THE EFFECTS OF INVASIVE *TYPHA* X *GLAUCA* ON ABIOTIC FACTORS AND FISH COMMUNITIES IN A GREAT LAKES COASTAL WETLAND

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The fishes of the Great Lakes utilize the wetlands of the region as forage sites and nurseries. These habitats are being invaded by the cattail hybrid Typha x glauca, which outcompetes native marsh plants and can create large plots of monoculture. This study investigated the impact of this plant on the abiotic factors within wetlands as well as the fish communities. We measured a variety of abiotic factors, including nutrient levels, water temperature, and dissolved oxygen. We also compared the biodiversity of plots invaded by Typha x glauca and plots of native plants. The dissolved oxygen levels and water temperature were significantly higher in the native marsh plots. Nutrient levels varied depending on the nutrient type, with ammonium and phosphorus being higher in native plots but the total nitrogen being higher in the invaded plots. We found that species richness, species abundance, and biodiversity were significantly higher in the native marshes. The interactions between the abiotic and biotic factors of the wetlands require further study, but the protection of the GLCW from invasive cattails is imperative for the preservation of diverse fish communities.

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The fishes of the Great Lakes utilize the wetlands of the region as forage sites and nurseries. These habitats are being invaded by the cattail hybrid *Typha* x *glauca*, which outcompetes native marsh plants and can create large plots of monoculture. This study investigated the impact of this plant on the abiotic factors within wetlands as well as the fish communities. We measured a variety of abiotic factors, including nutrient levels, water temperature, and dissolved oxygen. We also compared the biodiversity of plots invaded by *Typha* x *glauca* and plots of native plants. The dissolved oxygen levels and water temperature were significantly higher in the native marsh plots. Nutrient levels varied depending on the nutrient type, with ammonium and phosphorus being higher in native plots but the total nitrogen being higher in the invaded plots. We found that species richness, species abundance, and biodiversity were significantly higher in the native marshes. The interactions between the abiotic and biotic factors of the wetlands require further study, but the protection of the GLCW from invasive cattails is imperative for the preservation of diverse fish communities.

Introduction

The Great Lakes Coastal Wetlands (GLCW) are important, unique habitats for a large number of Great Lakes fishes; Uzarski et al. (2005) found 51 species of Great Lakes fishes present in the wetlands. These fishes use the GLCW as nurseries (Brazner & Beals, 1997) as well as forage areas (Brady et al., 2004). Besides directly benefiting the fishes, the species of the GLCW are important to fisheries and for commercial use (Trebitz & Hoffman, 2015).

Typha x *glauca* is an invasive cattail in the GLCW. It is a hybrid of native *Typha latifolia* and invasive *Typha angustifolia* (Smith 1987). This hybridization is the primary reason these cattails can proliferate extensively throughout the GLCW as the hybrids outperform their parent species (Travis et al., 2009). *Typha* x *glauca* is tolerant of a wide range of environmental conditions, such as acidity and a range of temperatures (Galatowitsch et al., 1999). Because *Typha* x *glauca* can reproduce using rhizomes, it spreads effectively throughout the marshes (Selbo & Snow, 2004).

Typha x *glauca* (hereafter referred to as *Typha*) affects abiotic factors of wetlands; regions with cattails have lower dissolved oxygen (DO) levels in comparison to regions containing bulrushes (Beutel & Gebremariam, 2008). DO and pH, are important factors influencing fish communities in wetlands (Rahel & Nutzman, 1994) (Rahel & Magnuson, 1983). Additionally, the litter resulting from the decomposition of *Typha* reduces temperature fluctuations (Freyman et al., 2012).

Typha alters the nutrient levels of wetlands as well. Invasive macrophytes hold nitrogen and phosphorus (Albert et al., 2018). The cattails are correlated with higher nutrient concentrations (Farrer & Goldber, 2009) (Currie et al., 2017) (Geddes et al., 2009), specifically nitrate and ammonium levels (Geddes et al., 2014). These high nutrient levels increase Typha's ability to proliferate (Farrer & Goldberg, 2009).

The invasive cattail hybrid also impacts biodiversity of the GLCW. For example, Typha has been shown to lower the abundance of macroinvertebrates (Bourke et al., 2016). It also decreases the diversity and richness of plant communities (Freyman et al., 20120) (Geddes et al., 2014). Fish abundance is strongly related to macrophytes (Jacobus & Webb, 2005), and vegetation is a key indicator of the types of fish present (Trebitz & Hoffman, 2015). Therefore, the presence of *Typha* can affect fish communities. The dense vegetation of *Typha* plots limits foraging (Smokorowski & Pratt, 2007) and prevents fishing from moving between safe inland waters and spacious open waters (Farrell, 2001). In sum, *Typha* has the potential to eradicate fish habitat (Brazner & Beals, 1997) (Hook et al., 2001).

In this study we investigated possible differences in the fish communities of both invaded and native marshes. If the invasive cattail is present, there will be lower fish biodiversity and lower species richness when compared to the native marsh. Because of their importance to fishes, we also investigated the levels of DO and pH. More acidic water could lead to better survival rates of the heartier *Typha* compared to the native plants, affecting the distribution of fishes. Thus, we investigated if pH was more extreme in the invaded marsh. If *Typha* is present, there will be lower levels of dissolved oxygen and a lower pH. As *Typha* can influence temperature and nutrient level, we studied these factors as well. Besides direct measurement of nutrient levels, we measured conductivity as it can be used as a metric for nutrients and sodium content in the water (Payne, 1984). In the absence of the invasive cattail, temperatures will be lower and there will be higher levels of nutrients.

Methods

Site

We sampled in the St. Ignace Marsh on the Straits of Mackinac in the southern Upper Peninsula of Michigan. We chose 3 plots of wetland invaded by Typha and 3 plots of native marsh (30m by 60 m) (Fig.1). Each plot had 4 subplots (A, B, C, and D).

Experimental Design

Conductivity (µs/cm), pH, and dissolved oxygen (mg/L) were measured on 7/26/18, 8/2/18, and 8/7/18. We measured temperature (°C) at every subplot every day that we collected. The depth (cm) at each trap was taken when the traps were set and when data was collected. We sampled the water at subplot B of every plot for nutrient analysis on 8/1/18 and 8/7/18. Timothy Viverica analyzed the samples for nitrate, ammonium, and soluble reactive phosphorus using ion chromatography and for total nitrogen and phosphorus by automated colorimetry.

Based on procedures outlined by Tuchman et al. (2015), solely minnow traps were used for collection. We placed a gang of 3 minnow traps at each subplot. In total, we used 72 minnow traps. The traps were set and baited initially on 7/22/18, and we collected data from 7/23/1 to 8/2/18. The total number of net-nights was 14.

Statistical Analysis

We used the IBM SPSS Statistics 24 program to run the statistical analyses.

The relationship between dissolved oxygen levels and time, as well as temperature and time, was analyzed using a Spearman's correlation for both treatments. Every DO measurement and every temperature measurement were used in these analyses. We averaged the DO and temperature measurements by treatment. The average DO level in the invaded treatment was compared to the average DO level in the native treatment using a t-test (alpha=0.05). The average temperature in the invaded treatment was compared to the average temperature in the native treatment using a t-test as well (alpha=0.05). We used a t-test rather than an analysis of covariance because the differences in the means of DO and temperature of the two treatments were assumed to be greater than the difference in DO and temperature over time.

The average conductivity in the native treatment was compared to the average conductivity in the invaded treatment. The conductivity at every subplot was averaged over the 14 net nights. We used a t-test to compare the means (alpha=0.05).

The nutrient measurements were averaged over the two sample dates. No subsequent analysis was done due to a lack of a normal distribution.

We used a Shannon Diversity Index to compare the diversity of fishes in the invaded plots and the native plots. The index was calculated for every subplot over the 14 net nights. We used a t-test to analyze the difference of the means of the invaded and native indices (alpha=0.05). Then, we removed outlier data of brown bullheads (*Ameiurus nebulosus*). Another t-test was used to compare the means (alpha=0.05).

A cluster analysis was run using the 12 subplots of the native plots and the 12 subplots of the invaded plots using squared Euclidean distance and centroid linkage between groups. The similarity between subplots based on species composition was analyzed using a Person correlation. Then, the correlation values were clustered together and constellation plot was constructed to compare subplots (program: JMP Pro 14).

The species richness was calculated for each subplot over the 14 net nights. Then, a t-test compared the mean species richness in native and invaded treatments (alpha=0.05). We found species abundance by counting the number of fish found at each subplot over the 14 net nights. The difference in the mean abundance for native and invaded plots was compared using a t-test (alpha=0.05). This same statistical procedure was used to compare the average number of crayfish found in the two treatments.

Results

Abiotic factors

Between the hours of 10:00am and 1:00pm, dissolved oxygen in the invaded treatment increased significantly (Fig. 2) (p<0.01, r^2=0.48). This was also seen the native marsh; dissolved oxygen increased significantly as time passed (Fig. 3) (p<0.01, r^2=0.58). The average DO in the native wetland was significantly higher than the average DO in the *Typha* plots (df=68, p<0.05) (Fig. 4).

Water temperature increased over time in the invaded plots (p<0.05, r^2=0.47) (Fig. 5). Temperature did not change significantly over time in the native treatment (p=0.29, r^2=0.10) (Fig. 6). The average temperature in the native plots was significantly higher than that of the invaded plots (df=216, p<0.05) (Fig. 7).

The average pH was significantly higher in the native treatment (7.19) than in the invaded treatment (7.06) (df=22, p<0.05) (Fig. 8). This trend was reversed with conductivity; the average conductivity was significantly higher in the invaded treatment (431) than in the native treatment (332) (df=22, p<0.0) (Fig. 9).

Nutrients

There was no observable trend in the total phosphorus between the native and invaded treatments, yet the amount of total nitrogen was slightly higher in the invaded treatments (Fig.

10). However, we did note a larger amount of PO_4 and NH_4 in the native plots (Fig. 11). There was no visible difference in nitrate and nitrite levels. All of these results were within error bars of 2 standard errors, indicating a lack of significance.

Biodiversity

The biodiversity in the two treatments was not significantly different when calculated including brown bullhead counts (df=22, p=0.14) (Fig. 12). The average Shannon Weiner diversity index value for the invaded plots was H=0.32. In the native plots, the average was H=0.21. However, when the brown bullhead data points were removed from the calculation, the native treatments had significantly greater Shannon Weiner index values, indicating higher biodiversity (df=15.8, p=0.0003) (Fig. 13). The invaded subplots were clustered closer to each other than to the native subplots (Fig. 14).

The average species richness was significantly higher in the native plots than in the invaded plots (df=22, $p<0.05$) (Fig. 15). For all of the subplots in the native marsh, the average species richness was 5 compared to 3 for the subplots in the invaded marsh. The total number of species found in the native plots was 13, while the number of species in the invaded plots was 5 (Table 1). The abundance of crayfish in the two treatments was significantly different over the 14 net nights; there were more crayfish in the invaded plots than in the native plots (df=22, $p<0.05$) (Fig. 16). The average amount for the invaded treatment was 21 and the average for the native treatment was 8. The average abundance of fishes was significantly higher in the native subplots than in the invaded subplots (df=22, $p<0.05$). There was an average of 45 individual fish found at each native subplot compared to an average of 15 individuals found at an invaded subplot (Fig. 17).

Discussion

The higher dissolved oxygen levels of the native plots were in line with our predictions. Other studies have also found that areas with invasive cattail have lower dissolved oxygen levels, which may be due to the high density of the plants preventing water flow (Gebremariam & Beutel, 2008). The presence of *Typha* may also be the reasoning for the unpredicted high water temperature in the native plots; the large amount of litter as well as the tall, dense stems prevent light from reaching the water (Freyman et al., 2012). Thus, the water in the native plots would receive more energy from the sun and subsequently heat to warmer temperatures.

While the difference in average pH between the two treatments was statistically significant, the difference was not large enough to impact fishes or plants. The two values differed by just 0.13; other studies have shown that fish communities begin to be impacted only once pH has decreased from 7.0 by at least 0.6 (Cooper and Wagner, 1973).

The average conductivity was higher in the invaded plots. This may indicate higher nutrient levels in the *Typha*-invaded areas. Increased nutrient levels in invaded marshes have been seen in other studies (Currie et al., 2017) (Geddes et al., 2009) (Geddes et al., 2014). The nutrient data indicated that the NH_4 and PO_4 levels were higher in the native plots, while the total nitrogen and total phosphorus as well as nitrate and nitrite levels were almost equal in both treatments. These results are contrary to the initial hypothesis, conductivity findings, and other studies. Many studies have indicated that *Typha* is usually correlated with higher nutrient levels (Currie et al., 2017) (Geddes et al., 2009) (Geddes et al., 2014). However, *Typha* is known to sequester nitrogen (Davis & van der Valk, 1983), lowering the levels of NH4 in the water column. This would partially explain the elevated NH4 levels in the native plots.

The biodiversity of the native plots was initially skewed due to the uneven spacial distribution of brown bullheads. Hundreds of members of this fish species were often found at a single subplot, or even in a single minnow trap. Therefore, the average diversity index of the native plots was lower than expected compared to the invaded plots. We removed the data on brown bullheads for the biodiversity calculation because we mainly caught young juvenile bullheads, which tend to school (Becker, 1983). Once the calculations were done without the brown bullheads, the biodiversity was higher in the native treatment, as predicted. Additionally, species richness was lower in invaded plots, as suggested by previous studies (Geddes et al., 2009). There were also less individual fishes which supports the suggestion that Typha eliminates fish habitat (Brazner & Beals, 1997) (Hook et al., 2001). These fishes may have preferred the oxygenated, warm water of the native marsh while also avoiding the dense, forage-limiting *Typha* (Smokorowski & Pratt, 2007).

Crayfish abundance was significantly lower in the native marsh. This may be due to the crayfish avoiding the large number of fishes in the native treatment, as many fish species prey on the crayfish (Stein, 1977). Additionally, according to one study, the crayfish may be avoiding the warmer water of the native plots and selecting the cooler water of the *Typha* plots (Tattersall et al., 2012).

In sum, Typha's impact on abiotic factors could be influencing the fish communities found in the invaded plots. In invaded wetlands, removing Typha could possibly help return to native levels of biodiversity. This has already proven to be effective for plant communities (Lishawa et al., 2015), and the impact of Typha harvesting on fish communities is currently being explored (Albert et al., 2015). Additionally, the native marshes support a larger number of species. Therefore, conserving the GLCW is important for preserving the habitats and providing for the future of many Great Lakes fishes.

Tables and Figures

	Invaded Marsh	Native Marsh
Notropis heterodon		X
Notropis heterolepis		X
Amia calva	X	X
Amieurus nebulosus	X	X
Neogobius melanostomus		X
Notemigonus crysoleucas		X
Fundulus diaphanus		X
Micropterus salmoides		X
Umbra limi	X	X
Esox lucius	X	X
Opsopoeodus emiliae		X
Lepomis gibbosus	X	X
Ambloplites rupestris		X

Table 1. If a species, its presence is indicated by ‘X’. All of the species caught in either site are listed.

Figure 1. The location of the subplots in the St. Ignace marsh are indicated in this map. The subplots (ABCD) are also labeled.

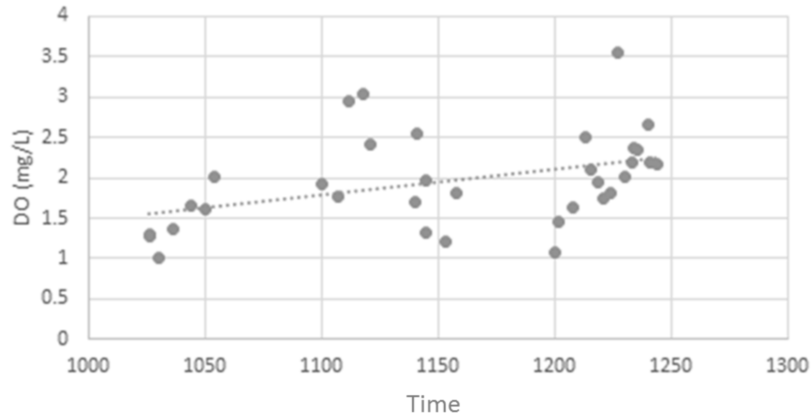

Figure 2. As time progressed from 10:00am to 13:00pm, dissolved oxygen levels in the *Typha* plots increased significantly (p<0.01, $r^2 = 0.5$).

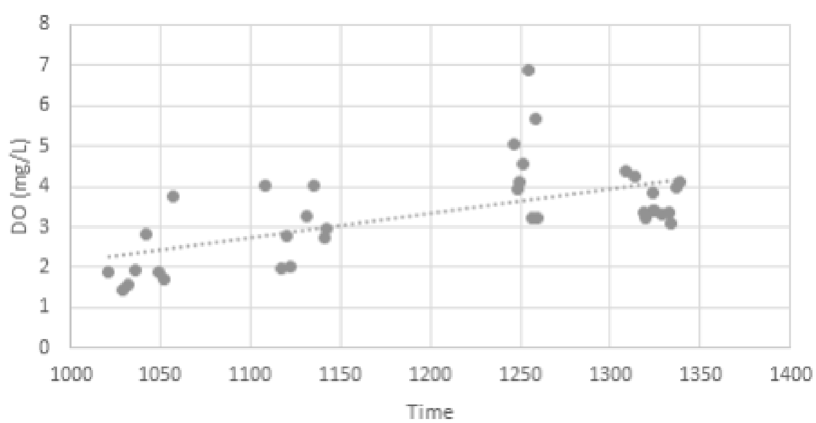

Figure 3. The DO levels increased significantly in the native marsh between the hours of 10:00am and 14:00pm (p<0.01, $r^2 = 0.585$).

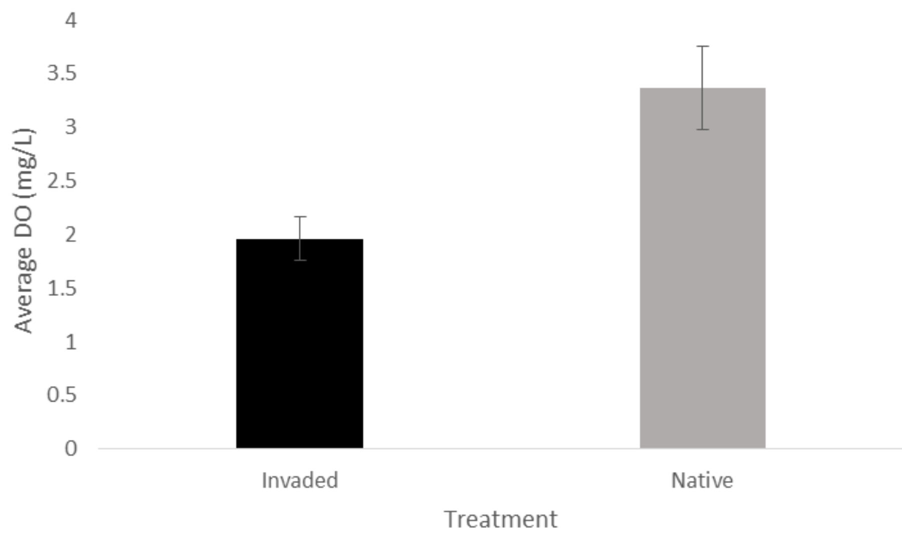

Figure 4. The average DO in the native treatment was significantly higher than the average DO in the invaded treatment (df=68, p<0.05). Error bars are 2 standard errors.

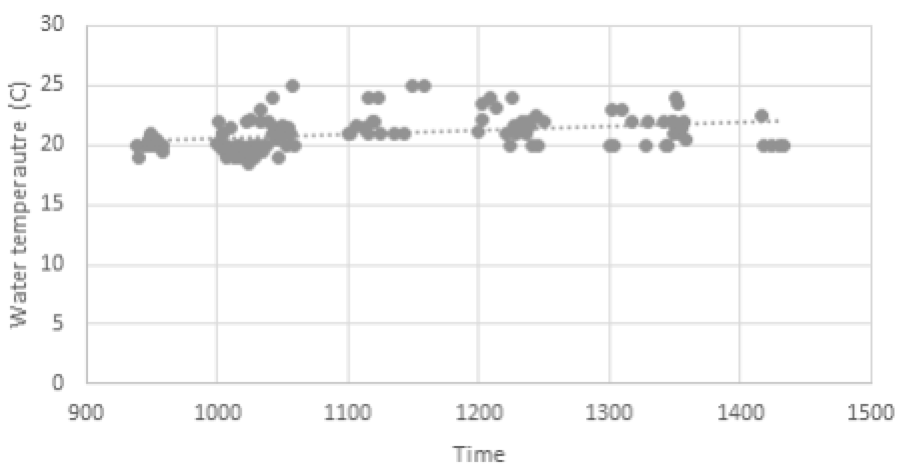

Figure 5. Water temperature increased significantly between the hours of 9:00am and 15:00pm in the invaded plots (p<0.05, $r^2 = 0.47$).

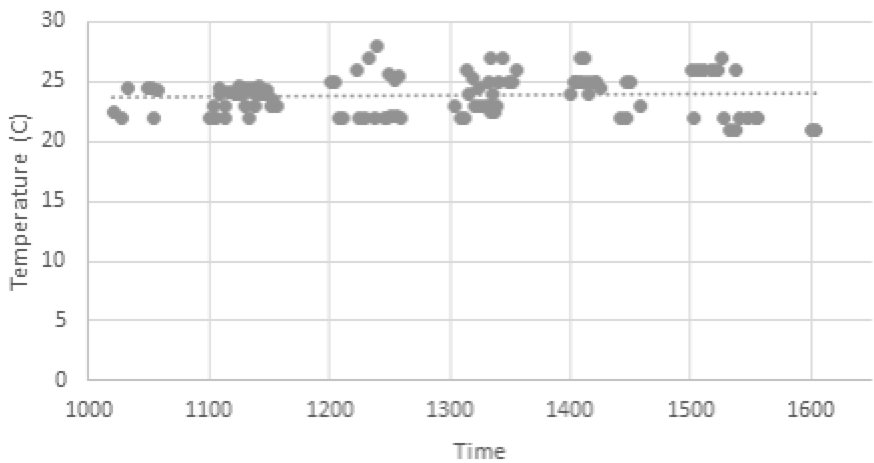

Figure 6. Water temperature did not increase or decrease significantly between the hours of 10:00am and 16:00pm in the native plots (p=0.29, $r^2 = 0.1$).

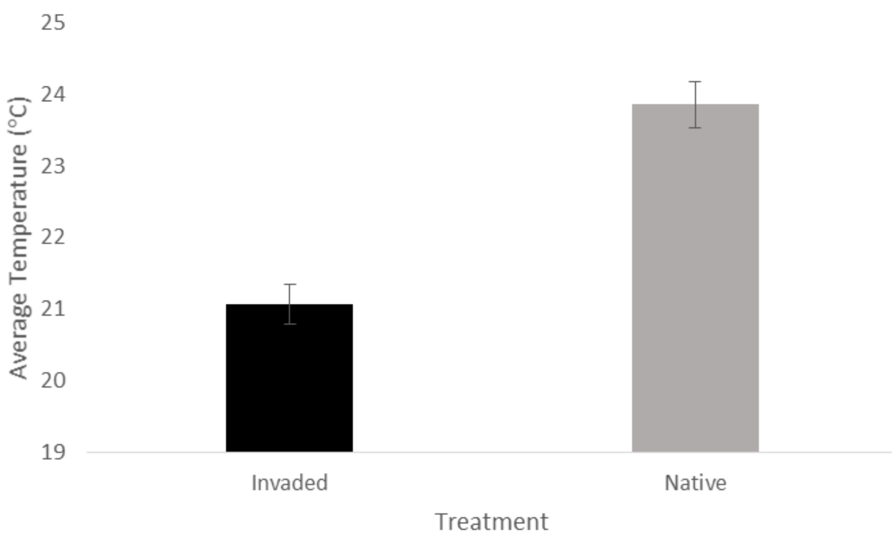

Figure 7. The average water temperature in the native treatment was significantly higher than the average water temperature in the invaded treatment (df=216, p<0.05). Error bars are 2 standard errors.

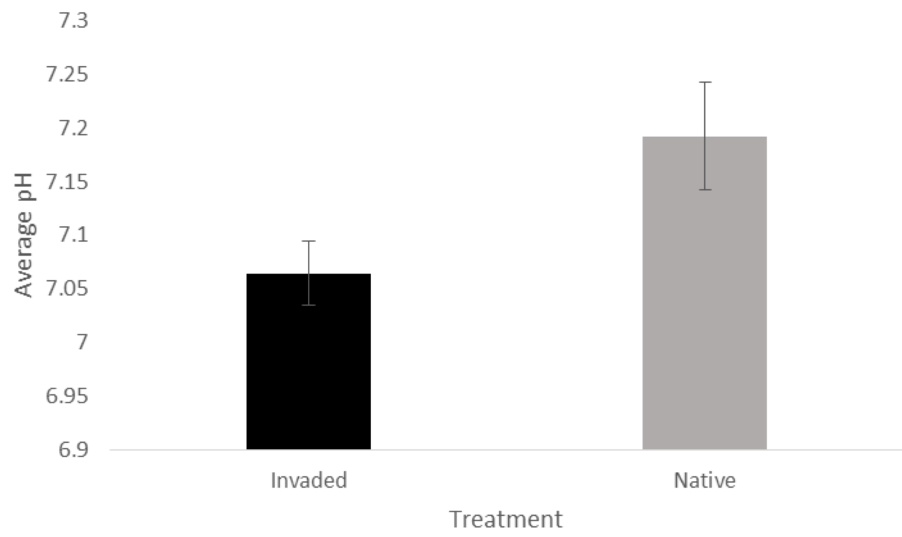

Figure 8. The average pH was significantly higher in the native treatment (df=22, p<0.05); the invaded treatment was significantly more acidic. Error bars are 2 standard errors.

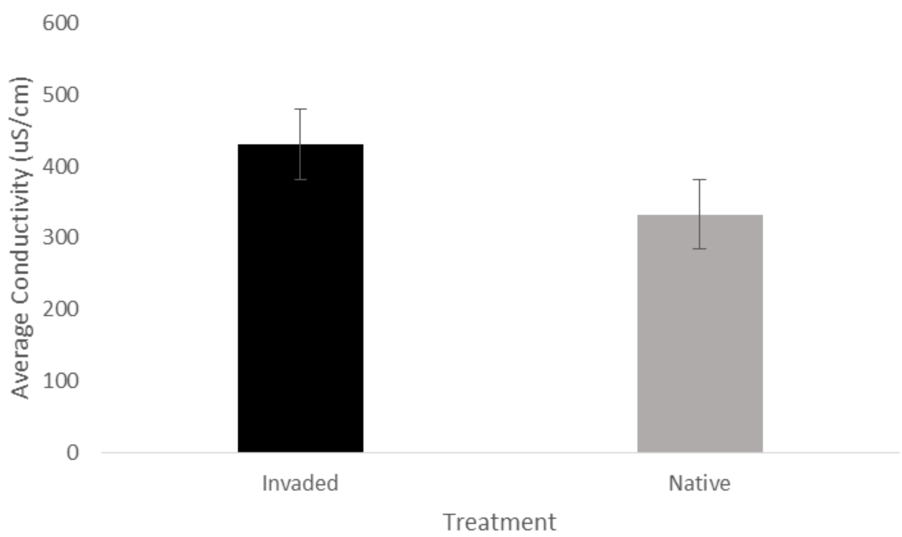

Figure 9. Conductivity was significantly higher in the invaded treatment (df=22, p<0.0). Error bars are 2 standard errors.

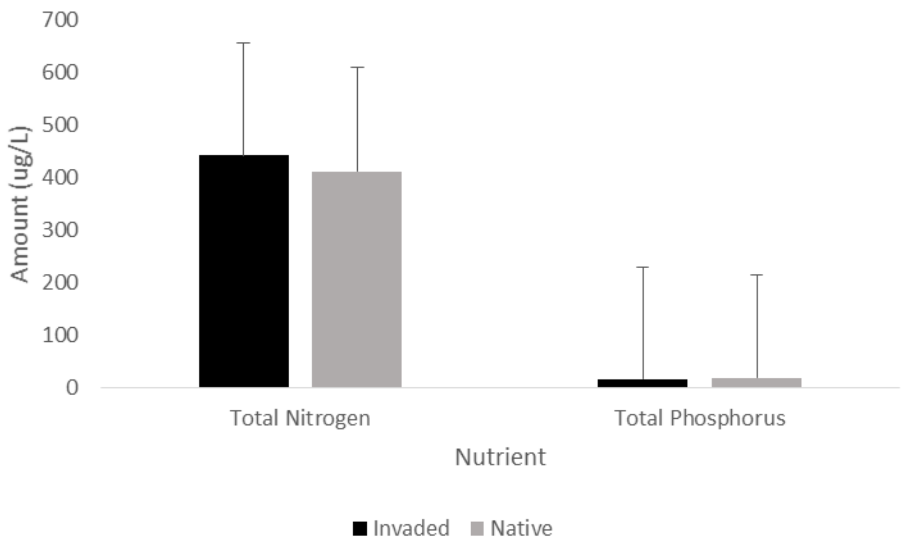

Figure 10. Nitrogen levels were observably higher in the invaded treatments, while there was no visible trend in the total phosphorus levels. Error bars are 2 standard errors. There are no below error bars as they may have been construed to indicate negative values.

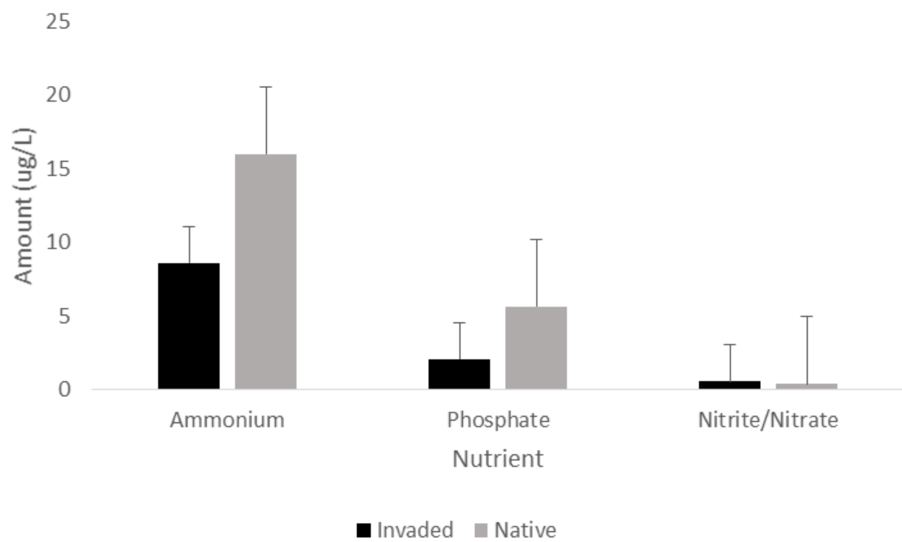

Figure 11. There was an observably larger amount of ammonium and phosphate in the native plots according to this graph. There is no discernable difference in the nitrite/nitrate levels between treatments. Error bars are 2 standard errors. There are no below error bars as they may have been construed to indicate negative values.

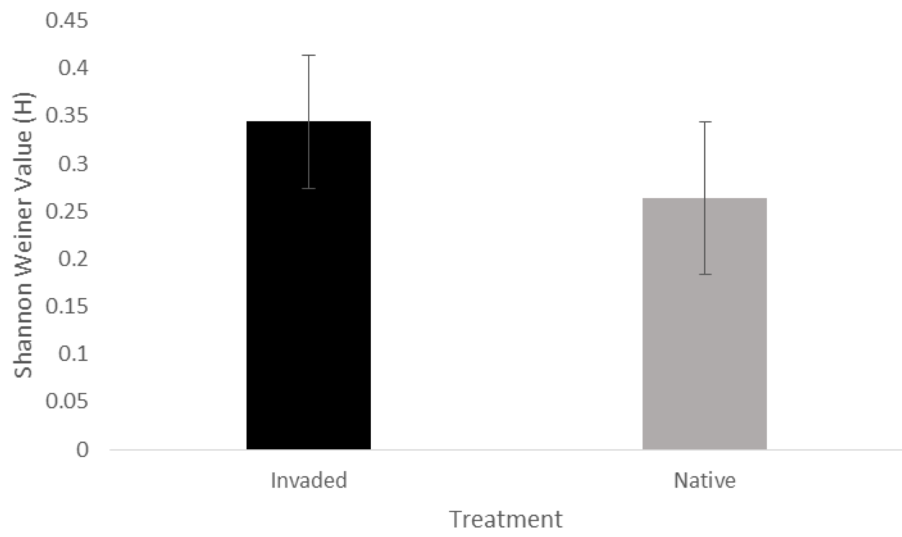

Figure 12. There was no significant difference in the average biodiversity between treatments (df=22, p=0.14). Error bars are 2 standard errors.

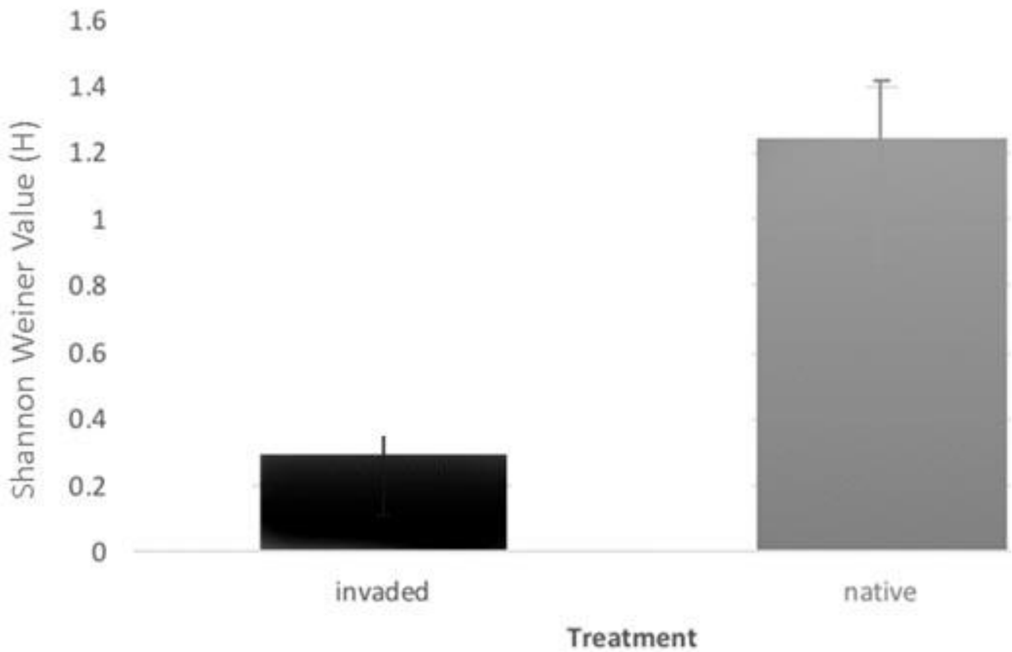

Figure 13. Excluding the brown bullheads which skewed evenness, the native treatments had significantly greater biodiversity that the invaded treatments (df=15.806, p=0.0003). Error bars are 2 standard errors.

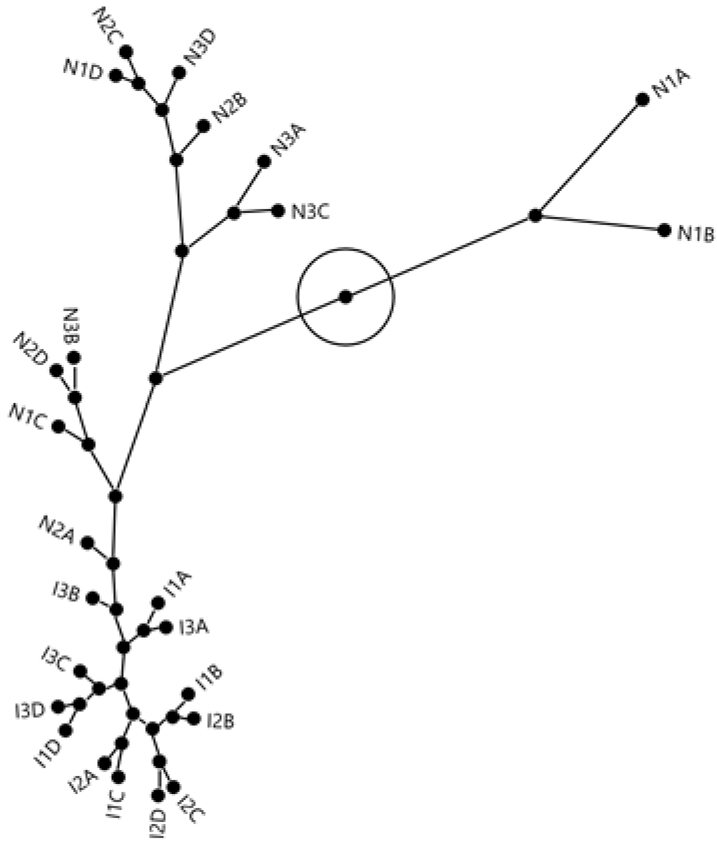

Figure 14. The subplots were clustered by species composition. All labels including I indicate an invaded subplot, and the natives are labeled N. The I subplots are all clustered together, indicating that their species composition was more similar to each other than to the N subplots.

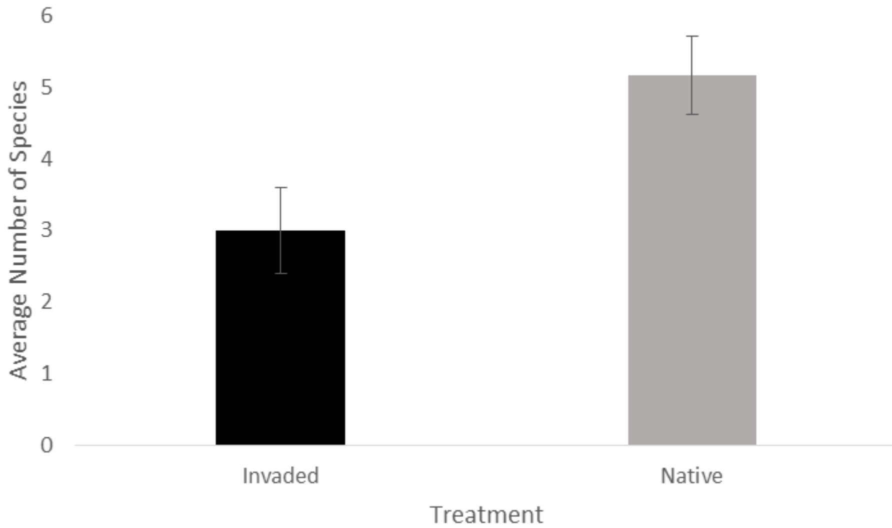

Figure 15. The average number of species at each subplot was significantly higher in the native treatment than the invaded treatment (df=22, $p<0.05$). Error bars are 2 standard errors.

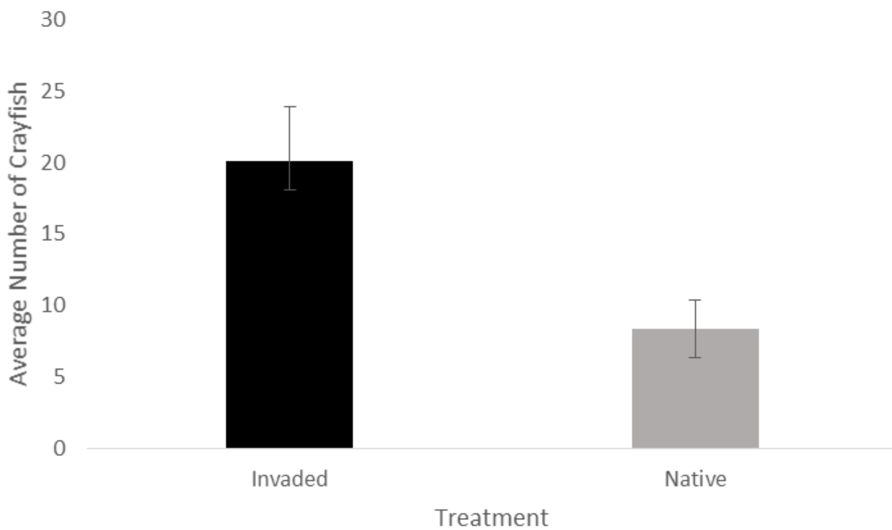

Figure 16. On average, there were significantly more crayfish in the invaded treatment than in the native treatment (df=22, $p<0.05$). Error bars are 2 standard errors.

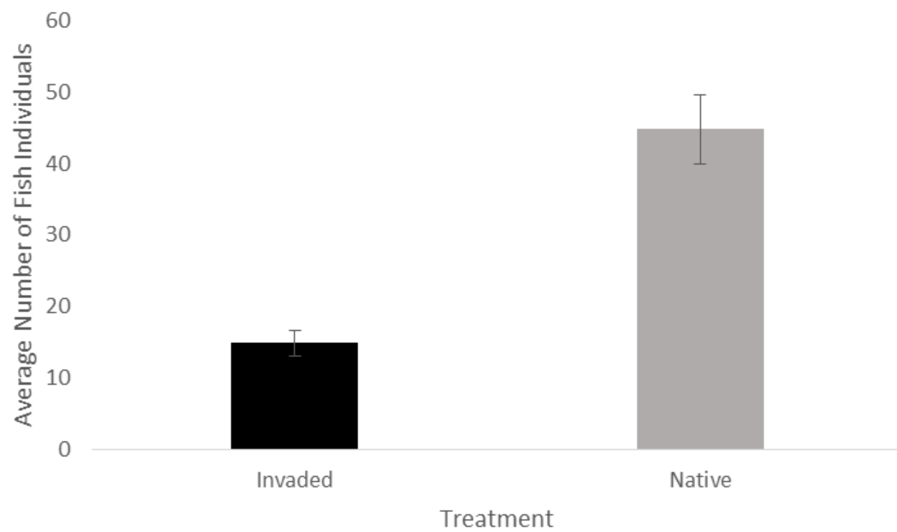

Figure 17. The average number of individual fish found in the native treatment was significantly higher than that found in the invaded (df=22, $p<0.05$). Error bars are 2 standard errors.

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