The Effects of a Recent Zebra Mussel Invasion on the Phytoplankton Community in Lake Leelanau in Northern Michigan

Erika L. Shankland
Mentor: Dr. Rex L. Lowe

Abstract

The discovery of zebra mussels was made in 1998 in Lake St. Clair, Michigan. Through recreational boating, canal building, and shipping, *D. polymorpha* soon colonized lakes around Michigan. Lake Leelanau, located in Leelanau County, Michigan, was invaded in 1996. Inland lakes as well as the Great Lakes have suffered invasion leading to altered water quality caused by toxic blue-green algae blooms and soiled beaches. This research project was an attempt to understand the impacts of zebra mussels on phytoplankton density and community structure.

Introduction

Urban, agricultural, and anthropogenic activities are not part of natural disturbance regimes [1]. Unlike a natural disturbance, such as fire, human induced change (like construction or soil excavation) or introduction of an exotic species, often leads to irreversible changes in community structure that are characterized with a lack of native species [1]. In many estuaries and rivers, disease, over-harvesting, and pollution have led to declines in bivalve populations. On the other hand, shipping, canal building, and recreational boating have led to the introduction of many exotic, or foreign, species of bivalves [2,3].

The introduction of zebra mussels (*Dreissena polymorpha*) has disturbed local ecology in much of the eastern United States [3]. The primary vectors for the dispersal of zebra mussels into inland lakes appear to be anthropogenic [2,3]. Zebra mussels exercise active filtration, which can lead to declines in phytoplankton over time [4]. Active filtration of water is one method of obtaining nutrients for a species' survival.

The grazing pressure, a measure of how intense the zebra mussels are filtering the water and ultimately, the phytoplankton, has increased since zebra mussels have been introduced. The increase in grazing pressure by *D. polymorpha* has been directly linked to a decrease in the phytoplankton community structure of freshwater bodies [3]. Zebra mussels filter particulate matter, such as phytoplankton, out of suspension in water [5]. Water clarity is increased, and the remaining nutrients (after the phytoplankton has taken dissolved nutrients out of the water) become sequestered into the benthos, not in the water column. By the decrease in nutrients in the water column and the zebra mussels removing particulate matter from the water, zebra mussels can alter plankton abundance [6]. Furthermore, benthic feeders, species that feed off the bottom of the water body, can be major consumers of phytoplankton, therefore decreasing phytoplankton biomass, or population size [7]. In addition to depletions in phytoplankton biomass, actual phytoplankton community structure can change [8]. One of the most frequent changes in the phytoplankton composition due to zebra mussel invasion is the appearance and increase of cyanobacteria [7]. Because of the decrease of nutrients in the photic zone, phytoplankton that cannot fix their own nitrogen are decreased, and there is an advantage given to nitrogen-fixing blue-greens, or cyanobacteria, which can convert elemental nitrogen (only breakable by cyanobacteria) into nitrates and nitrites (forms needed by the cell).

Visual clarity of water can change as a direct result of a decrease in the phytoplankton community. The Secchi disk is commonly used to measure changes in visual clarity with increasing depth by measuring the depth at which the disk disappears from the view of a surface observer [9]. The filtering of suspended particles from the water by zebra mussels can have an effect on algal growth, which in turn alters the transparency of the water [6,9]. Many studies have shown a decrease in phytoplankton biomass of up to 90% due to zebra mussel invasion, which has resulted in increasing Secchi depth [10,8]. In order for phytoplankton to play a role in increased visual clarity, decreases in algal growth must occur above the Secchi disk [9]. Although nutrients in the water column are also very important for algal growth, if there is an insufficient amount of light, nutrient enrichment will have little or no effect on growth [11].

Phosphorus and nitrogen concentrations in a water body are an important indicator of algal community structure. These two nutrients are most likely to be growth limiting [11]. In the northern United States, phosphorus has been found to be the primary growth-limiting factor [11]. Fairchild *et al*. manipulated nitrogen and phosphorus in Douglas Lake, Michigan, to study the quantities of nitrogen and phosphorus that are growth limiting [12]. They found that biomass of benthic algae was greatest with a combined increase of nitrogen and phosphorus, compared to a large increase with only phosphorus added and no change when only nitrogen was added [11]. Stephens and Gillespie found that a reduction in nitrogen in May was accompanied by a decline in the phytoplankton community in Great Salt Lake, Utah [13].

Caraco *et al*. found a massive decline in phytoplankton biomass concurrent with the invasion of *D. polymorpha* in the Hudson River Estuary. The zebra mussels became established in the fall of 1992 and reached high biomass levels in 1993 and 1994 [2]. Grazing pressure on phytoplankton was 10-fold greater than it had been prior to the zebra mussel invasion [2]. Over this same period, light availability increased and phosphate concentrations doubled, therefore these factors were not responsible for phytoplankton declines [2].

Zebra mussels invaded the south basin of Lake Leelanau in Leelanau County, Michigan, in 1996 [14]. The mussels spread north with the natural flow of the system and as a result of anthropogenic influences [8]. *D. polymorpha* now resides in both the north and south basins [8]. In 2003, the north end of the lake had a density of 3249 zebra mussels/ m^2, central Lake Leelanau had a density of 398 zebra mussels/ m^2 and south Lake Leelanau had a density of 1378 zebra mussels/ m^2. Lime Lake of Leelanau County, Michigan, has not been invaded by *D. polymorpha* [14].

My objective is to compare algal community structure between a zebra mussel invaded lake (Lake Leelanau) post-invasion and pre-invasion, using Lime Lake (non-invaded) as a control for the study. During the time peroids being studied for Lake Leelanau, there was no significant difference in the phytoplankton densities and community structure in Lime Lake. Based on the findings of previous studies, I predict that the phytoplankton samples taken from Lake Leelanau in 1993 will have a higher density and greater diversity of algae compared to the samples taken in 2004 after the invasion. I also predict that Lake Leelanau will have greater clarity in the 1997-2001 samples when the disturbance of zebra mussels was prominent than in the 1990-1996 samples because the algal density decreased due to zebra mussel invasion.

Figure 1: Map of Lake Leelanau area in Leelanau County, Michigan. The north and south basins are marked by arrows (Wearly 2004).

Materials and Methods

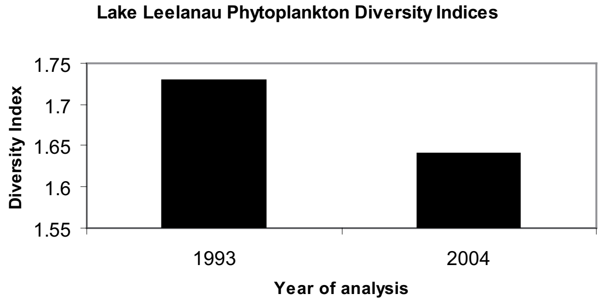
Study site

My study sites were two oligotrophic inland lakes (Lake Leelanau and Lime Lake) located in northern Michigan (Lake Leelanau, Latitude: **N45° 01.18'** Longitude: **W85° 44.51'**; Lime Lake, Latitude: **N44° 52.19'** Longitude: **W85° 57.84'**). Lake Leelanau is characterized by two basins (north and south) [Figure 1]. Lake Leelanau is 21 km. long, with a mean depth of 13 m. in the north basin and 8m. in the south basin [14]. Lake Leelanau is an ultra-oligotrophic to oligotrophic lake [8]. Lime Lake is an ultra-oligotrophic lake with its deepest point at 22.3 m. and its length being 0.32 kilometers long [8].

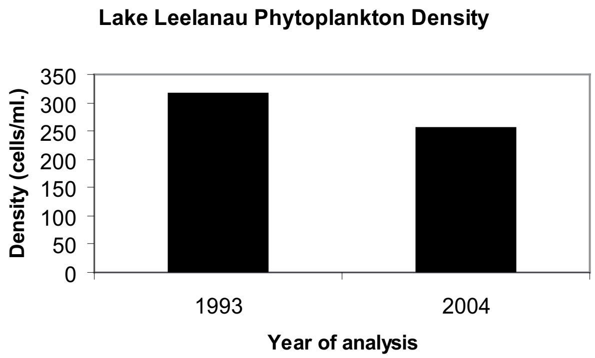
Sample collection

The Lake Leelanau Nature Conservancy collected phytoplankton (870 ml. whole-water samples) from Lake Leelanau in April and June of 2004. Samples were also collected from Lime Lake in May and June of 2004. The Lake Leelanau Nature Conservancy did a quantitative study of the phytoplankton in 1993 on Lake Leelanau and Lime Lake. In both water bodies, samples were collected at a depth of 1m. and 6-8m. Samples were preserved in 2% glutaraldehyde. Samples were settled for a minimum of six days prior to concentrating samples to a final volume of 5 ml. A hand-held siphon and pipette were used to concentrate samples. Care was taken to avoid siphoning floating algae (*i.e.*, blue greens) during each stage.

The Lake Leelanau Nature Conservancy estimated zebra mussel densities from photographs taken of the lake bottom in 2003 [15].



Graph 1a: Diversity indices of the phytoplankton samples in the two years of analysis.



Graph 1b: Density of phytoplankton samples in the two years of analysis.

Sample analysis

The Nature Conservancy hired Jan Stevenson to analyze the samples taken in 1993 from Lake Leelanau. I analyzed samples taken from May and June of 2004 at the University of Michigan Biological Station. Using a Palmer-Maloney counting cell, 0.1 ml. of each sample was examined. I used two different microscopes, one with 43x magnification (10x oculars) and the other with 45x magnification (10x oculars), to examine random points of view in the Palmer-Maloney cell. Three hundred cells in each sample were counted, with a minimum of 10 fields of view and a maximum of 150 fields of view when samples were especially dilute. Cells were categorized according to genera and species. Burn mounts of each sample were made to analyze relative percentage of diatoms under 100x magnification.

Statistical analysis

The Shannon diversity index (H) was used to characterize the species diversity in Lake Leelanau (pre- and post- invasion), as well as Lime Lake. $H = \Sigma pi \ln pi$, where pi is the proportion of species i relative to the total number of species and ln is a natural log function. A t-test was used to compare the diversity, density, phosphorus, nitrogen and Secchi depth values of Lake Leelanau pre-invasion and post-invasion. The same values were used to compare Lime Lake from 1990-1996 and 1997-2001.

Table 1: Mean total phosphorus, mean nitrate nitrogen and mean Secchi depth values for Lake Leelanau and Lime Lake during the time period 1990-1996 (pre-invasion) and 1997-2001 (post-invasion) (Keilty and Woller 2002).

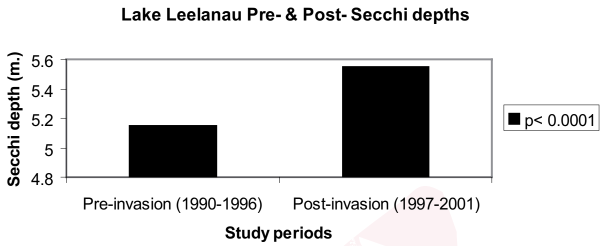
Lake Leelanau and Lime Lake Values for the Years (1990-1996) and (1997-2001)

	Mean Total Phosphorus (µg/L)	Mean Nitrate Nitrogen (NO_3) (µg/L)	Mean Secchi Depth in April, May & June (m.)
1990-1996			
Lake Leelanau	5.74	242.59	5.15
Lime Lake	5.03	230.12	3.01
1997-2001			
Lake Leelanau	4.7	168.43	5.55
Lime Lake	4.56	203.24	3.125

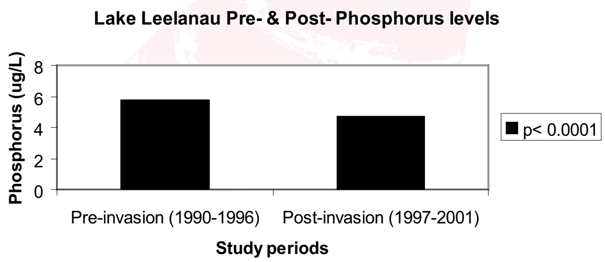
Results

Based on the quantitative study done by the Lake Leelanau Nature Conservancy and counts done by myself, in the control lake, Lime Lake, there was no significant difference in diversity and density between the years 1993 and 2004. There was also no significant difference found between the phosphorus, nitrogen and Secchi depth values for the years 1990-1996 and 1997-2001.

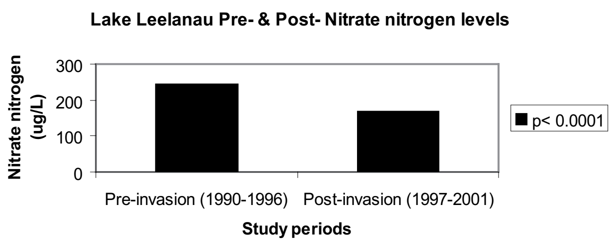
In the samples taken from Lake Leelanau in 1993, the Shannon's diversity index is 1.73, which is higher than the 1.64 diversity index for the samples taken in 2004 [Graph 1a]. The average density for the pre-invasion samples was 315.32 cells/ml, which is higher than the post-invasion samples measured to be 254.00 cells/ml [Graph 1b]. There was no significant difference found for either density or diversity values. As shown in Table 1 and Graph 2, the Secchi depth increased in the post-invasion samples, and the phosphorus and nitrogen values were lower in the post-invasion samples. The average Secchi depth in Lake Leelanau from 1990-1996 was 5.15 m., which is significantly lower than the average Secchi depth of 5.55 m in Lake Leelanau from 1997-2001 (t-value = -1.747, $p<0.042$, df-t = 122) (Graph 2a). There is also a significant difference in the variance of the two study sites (f-value = 1.556, C.V. = 1.53, $p = 0.05$). There is a significant difference in the phosphorus values of the two study sites, with the pre-invasion samples having a mean total phosphorus value of 5.74 (µg/L), and the post-invasion samples having a mean total phosphorus value of 4.70 (µg/L) (t-value = 5.488, $p < 0.0001$, df-t = 523) [Graph 2b]. The mean nitrate nitrogen of the pre-invasion samples is 242.59, and the mean nitrate nitrogen value for



Graph 2a: Secchi depths obtained from samples pre- and post-invasion.



Graph 2b: Phosphorus values obtained from samples pre- and post-invasion.

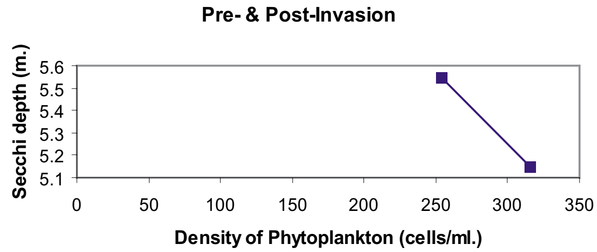


Graph 2c: Nitrate nitrogen values obtained from samples pre- and post-invasion.

the post-invasion samples is 168.43. Additionally, there is a significant difference in the mean nitrate nitrogen values of the two study sites (t-value = 7.077, $p < 0.0001$, df-t = 519) [Graph 2c], as well as a significant difference in the variance found for the mean nitrate nitrogen values of the two study sites (f-value = 4.197, C.V. = 1.53, $p = 0.02$).

Discussion

As expected, the phytoplankton samples taken during the spring bloom in 2004 are less dense and less diverse than those taken in 1993 [Graph 1]. Significantly deeper Secchi disk readings were obtained for the post-invasion samples (1997-2001) compared to the pre-invasion samples (1990-1996) [Table 1 and Graph 2a]. This result supports my hypothesis and compares to Holland's study (1993) that concluded zebra mussels can have an effect on algal growth leading to a change in the transparency of the water. Secchi disk readings are a reflection of the amount of light penetrating the



Graph 3: As the density of phytoplankton in Lake Leelanau decreased after zebra mussels invaded, the clarity of the water became greater.

epilimnion. My results show a direct correlation between the phytoplankton density measurements and the clarity of the water [Graph 3]. Furthermore, in 2004, zebra mussels had become established with up to 3249 zebra mussels/ m^2 in Lake Leelanau, with a correlation to decreasing densities in the phytoplankton community. Zebra mussels filter and digest necessary nutrients and phytoplankton, making it nearly impossible for a present phytoplankton community to survive an invasion. In addition to the decrease in biomass of the phytoplankton after the invasion of zebra mussels, the community structure of the phytoplankton changed, shown by the decrease in diversity of species in 2004 [Graph 1]. Community structure can change as a result of competition between species of algae. Since the zebra mussels filter nutrients, there are fewer available for the usually large amount of phytoplankton [6]. The algae that can survive in environments with low nutrients (such as nitrate nitrogen and phosphorus) will be able to live simultaneously with *D. polymorpha* better than those that need more nutrients to live [7]. Furthermore, a species of algae that can synthesize its own nitrates and nitrites from elemental nitrogen is going to be able to live much more successfully than an alga that is not able to make its own useful forms [7]. The decrease in phytoplankton diversity in the post-invasion samples is shown in Graph 1a.

Similar to studies done by Stephens and Gillespie and Fairchild *et al*., I found that there is a significant decrease in both phosphorus and nitrogen in the post-invasion samples. This was expected since zebra mussels filter the particulate matter out of water. My results suggest that as zebra mussels become more prominent in Lake Leelanau, they filter more growth-limiting nutrients, which leads to a decrease in the density and diversity of the phytoplankton community. Phosphorus has been found to be the primary growth-limiting factor for phytoplankton in the northern United States [11]. Because phosphorus is such an important nutrient for phytoplankton, the abundance of algal communities is expected to decrease when less phosphorus becomes available.

In past years (2001-2003) between May and August, there have been phytoplankton analyses of Lake Leelanau. These analyses have concluded that the most obvious impact on Lake Leelanau by the zebra mussel invasion has been the mid to late summer blooms of *Microcystis aeruginosa* [15]. These blooms occur during the peak recreational use period. *M. aeruginosa* is a toxic blue-green alga that is altering the water quality and is therefore affecting human use and enjoyment [15]. Since *M. aeruginosa* is a toxic alga, it also has the potential to affect wildlife and human health [8]. Furthermore, in Lake Michigan (Leelanau County), *Cladophora* growth is increasing due to the recent invasion of zebra mussels [15]. Zebra mussel psuedofeces in the benthic region of the lake are apparently supplying the necessary phosphorus to promote luxuriant *Cladophora* growth that ultimately washes up to the shore and soils beaches with decaying plant material [15]. This research project was an attempt to understand the zebra mussel growth occurring in the inland lakes of Michigan. Further studies can extend the current research and aim toward gaining awareness on the biology, life history and dispersal mechanisms of zebra mussels in order to slow the spread of invasion by this exotic species to the lakes in Leelanau County and other lakes in the region. Preventing any further invasion will help keep Michigan lakes pristine and beautiful.

Acknowledgements

The author thanks her mentor and dear friend, Rex L. Lowe, as well as Jared Rubenstein and Paula Furey for their technical help. Dr. Rex L. Lowe funded this work.

References

1. Stylinski, C.; Allen, E. *Journal of Applied Ecology*. **1999**, *36*, 544.
2. Caraco, N.; Cole, J.; Raymond, P.; Strayer, D.; Pace, M.; Findlay, S.; Fischer, D. *Ecology*. **1997**, *78,* 588.
3. Perry, W.; Lodge, D.; Lamberti, G. *American Midland Naturalist*. **2000**, *144*, 308.
4. Welker, M.; Walz, N. *Limnology and Oceanography*. **1998**, *43*, 753.
5. Roditi, H.; Fisher, N. *Limnology and Oceanography*. **1999**, *44*, 1730.
6. Holland, R. *Journal of Great Lakes Research*. **1993**, *19*, 617.
7. Bastviken, D.; Caraco, N.; Cole, J. *Freshwater Biology*. **1998**, *39*, 375.
8. Wearly, J. Unpublished masters'thesis, Bowling Green State University, Bowling Green, Michigan, USA. **2004**.
9. Jassby, A.; Goldman, C.; Reuter, J.; Richards, R. *Limnology and Oceanography*. **1999**, *44*, 282.
10. Lowe R.; Pillsbury, R. *Journal of Great Lakes Research*. **1995**, *21*, 558.
11. Stevenson, R.; Bothwell, M.; Lowe, R. San Diego: Academic Press. **1996**, 753p.
12. Fairchild, G.; Lowe, R.; Richardson, W. *Ecology*. **1985**, *66*, 465.
13. Stephens, D.; Gillespie, D. *Limnology and Oceanography*. **1976**, *21*, 74.
14. Keilty, T.; Woller, M. Publication of the Leelanau Watershed Council, Leelanau Conservancy. **2002**, *2*, 1.
15. Keilty, T.; Woller, M. Final Report prepared for the USEPA-GLNPO by the Leelanau Watershed Council, Leelanau Conservancy. **2004**.
16. Rickleffs, R. *The Economy of Nature*. **2001**, 5, 417.