

THE EFFECTS OF TURBIDITY ON HABITAT
SELECTION BY FISHES UNDER THE THREAT OF
PREDATION

By

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Abstract:

Previous literature indicates Bluegill (*Lepomis macrochirus*) sacrifice optimal foraging behavior for refuge in dense vegetation while under the threat of predation, resulting in reduced growth rates. The majority of these studies were performed in clear water, which is uncommon under typical field conditions, especially under increasing anthropogenic disturbances. I investigated the effects of turbidity on habitat use by Bluegill under the threat of predation in the laboratory, followed by a corresponding field study. Laboratory trials were conducted in 6.5-m diameter tanks with artificial vegetation on one side and open water on the other. Bluegill and Largemouth Bass (*Micropterus salmoides*; a common predator of Bluegill) were given 18 hours to interact at one of five turbidity levels (0, 5, 10, 30, or 50 Nephelometric Turbidity Units [NTU]), after which a divider was dropped, allowing us to quantify the number of fish on the vegetated and open-water side of each tank. At all turbidity levels above 0 NTU, significantly fewer Bluegill were found on the vegetated side of the tank. However, vegetated habitat was always preferred to open water habitat, regardless of turbidity. In the field, pop nets were used to sample artificial vegetation in the spring of 2018 at Sooner Lake, Stillwater, Oklahoma, USA. Unfortunately, water of the field study was never turbid enough to test the results of the corresponding laboratory study, and no clear trends relating turbidity to the number of fish captured were observed. However, results from the laboratory experiment indicate vegetation manipulation and establishment efforts designed to provide juvenile fish refuge, and to provide fishing opportunities, may be useful for management in systems with turbidities as high as 50 NTU. Habitat additions may be more useful in clear systems, given Bluegill may not use vegetation as a refuge as frequently as when predated under higher turbidities.

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CHAPTER I

THE EFFECTS OF TURBIDITY ON THE USE OF VEGETATION BY BLUEGILL UNDER THE THREAT OF PREDATION: LABORATORY STUDY

Introduction

Structurally-complex habitat is important to a healthy fishery. Habitats with increased physical structure have more microhabitats, leading to greater niche space (Crowder and Cooper, 1982; Willis et al., 2005), which allows for the coexistence of both predators and prey (Crowley, 1978). Structurally-complex habitats aid in primary production by providing attachment points for periphyton (Cattaneo et al., 1998; Dam et al., 2002), as well as allowing for colonization of macroinvertebrates (Cattaneo et al., 1998; Strayer et al. 2003). In addition, structurally-complex habitats provide both refuge and foraging opportunities for fish (Savino and Stein, 1982; Gotceitas and Colgan, 1989; Gotceitas, 1990; Gotceitas and Colgan, 1990). Thus, habitat enhancement and restoration efforts are often aimed towards establishing or enhancing structurally-complex habitats (e.g., planting macrophytes, sinking artificial structures or brush piles, removing invasive plant species that form less-complex monocultures, etc.).

Fishery managers and restoration ecologists are often advised to provide an intermediate level of structured habitat to maximize growth rates while also allowing adequate survival of juvenile age classes (Crowder and Cooper, 1982; Dibble et al., 1996; Trebitz and Nibbelink, 2011). Too much structural complexity can negatively affect foraging success of many fishes by

impeding swimming and obstructing sight (Werner et al., 1983a; Gotceitas and Colgan, 1987; Manatunge et al., 2000), resulting in decreased growth rates (Werner et al., 1983a, 1983b; Mittelbach, 1984; Maceina and Shireman, 1985). On the other hand, too little structural complexity can result in decreased recruitment (Dibble et al., 1996). As reservoirs often lack structured habitat (Miranda et al., 2010), considerable effort and capital are invested to increase structural complexity (Bassett, 1994; Tugend et al., 2002) and to attract fish for anglers (Lynch and Johnson, 1989; Johnson and Lynch, 1992; Moring and Nicholson, 1994). Given the large amount of effort spent establishing proper habitat, it is vital to ensure this results in a positive impact on the target species. However, these actions are often based on studies conducted in clear water and have ignored that natural systems are typically turbid. The importance of habitat management may be lessened in turbid systems if turbidity reduces visibility in a way that alters the risk perceived by prey (as suggested by Miner and Stein, 1996; Shoup and Wahl, 2009).

Increased turbidity can alter antipredator behavior exhibited by prey species (Miner and Stein, 1996; Shoup and Wahl, 2009). Turbidity typically reduces visual acuity (Abrahams and Kattenfeld, 1997; Robertis et al., 2003), and consequently, reaction distances of both predator and prey (Vinyard and O'Brien, 1976; Aksnes and Giske, 1993; Miner and Stein, 1996; Hansen et al., 2013). Therefore, fish must rely more on non-visual senses in turbid environments (Vinyard and O'Brien, 1976; Rowe et al., 2003). For some fish, this results in an increased antipredator response (Hartman and Abrahams, 2000; Golub et al., 2005; Leahy et al., 2011) because they sense predators but cannot gauge the level of threat. Conversely, other species exhibit a decreased antipredator response because they are unable to see predators in the area (Gregory, 1993; Lehtiniemi et al. 2005). In clear water, many prey species utilize structured habitat when there is a risk of predation (Savino and Stein, 1982; Gotceitas and Colgan, 1989; Snickars et al., 2004; Stahr and Shoup, 2015). Because turbidity can alter the perceived risk of predation, it may also alter prey species' use of structured habitat.

To date, there have been two studies addressing the influence of turbidity on the use of structurally complex habitats by a prey species under the threat of predation, both using Eurasian Perch (*Perca fluviatilis*) as prey and Northern Pike (*Esox lucius*) as predator (Snickars et al., 2004; Skov et al., 2007). Snickars et al. (2004) found Eurasian Perch utilize structured habitat less in turbid conditions. However, Skov et al. (2007) found Eurasian Perch utilized structured habitat more often under turbid conditions. The clear discrepancy that exists between these studies strongly indicates the need for further investigation. Furthermore, different prey and predator species often exhibit different behaviors (i.e., Northern Pike are ambush predators whereas Largemouth Bass are roving predators; Savino and Stein, 1989). Also, it has been reported that effects of turbidity differs between fish species (Kemp et al., 2011). Consequently, applying results from only a few studies to other predator-prey pairings may be misleading, or lead to incorrect management decisions.

I am unaware of any studies which examine the effects of turbidity on the use of structurally-complex habitat of fishes in North America; however, anecdotal evidence suggests that increases in turbidity may reduce the use of structurally-complex habitats by some prey species. Bluegill (*Lepomis macrochirus*) and Largemouth Bass (*Micropterus salmoides*) are two of North America's most popular sport fish (USDI 2017), and they often inhabit turbid systems. In clear water, Bluegill are confined to shallow-water habitat in tanks lacking structurally-complex habitat when Largemouth Bass are present, but they will venture into deeper water when turbidity increases above 10 Nephelometric Turbidity Units (NTU) (Miner and Stein, 1996; Shoup and Wahl 2009). This observed change in antipredator behavior by Bluegill suggests they may also use cover less frequently in turbid conditions, similar to the results of Snickars et al. (2004) with Eurasian Perch. If this hypothesis is correct, habitat establishment efforts intended to benefit Bluegill survival may prove futile in turbid environments. However, the effects of turbidity on the selection of structurally complex habitat by Bluegill has not been tested. Therefore, my study assessed the effects of turbidity on the use of structurally complex habitat by

Bluegill while under the threat of predation by Largemouth Bass in a laboratory setting. This information is needed to determine if implementation of complex habitats to management practices in turbid systems will be used by Bluegill.

Methods

Bluegill (50-75 mm total length [TL]) were seined from Sanborn and Boomer lakes, OK; fish in these lengths utilize vegetated habitat under predation pressure in relatively clear-water systems (Hall and Werner, 1977; Mittelbach, 1981; Mittelbach, 1984). Largemouth Bass (250-350mm TL) were collected by boat electrofishing from Lake Carl Blackwell and Boomer Lake, OK. Largemouth Bass of these sizes can easily capture Bluegill in the 50-75 mm size range (Lawrence, 1957). Collected fish were transported to the Oklahoma State University Fisheries and Aquatic Ecology Wet Laboratory where they were transferred into holding tanks and allowed to acclimate for at least 48 hours.

Trials were conducted indoor in five round polyethylene tanks (2-m diameter, 1-m deep) with artificial vegetation on one side and open water on the other. Tanks were filled to 46-cm in depth with filtered tap water, kept at ambient temperature (22-24°C), and illuminated by natural light from skylights. On the vegetated side of the tank, I simulated vegetation using 0.6-m long pieces of 3-mm diameter yellow polypropylene rope attached to 1.27-cm square hardware cloth in 30cm x 30cm mats. Ropes were attached to hardware cloth mats in a uniform arrangement at a stem density of 1000 stems/m². Bluegill select vegetation densities between 500-1000 stems/m² when under the threat of predation (Savino and Stein, 1982; Gotceitas, 1990; Gotceitas and Colgan, 1987), and these are densities commonly found in natural beds of aquatic vegetation (Sheldon and Boylen, 1977). Artificial vegetation patches were anchored with a 10x20x5-cm brick on each mat. To simulate a more natural habitat, vegetated mats were arranged in a uniform pattern that covered 50% of the area on the vegetated side of the tank (i.e. checkerboard arrangement of vegetated patches and open water), generating an overall stem density of 500

stems/m² from the combination of 1,000 stem/m² patches and interstitial spaces (30 cm x 30 cm) without vegetation between vegetation mats (Figure 1).

We used bentonite clay to produce turbidity levels of 0, 5, 10, 30, and 50 NTU ($\pm 10\%$), which are typical levels found in North American lakes (Weiss and Kuenzler, 1976; Shoup and Lane, 2015). Due to significant variation in turbidity readings across nephelometers (Duchrow and Everhart, 1971; Austin, 1973), we developed a secchi depth-NTU regression to provide cross-study comparisons: 5 NTU \approx 40 cm, 10 NTU \approx 27 cm, 30 NTU \approx 15 cm, 50 NTU \approx 12 cm Secchi depths (Figure 2). The 0 NTU treatment used dechlorinated tap water and was too clear to receive a secchi depth. Clay was kept in suspension by a 150-cm air stone placed near the middle of each tank, just inside the vegetated side. Turbidity was measured at the beginning and end of each trial with a LaMotte® model 2020 tungsten-lamp nephelometric turbidity meter calibrated with a 40-NTU formazine standard.

Prior to starting a trial, each tank was stocked with 20 Bluegill and 1 Largemouth Bass, which produced natural densities for both species (Hackney, 1979). Both Bluegill and Largemouth Bass were free to move about the tank as confining a predator could have resulted in skewed prey behavior (Skov et al., 2007). Each trial lasted 18 hours, at which time a plywood divider was dropped to separate fish on the vegetated and open water sides of the tank. The divider was nested in a 2.81 cm diameter PVC pipe with a vertical slit cut lengthwise in the pipe that allowed the divider to fall quickly and precisely to completely isolate fish on each side of the tank. Trials were always started such that they ended in the early afternoon (11am-1pm) and encompassed one dusk and dawn cycle. Once dividers were dropped, Largemouth Bass were quickly removed by seining to prevent further predation losses and tanks were partially drained to recover prey. The number of Bluegill on each side of the tank and the position of the Largemouth Bass were recorded. Bluegill were then transferred back into a common holding tank to re-mix with all Bluegill (approximately 200 individuals) and Largemouth Bass were moved to the next randomly-assigned tank for the next trial. Bluegill were fed in the holding tank between trials, but

Largemouth Bass were not fed outside the experiment to ensure they would try to feed during trials. Any dead fish that were recovered were not counted as present on either side. Bluegill habitat use was quantified as the percentage of surviving Bluegill in open water habitat to account for uneven numbers of fish, as some fish were consumed by Largemouth Bass during trials.

Each turbidity was tested 30 times (6 times in each of the 5 tanks). A stratified randomized block design was used such that on each trial date, one replicate of each turbidity level was used, but the actual turbidity order in each tank was randomized. Additionally, the side of the tank containing vegetation was randomly stratified such that each tank had an even number of trials with vegetation on each side. Using a generalized linear mixed model, difference in percentages ($\arcsin(\sqrt{x})$ transformed) of Bluegill in the open water side of tanks were compared among turbidity levels (proc glimmix in SAS; SAS Institute, 2013). Day and vegetation side were not significantly related with Bluegill distribution, therefore, these variables were not included in the final model. Tank ID was used as a random effect in the statistical analyses to account for repeated measurements made in tanks. The group option was used to account for different variances among groups. Tukey's HSD test was used to make pair-wise comparisons when main effects were significant. In addition, I tested if turbidity had an effect on which side the predator (Largemouth Bass) chose using a binomial logistic regression model with tank ID as a random effect, using the glm function in program R (R Development Team).

Results

Bluegill used open water habitat less in clear water trials (mean = 4.8%) than in all other turbidities (5, 10, 30, 50 NTU; mean = 24.1%; $F_{4,16} = 11.29$, $P < 0.01$; Figure 3). Bluegill were found in open water with similar frequency (mean across treatments = 24.1%) across the 5 NTU, 10 NTU, 30 NTU, and 50 NTU treatments (all Tukey $P > 0.45$). However, no treatment had >50% of Bluegill found in the open water, indicating structurally complex habitat was preferred over open water at all turbidities. Largemouth Bass were found on the vegetated side of the tank

in the majority of the trials (93.6% of all trials [141 times out of 150 trials]), with no difference among turbidity levels (χ^2 2.45, $df = 1$, $N = 150$, $p = 0.12$).

Discussion

Bluegill increased their use of open water as turbidity increased, but structurally complex habitat was still used more than open water at all turbidities tested. Thus, the practice of providing structure (e.g., planting vegetation, sinking brush piles, etc.) to concentrate fish and provide refuge from predation for juveniles should still be useful even in turbid systems, although its effects will likely be more pronounced in clearer systems. This is consistent with the findings of Baumann et al. (2016), who found fish still concentrated around artificial structures in turbid lakes. Therefore, my results support the use of structurally complex habitats to aid in fishery health in systems with turbidities ranging from 0 NTU to 50 NTU (approximately 12 cm visibility).

In my study, 24% of Bluegill utilized open water habitat in turbid treatments, which was greater than the percent observed in clear water (about 5%), but was not as pronounced as the shift from shallow to deep water described by Miner and Stein (1996). Miner and Stein (1996) reported fewer than 10% of Bluegill used deep-water habitat in clear water, but when exposed to turbidity levels ≥ 10 NTU, 60-90% of Bluegill used deep-water habitat. No secchi depths were given by Miner and Stein (1996), but Bluegill reaction distances to Largemouth Bass in that experiment were about 25 cm at their 10 NTU turbidity treatment, suggesting this studies' 10 NTU measurement was similar to or just slightly more turbid than mine (27 cm secchi depth). My study differed from Miner and Stein (1996) in that I provided Bluegill artificial vegetation as a predation refuge instead of shallow water. The differences observed between my study and Miner and Stein (1996) may indicate a differential preference for habitat by Bluegill; structural complexity may be preferred over shallow water. Alternatively, greater use of refuge habitat in my study could have been driven by factors other than antipredator behavior as natural structured

habitat provides foraging opportunities in addition to refuge from predators (Savino and Stein, 1982), whereas shallow water simply provides a refuge from predators (DeVries, 1990; Miner and Stein, 1996). Future research should investigate how turbidity effects the interactive effects of depth and structural complexity, as shallow water and structured habitat often co-occur in the littoral zone.

Several mechanisms could explain why Bluegill utilized open water habitat with greater frequency in turbid conditions. First, Bluegill have decreased visual acuity at high turbidity (Miner and Stein, 1996; Hansen et al., 2013). Therefore, at increased turbidities they may lose sight of cover and therefore venture further from it. Second, Bluegill may not perceive that there is a threat of predation if they cannot see the predator, leading them to discontinue exhibiting antipredator behavior (e.g., selecting vegetation) (Miner and Stein, 1996). In addition, Largemouth Bass foraging efficiency decreases as turbidity increases (Shoup and Wahl, 2009; Huenemann et al., 2012; Shoup and Lane 2015). Therefore, Bluegill may venture into open water more often in turbid conditions to take advantage of increased foraging return associated with open-water habitat (Mittelbach, 1981), given their predation risk is reduced. My experiment did not include availability of food, and therefore no difference in foraging return between habitats, however fish may still express this behavior. Finally, natural increases in turbidity are often caused by storm and flooding events (Chou and Wu, 2010), resulting in sharp increases in nutrient availability (Vanni et al., 2006; Drupp et al., 2011) that occur as turbidity increases. These nutrient increases can, in turn, lead to increases in phytoplankton (Bum and Pick, 1996; Basu and Pick, 1997) and zooplankton (McCauley and Kalff, 1981; Basu and Pick, 1997), a valuable food source for juvenile fishes (Mittelbach, 1981; Bass et al., 1997). Furthermore, following flood pulses, there is an increase in macroinvertebrates in newly inundated water (Bayley, 1988; O'Leary and Wantzen, 2012), providing another valuable foraging opportunity for fish. Consequently, turbidity may be an innate cue that triggers fish to leave structurally complex habitats due to the increased foraging return associated with storm events, with concomitant

increases in turbidity. All of these mechanisms likely co-occur, and the use of open water is therefore expected to increase even more if turbidity changes are accompanied by increased food availability in open water.

My data suggest a threshold turbidity level exists between 0 and 5 NTUs (clear to 40cm secchi depths, respectively) where Bluegill increase their use of open water habitat. Similar turbidity thresholds have been observed in habitat use of Eurasian Perch (Snickars et al., 2014), and reaction distances (Hansen et al, 2013) and foraging rates (Gregory and Northcote, 1993) of juvenile Chinook Salmon (*Oncorhynchus tshawytscha*). Both increases in turbidity and vegetation density result in decreased visual acuity for fish (Abrahams and Kattenfeld, 1997; Manatunge et al., 2000). Thus, fish may perceive turbidity similarly to vegetation density in terms of its value as a predation refuge, given both produce threshold responses in fish behavior. For example, Bluegill do not utilize vegetation while under threat of predation unless stem densities are above 516 stems/m² (Gotceitas and Colgan, 1989). This is similar to my observation that Bluegill only increased use of open water when turbidity was ≥ 5 NTU. Therefore, turbidity may be perceived as a predation refuge, providing a valuable opportunity to forage more in the open water without undue risk of predation (Gregory and Northcote, 1993).

Although high turbidity levels decrease foraging rates of Bluegill (Gardner, 1981), moderate increases in turbidity may increase growth rates if this allows Bluegill to forage in open water. Bluegill foraging efficiency is greater in open water than in dense vegetation (Mittelbach, 1984), so it is possible the energetic benefits of foraging in the open water may outweigh the decrease in foraging rates caused by increased turbidity. Furthermore, the increased contrast turbidity provides could actually increase prey detectability in open water (Utne-Palm, 2002), at least from low to moderate turbidity levels (i.e., Gardner (1981) did not test any turbidity levels between 0 NTU and 60 NTU when he concluded foraging return was negatively correlated with turbidity). Therefore, it is possible that periodic increases in turbidity may support increased

Bluegill growth, especially fisheries that contain dense vegetation where stunted Bluegill populations can develop (Olson et al., 1998). However, this hypothesis still needs to be tested.

Prior to my study, only two studies had addressed the effect of turbidity on the use of structurally complex habitats, both using Eurasian Perch and Northern Pike (Snickars et al., 2004; Skov et al., 2007). Differing conclusions by these previous studies may be explained by differences in how predators were presented to the prey species. Snickars et al. (2004) caged the predator in open water so it is logical that prey chose the vegetated habitat to avoid the predator in clear water. Conversely, Skov et al. (2007) allowed the predator to choose its location in the experimental arena, and it consistently chose the vegetated side causing the Eurasian Perch to avoid the structured side. In both studies, the predator avoidance behavior of the Eurasian Perch weakened as turbidity increased. In my study, the predator (Largemouth Bass) was also free to choose its location, and was usually found in the vegetated habitat. Therefore, one might expect results of my study to be similar to that of Skov et al. (2007), yet I found Bluegill continued to use vegetated habitat despite the presence of a predator. Largemouth Bass typically use edge habitat between vegetation and open water to forage (Trebitz et al., 1997); so it is possible the Largemouth Bass resided on the edge of the structured habitat, and only darted into the structured habitat when the divider dropped. Unfortunately, observations of Largemouth Bass location prior to dropping the divider were not possible, so this cannot be definitively determined. However, other studies have found prey select vegetation even in when Largemouth Bass were more abundant in that habitat (Stahr and Shoup, 2015), suggesting that vegetation may still provide effective protection when predators are present within vegetated habitats. Regardless, my study adds to management decisions by determining turbidity can alter habitat choice by prey under the threat of predation, suggesting benefits of vegetated habitat as a predation refuge in clear water (Crowder and Cooper, 1982; Savino and Stein, 1982; Hayse and Wissing, 1996) are not as important under turbid conditions.

My study indicates Bluegill prefer structured habitat over open water when predation risk exists, regardless of turbidity, although this preference is weakened at all turbidities ≥ 5 NTU. Therefore, my data supports the practice of adding/establishing structurally complex habitat to provide nursery habitat and/or attract sportfish, regardless of turbidity. However, clear (< 5 NTU) systems may receive additional benefit from these manipulations compared to turbid systems. Because multiple factors typically change as turbidity is altered in natural systems, further research is needed to test these results under field conditions. It is possible that changes in food abundance that co-occur with changes in turbidity make structured habitat less desirable than suggested by this study.

References

- Abrahams, M. V., and M. G. Kattenfeld. 1997. The role of turbidity as a constraint on predator-prey interactions in aquatic environments. *Behavioral Ecology and Sociobiology* 40:169-174.
- Aksnes, D. L., and J. Giske. 1993. A theoretical model of aquatic visual feeding. *Ecological Modeling* 67:233-250.
- Austin, R. W. 1973. Problems in measuring turbidity as a water quality parameter.
- Bass, J. A. B., Pinder, L. C. V., and D. V. Leach. 1997. Temporal and spatial variation in zooplankton populations in the River Great Ouse: an ephemeral food resource for larval and juvenile fish. *Regulated Rivers: Research and Management* 13:245-258.
- Bassett, C. E. 1994. Use and evaluation of fish habitat structures in lakes of the eastern United States by the USDA Forest Service. *Bulletin of Marine Science* 55:1137-1148.
- Basu, B. K., and F. R. Pick. 1997. Phytoplankton and zooplankton development in a lowland temperate river. *Journal of Plankton Research* 19:237-253.
- Baumann, J. R., Oakley, N. C., and B. J. McRae. 2016. Evaluating the effectiveness of artificial fish habitat designs in turbid reservoirs using sonar imagery. *North American Journal of Fisheries Management* 36:1437-1444.
- Bayley, P. B. 1988. Factors affecting growth rates of young tropical floodplain fishes: seasonality and density-dependence. *Environmental Biology of Fishes* 21:127-142.
- Bum, B. K., and F. R. Pick. 1996. Factors regulating phytoplankton and zooplankton biomass in temperate rivers. *Limnology and Oceanography* 41:1572-1577.
- Cattaneo, A., Galanti, G., Gentinetta, S., and S. Romo. 1998. Epiphytic algae and macroinvertebrates on submerged and floating-leaved macrophytes in an Italian lake. *Freshwater Biology* 39:725-740.
- Chou, F. N. F., and C. W. Wu 2010. Reducing the impacts of flood-induced reservoir turbidity on a regional water supply system. *Advances in Water Resources* 33:146-157.
- Crowder, L. B., and W. E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. *Ecology* 63:1802-1813.

- Crowley, P. H. 1978. Effective size and the persistence of ecosystems. *Oecologia* 35:185-195.
- Dam, A. A. V., Beveridge M. C. M., Azim, M. E., and M. C. J. Verdegem. 2002. The potential of fish production based on periphyton. *Reviews in Fish Biology and Fisheries* 12:1-31.
- DeVries, D. R. 1990. Habitat use by bluegill in laboratory pools: where is the refuge when macrophytes are sparse and alternative prey are present? *Environmental Biology of Fishes* 29:27-34.
- Dibble, E. D., Killgore, K. J., and S. L. Harrel. 1996. Assessment of fish-plant interactions. *American Fisheries Society Symposium* 16:357-372.
- Drupp, P., De Carlo, E. H., Mackenzie, F. T, Bienfang, P., and C. L. Sabine. 2011. Nutrient inputs, phytoplankton response, and CO₂ variations in a semi-enclosed subtropical embayment, Kaneohe Bay, Hawaii. *Aquatic Geochemistry* 17:473-498.
- Duchrow, R. M., and W. H. Everhard. 1971. Turbidity measurement. *Transactions of the American Fisheries Society* 100:682-690.
- Gardner, M. B. 1981. Effects of turbidity on feeding rates and selectivity of bluegills. *Transactions of the American Fisheries Society* 110:446-450.
- Golub, J. L., Vermette, V., and G. E. Brown. 2005. Response to conspecific and heterospecific alarm cues by pumpkinseeds in simple and complex habitats: field verification of an ontogenetic shift. *Journal of Fish Biology* 66:1073-1081.
- Gotceitas, V. 1990. Foraging and predator avoidance: a test of a patch choice model with juvenile bluegill sunfish. *Oecologia* 83:346-351.
- Gotceitas, V., and P. Colgan. 1987. Selection between densities of artificial vegetation by young bluegills avoiding predation. *Transactions of the American Fisheries Society* 116:40-49.
- Gotceitas, V., and P. Colgan. 1989. Predator foraging success and habitat complexity: quantitative test of the threshold hypothesis. *Oecologia* 80:158-166.
- Gotceitas, V., and P. Colgan. 1990. The effects of prey availability and predation risk on habitat selection by juvenile bluegill sunfish. *Copeia* 2:409-417.
- Gregory, R. S. 1993. Effect of turbidity on the predator avoidance behavior of juvenile chinook salmon (*Oncorhynchus tshawytscha*). *Can. J. Fish. Aquat. Sci.* 50:241-246.

- Gregory, R. S., and T. G. Northcote. 1993. Surface, planktonic, and benthic foraging by juvenile chinook salmon (*Oncorhynchus tshawytscha*) in turbid laboratory conditions. *Can. J. Fish. Aquat. Sci.* 50:233-240.
- Hall, D. J., and E. E. Werner. 1977. Seasonal distribution and abundance of fishes in the littoral zone of a Michigan lake. *Transactions of the American Fisheries Society* 106:545-555.
- Hansen, A. G., Beauchamp, D. A., and E. R. Schoen. 2013. Visual prey detection responses of piscivorous trout and salmon: effects of light, turbidity, and prey size. *Transactions of the American Fisheries Society* 142:854-867.
- Hartman, E. J. and M. V. Abrahams. 2000. Sensory compensation and the detection of predators: the interaction between chemical and visual information. *Proceedings of the Royal Society B* 267:571-575.
- Hayse, J. W., and T. E. Wissing. 1996. Effects of stem density of artificial vegetation on abundance and growth of age-0 bluegills and predation by largemouth bass. *Transactions of the American Fisheries Society* 125:422-433.
- Huenemann, T. W., Dibble, E. D., and J. P. Fleming. 2012. Influence of turbidity on the foraging of Largemouth Bass. *Transactions of the American Fisheries Society* 141:107-111.
- Johnson, D. L., and W. E. Lynch Jr. 1992. Panfish use of and angler success at evergreen tree, brush, and stake-bed structures. *North American Journal of Fisheries Management* 12:222-229.
- Kemp, P., Sear, D., Collins, A., Naden, P., and I. Jones. 2011. The impacts of fine sediment on riverine fish. *Hydrological Processes* 25: 1800-1821.
- Lawrence, J. M. 1957. Estimated sizes of various forage fishes largemouth bass can swallow. *Proceedings of the annual conference Southeastern Association of Fish and Wildlife Agencies.* 11:220-225.
- Leahy, S. M., McCormick, M. I., Mitchell, M. D., and M. C. O. Ferrari. 2011. To fear or to feed: the effects of turbidity on perception of risk by a marine fish. *Biology Letters* 7:811-813.
- Lehtiniemi, M., Engström-Öst, J., and Viitasalo, M. 2005. Turbidity decreases anti-predator behaviour in pike larvae, *Esox lucius*. *Environmental Biology of Fishes* 73:1-8.
- Lynch, W. E., Jr., and D. L. Johnson. 1989. Influences of interstice size, shade, and predators on the use of artificial structures by Bluegills. *North American Journal of Fisheries Management* 9:219-225.

- Maceina, M.J., and J. V. Shireman. 1985. Influence of dense hydrilla infestation on black crappie growth. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 36:394-402.
- Manatunge, J., Asaeda, T., and T. Priyadarshana. 2000. The influence of structural complexity on fish-zooplankton interactions: a study using artificial submerged macrophytes. Environmental Biology of fishes 58:425-438.
- McCauley, E., and J. Kaliff. 1981. Empirical relationships between phytoplankton and zooplankton biomass in lakes. Canadian Journal of Fisheries and Aquatic Sciences 38:458-463.
- Miner, J. G., and R. A. Stein. 1996. Detection of predators and habitat choice by small bluegills: effects of turbidity and alternative prey. Transactions of the American Fisheries Society 125:97-103.
- Miranda, L. E., Spickard, M., Dunn, T., Webb, K. M., Aycock, J. N., and K. Hunt. 2010. Fish habitat degradation in U.S. reservoirs. Fisheries 35: 175-184.
- Mittelbach, G. G. 1981. Foraging efficiency and body size: a study of optimal diet and habitat use by bluegills. Ecology 62:1370-1386.
- Mittelbach, G. G. 1984. Predation and resource partitioning in two sunfishes (*centrarchidae*). Ecology 65:499-513.
- Moring, J. R., and P. H. Nicholson. 1994. Evaluation of three types of artificial habitats for fishes in a freshwater pond in Maine, USA. Bulletin of Marine Science 55:1149-1159.
- O'Leary, S. J. and K. M. Wantzen. 2012. Flood pulse effects on benthic invertebrate assemblages in the hypolacustric interstitial zone of Lake Constance. International Journal of Limnology 48:267-277.
- Olson, M. H., Carpenter, S. R., Cunningham, P., Gafny, S., Herwig, B. R., Nibbelink, N. P., Pellett, T., Storlie, C., Trebitz, A. S., and K. A. Wilson. 1998. Managing macrophytes to improve fish growth: a multi-lake experiment. Fisheries 23:6-12.
- Robertis, A. D., Ryer, C. H., Veloza, A., and R. D. Brodeur. 2003. Differential effects of turbidity on prey consumption of piscivorous and planktivorous fish. Canadian Journal of Fisheries and Aquatic Sciences 60:1517-1526.
- Rowe, D. K., Dean, T. L., Williams, E., and J. P. Smith. 2003. Effects of turbidity on the ability of juvenile rainbow trout, *Oncorhynchus mykiss*, to feed on limnetic and benthic prey in laboratory tanks. New Zealand Journal of Marine and Freshwater Research 37:45-52.

- Savino, J. F., and R. A. Stein. 1982. Predator-prey interactions between largemouth bass and bluegills as influenced by simulated submersed vegetation. *Transactions of the American Fisheries Society* 111:255-266.
- Savino, J. F., and R. A. Stein. 1989. Behavioral interactions between fish predators and their prey: effects of plant density. *Animal Behaviour* 37:311-321.
- Sheldon, R. B., and C. W. Boylen. 1977. Maximum depth inhabited by aquatic vascular plants. *The American Midland Naturalist* 97:248-254.
- Shoup, D. E., and W. D. Lane. 2015. Effects of turbidity on prey selection and foraging return of adult largemouth bass in reservoirs. *North American Journal of Fisheries Management* 35:913-924.
- Shoup, D. E., and D. H. Wahl. 2009. The effects of turbidity on prey selection by piscivorous largemouth bass. *Transactions of the American Fisheries Society* 138:1018-1027.
- Skov, C., Nilsson, P. A., Jacobsen, L., and C. Brönmark. 2007. Habitat-choice interactions between pike predators and perch prey depend on water transparency. *Journal of Fish Biology* 70:298-302.
- Snickars, M., Sandström, A., and J. Mattila. 2004. Antipredator behaviour of 0+ year *Perca fluviatilis*: effect of vegetation density and turbidity. *Journal of Fish Biology* 65:1604-1613.
- Stahr, K. J., and D. E. Shoup. 2015. American water willow mediates survival and antipredator behavior of juvenile largemouth bass. *Transactions of the American Fisheries Society* 144:903-910.
- Strayer, D. L., Lutz, C., Malcom, H. M., Munger, K., and W. H. Shaw. 2003. Invertebrate communities associated with a native (*Vallisneria americana*) and an alien (*Trapa natans*) macrophyte in a large river. *Freshwater Biology* 48:1938-1949.
- Trebitz, A., Carpenter, S., Cunningham, P., Johnson, B., Lillie, R., Marshall, D., Martin, T., Narf, R., Pellett, T., Stewart, S., Storlie, C., Unmuth, J. 1997. A model of bluegill-largemouth bass interactions in relation to aquatic vegetation and its management. *Ecological Modelling* 94:139-156.
- Trebitz, A. S., and N. Nibbelink. 2011. Effect of pattern of vegetation removal on growth of bluegill: a simple model. *Canadian Journal of Fisheries and Aquatic Sciences* 53:1844-1851.
- Tugend, K. I., Allen, M. S., and M. Webb. 2002. Use of artificial habitat structures in U.S. lakes and reservoirs: a survey from the southern division American Fisheries society reservoir committee. *Fisheries* 27:22-27.

Utne-Palm, A. C. 2002. Visual feeding of fish in a turbid environment: physical and behavioural aspects. *Marine and Freshwater Behaviour and Physiology* 35:111-128.

U.S. Department of the Interior: U.S. Fish and Wildlife Service. 2016 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: National Overview. Issued August 2017.

Vanni, M. J., Andrews, J. S., Renwick, W. H., Gonzalez, M. J., Noble, S. J. 2006. Nutrient and light limitation of reservoir phytoplankton in relation to storm-mediated pulses in stream discharge. *Archiv fuer Hydrobiologie* 167:421-445.

Vinyard, G. L., and W. J. O'Brien. 1976. Effects of light and turbidity on the reactive distance of bluegill (*Lepomis macrochirus*). *Journal of the Fisheries Research Board of Canada* 33:2845-2849.

Weiss, C. M., and E. J. Kuenzler. 1976. The trophic state of North Carolina lakes. Water Resources Research Institute, University of North Carolina Report 119, Raleigh, North Carolina, USA.

Willis, S. C., Winemiller, K. O., and H. Lopez-Fernandez. 2005. Habitat structural complexity and morphological diversity of fish assemblages in a Neotropical floodplain river. *Oecologia* 142:284-295.

Werner, E. E., Gilliam, J. F., Hall, D. J., and G. G. Mittelbach. 1983a. An experimental test of the effects of predation risk on habitat use in fish. *Ecology* 64:1540-1548.

Werner, E. E., Mittelbach, G.G., Hall, D.J., and J. F. Gilliam. 1983b. Experimental test of optimal habitat use in fish: the role of relative habitat profitability. *Ecology* 64:1525-1539.

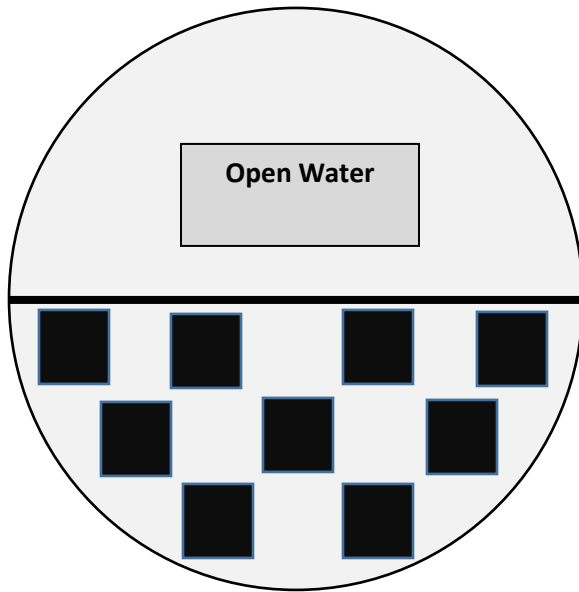


Figure 1: Tank design used to test the effects of turbidity on the use of structurally-complex habitat by Bluegill under the threat of predation. Squares represent artificial vegetation mats (1000 stems/m² with 50% of the area covered by vegetated mats resulting in overall vegetation density of 500 stems/m² on the vegetated side of the tank) and the dark line represents the middle of the tank where a divider was dropped to end trials and determine which tank side fish used most.

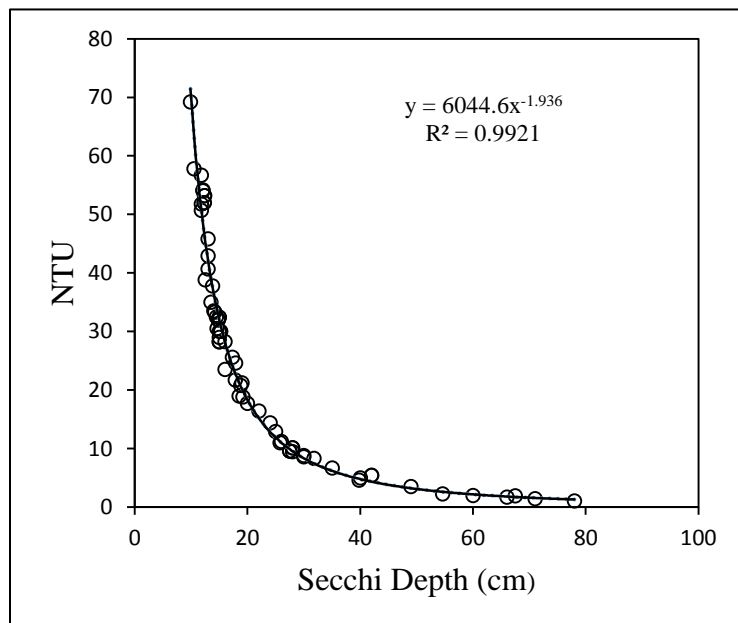


Figure 2: Relationship between nephelometric readings (NTU) and secchi depth readings in cm.

Bluegill Habitat Use in Relation to Turbidity

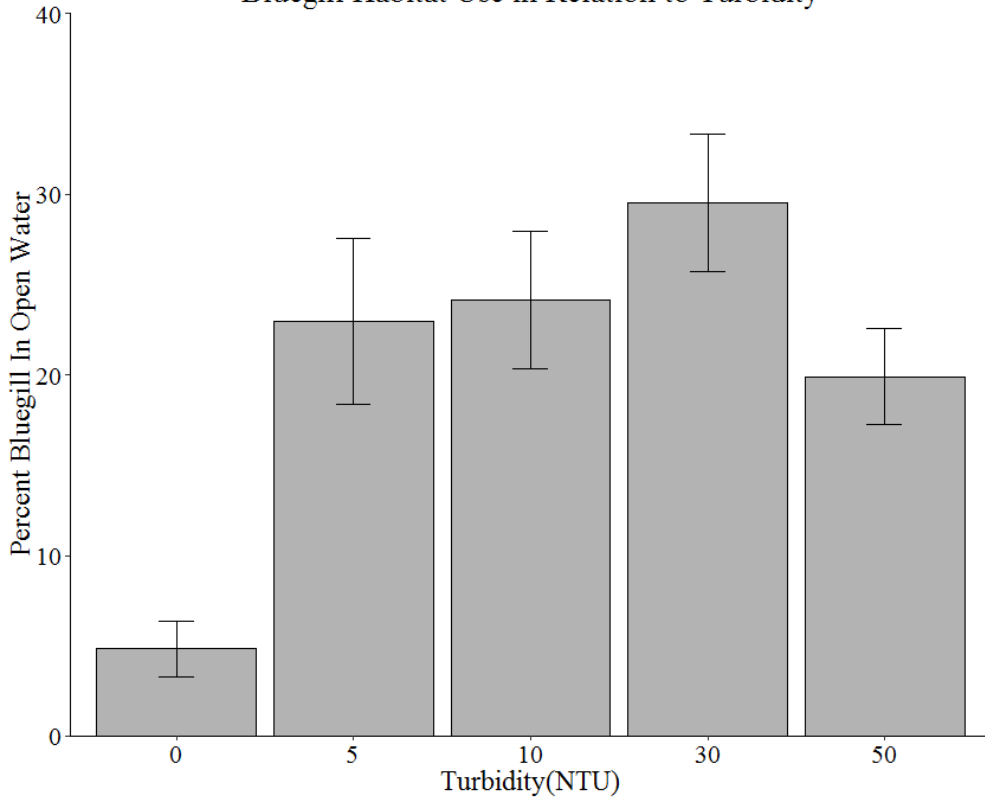


Figure 3: Percentage of Bluegill in the Open Water across selected levels of turbidity (NTU). Bars represent means with standard error bars. Trials with turbidities of 5, 10, 30, and 50 NTU were all significantly different than the 0 NTU trials, but were not significantly different from one another.

CHAPTER II

THE EFFECTS OF TURBIDITY ON THE USE OF STRUCTURALLY COMPLEX HABITAT BY FISHES IN RESERVOIRS: FIELD STUDY

Introduction

Turbidity increases from a variety of sources, is common in aquatic systems, and has the ability to drive fish community structure (Wood and Armitage, 1997; Henley et al., 2000; Kemp et al., 2011). Generally, suspended sediment is the major source of turbidity (Kirk, 1985; Daphne et al., 2011; Teixeira et al., 2016), although phytoplankton can also contribute to turbidity (Ali and Cagauan, 2007; Sánchez et al., 2017). Turbidity is influenced by both natural events (Chou and Wu, 2010), and anthropogenic activity (Anderson and Potts, 1987; Cornish, 2001). Therefore, it is important to understand turbidity's effects on local ecosystems, especially given increased anthropogenic activity can result in greater sediment loads entering nearby watersheds (Anderson and Potts, 1987; Mallin et al., 2009).

Turbidity affects aquatic systems primarily through scattering and attenuating light (Kirk, 1985; Lloyd et al., 1987; Benfield and Minello, 1996; Greycay and Targett, 1996; Cloern, 1996), resulting in decreased primary production (Cloern, 1987; Guenther and Bozelli, 2004; Sobolev et al., 2009). This effect ripples through the food chain, altering abundance of zooplankton (Moghraby, 1977; Carvalho, 1984), macroinvertebrate (Lloyd, 1987; Meutter et al., 2005), and fish species (Lloyd et al., 1987; Kemp et al., 2011). Fish are particularly sensitive to changes in

turbidity (Kemp et al., 2011), and in some instances, chronic increases in turbidity can lead to major declines in fish populations (Greig et al., 2005). Thus, sediment management techniques, such as riparian buffer zones, are recommended to minimize anthropogenic sediment input into local watersheds (Henley et al., 2000; Anbumozhi et al., 2005), and dampen negative effects on fish populations (Henley et al., 2000; Kemp et al., 2011).

Increased turbidity generally decreases visual acuity of fish (Abrahams and Kattenfeld, 1997; Robertis et al., 2003), resulting in decreased reaction distances of both predator and prey (Vinyard and O'Brien, 1976; Aksnes and Giske, 1993; Miner and Stein, 1996; Hansen et al., 2013). This can lead to decreased feeding rates (Gardner, 1981; Eccles, 1986; Gregory and Northcote, 1993; Lehtiniemi et al., 2005; Shoup and Wahl, 2009; Carter et al., 2010; Huenemann et al., 2012) and subsequent declines in growth rates (Sigler et al., 1984). Furthermore, turbidity can alter both the perceived risk of predation (Hartman and Abrahams, 2000; Leahy et al., 2011) and the antipredator behavior exhibited by prey fish species (Miner and Stein, 1996), ultimately leading to reduced use of structured habitat for some fish species (e.g., vegetation, brush, etc.) in response to elevated turbidity (Miner and Stein, 1996; Snickars et al., 2004; Skov et al., 2007; Mosle, 2018).

Changes in turbidity are often accompanied by other environmental changes, which can also elicit shifts in habitat use. Storm-induced changes in turbidity (Chou and Wu, 2010) are regularly accompanied by sharp increases in nutrients (Vanni et al., 2006; Drupp et al., 2011) and food (O'Leary and Wantzen, 2012), which can alter habitat use by fish (Hugie and Dill, 1994). In addition, flooding events alter water temperature (Tockner et al., 2000) and dissolved oxygen concentrations (Junk et al., 1989), which also can result in habitat shifts by fish (Kramer, 1987; Huey, 1991; Hari et al., 2006). Furthermore, flood pulses into reservoirs can result in thermocline erosion (Wei et al., 2011), further altering habitat use by fish (Crowder and Magnuson, 1982). Thus, turbidity is only one piece of an ecological puzzle that explains fish habitat use. Therefore, to understand the complete role of turbidity on habitat use, alteration in turbidity should be

studied with the full suite of other environmental changes. While laboratory-based studies investigating the effects of turbidity on fish habitat selection are useful as baseline predictions, these studies cannot incorporate all environmental factors; thus, field studies are necessary to further our understanding of turbidity-specific habitat selection by fish.

To date, no study has investigated how turbidity alters the use of structured habitat by fish in the field. Structured habitat provides juvenile fish critical refuge from predation (Mills and Mann, 1985; Langler and Smith, 2001; Strakosh et al., 2009). Thus, fisheries managers expend both money and time establishing structured habitat (Bassett, 1994; Tugend et al., 2002). From laboratory studies, we know that fish use cover less frequently in turbid water (Miner and Stein, 1996; Snickars et al, 2004; Mosle, 2018-chapter 1), yet much effort still goes into increasing habitat complexity in turbid lakes. This may be a waste of resources if structured habitat is not important in turbid systems. Thus, it is essential that managers understand how fish alter their use of habitat in turbid conditions to maximize management efforts. The goal of my study is to test the findings of Mosle (2018-chapter 1) that fish use structured habitat less frequently under turbid conditions, as compared to clear water, using a field based study. This information will determine if habitat enhancement is useful at high turbidity levels.

Methods

Pop nets with artificial macrophytes were used to quantify the use of structured habitat by fishes at different turbidity levels in Sooner Lake, OK. Sooner Lake has abundant Bluegill (*Lepomis macrochirus*) and Largemouth Bass (*Micropterus salmoides*), and typically has secchi depths ranging 39-74cm (Shoup and Lane, 2015), which is ideal for testing the findings of Mosle (2018-chapter 1). Sampling was conducted from mid-May 2018 through June 2018 because of the high frequency of storms that typically produce changes in turbidity during this time of the year.

Artificial vegetation (1000 stems/m²) was constructed by attaching 1-m long pieces of 4-mm diameter yellow polypropylene rope to 1.27-cm square hardware cloth in 30-cm x 30-cm

tiles. For each pop net, a total of 18 vegetation tiles (1.7m²) were arranged in a checkerboard pattern that alternated vegetated and empty space so that only half of the total sampling area (total area = 3.4m²) was covered. This resulted in a patchy distribution with an overall stem density of 500 stems/m², a common density (Sheldon and Boylen, 1977) selected by juvenile Bluegill (Savino and Stein, 1982; Gotceitas and Colgan, 1987; Gotceitas, 1990) and juvenile Largemouth Bass (Strakosh et al., 2009; Stahr and Shoup, 2015) under the threat of predation. Vegetation tiles were set in the field one month prior to data collection to allow time for periphyton growth (Villanueva et al., 2011) and fish attraction.

Five square pop nets (Larson et al., 1986) with artificial vegetation mats were used for the experiment. Pop nets were fabricated using 4.9-cm diameter PVC frame and 0.6-cm knotless ace netting with a total base area of 3.4m² (1.8-m x 1.8-m). Nets were constructed with a closed bottom. The artificial vegetation was placed on the bottom panel of each pop net so that when deployed, the pop net would encompass the artificial vegetation and capture any inhabiting fish.

Pop nets were set at two different sites which were both located in the same cove on the Eastern side of Sooner Lake (two nets at site 1, and three at site 2). Sites were selected based on similar substrate size and type, depth (approx. 1.0 - 1.3 m), water temperature, and proximity to existing structured habitat (primarily downed timber and large rocks), although sites with extensive existing structured habitat were avoided to allow artificial structure to be perceived as quality refuge habitat relative to surrounding options. In addition, sites that had high macrophyte growth were avoided. Preliminary sampling also indicated abundant Bluegill densities at both sites, ensuring results would be comparable to Mosle (2018-chapter 1).

Prior to pop net deployment, water temperature and dissolved oxygen were measured using a YSI meter (YSI 55A Handheld Dissolved Oxygen Meter), and turbidity was measured using a 30-cm secchi disk. To quantify natural vegetation growth, a 10-cm x 10-cm area of vegetation adjacent to each pop net site was sampled by clipping all vegetation (primarily sago pondweed and American pondweed) at sediment level. Vegetation was placed in a mesh bag,

swung around 20 times to remove excess water, and weighed to assess a plant biomass index. All pop nets were triggered at roughly the same time (between 9:00am and 11:00am) by pulling a 10-m leaded rope attached to the trigger mechanism (Larson et al., 1986). Once all nets were triggered, artificial vegetation was removed and each pop net was taken to shore where fish were identified, measured (total length [TL]), and released. Each of the five pop nets was sampled between 11 and 14 times (for a total of 61 replicates) during the experiment with at least 18h between samples.

To include trials using live vegetation, additional sampling was conducted with paired (vegetated and open water samples) 9.1-m bag seine samples taken at three sites in dense macrophyte growth, adjacent to open-water habitat. At each site, seine hauls through vegetation and open water were collected with equal effort (i.e., similar area seined, typically 100-m²). Prior to seining at each site, a secchi depth measurement was recorded.

Results were analyzed using a linear mixed-effects model (lmer) to test the effect of turbidity on the number of fish captured in pop nets using the lmer function of the lme4 package (Ben Bolker) in program R (R Development Team). All fish <100mm TL were included in the analysis as they were small enough for piscivores to easily consume (Dennerline and Van Den Avyle, 2000; Vatland and Budy, 2007) and, as such, would have high predation risk. In addition, Bluegill in this size range are known to utilize cover when under predation risk (Mittelbach, 1981), and were one of the most common fish collected in my study sites. Natural vegetation density, date, and pop net number were treated as random factors in the model. In addition, pop nets were nested in site, which was also treated as a random factor in the model. For the seine data, a lmer model was also used to test the effect of turbidity on the percentage of fish in the open (calculated as the number of fish in the open water seine haul divided by the number of fish in the open and vegetated seine haul) with site and date as blocking factors.

Results

There was no significant effect of turbidity on the number of fish caught in pop nets ($F_{1,41.3}=0.45$, $p=0.51$; Marginal $R^2=0.01$), nor was there a significant effect of turbidity on the percentage of fish found in the open water in the paired seine pulls ($F_{1,12.7}=0.37$, $p=0.55$; Marginal $R^2=0.01$; Figure 4). Fish species caught in seine pulls included: Bluegill, Largemouth Bass, Longear Sunfish (*Lepomis megalotis*), Orangespotted Sunfish (*Lepomis humilis*), White Perch (*Morone americana*), Atlantic Silverside (*Menidia menidia*), Gizzard Shad (*Dorosoma cepedianum*), Saugeye (*Sander canadensis*), Green Sunfish (*Lepomis cyanellus*), Common Carp (*Cyprinus carpio*), and Bluntnose Minnow (*Pimephales notatus*). The number of fish captured per pop net ranged from 1 to 32 fish for each sampling event, with an average of 11.39 fish per net set (3.35 fish/m²), which is on the lower end of the average catch rates reported in previous studies (3-7fish/m²; Dewey et al., 1989; Dewey, 1992). Bluegill and Largemouth Bass were the most commonly captured species in the pop net samples (Table 1), although there were other fish species caught in lower numbers. Other fish species caught in pop nets included: Longear Sunfish, Orangespotted Sunfish, White Perch, Atlantic Silverside, and Gizzard Shad.

Discussion

I did not find a correlation between the number of fish captured in complex habitats and turbidity, likely because the range of turbidities observed throughout the study were all at the clear-water end of the turbidity spectrum (91cm-488cm, secchi depth). The most turbid water observed in my study (secchi depth: 91cm), equates to approximately 1 Nephelometric Turbidity Unit (NTU) based on the NTU-secchi disc curve generated by Mosle (2018-chapter 1). Mosle (2018-chapter 1) found fish change their use of habitat somewhere between 0 and 5 NTU. Thus, without any field data from ≥ 5 NTU, I am unable to confirm if the shift observed by my corresponding laboratory study occurs under field conditions.

I observed shifts in fish communities that were not associated with turbidity. Bluegill were frequently caught early in the season when natural vegetation was absent but were caught less frequently as the vegetation grew throughout the season, suggesting that natural vegetation may have been more attractive than the artificial vegetation. Although this has not been explicitly investigated with regards to Bluegill, van Dam et al. (2002) discovered natural materials (i.e., brush piles) provided a better attachment point for periphyton growth than synthetic material (i.e., PVC), potentially leading to greater fish attraction by natural habitats (Bolding et al., 2004). Early in my study, there were large numbers of fry Largemouth Bass (investigator observation). When these Largemouth Bass increased to a fingerling size (approximately 36mm), they were large enough to be caught in the pop nets and were frequently sampled during the middle dates of my study (dates: 6/10-6/16). The number of fingerlings in my samples quickly reduced as they were likely making an ontogenetic shift to piscivory (Olson, 1996), and therefore feeding in open water. A second pulse of Largemouth Bass fingerlings were also caught near the end of my sampling (dates: 6/30-7/1), suggesting there was a second cohort spawned this year, similar to the findings of Waters and Noble (2004). Therefore, most changes in fish abundance are likely to be explained by vegetation abundance or recruitment of young-of-year fish, so these are factors that should be accounted for in future studies of prey fish habitat selection.

Pop nets were selected because they are effective in sampling fish in both dense macrophytes (Killgore et al., 1989; Dibble et al., 1996) and artificial structures (Larson et al., 1986; Johnson and Lynch, 1992). However, I found that pop nets are easily fouled by wave action. Storm events often caused the netting of the pop nets to get caught around the trigger mechanism or the PVC frame. This resulted in a 73% success rate when attempting to trigger the nets, which is similar to the success rate Larson et al. (1986) observed in the field (79%). However, the failures I observed were caused strictly by rough water, where Larson et al. (1986)'s failures were caused by fisherman interaction. Luckily, this was not a problem in my study. The failures I experienced can be minimized in future studies by shortening the time

between setting and releasing the pop nets; in my study I left the nets set for at least 18 hours, where other studies only left them for approximately 1 hour prior to “popping” them (Dewey et al, 1989; Kovalenko et al., 2009; Collingsworth and Kohler, 2010). Thus, pop nets should be triggered fairly quickly after they are set (allowing at least one hour of soaking [Slade et al., 2005]), especially in the field when turbulent water is expected. If setting for longer periods of time or in areas that commonly experience turbulent water, it is best to seek other sampling methods. In particular, sonar imaging is efficient in sampling structured habitat in turbid water (Baumann et al., 2016).

The major turbidity swings I observed were either due to wind action or phytoplankton blooms rather than storm runoff. This was in part because we experienced few storm events during my study period, but also because Sooner Lake is not a main-stem impoundment. If turbidities did reach levels to test the results of Mosle (2018-chapter 1), this may have resulted in a different response by fish in comparison to turbidity swings produced by storm runoff. Although not explicitly investigated, wind-induced turbidity likely does not have the same influx of nutrients and food resources as runoff-induced turbidity (Vanni et al., 2006; Drupp et al., 2011; O’Leary and Wantzen, 2012). Furthermore, the interaction of phytoplankton turbidity vs sediment turbidity would be interesting to investigate as different types of turbidity may result in differential behavior by fish. For example, phytoplankton-generated turbidity only affects the euphotic zone (i.e., where phytoplankton grow) whereas sediment-induced turbidity is more uniform throughout the water column. Studies investigating turbidity changes from different sources (e.g., natural vs anthropogenic, wind vs flood, phytoplankton vs sediment) would add considerably to our current understanding of fish response to turbidity.

The presence of structured habitat can alter turbidity levels. Aquatic vegetation can decrease water velocity (Sand-Jensen and Mebus, 1996), allowing for sediment to fall out of suspension (Petticrew and Kalff, 1992). This results in clearer water within a patch of vegetation relative to open water (Vermaat et al., 2000; Madsen et al., 2001). Thus, fish residing in

vegetation may not perceive an increase in turbidity until it reaches a threshold level, as described by Mosle (2018-chapter 1), within the vegetation patch itself. This level of turbidity likely would not be reached until open water turbidity is at much higher levels than the threshold level. Thus, future studies should focus on both in-vegetation and open-water turbidities to determine which turbidity measurement fish respond to more strongly.

Many anthropogenic activities, including logging, agricultural practices, road building, and grazing, increase turbidity of streams and lakes (Anderson and Potts, 1987; Mander et al., 1997; Cornish, 2001; Anbumozhi et al., 2005; Klein et al., 2012). In addition, poor management of urban storm-water runoff can lead to large sediment loads in nearby watersheds, resulting in increased turbidity (Mallin et al., 2009). Thus, it is important to understand how increased turbidity affects organisms living in local ecosystems, especially because sediment is one of the most detrimental pollutants to aquatic ecosystems (Ritchie, 1972; Lemly, 1982; Izagirre et al., 2009) and often negatively affects fish (Kemp et al., 2011). Unfortunately, the needed range of turbidities did not occur during my current field study, so I was unable to test the predictions of Mosle (2018-chapter 1). However, the observations of my study can be used to help create proper framework to successfully further investigate the effects of turbidity on the use of structured habitat by fish in field conditions.

References

- Abrahams, M. V., and M. G. Kattenfeld. 1997. The role of turbidity as a constraint on predator-prey interactions in aquatic environments. *Behavioral Ecology and Sociobiology* 40:169-174.
- Aksnes, D. L., and J. Giske. 1993. A theoretical model of aquatic visual feeding. *Ecological Modeling* 67:233-250.
- Ali, M. H., and A. G. Cagauan. 2007. Relationships between secchi disk visibility, water temperature and dissolved oxygen in freshwater fishpond. *Bangladesh Journal of Fisheries Research* 11:45-50.
- Anbumozhi, V., Radhakrishnan, J., and E. Yamaji. 2005. Impact of riparian buffer zones on water quality and associated management considerations. *Ecological Engineering* 24:517-523.
- Anderson, B., and D. F. Potts. 1987. Suspended sediment and turbidity following road construction and logging in western Montana. *Water Resources Bulletin* 23:681-690.
- Bassett, C. E. 1994. Use and evaluation of fish habitat structures in lakes of the eastern United States by the USDA Forest Service. *Bulletin of Marine Science* 55:1137-1148.
- Baumann, J. R., Oakley, N. C., and B. J. McRae. 2016. Evaluating the effectiveness of artificial fish habitat designs in turbid reservoirs using sonar imagery. *North American Journal of Fisheries Management* 36:1437-1444
- Benfield, M. C., and T. J. Minello. 1996. Relative effects of turbidity and light intensity on reactive distance and feeding of an estuarine fish. *Environmental Biology of Fishes* 46:211-216.
- Bolding, B., Bonar, S., and M. Divens. 2004. Use of artificial structure to enhance angler benefits in lakes, ponds, and reservoirs: a literature review. *Reviews in Fisheries Science* 12:75-96.
- Carter, M. W., Shoup, D. E., Dettmers, J. M., and D. H. Wahl. 2010. Effects of turbidity and cover on prey selectivity of adult smallmouth bass. *Transactions of the American Fisheries Society* 139:353-361.
- Carvalho, M. 1984. Influence of predation by fish and water turbidity on *Daphnia gessneri* population in an Amazonian floodplain lake, Brazil. *Hydrobiologia* 113:243-247.

- Chou, F. N. F., and C. W. Wu. 2010. Reducing the impacts of flood-induced reservoir turbidity on a regional water supply system. *Advances in Water Resources* 33:146-157.
- Cloern, J. E. 1987. Turbidity as a control on phytoplankton biomass and productivity in estuaries. *Continental Shelf Research* 7:1367-1381.
- Cloern, J. E. 1996. Phytoplankton bloom dynamics in coastal ecosystems: a review with some general lessons from sustained investigation of San Francisco Bay, California. *Reviews of Geophysics* 34:127-168.
- Collingsworth, P. D., and C. C. Kohler. 2010. Abundance and habitat use of juvenile sunfish among different macrophyte stands. *Lake and Reservoir Management* 26:35-42.
- Cornish, P. M. 2001. The effects of roading, harvesting and forest regeneration on streamwater turbidity levels in a moist eucalypt forest. *Forest Ecology and Management* 152:293-312.
- Crowder, L. B., and J. J. Magnuson. 1982. Thermal habitat shifts by fishes at the thermocline in Lake Michigan. *Canadian Journal of Fisheries and Aquatic Sciences* 39:1046-1050.
- Daphne, L. H. X., Utomo, H. D., and L. Z. H. Kenneth. 2011. Correlation between turbidity and total suspended solids in Singapore rivers. *Journal of Water Sustainability* 1:313-322.
- Dennerline, D. D., and M. J. Van Den Avyle. 2000. Sizes of prey consumed by two pelagic predators in US reservoirs: implications for quantifying biomass of available prey. *Fisheries Research* 45:147-154.
- Dewey, M. R., Holland-Bartels, L. E., and S. J. Zigler. 1989. Comparison of fish catches with buoyant pop nets and seines in vegetated and nonvegetated habitats. *North American Journal of Fisheries Management* 9:249-253.
- Dewey, M. R. 1992. Effectiveness of a Drop Net, a Pop Net, and an Electrofishing Frame for Collecting Quantitative Samples of Juvenile Fishes in Vegetation. *North American Journal of Fisheries Management* 12:808-813.
- Dibble, E. D., Killgore, K. J., and S. L. Harrel. 1996. Assessment of fish-plant interactions. *American Fisheries Society Symposium* 16:357-372.
- Drupp, P., De Carlo, E. H., Mackenzie, F. T, Bienfang, P., and C. L. Sabine. 2011. Nutrient inputs, phytoplankton response, and CO₂ variations in a semi-enclosed subtropical embayment, Kaneohe Bay, Hawaii. *Aquatic Geochemistry* 17:473-498.
- Eccles D. H. 1986. Diet of the cyprinid fish *Barbus aeneus* (Burchell) in the P.K. le Roux Dam, South Africa, with special reference to the effect of turbidity on zooplanktivory. *South African Journal of Zoology* 21:257-263.

- Gardner, M. B. 1981. Effects of turbidity on feeding rates and selectivity of bluegills. *Transactions of the American Fisheries Society* 110:446-450.
- Gotceitas, V. 1990. Foraging and predator avoidance: a test of a patch choice model with juvenile bluegill sunfish. *Oecologia* 83:346-351.
- Gotceitas, V., and P. Colgan. 1987. Selection between densities of artificial vegetation by young bluegills avoiding predation. *Transactions of the American Fisheries Society* 116:40-49.
- Greco, P. A., and T. E. Targett. 1996. Effects of turbidity, light level and prey concentration on feeding of juvenile weakfish *Cynoscion regalis*. *Marine Ecology Progress Series* 131:11-16.
- Gregory, R. S., and T. G. Northcote. 1993. Surface, planktonic, and benthic foraging by juvenile chinook salmon (*Oncorhynchus tshawytscha*) in turbid laboratory conditions. *Canadian Journal of Fisheries and Aquatic Sciences*. 50:233-240.
- Guenther, M. and R. Bozelli. 2004. Effects of inorganic turbidity on the phytoplankton of an Amazonian Lake impacted by bauxite tailings. *Hydrobiologia* 511:151-159.
- Greig, S. M., Sear, D. A., and P. A. Carling. 2005. The impact of fine sediment accumulation on the survival of incubating salmon progeny: Implications for sediment management. *Science of the Total Environment* 344:241-258.
- Hansen, A. G., Beauchamp, D. A., and E. R. Schoen. 2013. Visual prey detection responses of piscivorous trout and salmon: effects of light, turbidity, and prey size. *Transactions of the American Fisheries Society* 142:854-867.
- Hari, R. E., Livingstone, D. M., Siber, R., Burkhardt-Holm, P., and H. Güttinger. 2006. Consequences of climatic change for water temperature and brown trout populations in Alpine rivers and streams. *Global Change Biology* 12:10-26.
- Henley, W. F., Patterson, M. A., Neves, R. J., and A. D. Lemly. 2000. Effects of sedimentation and turbidity on lotic food webs: a concise review for natural resource managers. *Reviews in Fisheries Science* 8:125-139.
- Hartman, E. J. and M. V. Abrahams. 2000. Sensory compensation and the detection of predators: the interaction between chemical and visual information. *Proceedings of the Royal Society B* 267:571-575.
- Huenemann, T. W., Dibble, E. D., and J. P. Fleming. 2012. Influence of turbidity on the foraging of Largemouth Bass. *Transactions of the American Fisheries Society* 141:107-111.
- Huey, R. B. 1991. Physiological consequences of habitat selection. *The American Naturalist* 137: S91-S115.

- Hugie, D. M., and L. M. Dill. 1994. Fish and game: a game theoretic approach to habitat selection by predators and prey. *Journal of Fish Biology* 45:151-169.
- Izagirre, O., Serra, A., Guasch, H., and A. Elosegi. 2009. Effects of sediment deposition on periphytic biomass, photosynthetic activity and algal community structure. *Science of the Total Environment* 407:5694-5700.
- Johnson, D. L., and W. E. Lynch Jr. 1992. Panfish use of and angler success at evergreen tree, brush, and stake-bed structures. *North American Journal of Fisheries Management* 12:222-229.
- Junk, W. J., Bayley, P. B., and R. E. Sparks. 1989. The flood pulse concept in river-floodplain systems. *Canadian Journal of Fisheries and Aquatic Sciences* 106:110-127.
- Kemp, P., Sear, D., Collins, A., Naden, P., and I. Jones. 2011. The impacts of fine sediment on riverine fish. *Hydrological Processes* 25:1800-1821.
- Killgore, K. J., Morgan II, R. P., and N. B. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. *North American Journal of Fisheries Management* 9:101-111.
- Kirk, J. T. O. 1985. Effects of suspensoids (turbidity) on penetration of solar radiation in aquatic ecosystems. *Hydrobiologia* 125:195-208.
- Klein, R. D., Lewis, J., and M. S. Buffleben. 2012. Logging and turbidity in the coastal watersheds of northern California. *Geomorphology* 139-140:136-144.
- Kovalenko, K., Dibble, E. D., and R. Fugi. 2009. Fish feeding in changing habitats: effects of invasive macrophyte control and habitat complexity. *Ecology of Freshwater Fish* 18:305-313.
- Kramer, D. L. 1987. Dissolved oxygen and fish behavior. *Environmental Biology of Fishes* 18:81-92.
- Langler, G. L., and C. Smith. 2001. Effects of habitat enhancement on 0-group fishes in a lowland river. *Regulated Rivers: Research and Management* 17:677-686.
- Larson, E. W., Johnson, D. L., and W. E. Lynch Jr. 1986. A buoyant pop net for accurately sampling fish at artificial habitat structures. *Transactions of the American Fisheries Society* 115:351-355.
- Leahy, S. M., McCormick, M. I., Mitchell, M. D., and M. C. O. Ferrari. 2011. To fear or to feed: the effects of turbidity on perception of risk by a marine fish. *Biology Letters* 7:811-813.
- Lehtiniemi, M., Engström-Öst, J., and Viitasalo, M. 2005. Turbidity decreases anti-predator behaviour in pike larvae, *Esox lucius*. *Environmental Biology of Fishes* 73:1-8.

- Lemly, A. D. 1982. Modification of benthic insect communities in polluted streams: combined effects of sedimentation and nutrient enrichment. *Hydrobiologia* 87:229-245.
- Lloyd, D. S., Koenings, J. P., and J. D. Laperriere. 1987. Effects of turbidity in fresh waters of Alaska. *North American Journal of Fisheries Management* 7:18-33.
- Madsen, J. D., Chambers, P. A., James, W. F., Koch, E. W., and D. F. Westlake. 2001. The interaction between water movement, sediment dynamics and submersed macrophytes. *Hydrobiologia* 444:71-84.
- Mallin, M. A., Johnson, V. L., and S. H. Ensign. 2009. Comparative impacts of stormwater runoff on water quality of an urban, a suburban, and a rural stream. *Environmental Monitoring and Assessment* 159:475-491.
- Mander, Ü., Kuusemets, V., Lõhmus, K., and T. Muring. 1997. Efficiency and dimensioning of riparian buffer zones in agricultural catchments. *Ecological Engineering* 8:299-324.
- Meutter, F. V., Stocks, R., and L. D. Meester. 2005. The effect of turbidity state and microhabitat on macroinvertebrate assemblages: a pilot study of six shallow lakes. *Hydrobiologia* 542:379-390.
- Mills, C. A. and R. H. K. Mann. 1985. Environmentally-induced fluctuations in year-class strength and their implications for management. *Journal of Fish Biology* 27:209-226.
- Miner, J. G., and R. A. Stein. 1996. Detection of predators and habitat choice by small bluegills: effects of turbidity and alternative prey. *Transactions of the American Fisheries Society* 125:97-103.
- Mittelbach, G. G. 1981. Foraging efficiency and body size: a study of optimal diet and habitat use by bluegills. *Ecology* 62:1370-1386.
- Moghraby, A. J. 1977. A study on diapause of zooplankton in a tropical river – The Blue Nile. *Freshwater Biology* 7:207-212.
- Mosle, S. 2018. The effects of turbidity on the use of vegetation by bluegill under the threat of predation: chapter 1. M.S. thesis: Oklahoma State University.
- O’Leary, S. J. and K. M. Wantzen. 2012. Flood pulse effects on benthic invertebrate assemblages in the hypolacustric interstitial zone of Lake Constance. *International Journal of Limnology* 48:267-277.
- Olson, M. H. 1996. Ontogenetic niche shifts in largemouth bass: variability and consequences for first-year growth. *Ecology* 77:179-190.
- Petticrew, E. L., and J. Kalff. 1992. Water flow and clay retention in submerged macrophyte beds. *Canadian Journal of Fisheries and Aquatic Sciences* 49:2483-2489.

- Ritchie, J. C. 1972. Sediment, fish and fish habitat. *Journal of Soil and Water Conservation* 27:124-125.
- Robertis, A. D., Ryer, C. H., Veloza, A., and R. D. Brodeur. 2003. Differential effects of turbidity on prey consumption of piscivorous and planktivorous fish. *Canadian Journal of Fisheries and Aquatic Sciences* 60:1517-1526.
- Sánchez, M. L., Rodríguez, P., Torremorell, A. M., Izaguirre, I., and H Pizarro. 2017. Phytoplankton and periphyton primary production in clear and turbid shallow lakes: influence of the light environment on the interactions between these communities. *Wetlands* 37:67-77.
- Sand-Jensen, K., and J. R. Mebus. 1996. Fine-scale patterns of water velocity within macrophyte patches in streams. *Nordic Society Oikos* 76:169-180.
- Savino, J. F., and R. A. Stein. 1982. Predator-prey interactions between largemouth bass and bluegills as influenced by simulated submersed vegetation. *Transactions of the American Fisheries Society* 111:255-266.
- Sheldon, R. B., and C. W. Boylen. 1997. Maximum depth inhabited by aquatic vascular plants. *The American Midland Naturalist* 97:248-254.
- Shoup, D. E., and D. H. Wahl. 2009. The effects of turbidity on prey selection by piscivorous largemouth bass. *Transactions of the American Fisheries Society* 138:1018-1027.
- Shoup, D. E., and W. D. Lane. 2015. Effects of Turbidity on Prey Selection and Foraging Return of Adult Largemouth Bass in Reservoirs. *North American Journal of Fisheries Management* 35:913-924.
- Sigler, J. W., Bjorn, T. C., and F. H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. *Transactions of the American Fisheries Society* 113:142-150.
- Skov, C., Nilsson, P. A., Jacobsen, L., and C. Brönmark. 2007. Habitat-choice interactions between pike predators and perch prey depend on water transparency. *Journal of Fish Biology* 70:298-302.
- Slade, J. G., Dibble, E. D., and Smiley Jr. P. C. 2005. Relationships between littoral zone macrophytes and the fish community in four urban Minnesota lakes. *Journal of Freshwater Ecology* 20:635-640.
- Snickars, M., Sandström, A., and J. Mattila. 2004. Antipredator behaviour of 0+ year *Perca fluviatilis*: effect of vegetation density and turbidity. *Journal of Fish Biology* 65:1604-1613.

Sobolev, D., Moore, K., and A. L. Morris. 2009. Nutrients and light limitation of phytoplankton biomass in a turbid southeastern reservoir: implications for water quality. *Southeastern Naturalist* 8:255-266.

Stahr, K. J., and D. E. Shoup. 2015. American water willow mediates survival and antipredator behavior of juvenile largemouth bass. *Transactions of the American Fisheries Society* 144:903-910.

Strakosh, T. R., Gido, K. B., and C. S. Guy. 2009. Effects of American water willow establishment on density growth, diet, and condition of age-0 Largemouth Bass in Kansas reservoirs. *Transactions of the American Fisheries Society* 138:269-279.

Teixeira, L. C., Paiva, J. B. D., Pereira, J. E. S., and R. M. Lisbôa. 2016. Relationship between turbidity and suspended sediment concentration from a small hydrographic basin in Santa Maria (Rio Grande do Sul, Brazil). *International Journal of River Basin Management* 14:393-399.

Tockner, K., Malard, F., and J. V. Ward. 2000. An extension of the food pulse concept. *Hydrological Processes* 14:2861-2883.

Tugend, K. I., Allen, M. S., and M. Webb. 2002. Use of artificial habitat structures in U.S. lakes and reservoirs: a survey from the southern division American Fisheries society reservoir committee. *Fisheries* 27:22-27.

Van Dam, A. A., Beveridge M. C. M., Azim, M. E., and M. C. J. Verdegem. 2002. The potential of fish production based on periphyton. *Reviews in Fish Biology and Fisheries* 12:1-31.

Vanni, M. J., Andrews, J. S., Renwick, W. H., Gonzalez, M. J., and S. J. Noble. 2006. Nutrient and light limitation of reservoir phytoplankton in relation to storm-mediated pulses in stream discharge. *Archiv fuer Hydrobiologie* 167:421-445.

Vatland, S., and P. Budy. 2007. Predicting the invasion success of an introduced omnivore in a large, heterogeneous reservoir. *Canadian Journal of Fisheries and Aquatic Sciences* 64:1329-1345.

Vermaat, J. E., Santamaria, L., and P. J. Roos. 2000. Water flow across and sediment trapping in submerged macrophyte beds of contrasting growth form. *Archiv fuer Hydrobiologie* 148:549-562.

Villanueva, V. D., Font, J., Schwartz, T., and A. M. Romani. 2011. Biofilm formation at warming temperature: acceleration of microbial colonization and microbial interactive effects. *Biofouling* 27:59-71.

Vinyard, G. L., and W. J. O'Brien. 1976. Effects of light and turbidity on the reactive distance of bluegill (*Lepomis macrochirus*). *Journal of the Fisheries Research Board of Canada* 33:2845-2849.

Waters, S. and R. L. Noble. 2004. Spawning season and nest fidelity of largemouth bass in a tropical reservoir. *North American Journal of Fisheries Management* 24:1240-1251.

Wei, L., Dingguo, J., and C. Tao. 2011. Effects of flood on thermal structure of a stratified reservoir. *Procedia Environmental Sciences* 10:1811-1817.

Wood, P. J., and P. D. Armitage. 1997. Biological effects of fine sediment in the lotic environment. *Environmental Management* 21:203-217.

Table 1: Average number of fish captured per pop net on different sampling days. Bluegill and Largemouth Bass were the two most commonly caught species. Also included is the mean turbidity among both sites as well as natural vegetation biomass adjacent to sampling sites.

Date	Mean Turbidity (±SE) (cm)	Mean Vegetation Biomass (g)	Mean Total Fish	Bluegill		Largemouth Bass	
				Mean Species Count (±SE)	Mean Size (mm) (±SE)	Mean Species Count (±SE)	Mean Size (mm) (±SE)
5/24/2018	195.6(±0.0)	0.0(±0.0)	8.0(±0.0)	8.0(±0.0)	57.8(±5.2)	0	0
5/27/2018	147.3(±0.0)	0.0(±0.0)	14.0(±0.0)	14.0(±0.0)	55.6(±3.8)	0	0
5/29/2018	312.4(±0.0)	2.0(±0.0)	10.0(±0.0)	10.0(±0.0)	56.2(±6.2)	0	0
5/31/2018	96.5(±0.0)	12.0(±0.0)	2.5(±0.5)	1.5(±0.5)	45.7(±4.6)	1.0(±0.0)	44.0(±3.0)
6/3/2018	162.6(±7.3)	23.0(±0.6)	3.3(±1.3)	2.7(±0.3)	64.5(±4.7)	1.0(±0.7)	46.0(±0.9)
6/5/2018	179.7(±18.4)	23.3(±3.3)	13.0(±5.8)	0.8(±0.3)	73.0(±12.1)	12.3(±6.0)	45.0(±1.0)
6/9/2018	146.5(±13.6)	28.7(±5.7)	11.0(±1.7)	1.0(±0.6)	71.3(±5.2)	9.7(±1.9)	52.7(±0.9)
6/10/2018	161.0(±11.8)	32.4(±3.9)	18.0(±3.9)	2.2(±1.7)	65.1(±4.1)	15.6(±4.0)	52.4(±0.6)
6/13/2018	184.4(±10.0)	36.2(±5.6)	23.4(±2.4)	2.0(±1.1)	58.3(±3.7)	20.4(±2.4)	57.0(±0.6)
6/14/2018	170.8(±17.2)	42.0(±4.0)	13.5(±2.7)	2.0(±0.4)	61.0(±3.1)	11.3(±2.3)	59.2(±0.9)
6/16/2018	176.3(±2.5)	49.6(±2.2)	19.8(±2.5)	3.2(±0.8)	61.9(±1.7)	16.0(±1.7)	59.4(±0.9)
6/19/2018	176.5(±14.0)	61.5(±1.5)	13.0(±4.0)	3.0(±1.0)	62.4(±1.7)	9.5(±4.2)	64.2(±1.4)
6/21/2018	149.0(±8.5)	64.0(±10.0)	8.0(±1.2)	2.0(±0.6)	92.0(±17.2)	5.0(±1.5)	64.7(±3.3)
6/22/2018	153.7(±3.8)	56.5(±16.5)	7.0(±1.0)	2.0(±0.0)	64.3(±5.5)	3.5(±0.5)	63.1(±6.0)
6/23/2018	104.1(±0.0)	80.0(±0.0)	5.0(±0.0)	0	0	5.0(±0.0)	48.8(±2.3)
6/27/2018	133.4(±8.1)	68.5(±4.9)	5.0(±0.8)	1.5(±1.0)	60.3(±3.7)	2.3(±0.5)	59.3(±5.4)
6/28/2018	158.8(±9.5)	102.5(±7.2)	5.5(±1.2)	1.0(±0.7)	60.0(±3.5)	2.3(±0.9)	58.4(±4.9)
6/29/2018	137.2(±8.8)	75.0(±2.9)	3.0(±0.0)	1.8(±0.6)	67.1(±3.2)	0.8(±0.5)	49.7(±9.8)
6/30/2018	166.0(±11.9)	79.0(±2.0)	11.7(±0.9)	0.7(±0.7)	69.5(±5.5)	8.7(±0.3)	60.3(±2.8)
7/1/2018	309.9(±0.0)	75.0(±0.0)	15.0(±0.0)	0	0	13.0(±0.0)	74.2(±3.7)

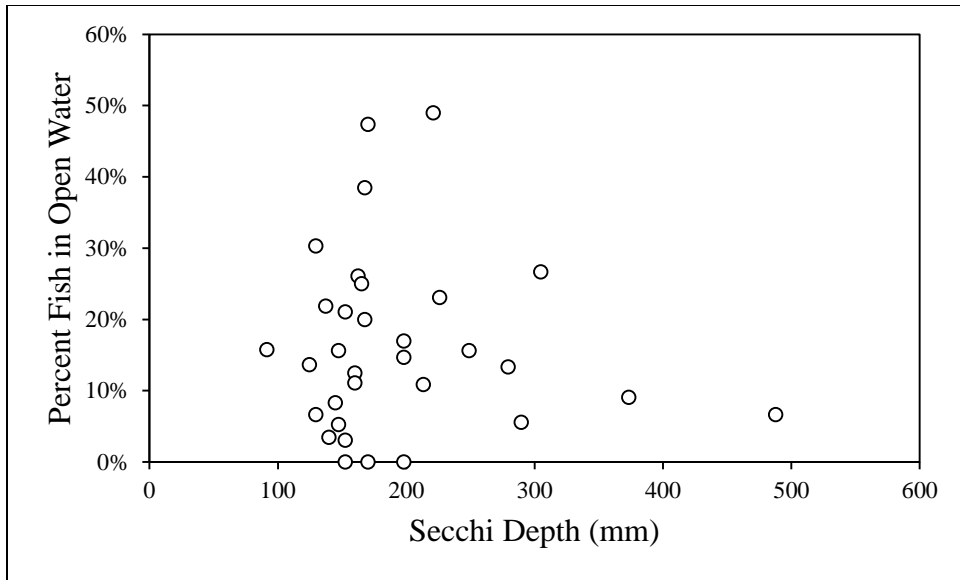


Figure 4: Percent fish captured in the open water in relation to turbidity using paired seine pulls. One seine pull was through dense macrophytes and the other was through open water. Percent fish numbers were generated by dividing the number of fish caught in the open water seine by the total fish caught by both seine pulls.

VITA

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