of $1,000 to $10,000. May be imprisoned for up to one year.
Possession of a restricted species with intent to damage natural resources	Felony subject to a fine of $1,000 to $250,000. May be imprisoned for up to two years.
Selling or offering to sell a restricted species	Civil fine of $1,000 to $10,000
Introduction of a restricted species without proper permit	Misdemeanor subject to a fine of $500 to $5,000. May be imprisoned for up to six months.
Introduction of a restricted species by one who knew or should have known it was nonnative	Misdemeanor subject to a fine of $1,000 to $10,000. May be imprisoned for up to one year.
Introduction of a restricted species knowing that it is unlawful	Felony subject to a fine of $1,000 to $250,000. May be imprisoned for up to two years.
Introduction of a restricted species with the intent to damage natural resources	Felony subject to a fine of $1,000 to $500,000. May be imprisoned for up to three years.

Table 6.1 Michigan Penalties for Violating Restricted Species Laws (Mich. Comp.Laws 1993-present)

In order to cover expenses created by zebra mussel infestation many states have established boat fees and other various dues. Collected money goes into the budget used to clean mussels from infested waters, to advertise and educate people, and other helpful means.

Value of the boat	**Fee**
Less than $1000	$5
At least $1000, but less than $3000	$10
At least $3000, but less than $5000	$15
At least $5000, but less than $10,000	$20
At least $10,000	$25

Table 6.2 Boating fee in Indiana (USPS.org 2003)

Appendix B: Purification

Spreading of zebra mussel mostly is due to boats and ships the mussel attaches to. In order to prevent the attachment of zebra mussels, numerous examples have been suggested. Chemicals such as chlorine Sodium and Vinegar are used to clean boats from mussels and safeguard them from future incidents. Following shows some important removal methods.

Disinfectant	Concentration	Contact Time	Usage Guidelines, Safety Precautions, Drawbacks
Vinegar	100%	20 min	Use appropriate personal protective equipment (PPE) and caution. Stay upwind of the spray. Is corrosive to metal and toxic to fish at this concentration, so thoroughly rinse with tap water or water from the next lake or river after disinfection. Ensure that solution does not run-off directly into waterways.
Chlorine	200 ppm	10 min	Use appropriate PPE and caution. Stay upwind of the spray. Is corrosive to metal and rubber and toxic to fish at this concentration, so neutralize with 800 ppm sodium thiosulfate and rinse thoroughly with tap water or water from the next lake or river. Ensure that solution does not run-off directly into waterways.
Power wash with hot water	>104° F	20 min	Use appropriate PPE and caution when using hot water due to possibility of burns/scalding. Temperature and contact times are crucial, as efficiency is weather dependent. Most effective when used in conjunction with air drying (see below). Power wash with hot water, including thoroughly flushing lower motor unit.
Freezing	<32° F	24 hrs	Boats, gear, and equipment should be thoroughly frozen. Ambient air temperature should remain below freezing for the entire contact time. No safety precautions.
Air drying	N/A	3-5 days in hot sun 48 hrs in hot sun	Must dry completely to be effective. Most effective when used in conjunction with hot water (see above). To be used for small nets, gear, pumps, etc., *ONLY AFTER* power washing with hot (104°) water for appropriate contact time.
Salt Bath	1%	24 hrs	Due to the long contact time, may only be used as a bath solution and not sprayed. To be used only for pieces of equipment, gear, and nets that can be completely immersed in the solution.

Table 7.1 Zebra Mussel disinfectants and Usage Guidelines for Boats and Equipment (MDC, 2007)

Disinfectant	1 gallon	2 gallons	5 gallons	20 gallons	100 gallons
100% Vinegar	1 gal	2 gal	5 gal	20 gal	100 gal
200 ppm Chlorine (household bleach, 5.25% Chlorine)	0.5 ounce (15 ml)	1.0 ounce (30 ml)	2.5 ounces (75 ml)	11.0 ounces (300 ml)	6 1/3 cups (1.5 L)
200 ppm Chlorine (HTH granular)	0.04 ounce (1.2 g)	0.08 ounce (2.4 g)	0.2 ounce (6 g)	0.8 ounce (24 g)	4.2 ounces (120 g)
800 ppm Sodium Thiosulfate	0.1 ounce (3 g)	0.2 ounce (6 g)	0.5 ounce (15 g)	2.1 ounces (60 g)	10.6 ounces (300 g)
1% Salt Bath (as NaCl)	1/8 cup	1/4 cup	2/3 cup	2 2/3 cups	13 1/3 cups

Table 7.2 Disinfectant Amounts to Make Needed Concentrations (MDC, 2007)