Undergraduate Honors Thesis

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How do algal and sedimentary turbidity affect the swimming performance of Emerald Shiner and Golden Shiner in Lake Erie?

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Common agricultural practices and urbanization have resulted in the deterioration of aquatic ecosystems globally and the loss of aquatic biodiversity. Aquatic systems affected by human-induced environmental change have consequently experienced new water quality regimes. Affected water bodies, especially lakes harboring economically important fish species, have become increasingly warmer, hypoxic, and have been exposed to higher levels of turbidity (i.e. cloudiness of the water from suspended particles). Turbidity can have deleterious effects on the persistence of fish populations. Direct effects include damage to the gill structure of fishes from clogging and abrasion. Metabolically-challenging processes such as swimming can become impacted in the case of gill damage from increased turbidity loads, since it is harder for the fish to take up oxygen. In Lake Erie, there are instances of both high sedimentary turbidity from increased runoff and high algal turbidity from excessive nutrient inputs. The physiology of fishes (i.e. the ability of the fish to engage in normal metabolic processes) can be quantitatively determined through the measurement of swimming performance. I performed a manipulative experiment to determine if the exposure of Emerald Shiner (*Notropis atherinoides*) and Golden Shiner (*Notemigonus crysoleucas*) to sedimentary turbidity or algal turbidity affects swimming performance relative to clear-water-acclimated fish. Both shiner species are non-game forage fishes essential to the Lake Erie ecosystem. I found that Emerald Shiner exposed to algal turbidity had decreased swimming performance compared to those in clear-water conditions. Conversely, neither algal nor sedimentary turbidity had a significant effect on the swimming performance of Golden Shiner. These results suggest species-specific physiological responses to elevated levels of turbidity. It is important to quantify the effects of anthropogenic environmental changes on native biota in order to encourage swift implementation of environmental policies and conservation efforts.

Introduction:

Freshwater systems are among the most threated ecosystems due to anthropogenic change. The relative extinction rates of North American freshwater fauna are five times higher than terrestrial fauna, and three times the rate of coastal areas (Ricciardi and Rasmussen, 1999). However, human activity and land-use change can cause damage to freshwater ecosystems globally (Chapman et al., 2001; Chapman and Chapman, 2002; Reid et al., 2018). Globally, aquatic ecosystems are becoming more turbid, warmer, deoxygenated, and chemically polluted, and these effects are further exacerbated by climate change (Parmesan and Yohe, 2003). These changes may lead to a reduction in biodiversity of aquatic ecosystems. This loss of biodiversity consequently strains associated biota. Knowledge on the underlying mechanisms that drive species declines are necessary for assessing critical habitat needs to facilitate conservation and restorations (Rosenfeld and Hatfield, 2006).

Increased turbidity (i.e. suspended particulates) has the potential to seriously impact aquatic systems and threaten freshwater biodiversity (Dudgeon et al., 2006; Kemp et al., 2011). Turbidity, for the purposes of this study, can be defined as the cloudiness or haziness of water from increased particle loads and is often used to estimate suspended sediment loads (Lewis, 1996). The United States Environmental Protection Agency listed suspended sediments among the top threats for aquatic health (USEPA, 2009). Two major forms of turbidity found in Lake Erie are sedimentary and algal turbidity. According to Kemp et al., (2009), increases in sediment flux associated with human activities – including deforestation, agriculture, and urbanization – are pushing sedimentary turbidity levels over natural occurrences for prolonged periods. Moreover, eutrophication of aquatic systems caused by nutrient runoff can increase organic turbidity, which can cause severe losses in biodiversity (Ricciardi and Rasmussen, 1999;

Donohue & Garcia Molinos, 2009). Thus, algal blooms can be considered a cause of turbidity (Wilson et al., 2010).

Changes in turbidity regimes can produce a variety of effects on fish, including alterations in reproduction, growth rate effects, and changes in feeding behavior. These physiological effects can come about from both chronic and acute exposure times (Hildebrandt & Parsons 2016). Turbidity can alter the visual environment by scattering light, therefore affecting the behavioral processes of fish like predator-prey interactions and reproductive displays (Abrahams and Kattenfeld 1997). A second major effect of turbidity exposure is that it can cause direct physiological responses that impair respiratory function. Gills of fish can become damaged and mucous-clogged through exposure to turbidity particles. Sutherland and Meyer (2007) found that two upland minnows, the Whitetail Shiner (*Cyprinella galactura*) and Spotfin Chub (*Cyprinella monacha*), experienced severe gill damage at high suspended sediment concentrations. Gill-clogging can be detrimental for fish because it prevents oxygen uptake and can impair metabolically challenging activities such as swimming. Therefore, we may expect turbidity to impact the fitness of fish on both the individual and population level. The effects of turbidity on swimming ability may shed light on the relationship between increased turbidity and biodiversity loss.

Although much work has been done to describe the role of turbidity as an environmental stressor, few studies have addressed turbidity in the context of swimming performance, particularly in regard to critical swimming speed (U_{crit}; Hildebrandt and Parsons 2016). Critical swimming speed is the maximum speed a fish can maintain for a predetermined time period, as introduced by Brett (1964), and is a commonly used method for measuring swimming performance. Furthermore, the swimming performance of a fish is an indicator of its aerobic

metabolism (Brett, 1964) and is used to determine its physiological health. Wilson et al. (2007) posited that swimming performance is an important diagnostic tool given its insight into both lower-level biological and mechanical effects as well as behavior and fitness effects. Of course, ecological relevancy must always be considered when choosing an appropriate laboratory measurement. Critical swimming speed provides a quantifiable and comparable index of the physical status of the fish, which is an ecologically relevant (Brauner et al., 1994). Since swimming performance is a measurement of aerobic metabolism, and therefore a determinant of physiologic health, a fish with poor swimming performance caused by environmental stressors may have reduced fitness. Reduced swimming capabilities may reduce foraging efficiency, mating, and predator avoidance in fish species exposed to elevated turbidity regimes.

In this study, I test sub-lethal physiological responses to determine the tolerance of two non-game forage fishes, the Emerald Shiner (*Notropis atherinoides*) and Golden Shiner (*Notemigonus crysoleucas*) to both sedimentary and algal turbidity. Critical swimming speed can be measured to quantitatively assess the effects of turbidity on the swimming ability of a fish. Gray et al. (2014) documented the effects of sedimentary turbidity on swimming performance of several cyprinids in the Laurentian Great Lakes region and found that prolonged exposure to sedimentary turbidity can result in the reduction of swimming performance. Importantly, Gray et al. (2014) found that endangered Pugnose Shiners (*Notropis anogenus*) acclimated to turbid waters exhibited decreased swimming ability. This difference in swimming performance between turbid and clear treatments indicates a decline in aerobic capacity under exposure to turbidity. Of the species tested, Pugnose Shiner is thought to be the most threatened of the group because of its strict habitat preference for clear waters. Gray et al. (2014) suggests that the low

U_{crit} of Pugnose Shiner in turbidity may, in part, provide insight into their sensitivity to turbidity and population extirpation in areas experiencing elevated sedimentary turbidity.

Emerald Shiner (Figure 1) is a non-game forage fish essential to the Lake Erie ecosystem, and is a common prey item of Walleye (*Sander vitreus*), which is a historically and commercially important sport fish (Hartman & Margraf, 1992). Emerald Shiners are planktivorous and known to consume cladocerans and other zooplankton (Hartman et al., 1992). In a study investigating overlapping diets and species interactions within western Lake Erie, Emerald Shiner was considered as a declining species (Hartman et al., 1992). It has been suggested that the large Lake Erie population of Walleye from 1965 to 1984 significantly taxed their prey populations, including Emerald Shiner (Hartman & Margraf, 1992). There has been no research done to understand the effects of turbidity on the swimming performance of Emerald Shiner.

Golden Shiner (Figure 1) is also a non-game forage fish found in Lake Erie and is a moderately-sized cyprinid (adults usually 75-175 mm; Hall et al., 1979). Previous research has been conducted to determine the effects of sedimentary turbidity on the swimming performance of Golden Shiner. Hildebrandt & Parsons (2016) found that Golden Shiner exposed to sedimentary turbidity had increased swimming performance compared to those tested in clear water. The authors offer a "hydrodynamic hypothesis" suggesting that turbidity particles may complement the size and shape of the Golden Shiner in a way that improves its hydrodynamic efficiency. However, an alternative explanation for the turbidity-mediated increase in swimming performance may be that the Golden Shiner is uniquely adapted to turbid waters (Hildebrandt & Parsons, 2016).

I hypothesized that both algal and sedimentary turbidity will have an effect on the swimming performance of Emerald and Golden shiners. Specifically, I hypothesized that fish

exposed to algal turbidity in both species would have the lowest U_{crit} while fish exposed to sedimentary turbidity would have only slightly negatively impacted U_{crit}. I predicted that algal turbidity particles would cause a greater degree of gill-clogging than sedimentary turbidity particles and therefore would result in lower critical swimming speeds for algal-turbidity-acclimated fish.

Methods:

To test if Emerald Shiner and Golden Shiner have decreased swimming performance because of exposure to turbidity, a set of laboratory physiological experiments using a swimming tunnel apparatus was conducted. This process involved fish collection and maintenance, the performance of physiological trials, and statistical analyses. All experiments were conducted in accordance with Ohio Department of Natural Resources permit #18–82 and The Ohio State University IACUC protocol #2014A00000055.

Fish Collection and Maintenance:

In June and July of 2018, Emerald Shiner and Golden Shiner specimens were collected from Lake Erie. Fish were brought back to South Bass Island (Put-In-Bay) and maintained in the wet laboratory owned by The Ohio State University's Stone Laboratory. A cast-net collection was initially attempted, which involves throwing a circular net into the lake, then drawing it closed immediately. Since there was a lack of success in capturing enough specimens, low populations required Lake Erie fish to be procured from local bait shops that catch the fish in the same way.

Both species were maintained in 20-gallon aquaria under ambient light and temperature conditions for approximately one week before physiological trials were conducted. Water used to fill all tanks was taken directly from Lake Erie and coarsely filtered. Water quality parameters (dissolved oxygen, conductivity, temperature, ammonia, nitrite) were monitored regularly (using a YSI Pro2030 multimeter probe) to ensure a healthy laboratory environment. Fish exhibiting signs of disease (i.e. specimens that displayed white patches and extensive scale loss) were swiftly removed and euthanized to ensure the longevity and health of other fish. Daily water changes (20%) were used to maintain water quality, and large water changes (40-50%) were executed following high instances of disease or poor water quality. Since holding tanks were kept in a wet lab without air conditioning, floating bags of ice were required and regularly replaced to maintain a low temperature (21±2ºC) that would suppress the metabolic rate of the fish and therefore slow the spread of disease.

Swimming Performance Apparatus:

To measure U_{crit}, I constructed a swimming tunnel system (Figure 2) adapted from Plaut (2001) and specifically based on the set-up used by Gray et al. (2014). The swimming tunnel consisted of a 35-cm-long clear tube placed within a 55-gallon aquarium that holds the source of ambient water. A water current runs through the tunnel, which forces the fish to either swim at that speed or be swept up in the current. The entirety of the cross-sectional area of the tube must produce equivalent flow speeds, otherwise a fish may move to an area of less resistance and not truly withstand the measured flow rate. To ensure that the flow is consistent throughout the entire cross-sectional area of the tube, I placed a collection of plastic straws (14cm in length) within the tunnel, which served to produce a uniformly microturbulent flow of water (Gray et al. 2014). The

terminal end of the swim tunnel was covered with a mesh cover that prevents the fish from escaping the tube. The mesh end cover had holes large enough to allow turbidity particles to pass through, so as not to cause an obstruction to the flow of water.

Attached to the intake end of the swimming tunnel was a plastic sump box, which was used as an intermediary piece between the swimming tunnel and pump. The sump box is used to compensate for a larger swimming tunnel width than the water pump output width (Figure 2). A hole saw drill bit was used to create input and output holes in the sump box, which matched the width of the water pump spout and the swim tunnel. Water pumped into the base of the sump box was pushed upward and then outward into the swimming tunnel, which was essential in creating a uniformly microturbulent flow of water.

Water was pumped through the apparatus using a large water pump (Leader Ecovort 520 – 115 V, 60 Hz, 6.5 A, 3,400 rpm). A variable transformer was used to control for the voltage transferred from the power source to the water pump so that flow speed could be easily manipulated. Each voltage level reading on the variable transformer (Variac TDGC-1 KM) had a predetermined corresponding flow rate, calibrated prior to each physiological trial. Since the exact positioning of the tube may have been adjusted from trial to trial, flow-speed was recalibrated to the correct voltage level before every trial. Flow speeds were calibrated using a flowmeter (Geopacks ZMFP51), which measures flow speed in rotations per minute. Rotations per minute were converted to m/s using a conversion equation (Appendix A).

The swimming performance apparatus was routinely disassembled, bleached, and thoroughly rinsed to ensure its continued functionality as well as to remove any leftover algal or sedimentary particles from previous trials.

Treatment Acclimation:

Fish were randomly assigned to one of four experimental treatments: control (0 NTU), sedimentary turbidity, algal turbidity, and a mixture of algal and sedimentary turbidity (~20 NTU). Sample sizes for each treatment were within the range n=10-13 (Table 1).

Each turbidity treatment was standardized to 20 NTU. This level of turbidity mimics the natural occurring range in Lake Erie (Wellington et al., 2010). The standardization of turbidity levels among treatments allows for comparisons to be drawn about the effects of different particle types. The sedimentary turbidity treatment solution was adapted from Nieman et al. (2018), where 20 g of Lake Erie benthic clay sediments (collected with an Eckman grab) was sieved and mixed with lake water (9,000 mg/l). To simulate algal turbidity, a solution composed of blended spinach and spirulina, as described by Wellington et al. (2010), was used. The proportions of the solution included 450g of spinach (emulsified through 1mm mesh), 10mL of water, and 1g of spirulina. For the combined turbidity treatment, an equivalent mixture of the algal turbidity and sedimentary was utilized in which sediment contributed to 10 NTU and the algal mix contributed the remaining 10 NTU.

The day before each fish was to undergo its physiological trial, it was removed from the general holding tank and placed in a 5-gallon treatment acclimation tank. To replicate the effects of a sudden spike in turbidity from an intense rain event, the acclimation tank was filled with water matching the assigned turbidity treatment for the specimen. Multiple fish were placed in the acclimation tank on days when multiple trials were conducted. A turbidimeter (LaMotte 2020we) was used to ensure the turbidity level was accurate (20±2 NTU). Additionally, a turkey baster was routinely used to stir settled turbidity particles. In the acclimation tank, food was withheld for 24 hours to ensure a post-absorptive state, to limit the energy allocated to digestion

during the trial (Gray et al., 2014). The overnight and in-treatment gill-clogging effect of the turbidity treatment was then tested during physiological trials.

Swimming Performance Trials:

Fish were individually tested, and tested only once. At the beginning of each trial, fish were acclimated in the swimming tunnel at a flow rate of 2 cm/s for 2 hours. According to Gray et al. (2014), congeneric fish of similar size were observed to resume normal swimming behavior within 15 minutes of being placed in the tunnel. Trials were conducted in the water condition that matched the treatment the individual fish was randomly assigned and acclimated to.

Following the 2-hour acclimation period, the trial started with flow speed increased to a rate of 5 cm/s. Water velocity was increased in 5 cm/s increments every 10 minutes. Fatigue is assumed when the fish is pushed against the mesh at the end of the tunnel and is confirmed by a lack of response to three prods. After fatigue was confirmed, the flow rate was returned to zero. For each specimen, standard length (SL; cm), total length (cm) and weight (g) were recorded. Then, each specimen was euthanized in a dilute clove oil solution (2 ml solution per 250 ml water), which was composed of 1:10 clove oil: 70% ethanol. Euthanized specimens were placed in individual falcon tubes, marked, and preserved in 10% buffered formalin.

Importantly, water conditions were measured every 20 minutes in the experimental aquaria to ensure consistency between trials. Among the conditions measured were temperature, dissolved oxygen, pH, and turbidity. Ice bags were consistently used and replaced to ensure a stable temperature range (Table 1). A YSI Pro2030 multimeter probe was used to measure dissolved oxygen levels. Low dissolved oxygen levels (<6.0 mg/L) were mitigated by the addition of air stones to the ambient tank. If the turbidity level fell outside of the range of 20±2

NTU, additional turbidity solution was added and the existing particles were stirred up using a turkey baster.

Analyses:

To determine whether there was a significant difference in U_{crit} between treatments and species, U_{crit} was calculated for each trial using the equation:

$$U_{crit} = U_i + [U_{ii}\left(\frac{T_i}{T_{ii}}\right)]$$

where U_i is the highest speed maintained for an entire 10-minute interval, U_{ii} is the water velocity increment (5 m/s), T_i is the time elapsed (s) at the fatigue flow rate, and T_{ii} is the time interval between flow increases (600 sec; Brett 1964, Gray et al. 2014).

Body lengths per second (BL/s) is an alternative dependent variable that reflects the number of body lengths per second a specimen could swim at its U_{crit}, thus accounting for size differences between fish. BL/s is calculated by:

$$\frac{BL}{s} = \frac{Ucrit}{SL * 0.01}$$

where BL/s is converted to the unit cm/s to provide values comparable to other studies.

Because of the lack of Emerald Shiner prevalence and availability toward mid-July and beyond, Emerald Shiner trials were only conducted in two treatments: clear and algal turbidity. However, Golden Shiner were tested in all four treatments. This omission limits the scope of inter-species comparisons to only clear and algal turbidity treatment conditions.

Specific data calculations and conversions were conducted in Microsoft Excel, and all statistical analyses were performed using JMP version 14 and SPSS Statistics version 25. Water quality data were analyzed to determine whether important parameters, such as temperature and

dissolved oxygen, were held constant between treatment conditions. Two ANCOVAs, one for U_{crit} and one for BL/s, were used to test for an effect of treatment (clear vs. turbid) on swimming performance. To determine whether there was an effect of temperature and/or dissolved oxygen on U_{crit} these variables were included as covariates in separate analyses. If the interaction term between treatment and temperature/DO was not significant, it was removed from the model.

A linear regression was run for Emerald Shiner with U_{crit} as a function of log transformed SL, separated by treatment. To analyze Golden Shiner data, a one-way ANOVA was used to test for a difference in U_{crit} between treatments. A Tukey's post-hoc test was applied to determine between-treatment differences in U_{crit}. A linear regression was run for Golden Shiner with U_{crit} as a function of log transformed SL, by treatment. Lastly, a two-factor ANOVA, with species and treatment as factors, was used to determine whether species were deferentially affected by algal turbidity.

Results

Since I observed temperature and dissolved oxygen fluctuations during the experimental trial process, it was necessary to test whether they affected U_{crit}. Using an ANCOVA with temperature as a covariate, I found no significant effect of temperature on U_{crit} ($F_{1,12} = 0.280$, $P = 0.606$). Additionally, an ANCOVA was run using dissolved oxygen as a covariate, and likewise found no significant effect of dissolved oxygen on U_{crit} ($F_{1,11} = 1.141$, $P = .260$). Emerald Shiner U_{crit} was significantly lower in algal turbidity compared to clear-water conditions (Table 2; Figure 3), as revealed by the ANCOVA, where SL was used as the continuous covariate ($F_{1,22} = 4.617$, $P = 0.0001$). Furthermore, regression analysis was used to determine the relationship between SL and U_{crit} (Figure 4). To meet normality assumptions, SL was log-transformed. For

Emerald Shiner exposed to clear-water, there was a significant and positive correlation between body length and U_{crit}, with longer fish exhibiting higher aerobic capacity ($F_{1,9}$ = 8.1508, P = 0.0189, R^2=0.475). Similarly, there was a (non-significant) trend toward a correlation between swimming performance and body length in Emerald Shiner exposed to algal turbidity ($F_{1,11}$ = 3.376, P = 0.0933, R^2 = 0.235; Table 4).

Golden Shiner swimming performance was found to be significantly affected by treatment (Figure 5). I used a one-way ANOVA to test the effect of treatment on Golden Shiner swimming performance ($F_{3,37}$ = 3.155, P = 0.0361) (Table 3). There was a marginally significant difference in U_{crit} between clear and algal turbidity treatments (Tukey's test, P = 0.053). Post-hoc analysis also revealed a marginally significant difference in average U_{crit} between algal and sedimentary turbidity (P = 0.057). Regression analysis to determine the relationship between Golden Shiner SL (log-transformed) and U_{crit} showed a similar positive correlation between body length and U_{crit} (Figure 6). However, three of the four correlations were not significant when tested independently (Clear: $F_{1,9}$ = 0.9448, P = 0.357, R^2 = 0.095. Algal: $F_{1,8}$ = 1.972, P = 0.198, R^2 = 0.197. Mixed: $F_{1,8}$ = 7.449, P = 0.026, R^2 = 0.482. Sedimentary: $F_{1,8}$ = 4.112, P = .0771, R^2 = 0.340; Table 5).

To compare U_{crit} between different species that are morphologically distinct, the critical swimming speed measurement must account for body length. I therefore used BL/s as an alternate dependent variable to U_{crit} to compare BL/s between species (Figure 7). A two-factor ANOVA, with treatment and species as fixed factors revealed a significant interaction between species and treatment in relation to BL/s ($F_{1,31}$ = 19.245, P < 0.001; Table 6). This test was only conducted considering data collected for clear and algal turbidity treatments.

Discussion

Since survival is directly affected by U_{crit} and aerobic capacity (Brett 1964), the results of this study suggest possible deleterious effects of turbidity on fitness. Emerald Shiner exhibited significantly lower swimming performance in algal turbidity compared to clear-water. Such a decrease in swimming ability suggests that algal turbidity particles had a negative impact on Emerald Shiner. One possibility is that mucous build-up on the gills in response to algal particles inhibited aerobic respiration. The effect of algal turbidity on Golden Shiner swimming performance was only marginally lower relative to clear water, but may suggest that both minnow species were affected by algal turbidity.

My study suggests that algal turbidity has strong effects on the swimming ability of Emerald Shiner, filling in a previous gap in knowledge on the effects of turbidity on Emerald Shiner swimming performance. In fact, a significant decline in swimming ability from clear to algal conditions, as shown by my study, may insinuate a bleak prognosis for the Emerald Shiner in Lake Erie. As algal blooms in the western basin of Lake Erie recur each year (Steffen et al., 2014), Emerald Shiners will repeatedly experience conditions detrimental to survival and physiological fitness.

Interestingly, there was no effect of sedimentary turbidity or a mixture of the two types of turbidity on Golden Shiner swimming performance. The relatively small effect of sedimentary turbidity on the swimming performance of Golden Shiner suggests a species-specific adaptation to high sediment turbidity environments. In fact, previous research on Golden Shiner swimming performance found an increase in U_{crit} in turbid conditions. Such an improvement in aerobic respiration abilities in degraded environments indicates the Golden Shiner may be adapted to less-than-pristine conditions (Hildebrandt and Parsons 2016). Since harmful algal blooms in the

western basin of Lake Erie have expanded in size and duration in recent years (Steffen et al., 2014), it is possible that the Golden Shiner is not adapted to withstand algal turbidity in the same way as sedimentary turbidity, though seems more tolerant than Emerald Shiner based on my study.

Holm and Mandrak (2002) concluded that turbidity and loss of vegetation may be among the most plausible serious threats to aquatic biota in the Laurentian Great Lakes region. This study substantiates one component of this conclusion as it suggests deleterious effects of algal turbidity on Emerald Shiner and Golden Shiner swimming performance, thereby advancing the understanding of how fishes respond to pervasive environmental stressors. Recent studies suggest that stress may be evoked by turbidity itself, rather than by physical gill damage (Newcombe, 2003; Michel et al., 2013). Not only can suspended particles generate stress for fish, but also reductions in food uptake (from pre-trial starving periods) can cause metabolic stress, which Michel et al. (2013) note cannot be accurately deciphered between. In addition, it is possible that a fish taken away from a group holding tank experienced decreased performance because of the stress associated with being alone (Boyd and Parsons, 1998). Both Emerald and Golden shiners typically swim in schools, and Golden Shiner demonstrate increased swimming performance in schools than when alone, which is thought to be a result of a hydrodynamic advantage of the schooling (Boyd and Parsons, 1998). Thus, swimming alone may have induced stress in both Emerald and Golden Shiner in this study and could have resulted in decreased performance. Future studies should test fish both individually and in schools in order to elucidate the true relationship between isolation and swimming performance.

It is important to note that this study does not simulate the toxic effects of cyanobacteria and microcystin in the algal turbidity treatment. Instead, this study deliberately isolates turbidity

and its potential effects. Future studies would benefit from consideration of toxic effects on swimming performance as toxicity may play a role in a host of additional physiological effects on aquatic animals. Microcystins (toxins produced by the dominant cyanobacteria that causes harmful algal blooms) have been shown to affect growth rate and osmoregulation in fish and to accumulate mainly in the liver (Malbrouck and Kestemont, 2005). Additionally, this study did not include the removal of the gills of each specimen to check for gill mucous clogging. Though gills were not individually examined and quantified, there still was likely mucous clogging of the gills. Gray et al. (2014) found a build-up of grey mucus observable around the gill lamellae of fish in turbidity treatments.

An ANCOVA revealed there to be no significant effect of temperature on U_{crit}. Hildebrandt and Parsons (2016) found no effect of temperature on the U_{crit} of Golden Shiner, despite having used temperature as an additional independent variable.

In this study, I did not attempt to address differences in swimming performance from turbidity exposure based on exposure time. Since each individual fish was acutely exposed to turbidity during an overnight treatment, this study mimicked the immediate effects of a sudden increase in turbidity—such as after a rain event—on the swimming performance of two cyprinids. Future studies would benefit from long-term exposure protocol. On a similar note, trials in this study were conducted in water conditions matching those of each specimen's assigned turbidity treatment. Gray et al. (2014), on the other hand, conducted all swimming performance trials in clear water, despite the fish being acclimated for several months in turbidity treatments. Testing fish in turbid water may intensify the injurious effects of gill clogging, as fish are forced to swim faster and pump more water—and therefore turbidity particles—over their gills.

Knowledge of the effects of human-induced environmental change on native biota is important for a variety of reasons. First, policy that is informed by science is inherently better for conservation. Evidence of anthropogenic environmental stressors having deleterious and population-threatening effects on a species may prompt new conservation policies to be made or existing policies to be strengthened. Furthermore, today's environmental legislation often requires environmental or economic impact assessment before any potentially destructive action is taken. Such action, according to Ludwig et al. (1993), is supposed to be based upon scientific consensus. However, scientific consensus is seldom achieved. Conservation efforts should therefore protect critical habitat for species and should be initiated with existing information (Rosenfeld & Hatfield 2006); a lack of information should not excuse inaction or stalling (Ludwig et al., 1993). Second, knowledge of the effects of environmental stressors on biota is important for environmental managers in prioritizing time, money, and resources. From this study, managers can apply newfound knowledge of the harmful effects of algal turbidity on native fishes in an initiative to devote more resources and effort to the rehabilitation of Lake Erie. Third and finally, knowledge of native biota becoming threatened by anthropogenic changes may promote the public to adopt sustainability and conservation-minded practices into their lifestyles. Since Emerald and Golden shiners are particularly important bait fish for the Lake Erie recreational angling industry, key stakeholders, namely anglers and the general public, may realize a newfound interest in the health of Lake Erie.

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Tables and Figures

Table 1. Mean (±SE) ambient water quality measurements during physiological trials for Emerald Shiner and Golden Shiner.

Species/Treatment	Fish Sample Size (n)	Turbidity (NTU)	Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	pH
Emerald Shiner	*24*					
Clear	11	2.95(0.28)	23.8(0.73)	6.9(0.13)	312(6.2)	9.5(0.02)
Algal Turbidity	13	19.49(0.22)	23.1(0.49)	6.4(0.14)	306(11.4)	9.3(0.04)
Golden Shiner	*41*					
Clear	11	1.52(0.08)	22.9(0.20)	7.0(0.07)	281(1.7)	9.6(0.01)
Algal Turbidity	10	19.84(0.22)	22.9(0.29)	6.5(0.15)	296(3.4)	9.3(0.05)
Sedimentary Turbidity	10	20.51(0.39)	22.1(0.18)	7.3(0.07)	278(1.4)	9.5(0.01)
Mixed Turbidity	10	19.94(0.24)	22.0(0.24)	6.7(0.11)	276(2.3)	9.3(0.04)

Table 2. Mean (±SE) physiological trial dependent variable calculations for Emerald Shiner and Golden Shiner

Species/Treatment	**Fish Sample Size (n)**	**U_{crit} (m/s)**	**BL/s (cm/s)**
Emerald Shiner	*24*		
Clear	11	0.390(0.012)	7.74(0.23)
Algal Turbidity	13	0.287(0.018)	5.35(0.42)
Golden Shiner	*41*		
Clear	11	0.283(0.006)	5.93(0.18)
Algal Turbidity	10	0.256(0.006)	5.54(0.13)
Sedimentary Turbidity	10	0.281(0.007)	5.92(0.13)
Mixed Turbidity	10	0.278(0.008)	5.84(0.12)

Table 3. One-way ANOVA comparing Golden Shiner mean U_{crit} in all four treatments and Tukey HSD post-hoc test comparing combinations of between-treatment differences in U_{crit}.

	Sum of Squares	**df**	**Mean Square**	***F***	**Significance**
ANOVA results					
Between Groups	0.005	3	0.002	3.156	0.036**
Within Groups	0.019	37	0.001		
Tukey HSD post-hoc test					
Sedimentary vs. Algal					0.058*
Clear vs. Algal					0.053*
Mixed vs. Algal					0.160
Sedimentary vs. Mixed					0.961
Clear vs. Mixed					0.965
Sedimentary vs. Clear					1.000

*Indicates marginally-significant p-value at α=0.05.
**Indicates significant p-value at α =0.05.

Table 4. Simple linear regression analysis of log standard length vs. U_{crit} for Emerald Shiner, by treatment.

	Sum of Squares	**df**	**Mean Square**	***F***	**Significance**
Clear					
Regression	0.008	1	0.008	8.1508	0.0189*
Residual	0.009	9	0.001		
Algal Turbidity					
Regression	0.013	1	0.013	3.376	0.0933
Residuals	0.042	11	0.004		

a) R^2= 0.475 b) R^2= 0.235

Table 5. Simple linear regression analysis of log standard length vs. U_{crit} for Golden Shiner, by treatment.

	Sum of Squares	**df**	**Mean Square**	***F***	**Significance**
a) Clear					
Regression	0.000	1	0.000	0.945	0.357
Residual	0.004	9	0.000		
b) Algal Turbidity					
Regression	0.001	1	0.001	1.972	0.198
Residuals	0.003	8	0.000		
c) Sedimentary Turbidity					
Regression	0.001	1	0.001	4.112	0.077*
Residuals	0.003	8	0.000		
d) Mixed Turbidity					
Regression	0.003	1	0.003	7.449	0.026**
Residuals	0.004	8	0.000		

a) R^2= 0.095 b) R^2= 0.197 c) R^2= 0.340 d) R^2= 0.482

*Indicates marginally-significant p-value at α=0.05.
**Indicates significant p-value at α =0.05.

Table 6. Two-factor ANOVA, with species and treatment as fixed factors in order to determine whether species had different critical swimming speeds in different treatments.

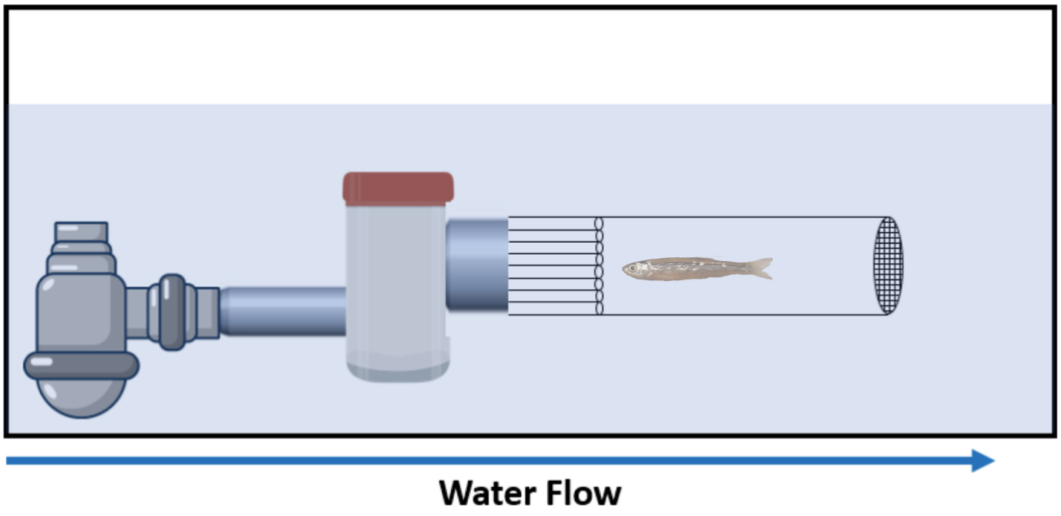
	F	**df**	**Significance**
Treatment	37.608	1, 31	0.000
Species	16.472	1, 31	0.000
Treatment * Species	19.245	1, 31	0.000

a)

b)

Figure 1: Photograph of *a)* Emerald Shiner (*Notropis atherinoides*) and b) Golden Shiner (*Notemigonus crysoleucas*).

a)



b)

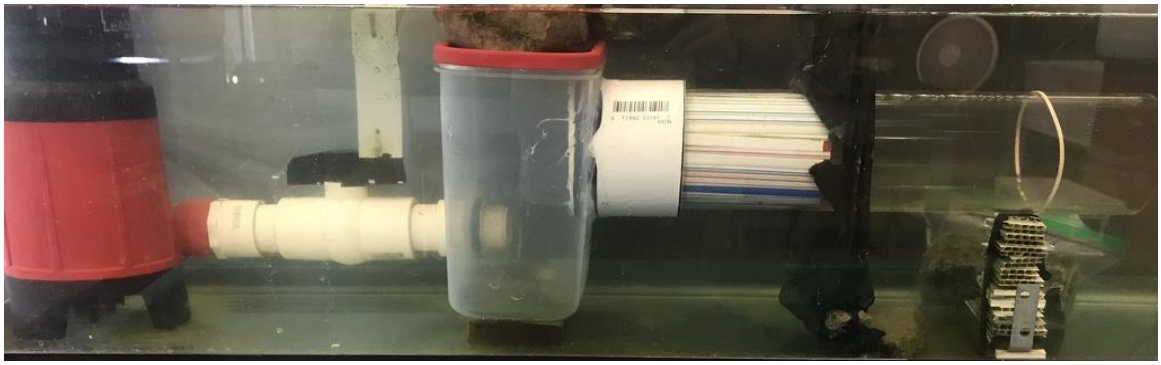


Figure 2: Swimming performance apparatus used to determine critical swimming speed for each fish. *a)* A rendering of the essential components of the apparatus (Design Credit: Tiffany Atkinson MS). On the left side, the water is pushed through the tunnel via a water pump. Water enters the plastic sump box (middle) and is pushed upward and into the wider-circumference swimming tunnel. The tunnel is outfitted with a baffle of tightly-fitting plastic straws to ensure uniformly microturbulent flow. *b)* The actual swimming tunnel apparatus used for the study.

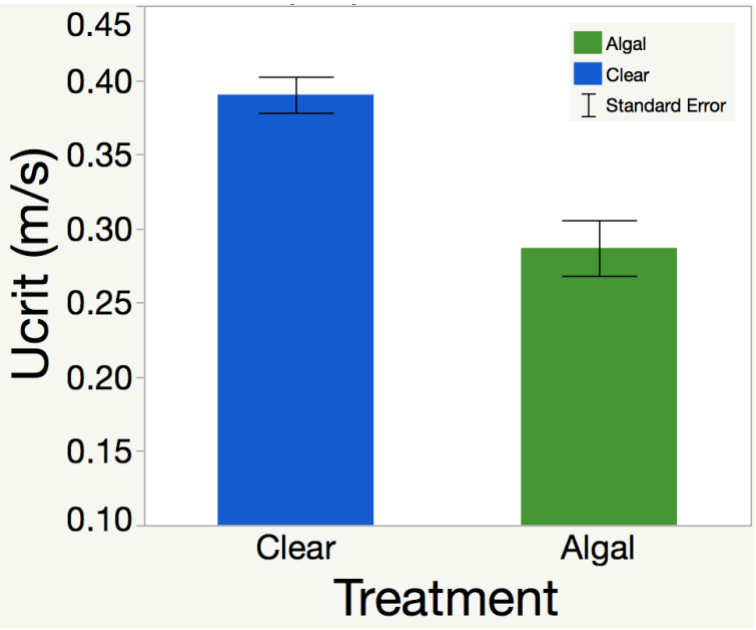


Figure 3: *T*-test used to test for a difference in critical swimming speed (U_{crit}) between clear water and algal turbidity for Emerald Shiner. ($T_{1,22} = 4.617$, $P = 0.0001$)

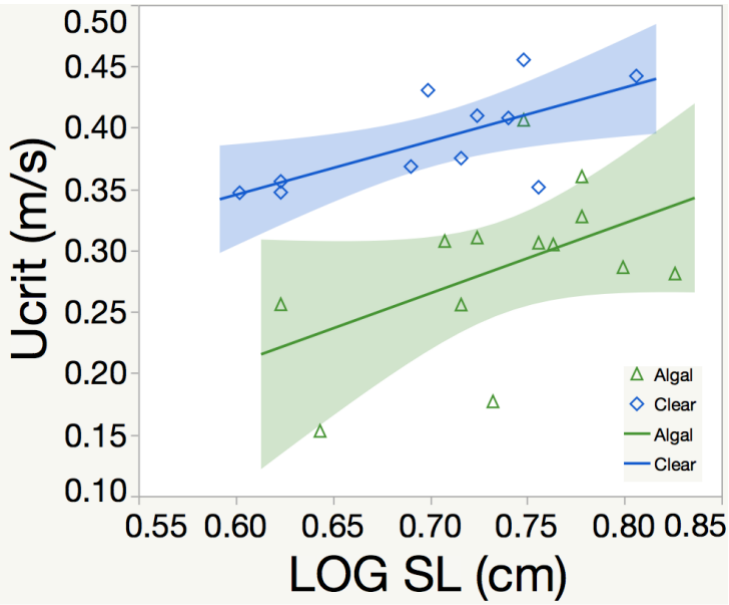


Figure 4: Emerald Shiner simple linear regression with U_{crit} as a function of log standard length by treatment. Clear (Blue): $F_{1,9} = 8.1508$, $P = 0.0189$, $R^2 = 0.475$. Algal (Green): $F_{1,11} = 3.376$, $P = 0.0933$, $R^2 = 0.235$.

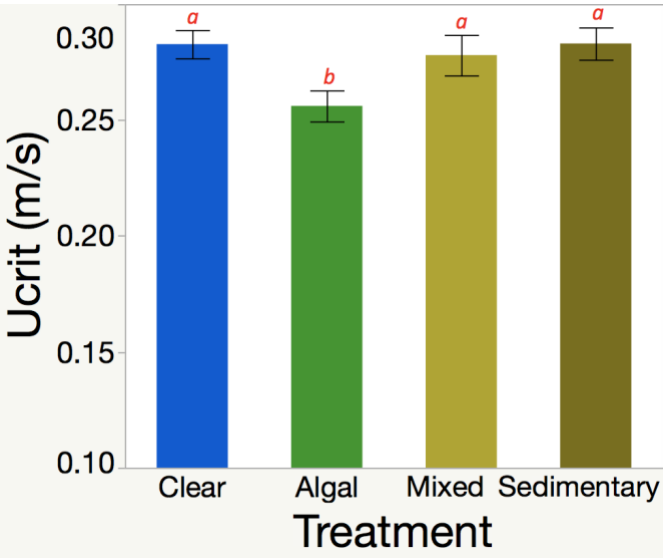


Figure 5: Golden Shiner**,** one-way ANOVA testing for differences in U_{crit} between treatments. ($F_{3,37}$ = 3.155, P = 0.036). Letters represent significantly different U_{crit} values between treatments revealed by Tukey's post-hoc analysis.

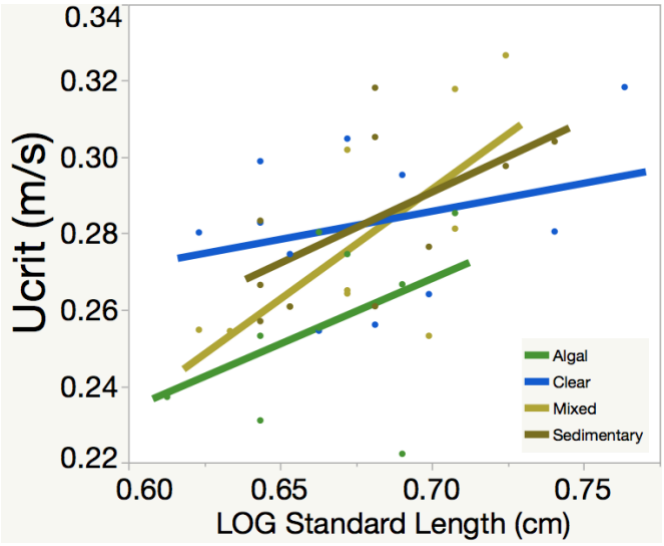


Figure 6: Golden Shiner linear regression with U_{crit} as a function of log standard length by treatment. Clear (Blue): $F_{1,9} = 0.9448$, $P = 0.357$, $R^2 = 0.095$. Algal (Green): $F_{1,8} = 1.972$, $P = 0.198$, $R^2 = 0.197$. Mixed (Tan): $F_{1,8} = 7.449$, $P = 0.026$, $R^2 = 0.482$. Sedimentary (Brown): $F_{1,8} = 4.112$, $P = .0771$, $R^2 = 0.340$.

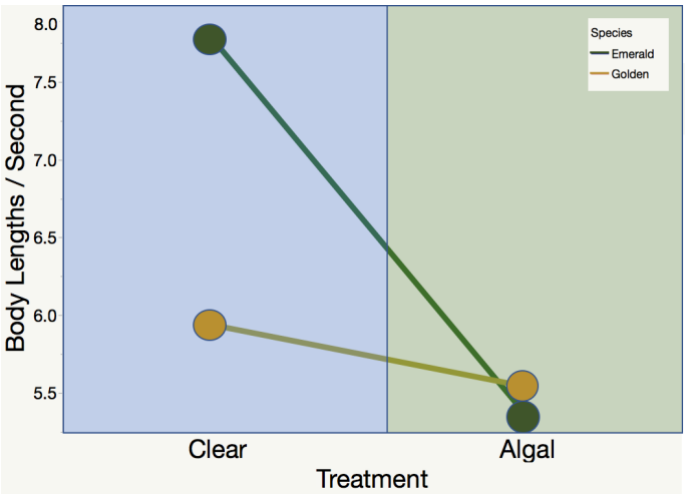


Figure 7: Graph representing the swimming performance of Emerald Shiner (Green) and Golden Shiner (Gold) in clear water and algal turbidity in units of body lengths per second.

Appendix:

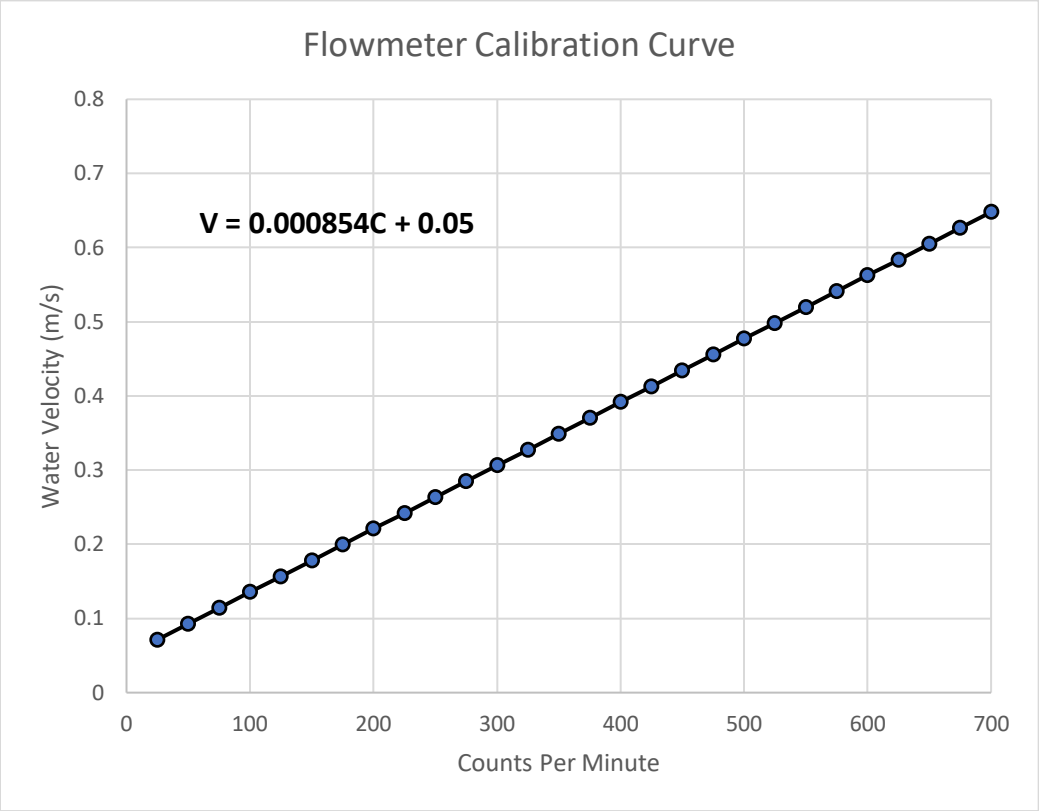


Figure A1: Flowmeter calibration curve, which is used to convert counts per minute recorded by the flowmeter to corresponding water velocity.