Ability and Behavior of Foraging Sunfish (*Lepomis* spp.) Communities in Northwestern Wisconsin Lakes of Differing Turbidity

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Abstract

Sunfish (*Lepomis* spp.) are predators which depend on visual cues to forage. These visual cues can be inhibited by the turbidity of the water in which the population is residing, affecting the optimal diet of that population. Turbidity also inhibits the prey populations' antipredatory behaviors by reducing the distance of interaction. This creates a balance of turbidity's effects which differs by predator and prey species and greater ecological context. To determine the impact turbidity has on sunfish's macroinvertebrate foraging abilities in Northern Wisconsin lakes, a diet study was conducted within two lakes of differing turbidity: Morris and Crampton Lakes. The health of populations caught in fyke nets was estimated using relative weight (W_r) as a measure of fish plumpness. Gastric lavage was used to collect stomach contents for analysis on the mass and contents of sunfish diets. T-tests were used to determine if any of the health, foraging ability, or foraging behavior differed between lakes. Statistical differences were found for relative weight and foraging ability between the two lakes, suggesting sunfish are capable of greater consumption in turbid waters. From this study, we were able to find that, for sunfish, turbidity can have an enhancing effect on foraging ability.

Introduction

As a necessity for life, feeding is a common research topic which can help protect wildlife species. Foraging is the active, multistage process of searching for, handling, and assimilating food resources to maximum efficiency. Due to the interdependent nature of each of these stages of foraging, a balance must be struck between the costs and benefits of foraging. According to foraging theory, the optimization of an individual's foraging can be broken into four distinct components: optimal diet, space, period, and group size (Schoener 1971). Despite

being a universal behavior, optimal foraging is unique to each individual due to a whole host of factors. These factors include abiotic variables such as temperature, salinity, pH, substrate composition, and turbidity, as well as biotic factors, such as vegetation, predator and competitor populations, prey availability, and parasites (Abrahams and Kattenfeld 1997; Bœuf and Payan 2001; Fraser, Metcalfe, and Thorpe 1993; Fullerton et al. 1998; Fullerton and Lamberti 2006; Graeb et al. 2011; Janssen and Luebke 2004). Theoretical balancing of the many external factors with the internal characteristics of an individual requires an arbitrary oversimplification of the system (Johnson 1980). As such, modeling and derivation of foraging from natural experimentation can be the best estimator of the impact particular factors can have. Experimentation can also reveal that some external factors are dependent on the individual characteristics interacting with them.

The turbidity of water has been shown to be among these factors which impact the foraging behaviors of fishes (Abrahams and Kattenfeld 1997). Turbidity is a measure of the attenuation of contrast between objects in water which affects the extent of an individual's distinctive sight (Swift et al. 2006). Turbidity is measured as a Secchi depth, or the depth at which a black and white disc is no longer distinguishable to the observer at the surface. Secchi depth is the most valid measure of water turbidity since it includes both water color and particulate material, making it representative of total visibility for fish residents. Many lake dwelling fish must be capable of sight for foraging, making turbidity an important factor influencing foraging ability. Some species have developed non-visual capabilities in response to decreased visibility; however, the majority of lake fishes continue to rely on sight to forage (Werner and Hall 1974). Rather than alter foraging function, these species have been known to undergo a shift in optimal behavior or diet given their environmental conditions (Abrahams and

Kattenfeld 1997; Murdoch 1969; Werner and Hall 1979). The extent of diet shift is complicated

by turbidity acting equally on prey being foraged, resulting in new or less antipredator behaviors

or traits (Abrahams and Kattenfeld 1997). Collecting natural diets of residents within lakes of

different turbidities will allow analysis of the impact vision has on the optimal diet of fishes.

Sunfish (*Lepomis* spp.) are among the most common lake fishes in the Midwest, and their

populations often make up the majority of a lake community. The diets of these populations are

thus representative of a general response to turbidity and other lake factors. There is also

significant knowledge about the optimal foraging behavior of these species in ideal, experimental

conditions (Werner and Hall 1974). These studies have found sunfishes to be size selective,

meaning that, given the choice, individuals will pass up a small prey item to consume larger

options first. Size selection as a behavior is dependent upon the knowledge that other options are

available, making it sensitive to visibility and turbidity of water (Abrahams and Kattenfeld

1997). Selection of prey by size, or any characteristic, indicates normal foraging behavior

including detection of alternative prey. The selectivity of an individual is often measured as a

ratio of use to availability of a particular resource (Chesson 1978). In the absence of reliable

measurements of available resources, a measure of diet diversity indicates the relative extent of

selection involved in foraging by that individual. Use of the linear true diversity measure of

effective number of species (ESN) balances evenness and richness of items within a diet to

represent whether foraging had selective intent or was opportunistic consumption.

In this study, we intend to show that foraging behaviors of fish adapt to their

surroundings to provide the optimal diet. We hypothesize that these behavioral modifications

will result in a greater diversity of diet when foraging within a turbid environment due to low

selectivity. To indicate optimal diets are being achieved in both lakes, we further hypothesize that the relative weight and standardized diet mass will not differ between lakes.

Methods

Study Site

Fish stomach contents were collected from sunfishes caught in fyke nets. Fyke nets were set in several locations within Morris and Crampton Lakes on the University of Notre Dame's Environmental Research Center (UNDERC) property in the Upper Peninsula of Michigan. Study sites were selected based on historical records of water quality in lakes on property to represent turbidity extremes (UNDERC 1987). Morris Lake was selected as a dark and turbid lake while Crampton Lake is both clearer and less dark for water visibility contrast. Fyke nets were left in a single location for 12 hours before collection and relocation.

Study Species

Bluegill (*Lepomis macrochirus)* and Pumpkinseed (*Lepomis gibbosus*) were collected and defined by physical characteristics with hybrids being labeled according to their dominant features. Net sampling was supplemented with baitless, line fishing. Sunfishes were chosen as a common genus which is most often non-piscivorous to increase the rate of stomach occupation (Vinson and Angradi 2011). All individuals were analyzed equally as sunfish due to minor dietary differences and population overlaps resulting in hybridization. Fish were processed for total length, mass, and stomach contents within an hour of collection. Stomach contents were collected by gastric lavage, preserved with 70% ethanol, and frozen at -4ºC until analysis (Hartleb and Moring 1995). Stomach contents were analyzed using a binocular dissecting scope to their furthest possible classification, counted, and weighed to the nearest 0.01 g.

Statistical Analysis

Each of the following parametric tests were done using a significant α=0.05. The first method for comparison was based on the general health of individuals quantified as relative weight (W_r) which is calculated as the ratio of observed weight:standard weight. Standard weights were calculated using the following formula:

$$log_{10}(W_s) = a + b(log_{10}(TL))$$

with a and b representing intercept and slope respectively (Blackwell, Brown, and Willis 2000). W_r was compared across lake samples with a t-test using R (V 1.0.136, 2016). Stomach contents were analyzed first as composite by standardizing total mass of stomach contents to fish mass and compared with a t-test. Linear regression was used to compare the standardized diet mass with the relative weight of individuals for explanatory purposes. To contrast foraging behavior, rather than ability, the diversity of identified contents was calculated for individuals. The effective number of species was employed to measure the richness and evenness of species while remaining linear for parametric statistic comparison. Effective species was calculated using the formula:

$$H` = e^{-\sum_{i=1}^{R} p_i \ln(p_i)}$$

where p_i is the proportion of individuals of a species to total individuals in the diet and R is the number of species present. These H` values were compared between lakes using a t-test.

Results

Morris and Crampton lakes were averaged to have Secchi depths of 1.2 m and 3.45 m respectively (SE ± 0.07 and SE ± 0.14, Table 1). Sample sizes of sunfish from each lake were 53 from Crampton Lake and 28 from Morris Lake. The average sunfish, above 50 mm, caught was

164.7 mm in total length and 86.41 g. These averages were higher in Crampton Lake, 177.2 mm

and 99.89 g, than in Morris Lake, 148.1 mm and 66.26 g. Relative weight, W_r, for these sunfish

populations was significantly higher in Morris Lake than in Crampton ($Mean_{Morris} = 84.20 \pm SE$

1.142, $Mean_{Crampton} = 78.73 \pm SE$ 0.833, t = 3.9656, df = 89, p<0.001, Figure 1). Diet mass

standardized to the mass of the fish was also significantly larger in Morris Lake diets than

Crampton's ($Mean_{Morris} = 0.21 \pm SE$ 0.054, $Mean_{Crampton} = 0.09 \pm SE$ 0.016, t = 2.6634, df = 79,

p<0.01, Figure 2). Standardized diet mass of an individual was related with its relative weight

through linear regression (F = 7.405, df = 79, p = 0.008, Figure 3). The more specific measures

of these diets were done by the diversity measurements, which provided linear measurements for

effective species numbers. These numbers ranged from 1 to 4.883 with the average for all diets

being 1.979. The two populations of Morris and Crampton were not significantly different for

this diversity within their diet ($Mean_{Morris} = 2.11 \pm SE$ 0.205, $Mean_{Crampton} = 1.91 \pm SE$ 0.124, t =

0.9151, df = 79, p = 0.3629, Figure 4).

Discussion

Analysis of Morris and Crampton lake sunfish populations revealed differences between

the lakes. The greater W_r of Morris sunfishes detected indicates variable health between the two

lakes. Relative weight as a condition index indicates health as it measures the plumpness of

individuals according to their length (Blackwell et al. 2000). The health of individuals is often a

reflection of the extent to which they are able to forage, but can also be influenced by predation,

overpopulation, or contamination (Chizinski et al. 2010; Gosch, Pierce, and Pope 2010). Because

the standardized diet mass was positively related with relative weight it can be concluded that the

increased Morris foraging was a cause of the differential health. While this study was a snapshot

of diets within these lakes, these are meant to indicate the typical foraging of the fish. This typically increased consumption within the more turbid lake suggests greater ability for sunfish to forage in higher turbidity. Cumulative diets refer merely to ability because it does not analyze what the individual is choosing to consume. This simple ability to forage could be a reflection of the availability of resources in the lakes. Availability to an individual is a balance of the prey community and the fish population itself, which together are difficult to quantify. Based on a trophic state index (TSI) calculated from Secchi depth measurements the trophic level of the two lakes was categorized equally as meso-eutrophic ($TSI_{Morris} = 57.4$ and $TSI_{Crampton} = 42.1$, Table 1) (Carlson 1977). This indicates that while Secchi depth presents two lakes with markedly different visibilities, their differences are subtle on the spectrum of trophic state (Carlson 1977; Swift et al. 2006). Under the assumption that Crampton and Morris are trophically similar, turbidity and visibility are left as the factor to explain foraging ability by sunfishes in these lakes.

Water turbidity measured with Secchi depth represents the ability which an occupant of the lake has to visualize its surroundings. As visual predators, sunfish rely on this ability to forage effectively and consequently extreme turbidity can inhibit foraging. This effect which turbidity has upon the predator is the same as that upon their prey diminishing their antipredator behaviors or the effectiveness of those behaviors (Abrahams and Kattenfeld 1997). Our results indicate that turbidity at this level provides a foraging advantage to the sunfish, and one which is consistent throughout the lifetime of the fish. This foraging increase was done generally, but analysis of the items allowed measuring the behavior of the populations within the lakes.

Diversity of species eaten represents the foraging behavior of individuals as a measure similar to selectivity. If an individual has a large number of species in equal proportion in its diet, then it seemingly does not reject any food resources which it comes across. A selective diet

would have very few species present or one species present in greater amounts than all others, neither of which were found in these diets (Figures 5 and 6). Any level of selectivity in efficient foraging requires that the predator has other options available to it. The extent of other available options is often a reflection of the actual density of the prey, but in reality the effective density is the only impactful criteria as it determines what the individual is aware of as options (Werner and Hall 1974). Because effective density is dependent upon the visual field of the individual, it is indirectly related with the turbidity. Theoretically, this leads to a greater diversity in more turbid lakes. While the trend parallels this theory, there was no statistical difference detected between the samples. We suspected that the disagreement between the theoretical and observed results were due to a decreased diversity in Morris lake or a decreased foraging space by sunfish in this lake. Diversities for whole lakes were calculated by compiling diets of the populations, and diversity of resources consumed by the Morris sunfish population was lower than that of Crampton's ($ESN_{Morris} = 3.87$, $ESN_{Crampton} = 4.68$, Table 1). This consumed diversity can be a reflection of actual reduced diversity of resources within the lake, or, more likely, a reduced foraging space by Morris lake sunfish. Due to the increased foraging success which an individual is able to have in greater turbidity, as shown before, foraging space is likely reduced in turbid waters to increase foraging efficiency to achieve the optimal diet (Schoener 1971). In this reduced space there is a lower diversity than a greater area of even a homogenous habitat according to the species-area curve (Colwell et al. 1994; Rice and Kelting 1955).

The accuracy of these conclusions can be investigated with further experimentation. Determination of foraging space, regardless of diet breadth, for the populations within each lake can help to confirm the observed reduction of diversity from the theoretical. The invertebrate densities and diversities can also contribute to an understanding of the driver of foraging

differences observed. Sampling of invertebrates would need to be done by a wide variety of methods to avoid arbitrary selection of available resources as well as developing an accurate measure of lake-wide diversity (Johnson 1980). Experimental manipulations of turbidity and available resources would also provide insight into the behavior and ability of sunfishes foraging in direction relation to turbidity alone. These future studies can help to confirm the behavior of fish foraging in Northern Wisconsin turbid lakes. An understanding of sunfish foraging behavior can lead to informed decisions about maintenance of water quality. Eutrophication of lakes can lead to variation in fish foraging abilities and in time fish population health. While maintaining actual prey density is essential, the impact of turbidity on the effective density is just as important to understand. This knowledge can also inform recreational fisherman searching for the biggest fish available, especially for sunfish which are a popular catch.

In conclusion, stomach contents were collected to measure the diets of sunfish in two lakes in Northwestern Wisconsin. The ability of foraging connected to turbidity was shown in contrast to our original hypothesis as greater turbidity allowed greater foraging. Despite this greater foraging, no diversity difference was measured. This consistency was most likely due to the increased ability to forage in decreasing foraging space; a significant difference in foraging behavior.

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References

Abrahams, Mark and Michael Kattenfeld. 1997. "The Role of Turbidity as a Constraint on Predator-Prey Interactions in Aquatic Environments." *Behavioral Ecology* 40(3):169–74. Retrieved (http://www.jstor.org/stable/4601315).

Blackwell, Brian G., Michael L. Brown, and David W. Willis. 2000. "Relative Weight (Wr) Status and Current Use in Fisheries Assessment and Management." *Reviews in Fisheries Science* 8(1):1–44. Retrieved (https://www.tandfonline.com/doi/full/10.1080/10641260091129161).

Bœuf, Gilles and Patrick Payan. 2001. "How Should Salinity Influence Fish Growth?" *Comparative Biochemistry and Physiology* 130:411–23.

Carlson, Robert E. 1977. "A Trophic State Index for Lakes." *Limnology and Oceanography* 22(2).

Chesson, Jean. 1978. "Measuring Preference in Selective Predation." *Ecology* 59(2):211–15.

Chizinski, C. J., K. L. Pope, G. R. Wilde, and R. E. Strauss. 2010. "Implications of Stunting on Morphology of Freshwater Fishes." *Journal of Fish Biology* 76:564–79.

Colwell, Robert K., Jonathan A. Coddington, Robert K. Colwell, and Jonathan A. Coddington. 1994. "Estimating Terrestrial Biodiversity through Extrapolation." *Philosophical Transaction: Biological Sciences* 345(1311):101–18.

Fraser, Neil H. C., Niel B. Metcalfe, and John E. Thorpe. 1993. "Temperature-Dependent Switch between Diurnal and Nocturnal Foraging in Salmon." *Proceedings: Biological Sciences*

252(1334):135–39.

Fullerton, Aimee H. and Gary A. Lamberti. 2006. "A Comparison of Habitat Use and Habitat-Specific Feeding Efficiency by Eurasian Ruffe (Gymnocephalus Cernuus) and Yellow Perch (Perca Flavescens)." *Ecology of Freshwater Fish* (Ogle 1998):1–9.

Fullerton, Aimee H., Gary A. Lamberti, David M. Lodge, and Martin B. Berg. 1998. "Prey Preferences of Eurasian Ruffe and Yellow Perch: Comparison of Laboratory Results with Composition of Great Lakes Benthos." *Journal of Great Lakes Research* 24(2):319–28. Retrieved (http://dx.doi.org/10.1016/S0380-1330(98)70823-8).

Gosch, NJC, LL Pierce, and KL Pope. 2010. "The Effect of Predation on Stunted and Nonstunted White Perch." *Ecology of Freshwater Fish* 19:401–7.

Graeb, Brian D. S. et al. 2011. "Ontogenetic Changes in Prey Preference and Foraging Ability of Yellow Perch: Insights Based on Relative Energetic Return of Prey." *Transactions of the American Fisheries Society* 135(6):1493–98.

Hartleb, Christopher F. and John R. Moring. 1995. "An Improved Gastric Lavage Device for Removing Stomach Contents from Live Fish." *Fisheries Research* 24(207).

Janssen, John and Michelle A. Luebke. 2004. "Preference for Rocky Habitat by Age-0 Yellow Perch and Alewives." *Journal of Great Lakes Research* 30(1):93–99. Retrieved (http://dx.doi.org/10.1016/S0380-1330(04)70332-9).

Johnson, Douglas H. 1980. "The Comparison of Usage and Availability Measurements for Evaluating Resource Preference." *Ecology* 61(1):65–71.

Murdoch, William W. 1969. "Switching in General Predators: Experiments on Predator Specificity and Stability of Prey Populations." *Ecological Monographs* 39(4):335–54.

Rice, Elroy L. and Ralph W. Kelting. 1955. "The Species--Area Curve." *Ecology* 36(1):7–11.

Schoener, Thomas W. 1971. "Theory of Feeding Strategies." *Annual Review of Ecology and Systematics* 2:369–404.

Swift, Theodore J. et al. 2006. "Water Clarity Modeling in Lake Tahoe : Linking Suspended Matter Characteristics to Secchi Depth." *Aquatic Science* 68:1–15.

UNDERC. 1987. *Aquatic Habitat Descriptions*.

Vinson, M. R. and T. R. Angradi. 2011. "Stomach Emptiness in Fishes: Sources of Variation and Study Design Implications." *Reviews in Fisheries Science* 19(2):63–73.

Werner, Earl E. and Donald J. Hall. 1974. "Optimal Foraging and the Size Selection of Prey by the Bluegill Sunfish (Lepomis Macrochirus)." *Ecology* 55(5):1042–52.

Werner, Earl E. and Donald J. Hall. 1979. "Foraging Efficiency and Habitat Switching in Competing Sunfishes." *Ecology* 60(2):256–64.

Tables

TABLE 1: LAKE CHARACTERISTICS CONTRIBUTING TO THE FORAGING OF THEIR FISH POPULATIONS. SECCHI DEPTH AS AN ACCEPTED MEASURE OF THE WATER CLARITY WAS USED TO CALCULATE CLARITY OF LAKE WATER, AND AVERAGES WERE FURTHER CALCULATED TO THE TROPHIC STATE INDEX (TSI) OF THE LAKE

MEASURE	Mean-Crampton	SE-Crampton	Mean-Morris	SE-Morris
SECCHI DEPTH	3.45 m	0.14 m	1.2	0.07

| TROPHIC STATE INDEX	42.1	NA	57.4	NA
EFFECTIVE SPECIES NUMBER	4.86	NA	3.87	NA

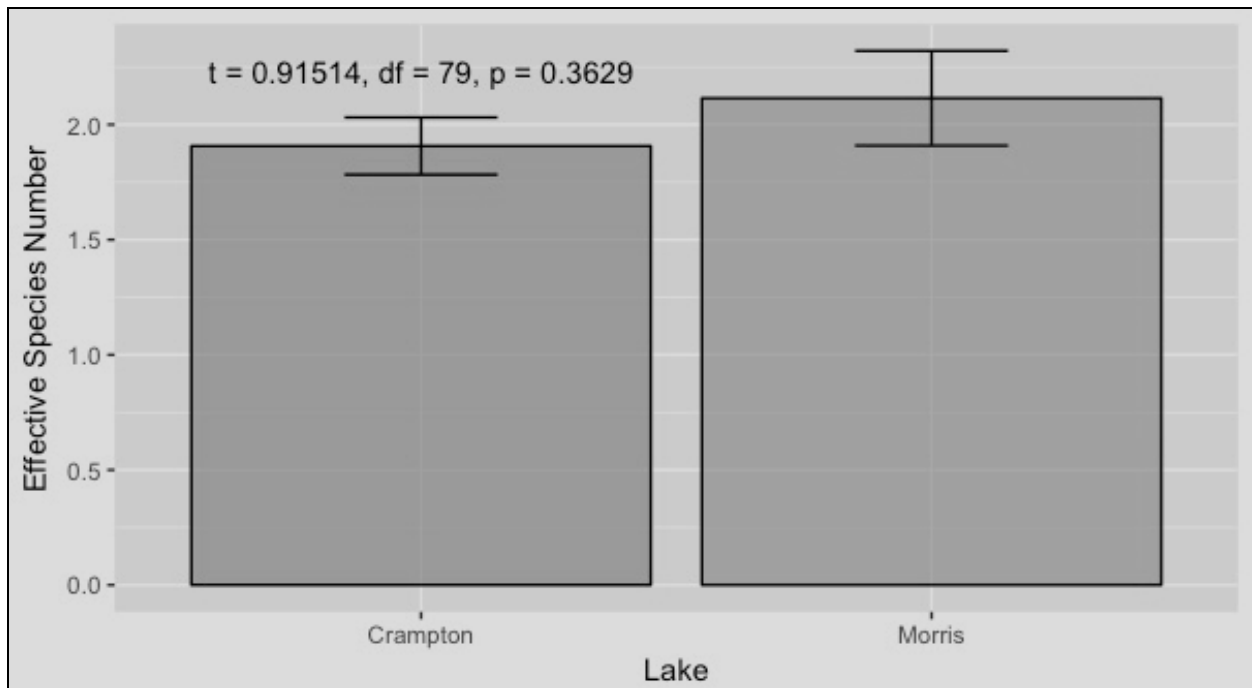**Figures**
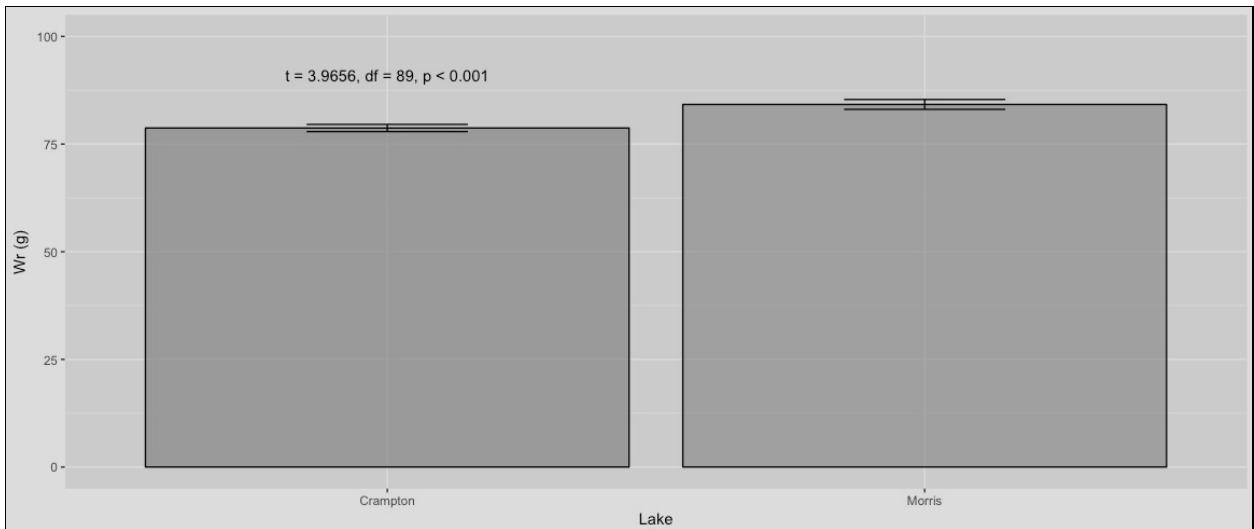
$t = 3.9656, df = 89, p < 0.001$

Figure 1: Health of sunfish populations measured by W_r differs between lakes. The average W_r of a fish in Morris lake was significantly higher than in Crampton indicating greater nutritional health in this turbid lake ($t = 3.9656$, df = 89, p<0.001).
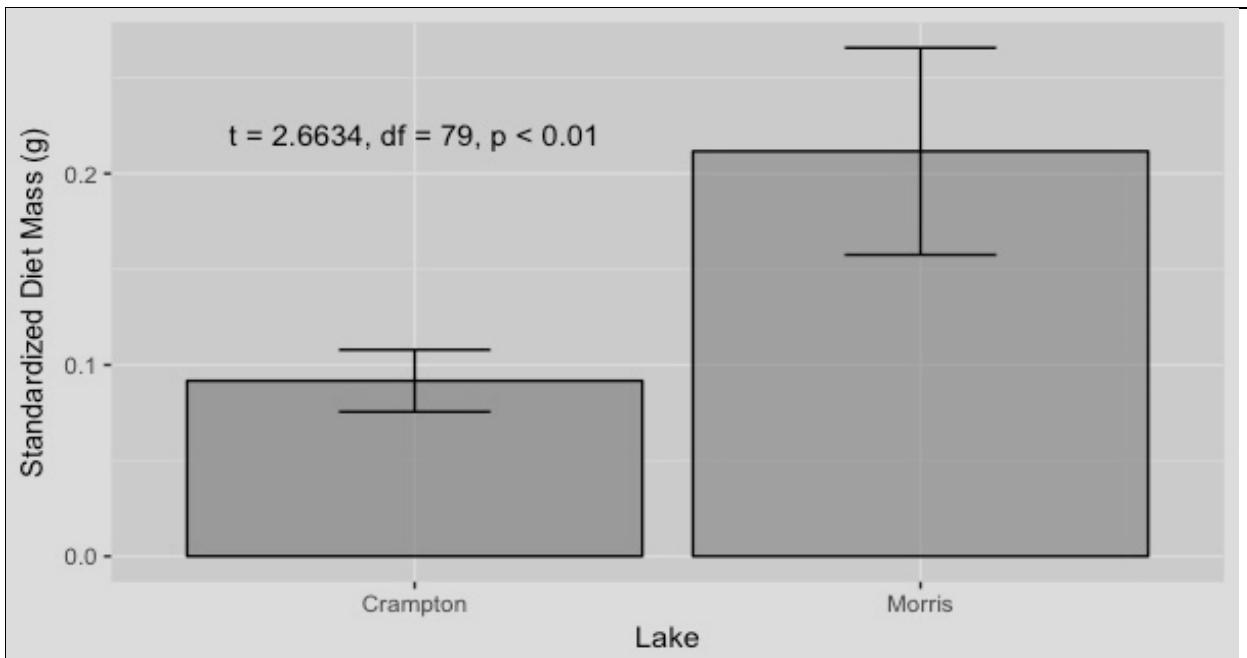
Figure 2: Standardized diet mass is greater in Morris lake. Diet mass standardized to body mass was larger in more turbid waters, which done consistently will result in greater health within the population (t = 2.6634, df = 79, p<0.01).
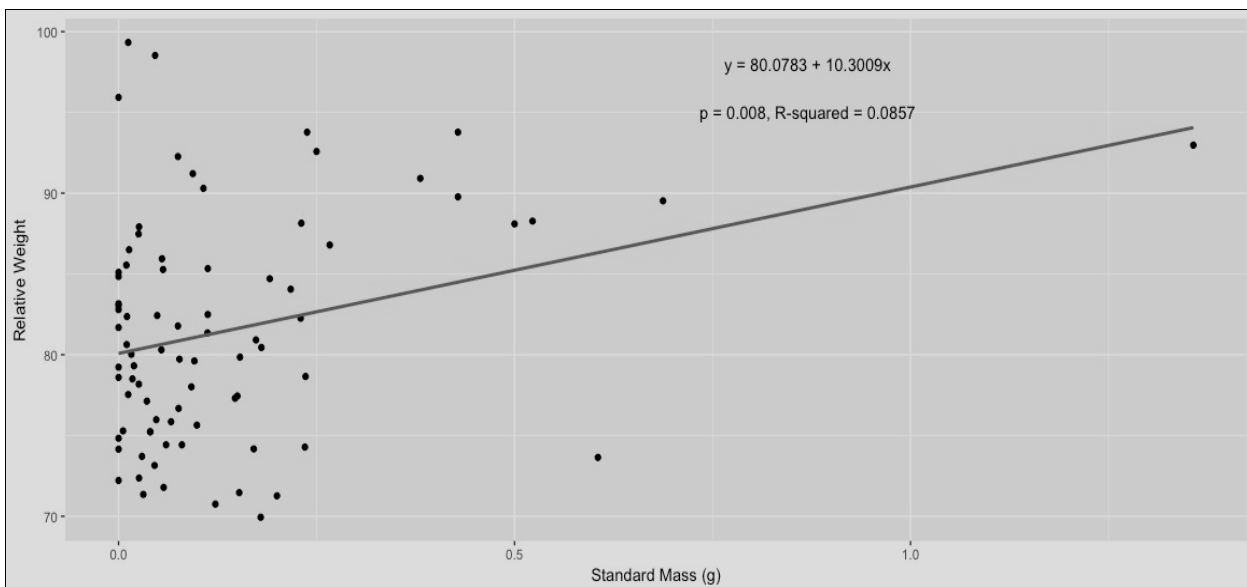
Figure 3: Standard Mass is positively related with relative weight. A significant, positive slope relating standard diet mass to the relative weight indicates that foraging ability is a cause of individual health (F = 7.405, df = 79, p = 0.008).

Figure 4: Diet diversity does not differ by lake turbidity. Diversity measured by the effective number of species within the diets of sunfish caught in Morris and Crampton lakes was not significantly different (t = 0.9151, df = 79, p = 0.3629).
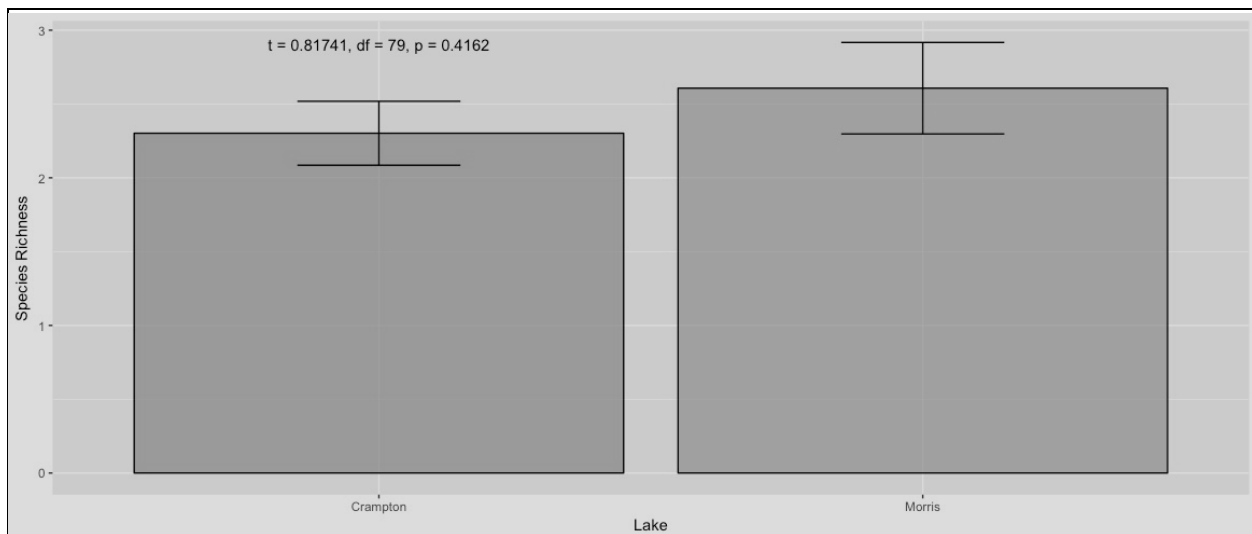
Figure 5: Species Richness does not differ by lake turbidity. In agreement with the diversity of species in diets, the average number of species present in a diet did not differ by lake (t = 0.81741, df = 79, p = 0.4162).
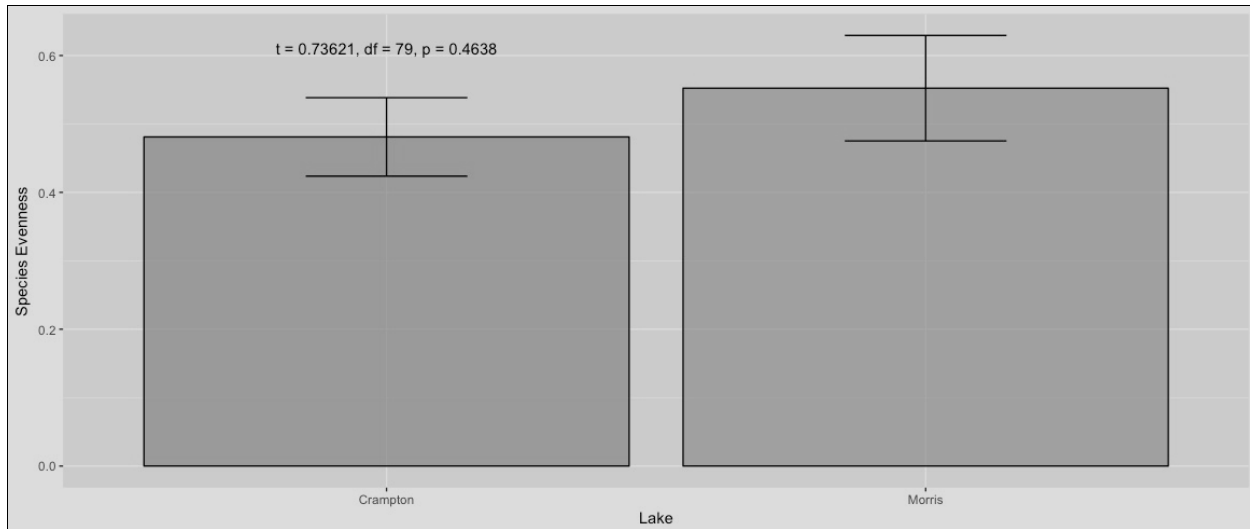
Figure 6: Species Evenness of diet is equal within the two lakes. Calculated by dividing the Shannon diversity index by the natural log of species richness, the evenness of diets was statistically equivalent in Morris and Crampton Lakes (t = 0.73621, df = 79, p = 0.4638).