ZEBRA MUSSELS (*Dreissena polymorpha*) IN NORTHERN MICHIGAN LAKES: A CALAMITY FOR NATIVE CLAM HEALTH

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Abstract

Zebra mussel (*Dreissena polymorpha)* infestation has expanded since the 1980's into inland lakes and rivers by contamination from boats and larval dispersal through streams. Consequently, costs of boat and water treatment plant repairs have increased, and the aquatic food web has been altered by the excess of zebra mussels. Native clam species are being colonized and wiped out in infested lakes. Inland lakes near the northern lower peninsula in Pellston, Michigan were surveyed for clam health on transects until one meter of depth. Clams were collected and surveyed for health, which was measured by shell width (mm) across the longest part of the shell, and clam weight (g). Douglas Lake, Burt Lake and Round Lake have zebra mussel infestations, and Round Lake was treated with Zequanox. Wycamp Lake and Lark's Lake are free of zebra mussels. We hypothesized that there would be an inverse linear relationship between the presence of zebra mussels and clam health, and we would see greater clam weights and shell widths in lakes with less or no zebra mussel infestation. Additionally, we hypothesized that the mean of the smallest clam shell widths would be similar across lakes, but the mean of the largest shells differs, then lakes with infestations are losing their largest clams. We found the healthiest clams based on weight to width ratio in Lark's Lake, followed by Wycamp, Douglas then Round. No clams were found in Burt Lake. We saw significant

differences in the mean shell widths of the five smallest and five largest clams between lakes. The largest clams in each lake had significantly larger mean shell widths in lakes without *D. polymorpha* infestation, while we found significant but not notable trends in the mean shell width of the smallest clams from each lake.

Introduction

The infestation of zebra mussels *(Dreissena polymorpha)* in the Great Lakes region has lead to the mortality of native unionid bivalve mollusks in inland lakes. Zebra mussels are native to the Black Sea, but began making a severe ecological impact on native unionid bivalve mollusks in 1985 in Lake St. Clair (Schloesser et al. 1996). Zebra mussels also change water chemistry, remove phytoplankton and alter nutrient availability in aquatic food chains (MCartney and Mallez 2018). When native unionid bivalves are colonized by a mass of zebra mussels equal or greater to the organisms' own mass, they are extirpated (Ricciardi 1996).

The contamination of zebra mussels between waterways is due to land transport of boats and aquatic equipment, aquatic recreation, and larval dispersal through streams (McCartney and Mallez 2018). Through external fertilization of *D. polymorpha,* veligers develop and are planktonic for about 4 weeks, allowing sufficient time for them to travel to other waters (Mackie 1991). *D. polymorpha* invasions affect aquatic ecosystems, but pose a large economic cost as well. They colonize and clog pipes which increases maintenance costs for water treatment and power plants, and cause boat to malfunction by clogging engines (Center for Invasive Species Research). Managing the damages caused by *D. polymorpha* costs an estimated $500 million per year (Center for Invasive Species Research).

In addition to altering nutrient availability, *D. polymorpha* encrust the bottom of lakes and rivers and prevent aquatic arthropods from burrowing in soft sediments (Center for Invasive Species Research). Clams live partially buried in sediment, allowing zebra mussels to attach to their exposed shell and colonize it. This inhibits clams' ability to move, feed, and respire, causing them to expend their winter energy stores on survival attempts (Ricciardi 1996).

Clam species native to Michigan lakes include *Anodonta ferussacianus, Elliptio complanata, Lampsilis siliquoidea, Ligumia nasuta,* and *Pyganodon grandis* (Hollandsworth et al., 2011). *D. polymorpha* differs from native clams morphologically with its anterior umbone that allows it to live on hard surfaces like clam shells and boats (Mackie 1991). They are difficult to remove from such surfaces as their flat ventral surface and byssal apparatus allow them to pull themselves tightly onto other surfaces (Mackie 1991). The byssal apparatus is made up of protein fibers within the shell that allow for such attachment (Schmitt et al., 2015). Their dorsally tapered shell prevents predators from getting a hold onto their shell (Mackie 1991).

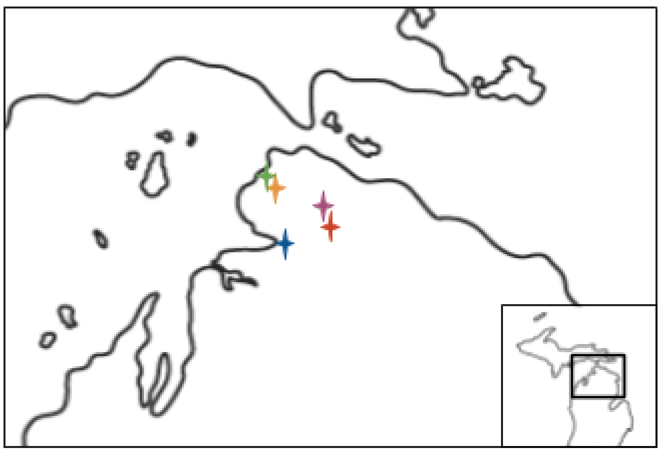

Figure 1. Map of survey sites. Green: Wycamp Lake. Yellow: Larks Lake. Pink: Burt Lake. Red: Douglas Lake. Blue: Round Lake

This study is a survey of clam populations in five lakes in the northern Lower Peninsula of Michigan; Burt Lake (45.4408°N, 84.7112°W), Douglas Lake (45.5770°N, 84.6929°W), Larks Lake (45.6044°N, 84.9326°W), Round Lake (46.1509°N, 86.7416°W), and Wycamp Lake (45.6565°N, 84.9596°W) (Fig. 1). Round Lake has a native clam population and three acres were treated with Zequanox® in 2017, which is a microbial biocontrol product created by Marron Bio Innovations that attacks the intestinal lining of zebra mussels but is non-toxic to other organisms (Watershed Council). Wycamp Lake and Larks Lake are known to have native clam populations and no zebra mussel infestations. Douglas Lake has had a zebra mussel infestation since 2001 and has a low clam population, but clams have been in refuge there since 2005 as the University of Michigan Biological Station encourages the removal of zebra mussels from native clams in the lake (Hollandsworth et al., 2011). Burt Lake has had a zebra mussel infestation since 1993 (Schloesser et al., 1996). These lakes were chosen to evaluate how zebra mussels affect clam size, and how the extent of the infestation is affecting the health of native clam species.

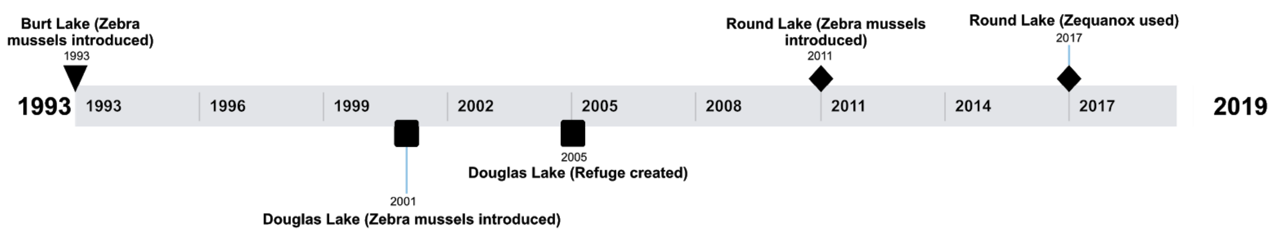

Figure 2. Timeline of zebra mussel presence and treatments in the lakes of study.

Figure 3. Diagram of native clam shell and defintion of "shell width" for the purposes of this study.

We measured clam width and weight along 400m transects in each lake if the population size allowed (Fig. 3). We hypothesized that there would be an inverse linear relationship between the presence of zebra mussels and clam health, and we would see greater clam weights and shell widths in lakes with less or no zebra mussel infestation. Additionally, we hypothesized that the mean of the smallest clam shell widths would be similar across lakes, but the mean of the largest shells would differ. This would suggest that lakes with *D. polymorpha* infestations are losing their largest clams.

Previous research in this region sampled lakes for Calcium to determine the effects on zebra mussel population size (Hollandsworth et al., 2011). Zebra mussels thrive in lakes with high calcium, like most lakes in the Lower Peninsula (Hollandsworth et al., 2011). Our study provides an updated survey of native clam populations in overlapping areas.

Methods

Lakes were chosen based on previous knowledge of clam and zebra mussel populations and proximity to the University of Michigan Biological Station in Pellston, Michigan (45°33'34.5"N 84°40'25.6"W). Douglas Lake did not have enough clams present to use transects, so we collected what we could find along 400 meters of beach at the Biological Station. At all other lakes, we completed 5 transects spanning 400 meters of coast. We looked for clams for 150 meters at Burt Lake but none were present.

For four out of five lakes, search on five transects until one meter of depth. We used glass-bottom buckets and snorkels to collect the clams when the water was not clear enough to see. Only living clams were collected. Using 100g spring-scales and plastic bags, we measured the weight of each clam. We recorded the width of the shell using manual calipers, and deposited clams back in the area from which they were collected.

We calculated a linear regression for the clam shell width versus weight to compare the clam health between lakes with and without mussels. We compared the median shell width and clam weight across lakes to evaluate clam population health at each location. To investigate the population dynamics of clams, we averaged the five highest and five smallest shell width in each lake and compared them with Analysis of Variance (ANOVA) and Tukey's post hoc tests. This provides insight into how the regional clam population size is changing, as well as for each lake. We also calculated linear regressions and correlation coefficients between clam shell width and weight to evaluate population health.

Results

To determine how the clam population dynamics are changing, we ran an ANOVA test using R Software to compare the five largest and five smallest mean shell widths. This indicates which lakes are losing small versus large clams. Results show a significant difference in the largest mean shell widths between lakes ($F [3, 16] = 8.535$, $p = 0.0013$).

Tukey's post hoc test shows that there is a significant difference between the mean largest clam widths in Lark's and Douglas Lake ($p < 0.01$). Larks Lake has clams that are an average of 2.18mm larger than the largest clams in Douglas Lake. Tukey's also shows a significant difference between the largest clams in Wycamp and Douglas Lake ($p < 0.05$). In Wycamp Lake, the largest clams are an average of 1.76mm larger than Douglas. Tukey's also shows a significant difference between the largest clams in Round Lake and Larks Lake; those in Round Lake are an average of 1.69mm smaller than those in Larks Lake ($p <0.05$). We found no significant difference in the largest clam shell size between Round and Douglas, Wycamp and Larks, or Wycamp and Round Lake.

An ANOVA test for the smallest clams found significant differences in mean shell width ($F [3, 16] = 53.23$, $p = 1.51x10^{-8}$). Among the smallest clams, Tukey's found a significant difference between Round and Douglas; Round Lake's smallest clams are an average of 2.87mm smaller than those in Douglas ($p < 0.01$; Fig. 4). Tukey's shows a significant difference in smallest mean clam size between Wycamp and Douglas; Wycamp's smallest clams are an average of 1.93mm smaller than those in Douglas ($p < 0.01$; Fig. 4). Round and Larks lake showed significant differences as well; the smallest clams in Round Lake are an average of 2.40mm smaller than those in Larks Lake ($p < 0.01$; Fig. 4). The smallest clams in Wycamp Lake are significantly different from those in Larks and Round; the smallest clams in Wycamp are an

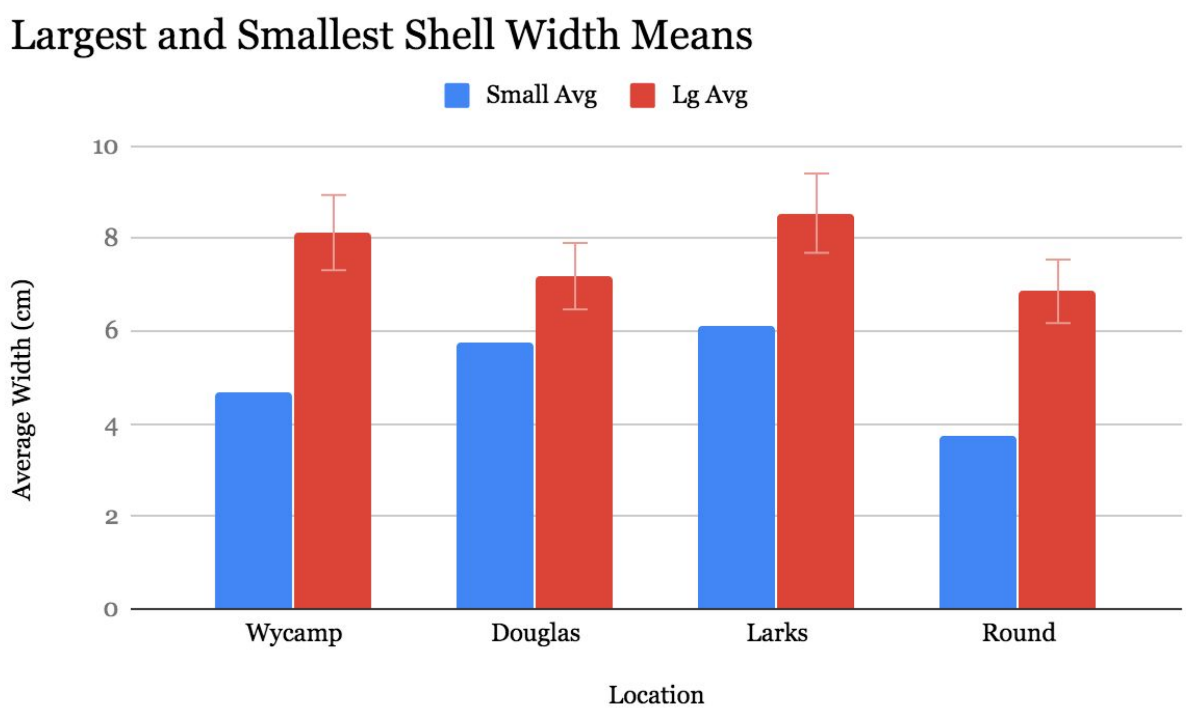

Figure 4. Mean of the five smallest (blue) and five largest (red) clam shell widths (mm) between lakes.

average of 1.46mm smaller than those in Larks, and an average of 0.94mm larger than those in Round ($p < 0.01$; $p < 0.05$; Fig. 4). Tukey's did not find a significant difference between the smallest clam size between Larks and Douglas.

Using a linear regression, we compared the shell weight to shell width at each location as a proxy for clam population health (Fig. 5). A larger slope indicates healthier clams as they have proportionate weight for their size, while smaller slopes indicate shallower shells and lighter clams. All Pearson's correlation coefficients indicate a moderate to strong positive relationship between shell width and clam weight (Fig. 5).

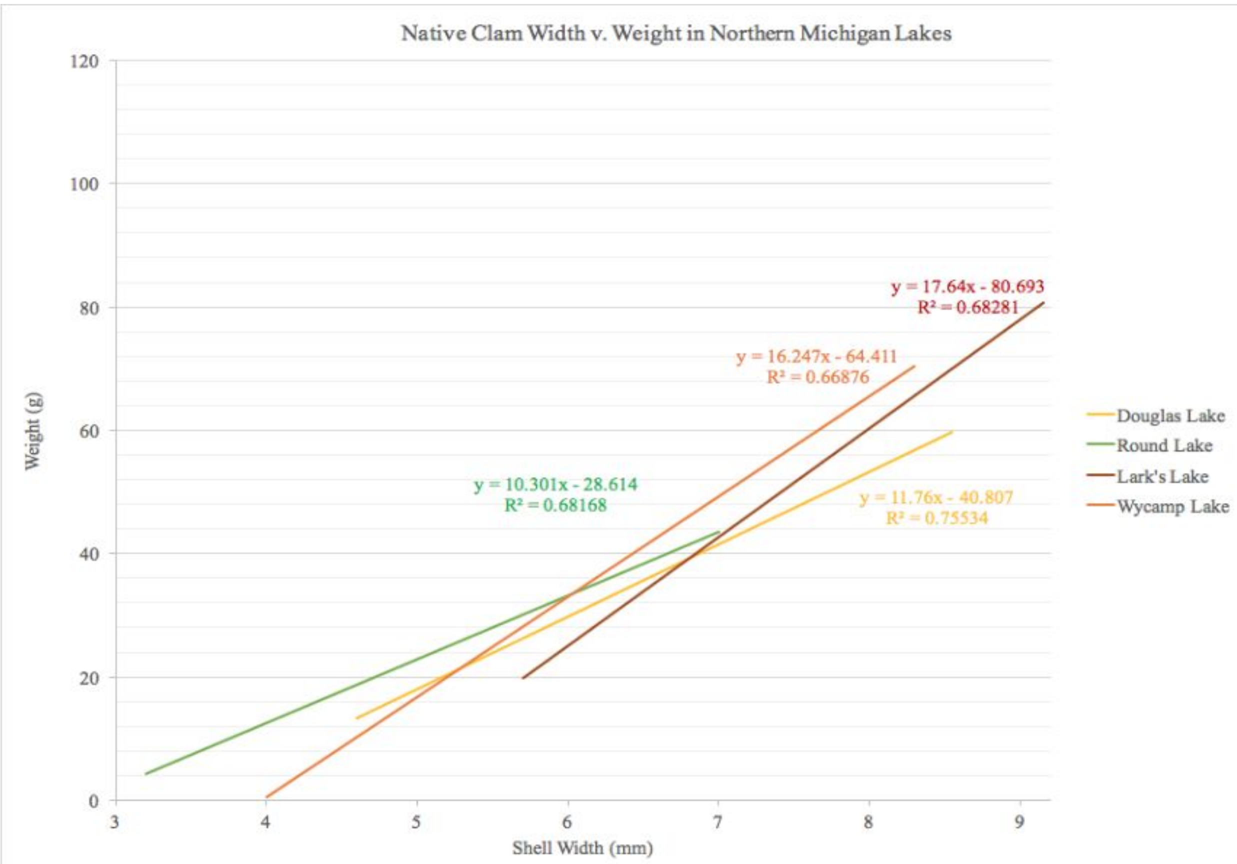

Figure 5. Linear regression and Pearson's correlation coefficient for weight (g) compared to shell width (mm) for each lake.

Discussion

The relationship between shell width and clam weight indicates survivorship, as thicker shelled, heavier clams have a more stable center of gravity and stronger musculature which allow them to retain the ability to move (Ricciardi 1996). Heavier clams are better able to bear the weight of the mussels and have increased survivorship (Haag et al., 1993). A previous study in Poland found that clams with heavier shells per unit shell width had higher levels of *polymorpha* colonization (Lewandowski 1976). Thus, clams with disproportionate weight to shell width ratios have poorer fitness. Based on the slopes of the weight v. width linear regressions, the

Lake	Status	Slope	R2
Round Lake	Zequanox used 2017	10.301	.68168
Douglas Lake	Refuge since 2005	11.76	.75534
Lark's Lake	No zebra mussels	17.64	.68281
Wycamp Lake	No zebra mussels	16.247	.66876
Burt Lake	Zebra mussels, no conservation efforts	No clams	No clams

health of clam populations is ranked as follows: Larks, Wycamp, Douglas, Round, Burt (Fig. 6).

Figure 6. Results of linear regressions from each lake and *polymorpha* status.

This is consistent with our hypothesis that non-infested lakes would have better clam health than infested lakes. The duration of *polymorpha* infestation has an effect on the clam health in these lakes; Burt Lake has been infected for the longest period of time and has an extirpated population, while Douglas Lake has been infested since 2001 and showed relatively better clam health (Fig. 2; Fig. 6). Furthermore, Round Lake has been infested since 2011 and treated in 2017, and showed a healthy clam population. The non-infested Larks Lake shows the healthiest clam population.

The means of the five largest clams in each lake supports our hypothesis that the longest non-infested lake, Larks, would have the highest mean widths in both the smallest and largest clams. However, Douglas Lake has higher mean widths than Wycamp, suggesting that the refuge has been successful in maintaining clam health, but not population size as only 10 clams were found. The small number of clams found in Douglas may be skewing these results as well. However, the phytoplankton population in Douglas has returned to normal this year for the first time since the *D. polymorpha* infestation began, which is a food source for native clams and may be contributing to their increased growth (Gassman et al., 2017).

While we hypothesized that infested lakes would have smaller mean widths for the smallest clams, the non-infested Round Lake has the lowest mean width for the small clams (Fig. 4). Therefore, the succession of clams in Round Lake is slower than other lakes despite being relatively free of *polymorpha.* This suggests that the clam population is returning more slowly than other lakes, possibly as a result of gradual comeback after the 2017 Zequanox treatment.

While zebra mussel infestations remain a problem in these lakes, Quagga mussels (*D. ostriformis bugensis)* have invaded many of these areas as well. Quagga mussels can colonize at greater depths than zebra mussels and do so at colder temperatures, so they are able to sustain a large population through the winter. Future research could investigate the presence of Quagga mussels in these lakes and how they are affecting native clam populations versus *D. polymorpha.* The *D. polymorpha* population has declined in the Great Lakes Region and Michigan inland lakes since 2014 (Burlakova et al., 2014).

The infestation of *polymorpha* in inland lakes leads to poorer health as defined by weight to width ratio of native clam species. The health of larger clams is affected more greatly than that of small clams, as there is a greater surface area for *D. polymorpha* to colonize. Clam succession does not appear to be affected by *D. polymorpha* presence, but overall population health is.

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