The Effect of Climate Change on *Dreissena polymorpha*, a Multiregional Invasive Species in North America

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Abstract

To study the effect of climate change across different latitudinal gradients on an aquatic invasive species in North America, filtration rates of *Dreissena polymorpha* were examined as part of a manipulative experiment. We took into consideration three regions across North America that the Intergovernmental Panel on Climate Change (IPCC) predicts to experience different increases in temperature by the year 2100. These three climates were simulated at the University of Michigan Biological Station in Pellston, MI and used as habitats for *D. polymorpha*. The effect of climate change was taken into consideration by measuring the chlorophyll A concentration at current average lake temperatures and temperatures adjusted for climate change predictions. We found that only the trials run at the mid-latitudinal region (Douglas Lake of Pellston, MI) showed a significant difference between *D. polymorpha* filtration rates at current and predicted climate change temperatures. We did not see a significant difference in filtration rates between the environments at current and predicted climate change temperatures at the higher (Flindt Lake of Ignace, ON) or lower (Lake Placid of Lake Placid, FL) latitudinal region. In addition, we examined the differences in *D. polymorpha* filtration rates due to increased temperature between the three latitudinal regions. Upon analysis of our data, we did not find a significant difference in this respect.

Key Terms
Climate Change, Invasive Species, Zebra Mussel (*Dreissena polymorpha*), Filtration Rates, Phytoplankton

Introduction

For the past two centuries, atmospheric carbon levels have been rising tremendously causing global climate change, resulting in a steady increase in global average water temperatures (Christensen *et al.,* 2007). As a consequence of climate change, many ecosystems have become highly vulnerable to disturbances, leading to increased susceptibility to invasive species. The International Union for Conservation of Nature (IUCN) identifies marine invasive

species as well as global climate change as two of the largest threats to Earth's total biodiversity (IUCN, 2009).

Dreissena polymorpha, commonly known as the zebra mussel, is native to the palearctic region of the world, the fresh water drainage basins of the Caspian and Black Seas and the Dniester, Volga, Danube, and Ural rivers (ADW, 2008; Poorter *et al*. 2009). The zebra mussel is a heterothermic ectotherm whose body temperature varies with environmental temperature fluctuations. Zebra mussel metabolic rates have shown a directly proportional relationship to environmental temperature change (ADW, 2008).

Zebra mussels are very effective filter feeders that are able to process up to one liter of water per day. Zebra mussels are an invasive species that was originally introduced to the Great Lakes in 1988. Since the zebra mussel preys upon phytoplankton and has become a widespread species throughout the Great Lakes, their presence can disturb the natural food web and affect many trophic levels (Vaughn *et al*., 2008). For example, a decrease in the phytoplankton population directly reduces the zooplankton population. Consequently, the populations of fish that feed on both phytoplankton and zooplankton may decrease, especially in areas where zebra mussels are present (ADW, 2008).

The goal of this study is to investigate the physiological response of zebra mussels to global climate change. The IUCN states the effects of climate change processes tend to favor introduced or invasive species in terrestrial environments, intensifying competition for resources with native species and altering the ecosystem (Poorter *et al*., 2009). We are investigating three North American lakes to see if the IPCC predicted increases in water temperature for the year 2100 affect zebra mussel filtration rates. We predict the mussels to show increased filtration rates with increasing temperature so by 2100, zebra mussels could become a strong competitor and outcompete native planktivores which could drastically modify the biodiversity of infested waters.

Materials and Methods

Locations were chosen based on 3 variables. Similar lake size was important to compare the different lake regions in order to standardize the environment. Since Douglas Lake in Pellston, MI, is approximately 3400 acres, comparable lakes were chosen at a more northern latitude and at a more southern latitude. We wanted to test lakes that had different current average water temperatures, so we chose Flindt Lake in Ignace, Ontario, Canada at 10°C,

Douglas Lake in Pellston, Michigan at 20°C, and Lake Placid in Lake Placid, Florida at 30°C. Also important to our study was projected water temperatures in the year 2100 that take climate change into account, so future water temperatures would increase in Canada to 15°C, in Michigan to 24°C, and in Florida to 32.5°C.

Environmental chambers for each region were assembled with 4 aquaria each: 3 experimental tanks and 1 control tank. Light was kept constant in each environmental chamber in order to prevent filtration rate differences which have been shown to vary between day and night (Horgan and Mills, 1997). Also consistent in each aquarium was volume of substrate (1 L), volume of Douglas Lake water (27 L total), number of zebra mussels (25 of similar size), and a simulated current. Phytoplankton was concentrated from Douglas Lake two days prior to the experiment and placed in the environmental chambers to allow for temperature acclimation. Zebra mussels were also gathered from Douglas Lake two days before the experiment and had 36 hours to acclimate inside the chambers. Previous studies have shown that 24 hours is the minimum acclimation period needed for the mussels to resume normal filtration activity following removal from a body of water (Horgan and Mills, 1997).

On experimental day 1, 1 liter of concentrated phytoplankton water was added to establish a initial concentration of phytoplankton to observe zebra mussel filtration. To determine filtration rates, 60 mL of water was extracted from each tank once an hour for eight hours ($t_0 - t_8$) and filtered through 0.45μm HAWP membrane filters to capture phytoplankton, allowing for an analysis of concentration differences throughout the experiment. The filtered water was returned to each tank in order to maintain water volume. Upon completion of extraction, each sample filter was folded and placed in aluminum foil and frozen in order to prevent chlorophyll A degradation via light and heat. To check consistency with previous studies that demonstrated zebra mussels are not selective feeders for algae species, a small amount of water from each tank was placed on a Palmer counting slide to examine phytoplankton species diversity to check for selective feeding (Horgan and Mills, 1997).

Further experimentation on day 2 required an increase in chamber temperature to mimic predicted water temperature increases due to climate change for each region by the year 2100. The temperature increase was staggered for each chamber to ensure all tanks reached the final temperature at the same time and also to allow the zebra mussels to acclimate to the new temperatures for the same amount of time. Three liters of water were removed and replaced with

concentrated phytoplankton water immediately before day 2 experimentation, again to establish a initial phytoplankton concentration. The same phytoplankton filtration method was used to extract samples each hour.

Upon completion of sample collection, flurometric analysis was conducted on the samples in order to determine hourly phytoplankton concentrations, and ultimately zebra mussel feeding rate, for each tank.

Results and Discussion

Chlorophyll A concentrations were analyzed for each hour of sampling. A best fit curve for the data was computed using regression analysis. The best fit curve line for each graph represents the change in chlorophyll A concentration over time, therefore, the slope of the best fit curve indicates the filtration rates of zebra mussels in each region and temperature situation. A more rapid filtration rate is represented by a more negative best fit curve slope. In order to conduct the analysis, only one experimental tank's data was used at both current temperature and at climate change temperature for each region. Figures comparing the complete data (3 experimental tanks and 1 control tank for each region) set can be found in the Appendix.
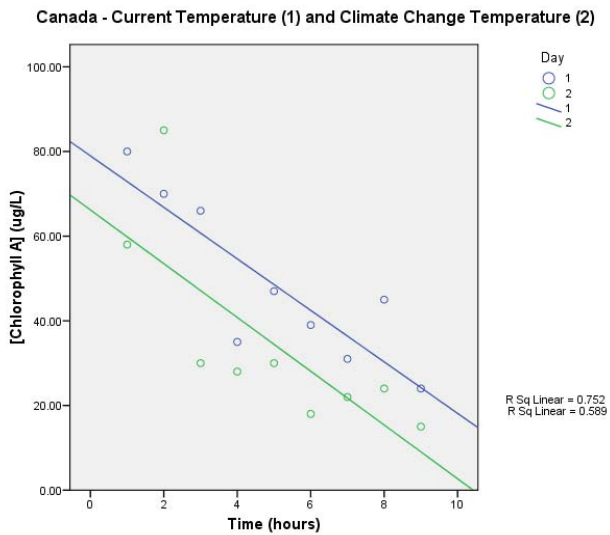

Figure 1: Canada Temperature Comparison - Experimental Tank 3

Temperature	Regression Equation	95% Confidence Interval	
		Lower Bound	Upper Bound
Current	[CA] = -6.03t + 78.97	-9.21	-2.96
Climate Change	[CA] = -6.35t + 66.19	-11.09	-1.61

Table 1: Canada Comparison - Regression and 95% Confidence Interval Analysis Output

Under Canada's conditions, the zebra mussel filtration rate in the current average water temperature (10°C) was -6.03µg/L/hr and the filtration rate in the predicted water temperature under climate change (15°C) was -6.35µg/L/hr.   Based on the complete 95% confidence interval overlap for the regression equations(see Table 1), the filtration rates are not significantly different between current temperature and climate change temperature, which is illustrated in Figure 1. The best fit curves are more or less parallel, indicating relatively little, if any, change in filtration rate at an increased temperature.
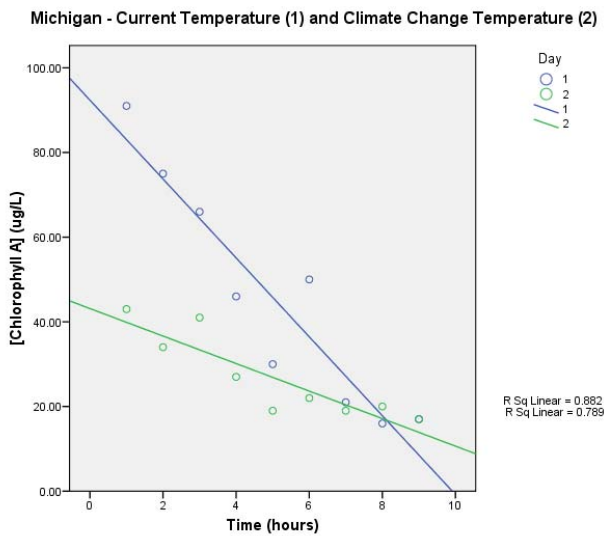
Figure 2: Michigan Temperature Comparison - Experimental Tank 2

Temperature	Regression Equation	95% Confidence Interval	
		Lower Bound	Upper Bound
Current	[CA] = -9.32t + 92.36	-12.36	-6.27
Climate Change	[CA] = -3.25t + 43.14	-4.75	-1.75

Table 2: Michigan Comparison - Regression and 95% Confidence Interval Analysis Output

Under Michigan conditions, the zebra mussel filtration rate in the current average water temperature (20°C) was -9.32µg/L/hr and the filtration rate in the predicted water temperature under climate change (24°C) was -3.25µg/L/hr. The filtration rate at current water temperature was much greater than at increased temperature. The filtration rate comparison can be seen in Figure 2. There was no overlap for the 95% confidence intervals of the regression equations, which indicates a significant difference in filtration rate between the two temperatures as seen in Table 2.
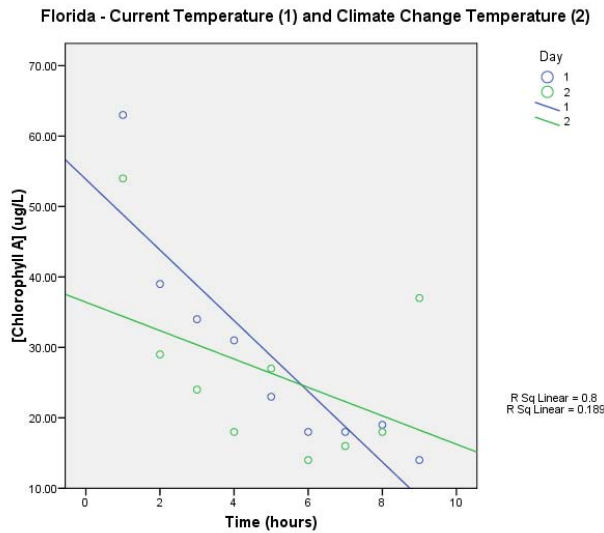
Figure 3: Florida Temperature Comparison – Experimental Tank 1

Temperature	Regression Equation	95% Confidence Interval	
		Lower Bound	Upper Bound
Current	[CA] = -5.02t + 53.86	-7.26	-2.78
Climate Change	[CA] = -2.02t + 36.42	-5.75	1.72

Table 3: Michigan Comparison – Regression and 95% Confidence Interval Analysis Output

Under Florida's conditions, the zebra mussel filtration rate in the current average water temperature (30°C) was -5.02μg/L/hr and the filtration rate in the predicted water temperature under climate change (32.5°C) was -2.02μg/L/hr. Even though the filtration rates appear to be different, they are not significantly different based on the 95% confidence interval overlap for the regression equations as seen in Table 3. Because there are outliers for both current water temperature data (see Figure 3) and increased water temperature data, it is possible that the outliers may have decreased the significance of the filtration rate difference. A potential explanation for the inconsistent data is that the Florida water temperatures may have approached the oxidative stress level for the zebra mussels in that climate situation. Zebra mussels under oxidative stress are unable to filter at their maximum potential.

The control samples from the tanks that did not have any zebra mussels had fairly stable horizontal slopes, which was expected due to no filtration activity occurring (see Figures 5, 7, 9, 11, 13, and 15 in Appendix). This is important to the experiment because we assumed that the chlorophyll A concentrations directly represent zebra mussel filtration of phytoplankton over

time. If the control chlorophyll A concentrations had not been stable, we would not have been to analyze our experimental data with the method that we used.

We conducted a one-way ANOVA test to analyze filtration rate differences between the three regions. Our analysis concluded that there was no significant difference between the regional filtration rates at both current average water temperatures (Table 4) and at increased average water temperatures due to climate change (Table 5). It is likely that the natural temperature range of zebra mussels was within the temperatures that we were testing, which could have been the reason why we saw no difference between the regions in terms of filtration rate.

Multiple Comparisons (Current Temperature)				
Location Tank	Location Tank	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3	0.958	-22.13	27.69
1	5	0.138	-5.13	44.69
3	5	0.224	-7.91	41.91

1=Canada, 3= Michigan, 5= Florida

Table 4: ANOVA Comparison of All Regions at Current Water Temperatures

Multiple Comparisons (Climate Change Temperature)				
Location Tank	Location Tank	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3	0.586	-11.36	26.47
1	5	0.541	-10.81	27.03
3	5	0.997	-18.36	19.47

1=Canada, 3= Michigan, 5= Florida

Table 5: ANOVA Comparison of All Regions at Climate Change Temperatures

In some samples, chlorophyll A concentration levels did not decrease consistently with the progression of time. This variance could be attributed to the sample collection method being used, as the distribution of phytoplankton in the tanks may not have been homogenous. Clumps of phytoplankton can occur within the tanks due to inconsistent water movement, which can be extracted and cause the concentration of chlorophyll A to appear to increase. According to a previous study of similar design, an increase in chlorophyll A can be also be attributed to the expulsion of pseudofeces by zebra mussels because they cannot digest all phytoplankton ingested

due to their high filtration rate (Nida and Ford, 1992). Pseudofeces contains partially digested algae containing viable chlorophyll A, which can give a false reading via fluorometric analysis. It is possible that we did not observe significant results for the other regions (Canada and Florida) because we were experimenting with zebra mussels already established in and acclimated to Douglas Lake.

Ecological Implications

Our study found that zebra mussels are able to persist in 3 different climate settings, which indicates that their persistence across a latitudinal gradient will most likely occur at increased temperatures due to climate change. Even though we did not find a statistically significant difference in filtration rate at different temperatures for Canada and Florida, we observed that zebra mussels were still intact and had the ability to filter, regardless of the differences in temperature stresses.

Climate envelope models predict that as climate change alters the temporal and biotic aspects of a region, the "envelope" of ecosystem characteristics encompassing a species or group of species will shift to another location to maintain similar conditions. Zebra mussels have been very successful in the Great Lakes region since their introduction and therefore climate change may cause a Northern expansion effect on the distribution of the species throughout North America survivorship in lower latitudes as well. Disruption of food webs due to expanded invasion of zebra mussels via increased water temperatures can cause ecological devastation of native species on all trophic levels within an ecosystem.

Further studies should be conducted to confirm and expand upon our results, as well as to gather additional information on the effects of climate change effects on aquatic ecosystems, especially water temperature variation.

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Appendix
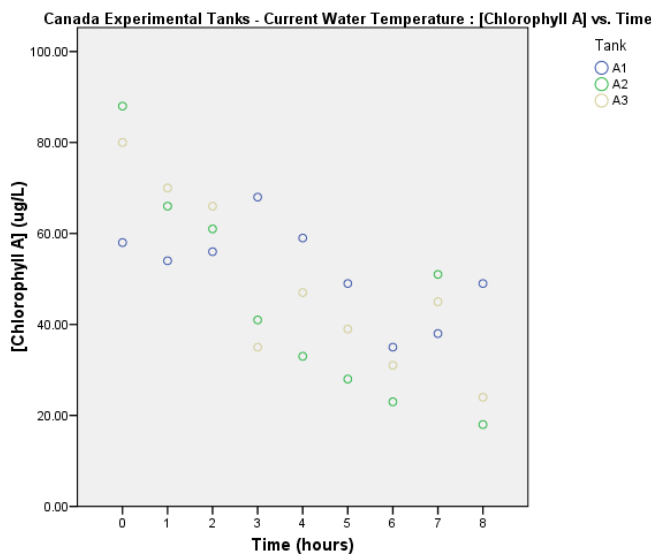
**Figure 4: Canada Experimental Tanks- Current Water Temperature. [Chlorophyll A] (ug/L) vs. Time (hrs). D.
polymorpha present.**

For the experimental tanks representing current Canada water temperature (10˚C), Figure
4 illustrates the distribution of chlorophyll A concentration over time as it changes due to *D.
polymorpha* filtration rate. All tanks showed an overall decreasing pattern in terms of

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chlorophyll A concentration in micrograms per liter over time in hours. The best fit regression line for this data is **[Chlorophyll A] = -5.13t + 74.26**, meaning that chlorophyll A concentration decreased by 5.13 µg/L/hr.
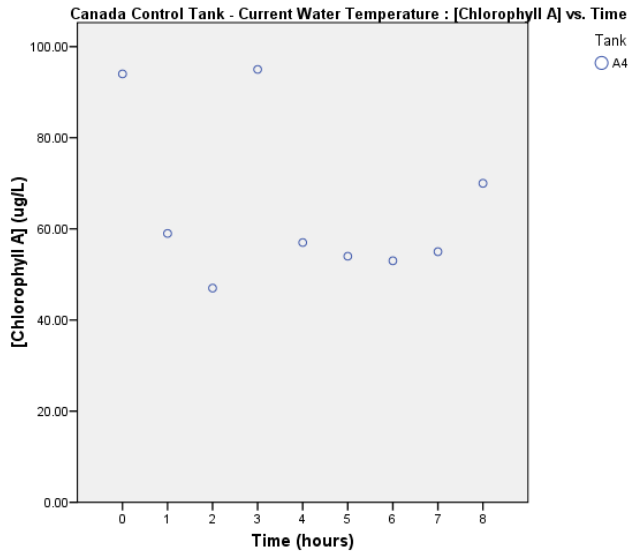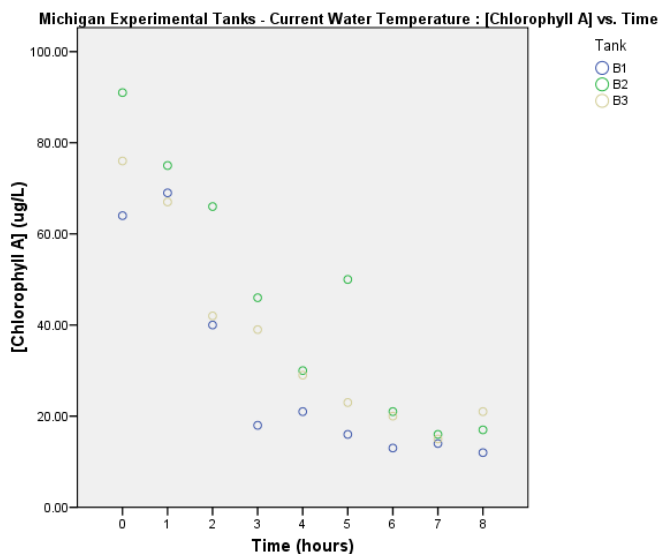

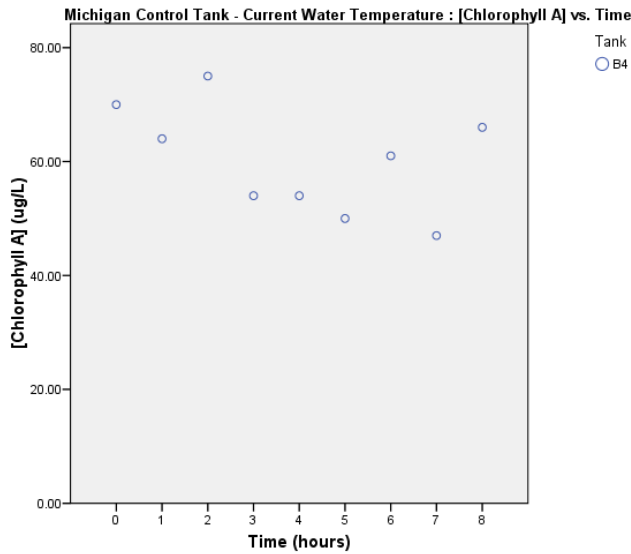**Figure 5: Canada Control Tank - Current Water Temperature. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha not present.**

For the control tank representing current Canada water temperature (10˚C), Figure 5 illustrates the distribution of chlorophyll A concentration over time as it changes due to *D. polymorpha* filtration rate. This tank showed a relatively stable pattern in terms of chlorophyll A concentration in micrograms per liter (µg/L) over time in hours. The best fit regression line for this data is **[Chlorophyll A] = -2.28t + 76.31**.

For the experimental tanks representing current Michigan water temperature (20˚C), Figure 6 illustrates the distribution of chlorophyll A concentration over time as it changes due to *D. polymorpha* filtration rate. All tanks showed an overall decreasing pattern in terms of chlorophyll A concentration in micrograms per liter over time in hours. The best fit regression line for this data is **[Chlorophyll A] = -7.91t + 77.00**, meaning that chlorophyll A concentration decreased by 7.91 µg/L/hr.

Figure 7: Michigan Control Tank - Current Water Temperature. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha not present.

For the control tank representing current Michigan water temperature (20˚C), Figure 7 illustrates the distribution of chlorophyll A concentration over time as it changes due to *D. polymorpha* filtration rate. This tank showed a relatively stable pattern in terms of chlorophyll A concentration in micrograms per liter (µg/L) over time in hours. The best fit regression line for this data is **[Chlorophyll A] = -1.65t + 68.36**.
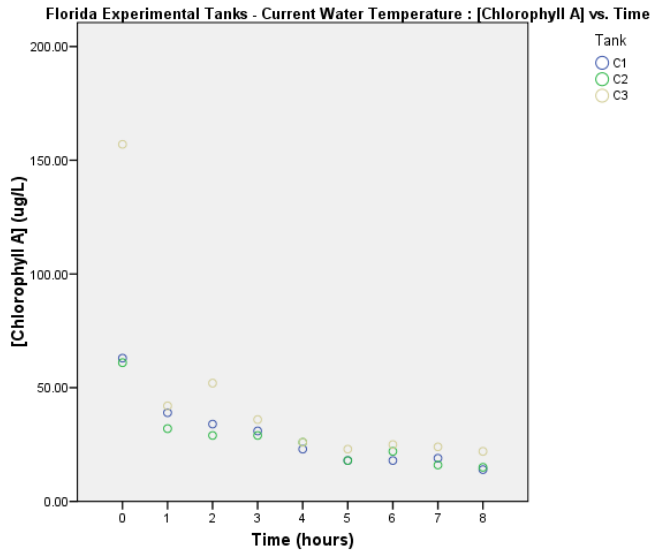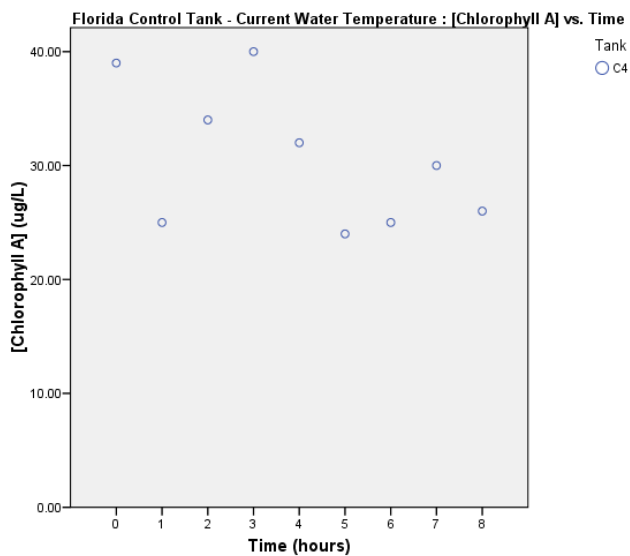
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Figure 8: Florida Experimental Tanks - Current Water Temperature. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha present.

For the experimental tanks representing current Florida water temperature (30˚C), Figure 8 illustrates the distribution of chlorophyll A concentration over time as it changes due to *D. polymorpha* filtration rate. All tanks showed an overall decreasing pattern in terms of chlorophyll A concentration in micrograms per liter over time in hours. The best fit regression line for this data is **[Chlorophyll A] = -6.77t + 67.71**, meaning that chlorophyll A concentration decreased by 6.77 µg/L/hr.

Figure 9: Florida Control Tank - Current Water Temperature. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha not present.

For the control tank representing current Florida water temperature (30˚C), Figure 9 illustrates the distribution of chlorophyll A concentration over time as it changes due to *D. polymorpha* filtration rate. This tank showed a relatively stable pattern in terms of chlorophyll A concentration in micrograms per liter (µg/L) over time in hours. The best fit regression line for this data is **[Chlorophyll A] = -1.18t + 36.47**.

Current Temperatures				
Location	**Region**	**Temperature**	**Tank Type***	**Regression Line**
1	Canada	10 deg C	Experimental	[Chlorophyll A] = -5.13t + 74.26
2	Canada	10 deg C	Control	[Chlorophyll A] = -2.28t + 76.31
3	Michigan	20 deg C	Experimental	[Chlorophyll A] = -7.91t + 77.00
4	Michigan	20 deg C	Control	[Chlorophyll A] = -1.65t + 68.36
5	Florida	30 deg C	Experimental	[Chlorophyll A] = -6.77t + 67.71
6	Florida	30 deg C	Control	[Chlorophyll A] = -1.18t + 36.47

*Experimental = Zebra mussels present; Control = No zebra mussels present
Table 6: Current Temperature Regression Equations for All Regions (Combined Experiemental Tanks vs. Control Tank)
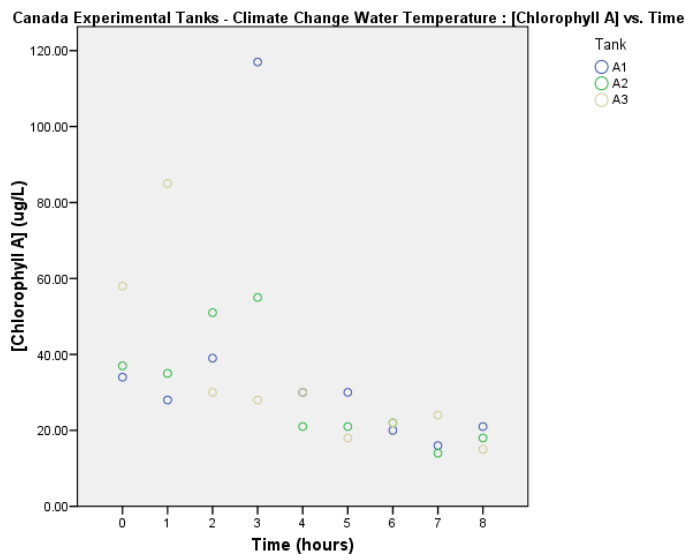

Figure 10: Canada Experimental Tanks – Climate Change Water Temperature. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha present.

For the experimental tanks representing Canada water temperature under climate change (15˚C), Figure 10 illustrates the distribution of chlorophyll A concentration over time as it changes due to *D. polymorpha* filtration rate. All tanks showed a relatively overall decreasing pattern in terms of chlorophyll A concentration in micrograms per liter over time in hours. The best fit regression line for this data is **[Chlorophyll A] = -4.58t + 56.95**, meaning that chlorophyll A concentration decreased by 4.58 µg/L/hr.
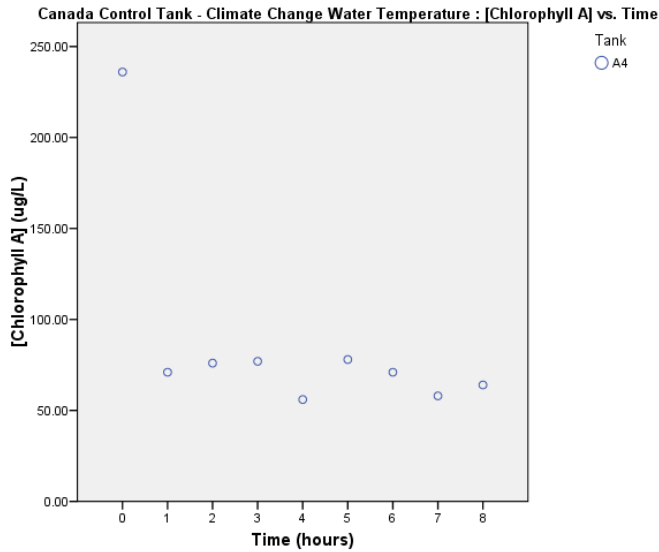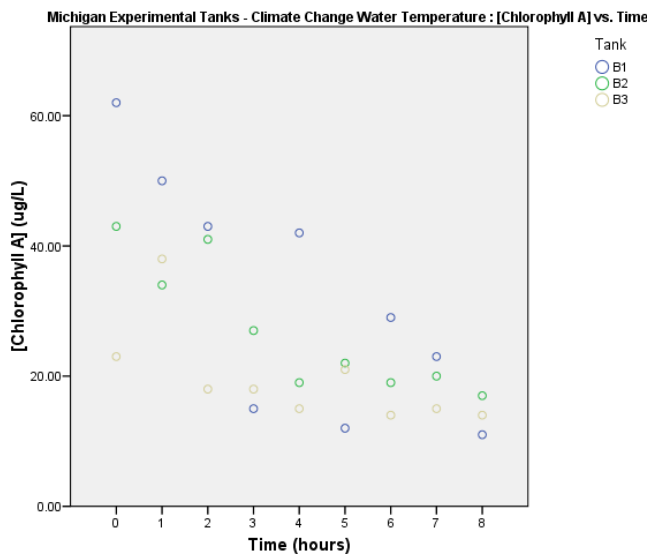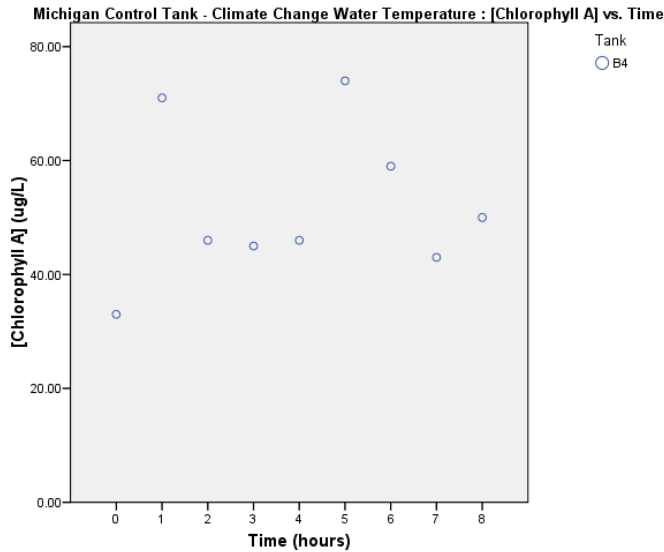
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Figure 11: Canada Control Tank – Climate Change Water Temperature. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha not present.

For the control tank representing Canada water temperature under climate change (15˚C), Figure 11 illustrates the distribution of chlorophyll A concentration over time as it changes due to *D. polymorpha* filtration rate. This tank showed a relatively stable pattern in terms of chlorophyll A concentration in micrograms per liter (μg/L) over time in hours. The best fit regression line for this data is **[Chlorophyll A] = -12.27t + 148.78**.

Figure 12: Michigan Experimental Tanks – Climate Change Water Temperature. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha present.

For the experimental tanks representing Michigan water temperature under climate change (24˚C), Figure 12 illustrates the distribution of chlorophyll A concentration over time as

it changes due to *D. polymorpha* filtration rate. All tanks showed an overall decreasing pattern in terms of chlorophyll A concentration in micrograms per liter over time in hours. The best fit regression line for this data is **[Chlorophyll A] = -3.45t + 43.36**, meaning that chlorophyll A concentration decreased by 3.45 μg/L/hr.

Figure 13: Michigan Control Tank – Climate Change Water Temperature. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha not present.

For the control tank representing Michigan water temperature under climate change (24˚C), Figure 13 illustrates the distribution of chlorophyll A concentration over time as it changes due to *D. polymorpha* filtration rate. This tank showed a relatively stable pattern in terms of chlorophyll A concentration in micrograms per liter (μg/L) over time in hours. The best fit regression line for this data is **[Chlorophyll A] = 0.65t + 48.64**.
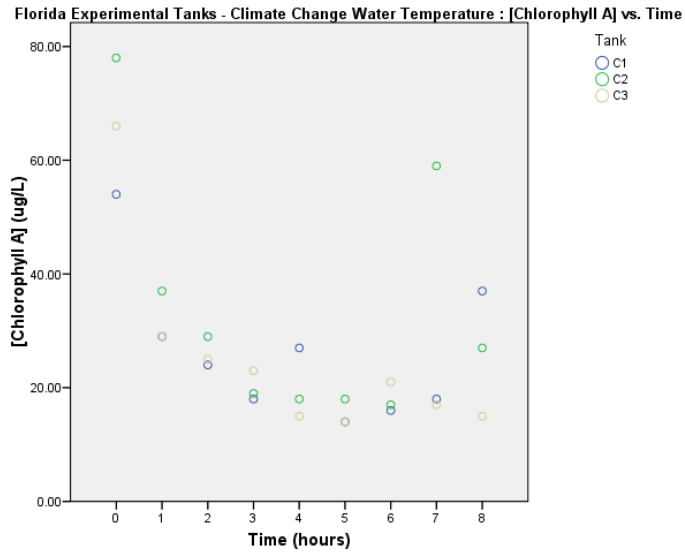
Figure 14: Florida Experimental Tanks – Climate Change Water Temperature. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha present.

For the experimental tanks representing Florida water temperature under climate change (32.5˚C), Figure 14 illustrates the distribution of chlorophyll A concentration over time as it changes due to *D. polymorpha* filtration rate. All tanks showed a relatively overall decreasing pattern in terms of chlorophyll A concentration in micrograms per liter over time in hours. The best fit regression line for this data is **[Chlorophyll A] = -3.01t + 43.32**, meaning that chlorophyll A concentration decreased by 3.01 μg/L/hr.
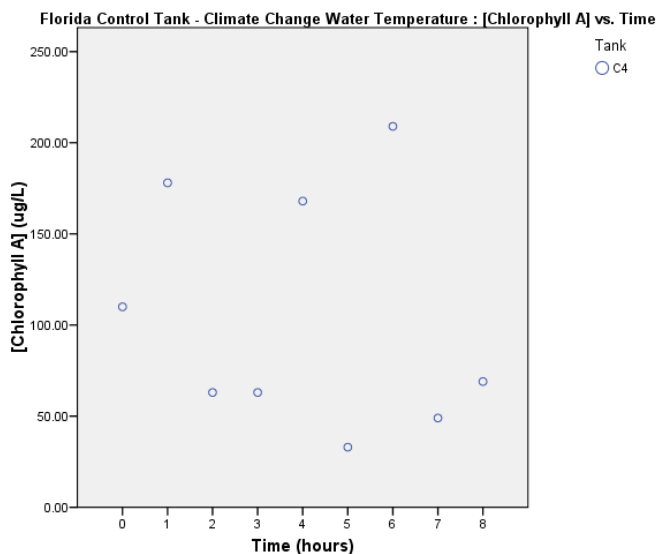

Figure 15: Florida Control Tank– Climate Change Water Temperature. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha not present.

For the control tank representing Florida water temperature under climate change (32.5˚C), Figure 15 illustrates the distribution of chlorophyll A concentration over time as it changes due to *D. polymorpha* filtration rate. This tank showed a relatively stable pattern in terms of chlorophyll A concentration in micrograms per liter (µg/L) over time in hours. The best fit regression line for this data is **[Chlorophyll A] = -4.82t + 128.75**.

Climate Change Temperatures				
Location	**Region**	**Temperature**	**Tank Type***	**Regression Line**
1	Canada	15 deg C	Experimental	[Chlorophyll A] = -4.58t + 56.95
2	Canada	15 deg C	Control	[Chlorophyll A] = -12.27t + 148.78
3	Michigan	24 deg C	Experimental	[Chlorophyll A] = -3.45t + 43.36
4	Michigan	24 deg C	Control	[Chlorophyll A] = 0.65t + 48.64
5	Florida	32.5 deg C	Experimental	[Chlorophyll A] = -3.01t + 43.32
6	Florida	32.5 deg C	Control	[Chlorophyll A] = -4.82t + 128.75

*Experimental = Zebra mussels present; Control = No zebra mussels present

Table 7: Climate Change Temperature Regression Equations for All Regions (Combined Experiemental Tanks vs. Control Tank)
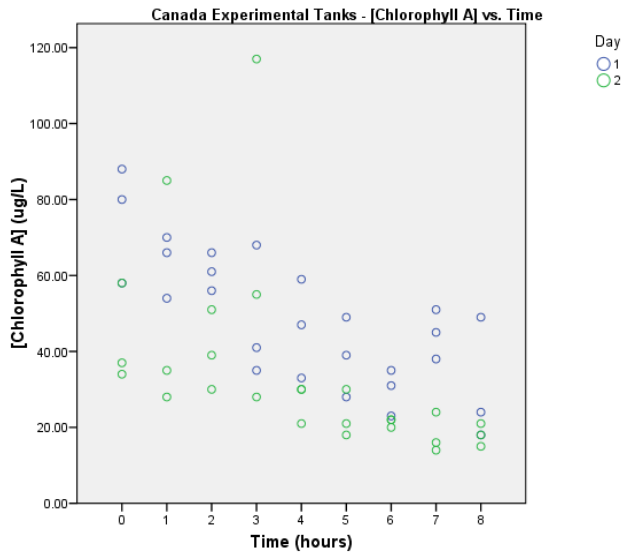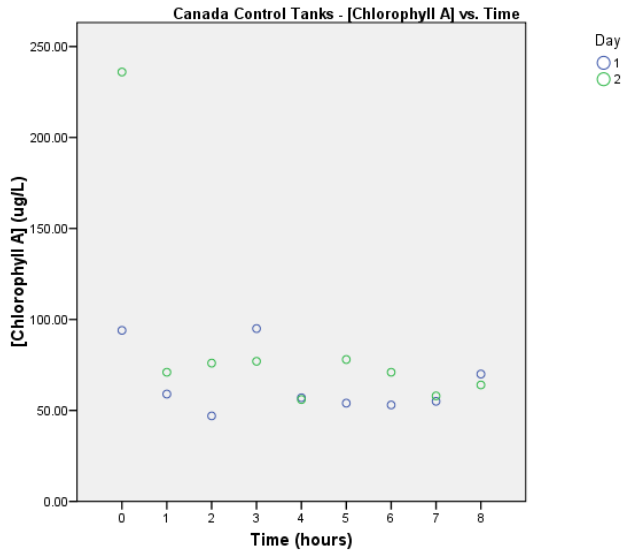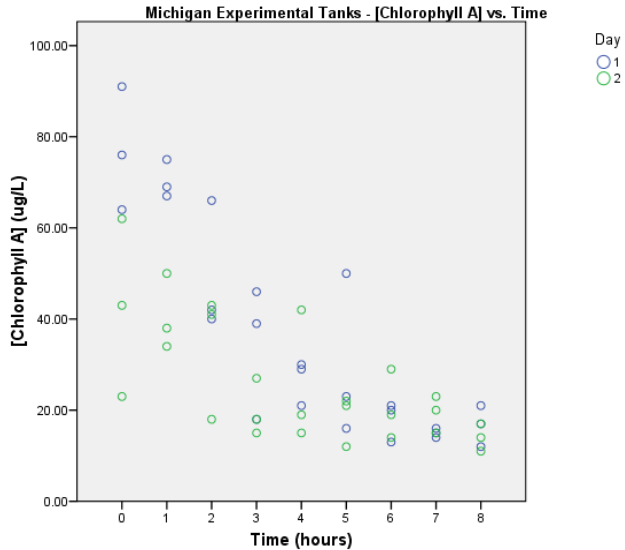

Figure 16: Canada Experimental Tanks – Comparison of Chlorophyll Concentration Rates Based on Different Water Temperatures. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha present. *Day 1=Current Water Temperature, Day 2=Climate Change Water Temperature

Figure 16 shows the overall Canada chlorophyll A concentration data, comparing the results between the two experimental treatments (Day 1 = Current Water Temperature = 10˚C; Day 2 = Climate Change Water Temperature = 15˚C).
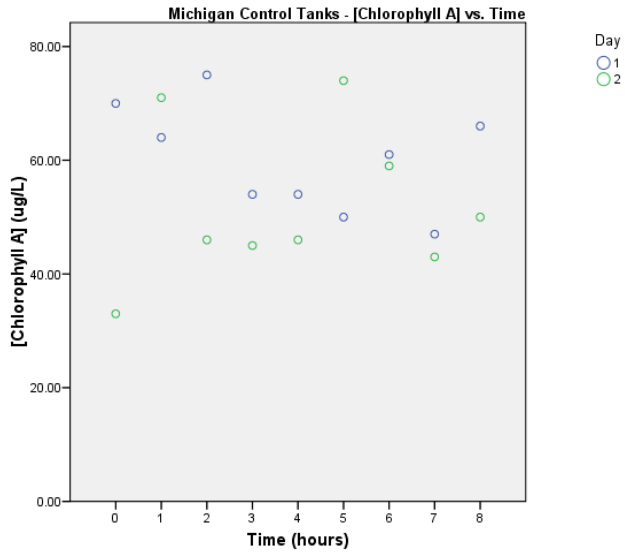
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Figure 17: Canada Control Tanks – Comparison of Chlorophyll Concentration Rates Based on Different Water Temperatures. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha not present. *Day 1=Current Water Temperature, Day 2=Climate Change Water Temperature

Figure 17 shows the overall Canada chlorophyll A concentration data, comparing the results between the two control tanks (Day 1 = Current Water Temperature = 10˚C; Day 2 = Climate Change Water Temperature = 15˚C).
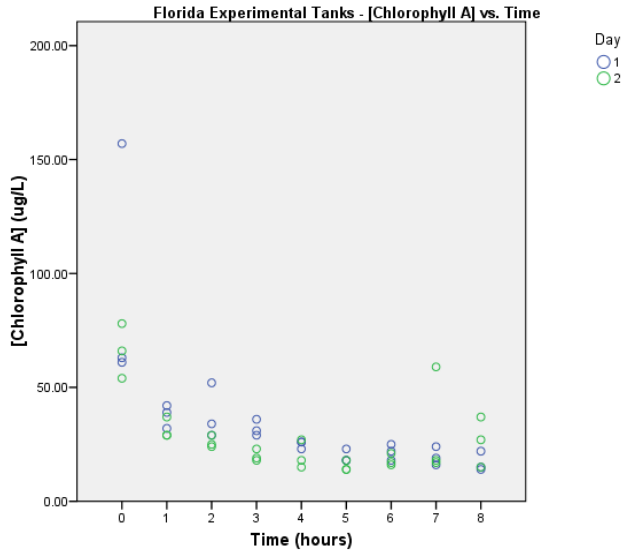

Figure 18: Michigan Experimental Tanks– Comparison of Chlorophyll Concentration Rates Based on Different Water Temperatures. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha present. *Day 1=Current Water Temperature, Day 2=Climate Change Water Temperature

Figure 18 shows the overall Michigan chlorophyll A concentration data, comparing the results between the two experimental treatments (Day 1 = Current Water Temperature = 20˚C; Day 2 = Climate Change Water Temperature = 24˚C).
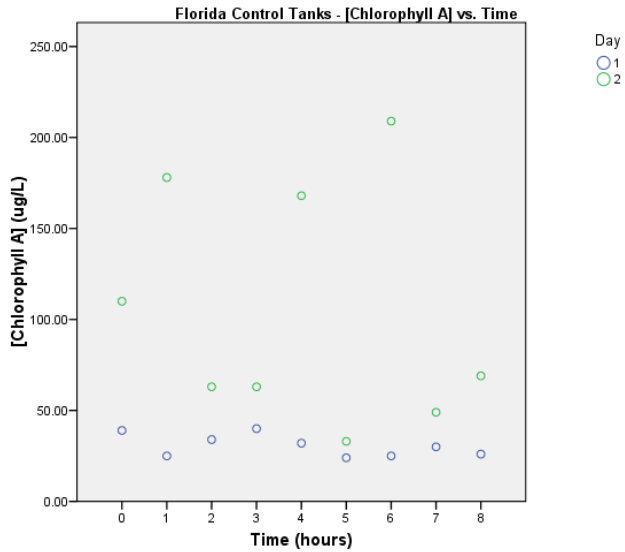
Figure 19: Michigan Control Tanks – Comparison of Chlorophyll Concentration Rates Based on Different Water Temperatures. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha not present. *Day 1=Current Water Temperature, Day 2=Climate Change Water Temperature

Figure 19 shows the overall Michigan chlorophyll A concentration data, comparing the results between the two control tanks (Day 1 = Current Water Temperature = 20˚C; Day 2 = Climate Change Water Temperature = 24˚C).

Figure 20: Florida Experimental Tanks – Comparison of Chlorophyll Concentration Rates Based on Different Water Temperatures. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha present. *Day 1=Current Water Temperature, Day 2=Climate Change Water Temperature

Figure 20 shows the overall Florida chlorophyll A concentration data, comparing the results between the two experimental treatments (Day 1 = Current Water Temperature = 30˚C; Day 2 = Climate Change Water Temperature = 32.5˚C).

Figure 21: Florida Control Tanks – Comparison of Chlorophyll Concentration Rates Based on Different Water Temperatures. [Chlorophyll A] (ug/L) vs. Time (hrs). D. polymorpha not present. *Day 1=Current Water Temperature, Day 2=Climate Change Water Temperature

Figure 21 shows the overall Florida chlorophyll A concentration data, comparing the results between the two control tanks (Day 1 = Current Water Temperature = 30˚C; Day 2 = Climate Change Water Temperature = 32.5˚C).