The effect of zebra mussel colonization on native snail species of Douglas Lake in Northern Michigan

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Abstract

The introduction of invasive species has caused extensive ecological and economic damage in freshwater ecosystems. In the Great Lakes region, zebra mussels (*Dreissena polymorpha)* have outcompeted native mollusks and driven many species towards extinction. They cause over $200 million of damage to the Great Lakes region annually. This study was performed to analyze the effect of zebra mussel colonization on native snail species of Douglas Lake in Northern Michigan. Four snail species: *Campeloma decisum, Elimia livescens, Planorbella campanulata,* and *Stagnicola emarginata* were collected with and without zebra mussels from South Fishtail Bay of Douglas Lake. The zebra mussel likelihood of colonization and horizontal movement as a measure of fitness were analyzed per species for differences between snails with zebra mussels and without. Our research showed that *C. decisum* and *E. livescens* were colonized most frequently. In addition, zebra mussel load was found to have a negative effect on horizontal movement of all snail species. Based on these results, our study concluded that zebra mussels have a significant negative effect on native snail species of Douglas Lake in Northern Michigan.

Introduction

Introductions of invasive species have caused great damage to ecosystems and communities. According to the United States Geological Survey, the Great Lakes are home to more than 136 invasive species (USGS 2008). The presence of invasive species leads to economic and ecological costs. The anthropogenic introduction of non-native species can negatively impact local populations and further lower the community's biodiversity (Huxel 1998). The effects are not only ecologically harming, but also devastating to local economies. Invasive species cause over $200 million of damage annually to fishing, wildlife watching, and tourism industries in the Great Lakes region (Finnoff and Lodge 2008). Growing populations and increased shipping traffic worldwide lead to greater exposure of invasive species to local habitats. Competition between exotic and native species can lead to displacement and possible extinction of native species in as little as five generations (Huxel 1998).

Invasive species have had a particularly detrimental effect on North American freshwater ecosystems. Their dispersal throughout the waters is often rampant and widespread, with increasing costs annually (Mills *et al*. 1993). North American mollusk populations have been greatly affected by invasive species. (Strayer 1999). *Dreissena polymorpha*, the zebra mussel, is arguably the most damaging and wide spread invasive specie of North American fresh water gastropods. (Nalepa 1994). According to a study of the world's worst invasive species, zebra mussels were listed among the top one hundred worldwide (Lowe *et al.* 2004).

The Great Lakes became vulnerable to invasive species as trade between ports increased after European colonization of America. Port cities established at this time, such as New York and Chicago, experienced extreme growth and shipping rates that led to them being 5 of the 15 biggest cities in the United States (Mills *et al.* 1993). Due to the rapid increase in trade, the release of ballast water from shipping boats that crossed the Atlantic introduced larval zebra mussels and other non-native species into the Great Lakes waterways. For this reason, human activity is primarily to blame for the introduction of zebra mussels into the Great Lakes. Zebra mussels were first discovered in Lake St. Clair in 1988 and have spread northward in the Great Lakes since (Albalak and Lamb 2005). However, these mussels were at least 2 years old, so the exact date of the first zebra mussel introduction is unknown. Since the initial colonization, they have quickly spread throughout the Great Lakes waterways. Despite efforts to avoid their spread, the first evidence of zebra mussel presence in Northern Michigan was in 2002 (Albalak and Lamb 2005).

Zebra mussels have strong byssal threads that allow them to fasten to various substrates, including gastropods (Albalak and Lamb 2005). They filter water of particulates, drastically limiting food availability for other filter feeding species. Zebra mussels have a unique life history strategy, which imparts upon them an unusual ecological advantage (Bies *et al.* 2010). Zebra mussel larvae are free swimming, which means the mussels can be relocated not only in the adult state, which is relatively easy to protect against, but also their microscopic larvae can be transported undetected. This abnormal life history contributes to their widespread dispersal and extensive colonization ability (Strayer 1999).

Zebra mussels have been known to attach to a number of different substrates, including live organisms, such as snails. One population where the effect of zebra mussels is evident is in

Douglas Lake, MI. Many snail species are found in the habitats of South Fishtail Bay in Douglas Lake. Four species of snails: *Campeloma decisum, Planorbella campanulata, Stagnicola emarginata,* and *Elimia livescens* can all be found in sandy habitats close to shore. Zebra mussels can impact survivorship of snails by increasing the surface area and allowing more attachment of other organisms or oviposition by other invertebrates (Stewart *et al*. 1999). However, literature is lacking on how zebra mussels affect different snail species. Our research focuses on the colonization likelihood and load of zebra mussels on *C. decisum, P. campanulata, S. emarginata,* and *E. livescens* in Douglas Lake. Biofouling ability of zebra mussels on native snail species could lead to decreased horizontal movement and an overall decrease in fitness. Previous studies have looked at the impact of zebra mussels on freshwater snails with results showing a negative impact on native bivalve community structure in the presence of zebra mussels. They contribute to a loss of food particles in the immediate vicinity of the snail (Haag *et al.* 1993). We wanted to determine whether or not zebra mussels colonize a specific snail species more often than others in Douglas Lake. Our research is premised on three main questions:

1. **Are zebra mussels more likely to colonize one species of snails over another?**

Our null hypothesis was that there is no preference for zebra mussel colonization on the four tested snail species. Since zebra mussels colonize open surfaces using byssal threads, large numbers are able to accumulate and zebra mussel biofouling leads to an increased load on the native snail species. Thus, we predict native snail species with larger surface area shells will be significantly colonized more than smaller ones.

2. **Is there an effect of zebra mussel load on overall fitness of a specific snail species in South Fishtail Bay of Douglas Lake?**

Our null hypothesis was that there is no effect of zebra mussel load on overall fitness. Snails horizontally move and burrow in sand. Thus, we predict zebra mussel weight on snails could have an impact on their horizontal movement ability. This change in horizontal movement ability would affect overall fitness by inhibiting their ability to graze and burrowing ability.

3. **Is one snail species affected more than another by zebra mussels?**

Our null hypothesis was that there is not difference in the effect of zebra mussel load relative to snail species in South Fishtail Bay. Zebra mussel load per snail species will be calculated in order to compare relative affect of zebra mussels on each species of snail. It is possible to forecast the future snail populations in South Fishtail Bay. We predict that zebra mussels will have an impact on snail movement, which could then affect survivorship of larger species compared to smaller ones. Directional selection toward smaller shell sizes could affect invertebrate populations in South Fishtail Bay, altering the community ecology of Douglas Lake.

Materials and Methods

Study Organisms

To test our questions, we used four species of snails found in South Fishtail Bay including: *Campeloma decisum, (C. decisum), Stagnicola emarginata (S. emarginata), Elimia livescens (E. livescens) and Planorbella campanulata (P. campanulata).* These four species of snails were specifically chosen because of their high relative abundance, similar habitat and life history strategies in South Fishtail Bay, of Douglas Lake.

C. decisum is often found in sand, mud or clay substrates in lakes and slow moving streams (Burch and Jung 1993). It feeds on decaying organic matter, has the ability to filter feed with gills (prosobranch) and burrows itself amongst the substrate (Burch and Jung 1993). *S. emarginata* is often found in similar habitats including sandy substrates in three meters of depth or less and grazes on algae and detritus (Burch and Jung 1993). *E. livescens* are found in a variety of freshwater environments mainly grazing for algae on rocks and substrates (Burch and Jung 1993). *P. campanulata* inhabit all slow moving fresh water environments with sand and gravel substrates. They feed mainly on decaying organic matter and algae (Burch and Jung 1993).

1. Zebra mussel likelihood of colonization on snail species

To determine if zebra mussels found in South Fishtail Bay of Douglas Lake had a likelihood of colonization on snail species, four types of snail species were collected. A total of 259 *C. decisum,* 220 *S. emarginata,* 112 *E. livescens,* and 88 *P. campanulata* were taken from various points around South Fishtail Bay (See Figure 1). Glass bottom buckets were used to see the bottom while sifting through substrate, collecting snails. Snails with and without zebra mussels were collected and minimally handled in order to reduce variability of exposure to air and human interference. The collected snail species were then taken back to the lab and counted. A Mettler AE240 analytical balance was used for all weight measurements. The number of zebra mussels, weight of zebra mussels, and ratio of snail to zebra mussel load was measured to determine the colonization of zebra mussels on the four snail species. In order to determine if there was a likelihood of colonization between the snail species, non-parametric Krruskal Wallis and Mann-Whitney U tests were run comparing average zebra mussel load per species.

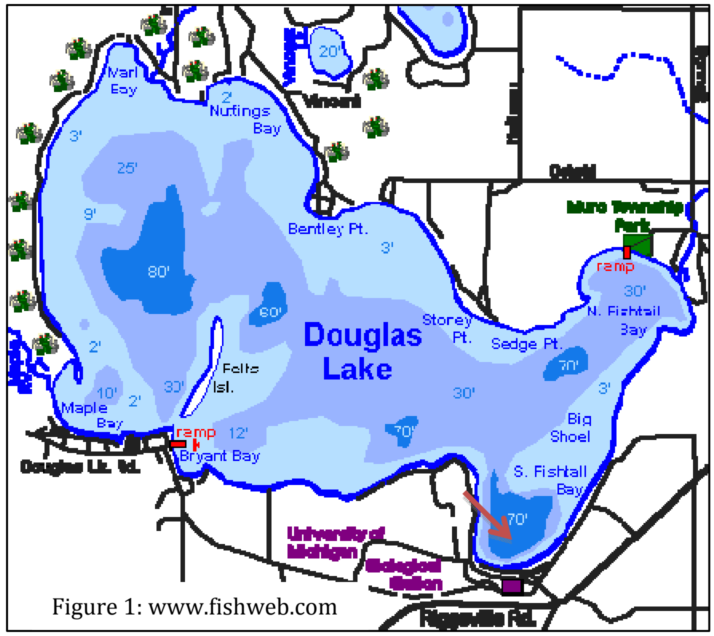


Figure 1: www.fishweb.com

2. Effect of zebra mussel load on overall fitness of snail species

To determine if zebra mussels found in South Fishtail Bay of Douglas Lake had a significant effect on overall fitness of snail species, four types of snail species were taken from various points around South Fishtail Bay (See Figure 1). Horizontal movement tests were conducted as a proxy for overall fitness. *P. campanulata* were also collected, however these trials were not used because the snails floated at the surface or traveled primarily on the glass which made measurements inconclusive. In order to test fitness, the collected snails with zebra mussels were placed in 10 gallon aquaria filled with sand and water directly from South Fishtail Bay. In order to reduce variability amongst trials, each aquarium received a thin layer of sand, to reduce burrowing ability, and filled a third of the way with lake water at 19°C. Two snails of the same species were at opposite sides of the tank and a red ink dot was placed on one snail in order to distinguish them apart. After one hour, distance traveled was measured using a piece of string and 25 meter measuring tape. The string was placed into the grooves of the sand that showed the trail of the snail, and then measured to the nearest millimeter.

Following trials, zebra mussels were then removed from the snail and a new weight was measured for each snail species. The same snail was then placed back in each position, the sand was redistributed evenly throughout the bottom and tests were run for another hour. Water temperature was taken and monitored to stay constant at 19°C. Following one hour, the same methods were used to measure horizontal distance for each snail. Using the previous calculations of zebra mussel load and distance, the proportion of zebra mussel load to distance traveled was calculated and statistical tests were run using this data. In order to test if there was an effect of zebra mussel load on the overall fitness of specific snail species in South Fishtail Bay of Douglas Lake, a paired t-test of the proportion of zebra mussel load to distance traveled with and without zebra mussels was conducted for each snail and compared between the three sampled snail species. We tried to normalize the data by taking the log and square of the differences between distances, but we were unable to due to negative values and zeros. Therefore, a paired t-test was run because t-tests are not as sensitive to non-normal distributions.

3. Relative effect of zebra mussel load on snail species

In order to test if one snail species was more or less affected by zebra mussel load relative to another species, multiple paired t-tests per species were conducted. Mean values of zebra mussel load relative to distance traveled for *C. decisum, S. emarginata* and *E. livescens*, were compared using a paired t-test. A chi-squared test was then run to measure the distance snails moved after zebra mussels were removed. Observed values were then compared to the expected value of 0.5 in order to determine if there was a significant effect of zebra mussel load on snail species' horizontal movements.

Results

Colonization Likelihood

To examine if it is more likely for one species of snails to be colonized by zebra mussels than another species, a Kruskal Wallis test was used.

Table 1: Kruskal Wallis Ranks

	Species	N	Mean Rank
Zebra mussel load	*C. decisum*	259	474.98
	E. livescens	112	287.16
	S. emarginata	220	248.63
	P. campanulata	88	238.42
	Total	679	

These ranks suggest that there is at least one species of snail that is colonized more often than another ($p < 0.0005$). In order to determine which species were colonized more, a Mann-Whitney U test was run to compare pairs of species.

Table 2: Mann-Whitney U Outputs

Species Combination	p-value
C. decisum vs. E livescens	<0.0005
C. decisum vs. S. emarginata	<0.0005
C. decisum vs. P. campanulata	<0.0005
E. livescens vs. S. emarginata	0.004
E. livescens vs. P. campanulata	0.004
S. emarginata vs. P. campanulata	0.368

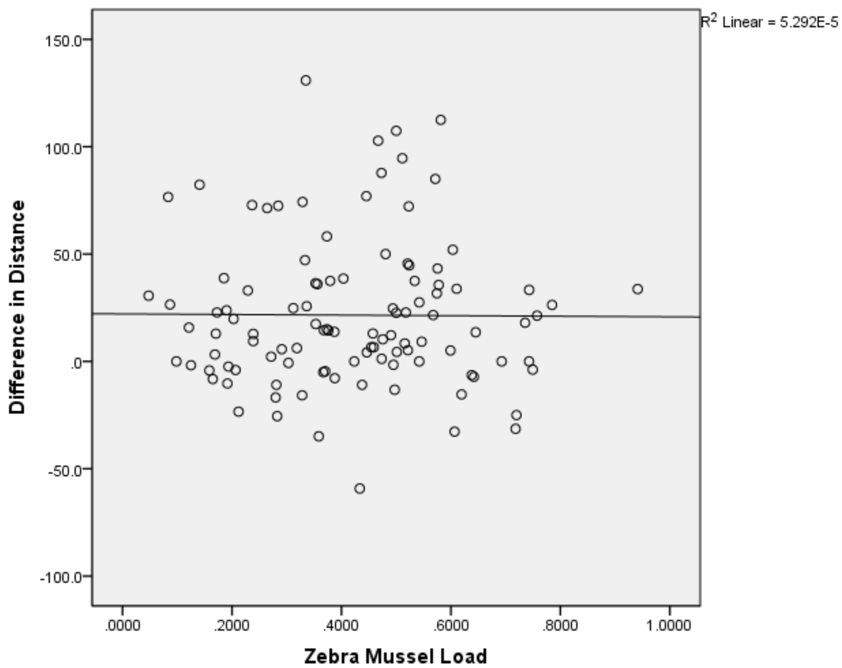
In comparing *C. decisum* with all other species, we found that zebra mussels colonized *C. decisum* more often. While comparing *E. livescens* with *S. emarginata* and *E. livescens* with *P. campanulata*, our results showed that *E. livescens* was colonized more frequently than these two other species. Finally, a comparison between *P. campanulata* and *S. emarginata* was run. There was no indication that zebra mussels colonized either of the species more often than the other.

Overall Fitness

To determine the potential impact of zebra mussel colonization on horizontal movement, which was used as a proxy for fitness, a paired t-test was run. The paired t-test compared the distance a snail moved with and without zebra mussels. Our results suggest that zebra mussel load had a significant effect on overall movement of snails (paired t-test, $p < 0.0005$, N=107).

Linear regression models were used to see if there was a correlation between zebra mussel load and difference in distance moved. Our results suggested that *C. decisum, E. livescens,* and *S. emarginata* were all equally impaired by any amount of zebra mussel load (R^2 = 5.292E-5).

Figure 2: Linear Regression Model for all snail samples



Specific Impact

To assess whether the overall fitness of one species of snail was affected more or less than other species, individual paired t-tests were run. Our results showed that all three species of snails' fitness was negatively affected by zebra mussel load in terms of distance they moved with and without zebra mussels attached to their shells. Compared to other species, *C. decisum* was more negatively affected. The species that was moderately impacted relative to *C. decisum* was *S. emarginata*. Finally, *E. livescens* was impacted the least compared to the other species.

Table 3: Paired t-test output

Species	N	p-value
C. decisum	63	<0.0005
E. livescens	18	0.044
S. emarginata	26	0.009

A chi-square test was run as well to measure the amount of snails that moved more or less after zebra mussels were removed. Our results indicated that *C. decisum* and *S. emarginata* had increased movement while *E. livescens* did not.

Table 4: Chi-square snail movement observations

Species	N	Increased Movement After Zebra Mussel Removal	Decreased Movement After Zebra Mussel Removal	p-value
C. decisum	63	49	14	<0.0001
E. livescens	18	11	7	0.4795
S. emarginata	26	20	6	0.0108

Discussion

Colonization Likelihood

Similar studies done on *C. decisum* in Douglas Lake, MI, found that the presence of *D. polymorpha* deters *C. decisum's* burrowing capabilities as well as growth rate (Van Appledorn *et al.* 2007). These impacts may decrease their fitness and survival as it becomes more difficult to hide from predators. *C. decisum* could also be more vulnerable to zebra mussel colonization because they burrow in soft substrata, so there are few hard surfaces zebra mussels can attach to (Van Appledorn and Bach 2007). *C. decisum* is the largest of the four snail species studied, so the higher zebra mussel colonization rate may be due to its size. In addition, *C. decisum* tends to live longer than other snail species, allowing them to grow larger and thicker shells. Zebra mussels may attach more often to thicker substrates, leading to an increase in the likelihood that they will colonize *C. decisum* over the other three snail species (Quinnan 2006).

The displacement of native mollusks from areas heavily colonized by *D. polymorpha* has been detected in past studies (Gizinski and Wolnomiejski 1982; Wisenden and Bailey 1995). This could lead to an expansive reconstruction of freshwater communities where zebra mussel populations are on the rise. The structure of the ecosystem could be altered due to interference in the food chain, disrupting the stability of higher trophic levels and leading to decreased availability of prey. A high infestation level of zebra mussels can be lethal to mollusk species, leading to a reduction in population size (Schloesser and Nalepa 1996). It is possible that a decline in *C. decisum* populations resulting from zebra mussel load could lead to a rise in other snail species with similar niches, as competition for food decreases. If zebra mussels were to displace *C. decisum* in Douglas Lake, there would be a greater abundance of food and resources available to the remaining snail species. This could lead to an increase in the population size of these snail species, allowing them to prosper with less competition. However, interspecific competition between snail species would prevent overexpansion. It is possible that other snail species would grow without the presence of *C. decisum*, but only if the negative impact of zebra mussels was strong enough to reduce the population size of *C. decisum*.

Overall Fitness

A similar study that looked at the effects of zebra mussel colonization on lateral movement found that biofouling often restricted movement (Bies *et al.* 2010). Our results also showed that, there was an overall effect on the movement of snails with and without zebra mussels. This could be due to the additional weight that zebra mussels add to the shell of the snail. Placement of the zebra mussels on the shell could also impact the snail's ability to move if it blocked the aperture, impeding the capacity of the snail to extend its foot. Using movement as a proxy for fitness, our results suggest that zebra mussels reduce overall fitness of snails. Some possible hindrances of zebra mussel colonization include avoiding predators, grazing, finding a mate, or inability to return to water after being washed onto the shore. Our linear regression indicated a decrease in fitness independent of the load of zebra mussels. However, other studies have found that the decrease in distance traveled was correlated with the relative load of zebra mussels (Appledorn and Bach 2007). Our study may have been limited by sample size because more trials were run using *C. decisum* than the other snail species. Ultimately, a small zebra mussel load was seen to have the same harmful effect on fitness compared to a larger zebra mussel load.

Individual Fitness

When expanding our results to look at potentially negative impacts that zebra mussels have on each species, we found that on average all three species of snails were adversely affected by zebra mussel colonization. However, *C. decisum* was impacted more significantly than other species. We hypothesized that this may be due to the increased likelihood of colonization on this species of snail. Since this snail is more likely to have zebra mussels attached, it is also likely to be more adversely affected. Another study done in Douglas Lake looked at the effects that zebra mussels have on the burrowing ability and growth rate of *C. decisum*. The results suggested that both burrowing ability and growth rate decreased when zebra mussels were attached to the shell of the snail (Van Appledorn *et al.* 2007). Our results may have been skewed towards *C. decisum* due to the larger sample size that was tested relative to the other species.

Our study may have been limited by a number of factors, such as research location and sample size. Trials were run in aquaria in which we attempted to mimic the lake habitat. However, we could not replicate the exact same ecosystem. In order to increase the number of trials we were able to run at once, we placed two snails in the same aquarium. This may have interfered with the snail's ability to move if they came into contact with the other snail. Snail movement also may have been impacted by the availability of food within the tanks. Other research has suggested that food location has an impact on a snail's movement (Calow 1974). We did not account for possibility of food within the sand or water that may have caused snails to move to a certain location within the tank.

Our results confirm zebra mussels have a negative impact on native snail species. Since zebra mussels have the potential to displace native species, they could negatively affect the lake community (Riccardi *et al.* 1996). If zebra mussels continue to inhabit Douglas Lake, it may affect the future ecosystem. Since *C. decisum* in Douglas Lake are parthenogenetic, they pass on consistent allele frequencies throughout generations. This leads to an inability to evolve mechanisms that inhibit the effect of zebra mussels, such as smaller shell size, because they are unable to produce a combination of alleles that would potentially create a favored phenotype. Yet, specific *C. decisum* that currently inhibit zebra mussel colonization could show population increases with this beneficial trait because they would be able to pass on favored phenotypes more easily. However, invasive species often outcompete native species before evolution and selection affect native populations.

Another study that looked at the effects of zebra mussels on burrowing ability and growth rate of *C. decisum* determined that the consequences of zebra mussel colonization could cause snail populations to decline in the future (Van Appledorn *et al.* 2007). The increased likelihood of colonization on *C. decisum* could result in greater mortality rates for *C. decisum*, which would lead to selection for species that could tolerate a different habitat where zebra mussels are less abundant. The displacement of *C. decisum* may allow other species, such as the phytoplankton that *C. decisum* feeds on, to thrive if population size is reduced drastically. This could lead to a greater abundance of resources and habitat available to other snails. Higher trophic levels could also be impacted, such as birds and other organisms that feed on snails, if zebra mussels displaced native snail species. For example, the displacement of snails, which are at the lower end of the food chain, would lead to a reduction in prey sources for certain fish. The lack of food available for fish that are directly above the snail on the food chain would cause a reduction in population sizes as their resources were depleted. This could also disrupt birds that prey on these types of fish because their sources of food would be reduced as well, destabilizing the overall food chain.

A study that looked at the dispersal rates of zebra mussels within the Great Lakes determined that rapid dispersal could be due to the unique free-swimming larva (Griffiths *et al.* 1991). Since zebra mussels are able to spread so rapidly, it is not likely that dispersal will be reduced. In addition, zebra mussels are filter feeders, which can lead to a reduction in phytoplankton (Beaupre and Christenson 2006). For instance, a study done in the Hudson River found that zebra mussel invasion led to increased bacterial populations, which may have been due to decreases in phytoplankton. This rise in bacterial numbers could affect economically important fish populations as they change the composition of the water (Strayer *et al*. 1999). Zebra mussels have the potential to be environmentally and economically destructive. As populations continue to grow indefinitely in the future, many ecosystems, such as the Great Lakes or other important waterways, have the prospect of being disrupted. Since a large number of people rely on these ecosystems for survival, uncontrollable zebra mussel invasions could lead to the devastation of several important communities.

Conclusion

Testing the effect of zebra mussels on *C. decisum*, *E. livescens, S. emarginata,* and *P. campanula* has furthered our understanding of the negative effects of invasive species. Invasive species such as *D. polymorpha* have the capacity to transform a long-established ecosystem like Douglas Lake or eliminate native species altogether (Caple *et al*. 2006). Since zebra mussel presence in Douglas Lake is relatively recent, the potential impacts of their dispersal is not fully understood. Future studies that develop a better understanding of invasive species could provide critical information in the creation of strategies for removal as well as the prevention of ecosystem collapse. Since each organism plays an important role in an environment, altering that structure can lead to irreversible and devastating consequences. If humans are able to reverse the damage they have created through the introduction of invasive species, they should implement conservation strategies that lead to increased protection of local ecosystems' biodiversity.

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