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HAVE GOVERNMENT INCENTIVES LED TO AN INCREASE IN THE ADOPTION OF SOLAR PANELS?

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Abstract—**The Inflation Reduction Act of 2022 provides a tax credit for installations of renewable energy or battery storage that are completed between 2022 and 2034. The primary goal was to encourage citizens of the United States to reduce the use of fossil fuels and progress toward our climate goal of being carbon neutral by 2050. Numerous states have additional benefits for installing solar on top of the federal tax credit. Through the findings of this research paper, solar panel adoption increased as the Inflation Reduction Act of 2022 went into effect.**

I. INTRODUCTION

In 2021, the United States' emissions reached 6,430 million metric tons of carbon dioxide, about 15 tons per person. Electricity generation accounts for 25% of the United States' total greenhouse gas emissions (United States Environmental Protection Agency [US EPA], 2023). Generation from fossil fuels, including coal, natural gas, petroleum, and others, accounted for about 60%, nuclear energy created about 19% and renewable energy made up the remaining 21% (Energy Information Administration [EIA] 2, 2023). To produce a single kilowatt-hour of electricity in the United States, it takes 1.12 pounds of coal or 7.36 cubic feet of natural gas (EIA 1, 2023). As our greenhouse emissions increase, global warming is increasing at an alarming rate, as we are quickly approaching our 1.5 ℃ cap outlined in the Paris Agreement in 2016 (Dwortzan, 2023). If no changes are made soon, the world will be at risk of thawing the permafrost and releasing enormous quantities of carbon dioxide. Many nations, including the United States, have reevaluated their emissions and are aiming to reduce them through the Net Zero Emissions 2050 Scenario, which aims for the greenhouse gases that a country releases to balance with those that they are extracting from the atmosphere (Dwortzan, 2023).

To accomplish this, the United States has experimented with incentives to encourage households to install solar. Have government incentives led to an increase in the adoption of solar panels for homes and businesses?

II. Background

Solar technologies are designed to collect solar radiation and convert it into electrical current. The most popular and well-known solar panels are photovoltaics. As light strikes the semiconductor material, the light's energy will be converted to electrons. They will flow to the front of the cell, creating voltage as there is an imbalance in electrical charges between the front and back of the surface. This energy is collected by conductors that will either hold it in a battery or use it immediately for electricity (Airis Solutions, 2022). The amount of electricity the system produces can vary based on the latitude, how much direct sunlight it receives, and the efficiency of the panels (Airis Solutions, 2022). There are different coverage types based on the expected performance of the system, varying from completely off the electrical grid to utilizing batteries to store more energy (Go Green Solar). Community solar is also becoming an increasingly popular option, being responsible for 5.8 gigawatts of solar production, powering an average of 3,750 homes. In the next five years, six gigawatts of community solar are expected to be added in the United States, allowing thousands more homes to be powered by clean energy (McDevitt, 2023).

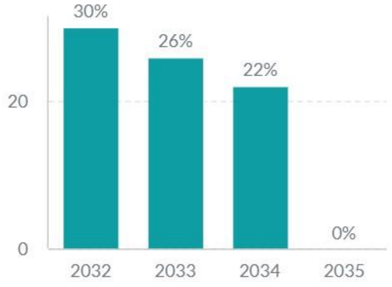
III. HISTORY

The government has the power to encourage the adoption of solar by incentivizing installations with tax credits. A tax break went into effect in 1977 and ended in 1984. During that span of time, about 924,000 households claimed the tax credit. Thirteen years later in 1997, President Clinton announced the Solar Roofs Initiative. In 2004, they had already reached an additional 900,000 systems (Kubasek, Silverman, 2013). The Energy Policy Act of 2005 created a 30% tax credit on solar energy technology. Initially meant to expire in 2006, it was extended through many laws till 2016, before dropping to a 10% credit (Solar Energy Industries Association [SEIA] 1).

IV. INFLATION REDUCTION ACT OF 2022

The Inflation Reduction Act of 2022 was signed into law by President Biden last year. The 10-year plan has the intention of advancing the United States towards its climate goals. Within its contents, there are credits on installations of renewable energy including solar, wind, geothermal, fuel cells, or battery storage. This tax credit, called the Residential Clean Energy Credit, is equal to 30% of the cost of new clean energy technologies that were fully installed between 2022 and 2032. For example, if a household spends $20,000 on the installation of solar panels on their home, they will receive a tax credit of $6,000. This amount would then reduce their income taxes by $6,000 that year. If their income tax does not exceed $6,000, it will be rolled over to the next year. After 2032, the percentage falls to 26% of expenses, to 22% in 2034, and reduced to 0% at the start of 2035 (Internal Revenue Service [IRS]). This is shown in Figure 1. Anyone in the United States can claim the tax credit if they own the system and have an income tax liability (Wigness, 2023).

Figure 1



Tax Credit Step Down. Data from IRS 2

V. State Incentives

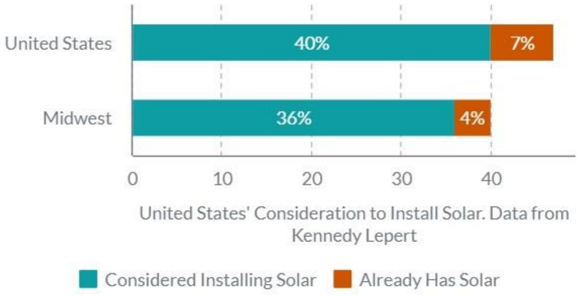
Not only does the United States have a tax credit for installations, but individual states have their own rebates or incentives for solar. In Minnesota, there are more than 100 incentives and rebates, including no sales or property tax (Database for State Incentives for Renewable and Efficiency [DSIRE USA], 2023).

Many states have adopted the same tax exemptions for solar. In Maine, a rebate from 2005 to 2008 led to a large increase in the adoption of solar panels. Similar situations have happened in other states like New Jersey, Washington, and Florida. Using tax exemptions and rebates, states can persuade citizens to adopt solar. In the United States, 40% of the population has considered installing solar, while 7% already has. In the Midwest, that number falls slightly to 36% have considered, and 4% already have (Leppert, Kennedy, 2022), demonstrated in Figure 2.

VI. Job Creation

Worldwide, there are almost four million people employed throughout the manufacturing, sales, installation, and maintenance of the solar industry. About 230,000 of which are in the United States (Ruiz, 2023). In Minnesota, there are about 4,000 (Minnesota Department of Natural Resources [MN DNR], 2021). Globally, solar heating and cooling employs another 820,000 people. There are now three times as many jobs in the solar industry than there were in 2012 (Ruiz, 2023). In the United States last year, the solar industry created more new jobs than any other energy subsector.

Figure 2



United States' Consideration to Install Solar. Data from Kennedy Lepert

VII. Benefits

Globally, 4.4% of global energy creation comes from solar (Ruiz, 2023). Adopting solar photovoltaic systems into the distribution grid will lower carbon consumption in the electricity sector. Solar systems installed before 2020 reduced over 860 million metric tons of carbon from electricity generation in the United States (International Energy Association [IEA], 2022). In 2010, renewable energy made up 8% of our energy production, solar energy produced only 1% (Kubasek, Silverman, pg. 336). Today, renewables are responsible for 21% of our electrical production, solar accounting for 3.5% (EIA 2, 2023). In Minnesota, a quarter of the state's power came from renewable sources in 2018, a large majority of it being sourced from wind (DSIRE USA, 2023). Today, there are 3.2 million homes that have solar installed (Ruiz, 2023). As the solar industry grows by 22% each year (SEIA 2), the prices are dropping, and the numerous credits, rebates, and incentives, makes the price per watt even cheaper. The average American home purchases 10,632 kilowatt-hours each year, about 886 kWh per month (Airis Solutions, 2022). As one solar panel on average generates about 0.17 to 0.35 kWh, it would take about 20 panels to fully power the average home (Watkins, 2023). Installation of solar panels was at an average cost of $0.381 per kilowatt hour in 2010. Today, not only are solar panels significantly more efficient, but the price has dropped to about $0.057 per kilowatt hour. After 8-12 years, the solar energy system should start making a profit for the average household (Ruiz, 2023).

VIII. Conclusion

The sun emits 173,000 terawatts of solar radiation on the Earth. Worldwide, electrical demand only adds up to 2.9 terawatts (University of Michigan, 2023). Only 0.3% of land would need to be covered with solar panels to provide enough energy for the world (Bellini, 2023). The United States' electrical demand could be met by covering 0.6% of land with solar panels (University of Michigan, 2023). In 2013, the world's solar capacity was at about 125 gigawatts. Since then, the world has reached 850.2 gigawatts of solar energy (Ruiz, 2023). Since the increase in solar adoption was during the same period as government incentives, we can conclude that the incentives were successful in their goal of increasing clean energy capacity.

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DO CHANNEL CATFISH CONSUME ZEBRA MUSSELS?

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Abstract**—Channel catfish *Ictalurus punctatus* are a generalized opportunistic feeder with a wide range of diet compositions. In the Midwest, zebra mussels *Dreissena polymorpha* have quickly spread, causing large effects on aquatic ecosystems structures and functions. Channel catfish are known to consume native mollusks, however, little research has been done on the potential predation of zebra mussels by channel catfish. Therefore, the objective of this study was to analyze channel catfish diets to determine if zebra mussels are consumed. The channel catfish were obtained from the Sauk River chain of lakes between the dates of 14 June and 28 July 2023. The stomach contents identified to the lowest classification possible and counted. A total of 4 zebra mussels were found in the 38 stomachs that were sampled. Channel catfish do eat zebra mussels but it is likely done unintentionally when targeting other prey.**

I. INTRODUCTION

Channel catfish *Ictalurus punctatus* are a benthic, dwelling species commonly found throughout Minnesota's large river systems and tributaries. Known to be a generalized opportunistic feeder, the species has been shown to have no dominant food source (Braun and Phelps 2016). Their diets consist of an abundance of different fish, aquatic invertebrates, and vascular plants, allowing for the species to thrive in a range of habitats. The wide habitat range can potentially provide a buffer from habitat degradation. In the Midwest, channel catfish are an important species as they provide great sportfish angling opportunities and are important commercially.

Zebra mussels *Dreissena polymorpha* are an invasive species to North America and are spreading throughout Minnesota. Existing as a freshwater bivalve filter feeder, this species can rapidly reproduce. Maturing within a year, females can produce up to a million eggs a year. (Borcherding 1991). Once established, zebra mussels are outcompeting the native filter feeders by feeding on algae, macroinvertebrates, bacteria, detritus, and other organic compounds (Vanderbush et al. 2021). This competition creates large effects on ecosystem structure and functions, as zebra mussels alter habitat, affect food availability for pelagic and benthic species, and affect oxygen availability, sedimentation rates, and mineralization of nutrients (Karatayev et al. 2002).

The introduction of zebra mussels has shown to provide additional prey items to certain species. Magoulick and Lewis (2002) found zebra mussels were the primary prey eaten by 52.9% of blue catfish *Ictalurus furcatus* and 48.2% of freshwater drum *Aplodinotus grunniens*. While channel catfish are known to feed on native mollusks, little research has been done on the potential predation of zebra mussels by channel catfish. However, Bowers and de Szalay (2007) has suggested large bodied molluscivorous fish like channel catfish can limit zebra mussel numbers in coastal wetlands. The objective of this study is to assess the diets of channel catfish to see if zebra mussels are preyed upon within the Sauk River chain of lakes.

II. METHODS

Channel catfish were collected using three different methods of capture, angling, hoop nets, and gillnets. All the fish were obtained from the Sauk River Chain of the lakes in Richmond Minnesota during the summer from the dates of 14 June to 28 July 2023. Four locations on the chain of lakes were chosen to account for different densities of zebra mussels. Zebra mussels were first documented in the system in 2017. Historically, the chain of lakes has been considered eutrophic to hyper eutrophic due to excessive nutrient loading. Lake-river ecotones provide good habitat for bivalves like zebra mussels due to easy access of food drifting lake to lake. Zebra mussels also prefer moderately eutrophic or highly eutrophicated lakes, which is likely caused by large amounts of food for zebra mussels in eutrophic systems (Czerniawski and Krepski 2021).

A total of 38 fish were captured by standard fishing equipment, line, and hook, tandem-set hoop nets, and gill nets. Gill nets were set in accordance with the standard survey methods of the Minnesota Department of Natural Resources (MNDNR 2023). Gill nets were set parallel with the shoreline in water 1.2-4.5 m deep. Tandem-set hoop nets were set with coinciding methodology from catch of channel catfish in lentic systems in Nebraska (Richters and Pope 2011). Tandem-set hoops nets consisted of three nets, attached bridle to cod end, with four concreate anchors. Anchors were attached to the cod end and middle nets to mitigate buoyancy and an anchor attached to the bridle end to prevent the hoop nets from collapsing. Nets were baited with powdered soy in a burlap bag with a float connected. The float was used to prevent fish from pulling the bag out of the hoop nets. Hoop nets measured 3.4 m in length, with seven fiberglass hoops. The largest fiberglass hoop measured approximately 0.7 m in diameter, successive hoops incrementally decreased by 3.8 cm towards the cod end of the net. The distance between each fiberglass hoop measured approximately 0.46 m. The netting was made with #15 nylon twine with two finger style attached to the second and fourth hoop. The finger style throats were attached with two 0.47 cm nylon twine that measure approximately 0.55 m. Attached to the cod end of the net were two 12.7 cm draw strings tied around the rear throat to reduce escape from the hoop nets. The hoop nets were set parallel to the shoreline in 1.8-3 m of water.

Once a fish was collected, total length (mm) and weight (g) were measured. Once measured, the stomach contents were removed from the fish, and the stomach contents were placed in a bag containing 70% ethanol. Ethanol was added to prevent decomposition of the stomach matter. The bag was given an identification number with the individual fish’s total length and weight attached. The bags were then stored at room temperature to be analyzed in the laboratory at a later date.

In the lab, items found in stomach contents were weighed, counted, and examined under a compound microscope. Stomach contents were then identified to the lowest classification possible. After the stomach contents were classified, diet items were then separated by species for each individual stomach, then put into a drying oven to obtain each stomachs dry weight.

Once all the diets were processed, program R was used to analyze the diets (R Core Team 2022). Frequency of occurrence and prey-specific abundance plot were created.

$$O_i = J_i/P$$

Frequency of occurrence (O_i) was calculated by dividing the number of fish diets (J_i) containing a certain prey item by the total number of fish diets (P).

$$P_i = S_i/Sti$$

Prey-specific abundance (P_i) was calculated by dividing the total number of prey-specific item (S_i) by the total number of prey items in diets that contained the specific prey item (S_{ti}).

The graphical model (Figure 11.3, Chipps et al. 2007) that depicts feeding strategy (specialized or generalized), relative prey importance (dominant or rare), and niche variation (individual or population pattern) was used to access any feeding strategies among the channel catfish.

III. Results

Stomach contents were collected from 38 channel catfish (345-620 mm TL). Across the 38 stomachs processed, a total of nine diet contents were found. Of the 293 diet items processed, four zebra mussels were consumed. Conidae were the most common diet item to be found, as they accounted for 74.40% of the diet items in channel catfish. Crangonyctidae were the second most common prey item found accounting for 16.38% of the diet items, while the third most common was *Lepomis* spp. accounting for 0.04%. Filamentous green algae were also found in the channel catfish stomachs, as 47.37% of stomachs contained algae (Figure 1).

Fig. 1. Channel catfish stomach containing filamentous green algae.

Frequency of occurrence and prey specific abundance plots were used to differentiate the population of channel catfish feeding habits, to an individual level. When channel catfish consumed *Lepomis* spp., it consisted of 86.67% of the stomach content items found across all stomachs sampled (Figure 2). The data also indicates that when channel catfish grew larger in length, the *Lepomis* spp. that they consumed were also larger.

IV. Discussion

A key finding of this study is that zebra mussels were consumed by channel catfish, however, in very low numbers. Channel catfish are considered to have a generalized opportunistic feeding strategy, in which they are omnivores (Braun and Phelps 2016). Within the stomachs that contained zebra mussels, filamentous algae was also found. Since channel catfish feed upon a variety of prey and in different habitats, the zebra mussels likely consumed unintentionally.

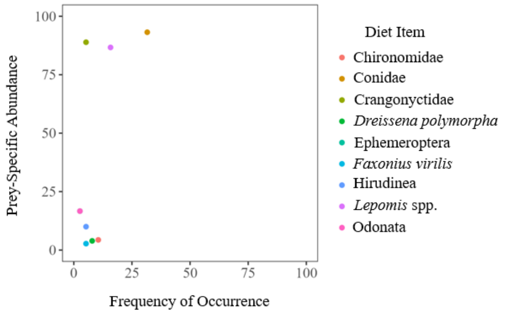

Fig. 2. Prey-specific abundance plotted against frequency of occurrence for each of the prey species in channel catfish.

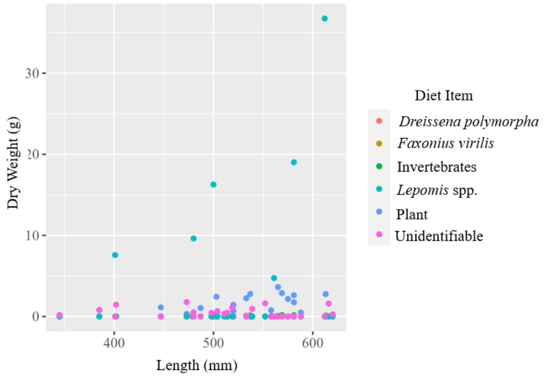

Fig. 3. Dry weight of stomach contents against length of channel catfish.

Another key finding from this study was that 47.37% of channel catfish stomachs contained filamentous green algae. The filamentous green algae had appeared to be important to larger fish (447-613 mm TL). This is similar to a study in California accessing diet contents of channel catfish. Filamentous algae had accounted for 17% of total biomass and had only been found in fish that were greater than 300 mm in total length (Marsh 1981).

The results showed that *Lepomis* spp. made up the bulk of the dry weight when ingested by channel catfish. *Lepomis* spp. consisted of 99% of the biomass of stomachs containing the diet item. In a similar study accessing channel catfish diets, when *Lepomis* spp. was consumed, it consisted of 77% of the diet (Braun and Phelps 2016). In this study, the other 1% of biomass present with *Lepomis* spp. consisted of two Conidae within one stomach. All other stomachs only contained *Lepomis* spp.

The results of this study concluded that channel catfish do consume zebra mussels, however, they are likely consumed unintentionally. Based on the results of this study, channel catfish should not be used as a management action to limit or decrease zebra mussel densities. The data suggests that there are potentially two different feeding styles of channel catfish. The first feeding style is one that feeds on the bottom consuming algae and invertebrates. The second feeding style is one that feeds on *Lepomis* spp., a free roaming prey item not found within the algae. However, it is unknown if individual channel catfish specialize in a feeding style or have a variety styles throughout the year.

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ESTIMATE OF LONG-TERM PHYTOPLANKTON BIOMASS IN LAKE BEMIDJI

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***Abstract*—Phytoplankton are photosynthetic organisms that are the base of aquatic food webs. In a dimictic temperate lake such as Lake Bemidji, the environment adjusts with the changing water temperatures and sunlight levels. The phytoplankton in a dimictic lake are adapted to subsist in long term seasonal changes but the exact change to the number of phytoplankton in unknown. The focus of this study was to estimate the biomass of phytoplankton in a long term period including winter stratification and summer peak. From a period between March 2023 and October 2023 water samples were collected from the lake in the south basin, filtered, and analyzed with spectrophotometry to find the chlorophyll a content. The data was graphed and analyzed with regression statistics to track the changing biomass of phytoplankton in the study period. The phytoplankton persisted in lower amounts under the ice, but significantly increased during the summer months, peaking in the fall and decreasing again along with decreasing temperatures.**

I. INTRODUCTION

Phytoplankton are organisms that make up the base of many aquatic ecosystems. Phytoplankton convert solar energy into food by photosynthesis, while also passing the energy on when getting consumed by other organisms. They can be found in the open water areas of water bodies and closer to shore. Phytoplankton can be found in bodies of water with high amounts of nutrients and primary productivity called eutrophic waters to those with a limited number of resources called oligotrophic waters.

In a stratified body of water, the majority of phytoplankton stay in a vertical layer called the deep chlorophyll maxima, influenced by mixing patterns, light availability, and nutrients (Klausmeier and Litchman 2001). Phytoplankton vertical distribution in a stratified water column is affected by an inverse relationship between light availability near the top and higher nutrient levels near the bottom (Mellard et al. 2011). There are qualities of phytoplankton that affect how they survive under the full year in a freshwater lake. Freshwater phytoplankton have a growth rate that is limited to water below 40 °C (Eppley 1972), meaning they can grow and reproduce under both winter and summer conditions of standard water temperatures. Some species of phytoplankton can regulate the intensity of light they receive by adjusting their depth in the water column, some even preferring lower intensity light (Richardson et al. 1983). The productive importance of phytoplankton species depends on the conditions of the lake. Depending on the season the dominant species of phytoplankton changes. In a simulation based on Lake Constance, the dominant species in late winter are diatoms or Cryptophycae. As the edible plankton get eaten by increasing herbivore populations, inedible plankton grow, and the herbivores decrease. The Cryptophycyeae and inedible algae dominate until diatoms become prominent, then diatoms are replaced by dinoflagellates (Sommer et al. 1986). Diatoms are more suited to colder water scenarios and in more temperate lakes than other phytoplankton (Lürling et al. 2013).

Phytoplankton exist in areas that can be covered in ice for a significant period of time. Lake Baikal, the largest freshwater lake by volume, has communities of microbes under the ice, mainly formed by groups of diatoms or dinoflagellates (Bashenkhaeva et al. 2015). In the arctic ocean, marine phytoplankton were found to bloom while still under ice cover with the right amount of sunlight (Hill et al. 2018). If not mobile, phytoplankton can survive under icy conditions through hibernation or reduced functionality, including the production of specialized cells (Bertilsson et al. 2013). In a seasonally freezing temperate lake, water temperatures decrease significantly when forming ice. Snowfall on top of the ice scatters some light away from the water, blocking out sunlight and decreasing photosynthesis. Wind is unable to mix the surface waters of the lake, with stratification of water levels occurring. Nutrients are not as distributed equally due to the stratification as well. Despite the negative changes phytoplankton have adaptations necessary to survive in the winter.

Lake Bemidji is a highly productive lake that freezes yearly. The organic compound chlorophyll a can be used to estimate the biomass of phytoplankton within the water. For example, a January 1981 study on four reservoirs in the Czech Republic found that as concentration of chlorophyll a in the reservoirs increased, the biomass of algae also increased (Desortová 1981). A study on five lakes of different trophic status in eastern Germany used four different methods of estimating phytoplankton biomass, including microscopic counts, constant chlorophyll a in proportion to wet weight, variable chlorophyll a ratio to wet weight in relation to biomass, and variable chlorophyll ratios to wet weight in relation to chlorophyll concentration. The three chlorophyll a based estimations all had strong statistical correlations to phytoplankton biomass (Kazprzac et al. 2008). It is important to know how phytoplankton species make an impact on a shallow eutrophic ecosystem during the winter months, first by measuring the concentrations of the chlorophyll.

Therefore, the objective of this study is to measure levels of chlorophyll a of Lake Bemidji in Minnesota from a time with ice covering the lake, until the fall turnover. This chlorophyll a data can be used to estimate how the biomass of phytoplankton changes over the seasons.

II. METHODS

Lake Bemidji, located in Bemidji, MN is a shallow eutrophic lake in the temperate region. Lake Bemidji is split into two basins and is connected to the Mississippi River for both the inflow and outflow of water. The sampling location was the south basin of Lake Bemidji (47.47930, -94.86962). Water sampling occurred every two weeks from March 1, 2023, to March 31, 2023, with a break during ice out, then from June 21, 2023, to August 9, 2023, and lastly a fall session from September 16, 2023 until turnover (Table 1).

TABLE 1: DATES OF DAYS WATER SAMPLES WERE COLLECTED FROM LAKE BEMIDJI SOUTH BASIN

Spring sessions	Summer sessions	Fall sessions
3/1/23	6/21/23	9/16/23
3/19/23	7/5/23	10/5/23
3/31/23	7/18/23	10/12/23
	8/9/23	10/19/23

During winter sampling, an ice auger was used to drill a hole into the ice and remove ice from the water. The HYDROLAB HL7 multiparameter sonde operating probe (OTT Hydromet, 2017) or YSI multiparameter meter were lowered into the water to measure water temperature and dissolved oxygen levels. Data was collected at the surface, one meter down, and if possible two meters down. With a two meter composite water sampler (a PVC pipe with two rubber stoppers), water was collected from the surface to two meters down. The pipe was lowered until close to submerged, and the top stopper was placed. The pipe was then removed from the hole as horizontally as possible, and the other stopper was placed on the other hole. The 1 L brown bottles were filled with water and placed into a cooler. The bottles were labeled with date and time. The process was repeated three times at close to 15 minute intervals. During warmer months, the sampling was conducted by boat. A boat was anchored around 30.5 m or less near the coordinates. From the boat the HYDROLAB or YSI were lowered into the water and operated per the procedure, and water collected into the brown bottles.

Each interval produced two brown bottles of sample water. The samples were filtered through 0.5 um 45 mm glass filters and placed into 15 mL plastic vials, with the water volume being recorded. The vials were kept cold in a refrigerator until needed, covered in aluminum foil. To prepare for spectrophotometry, 10 mL of acetone were placed in each vial for at least 10 hours before processing. The spectrophotometer machine was calibrated using 10 mL of acetone in a cuvette placed in the machine then the acetone disposed in a labeled container. The vials with the filters were placed in a centrifuge for five minutes with a speed of 2.8. When ready, the vial liquid was placed into the cuvette and placed into the machine for chlorophyll reading with a wavelength of 664. After reading, the liquid was disposed of in the waste bottle. Between every reading and calibration the cuvette was rinsed with deionized water. After every six vials, the spectrophotometer machine was recalibrated using acetone. Cuvette length, volume of acetone, volume of water sample, and the wavelength value were recorded.

Using a wavelength to concentration conversion, the chlorophyll content was produced.

$$\text{Chlorophyll (mg/m3)} = 12.31 * \lambda 664 * \text{Vol\_ext\_L}) / ((\text{Vol\_fil\_L}/1000) * \text{Cuvette\_length\_cm})$$

λ664 is the wavelength of light used for the spectrophotometer. (Vol_ext_L) is the volume of acetone added to each sample. (Vol_fil_L) is the volume of water filtered for each sample. (Cuvette_length_cm) is the length of the cuvette used for the spectrophotometry. The resulting concentrations were graphed in relation to the span of time of the study. To test for significant trends in chlorophyll, temperature, and dissolved oxygen over each individual season, regression was used.

III. RESULTS

Over the course of the study, water samples and probe data were collected from eleven separate days, divided into spring, summer, and fall sessions (Table 1). The number of chlorophyll samples totaled ninety-eight, and sixty-five data points for the water temperature and oxygen levels were collected.

In the spring session, the chlorophyll concentrations were below 5 mg/L (P=0.16). The chlorophyll increased significantly going into the summer session (P=0.01) until, where the chlorophyll

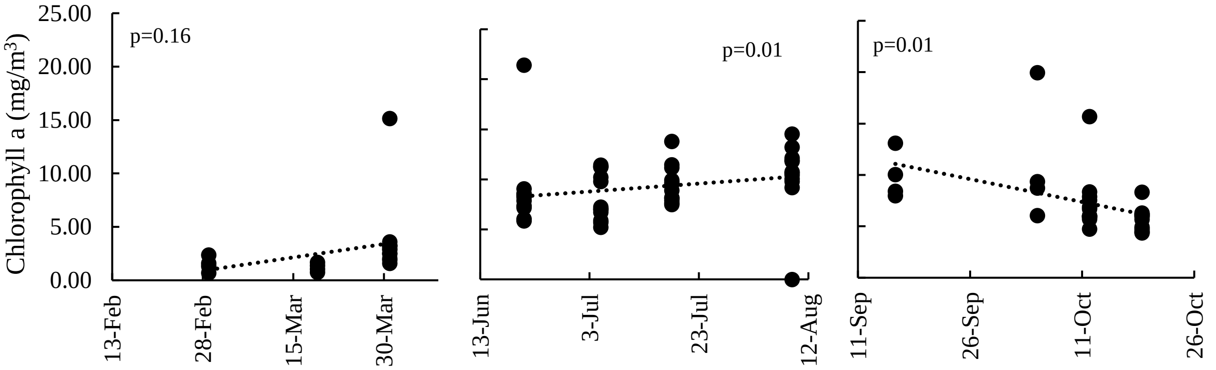

Fig. 1. Chlorophyll a measurements collected from Lake Bemidji water samples and processed using spectrophotometry. (Left to right: Spring session, Summer session, Fall Session; 2023)

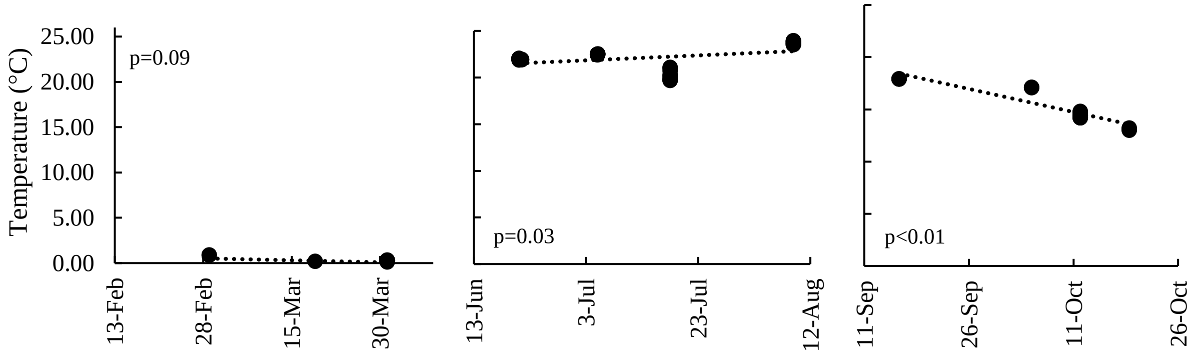

Fig. 2. Measured water temperatres (0-2 m) from Lake Bemidji Using HYDROLAB or YSI meters. (Left to right: Spring session, Summer session, Fall Session; 2023)

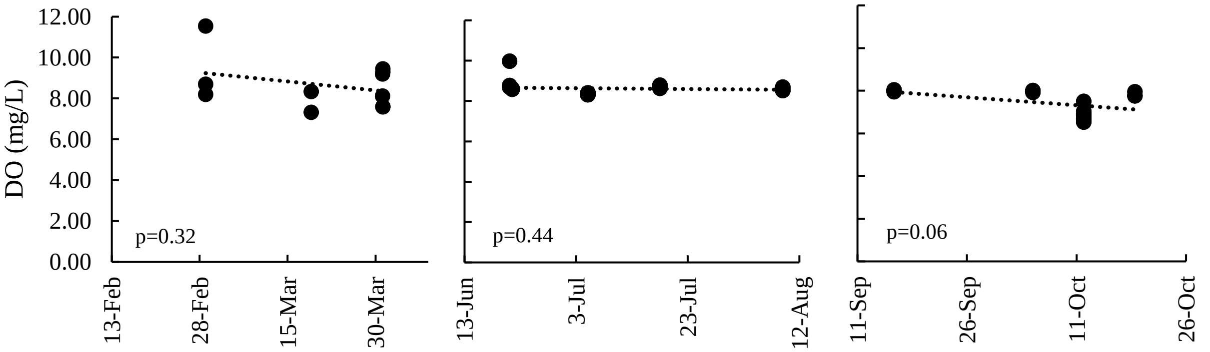

Figure 3: Dissolved oxygen concentrations measured from Lake Bemidji using HYDROLAB or YSI meters. (Left to right: Spring session, Summer session, Fall Session; 2023)

significantly decreases at (P=0.01). The water temperature data started in the spring between -0.13-0.93 °C (P=0.09), in relation to icy conditions of the lake (Figure 2). In the summer the water temperature increased substantially to levels between 19.30-23.95 °C (P=0.03). Temperatures decreased in the fall session between 17.93-13 °C (P<0.01).

The dissolved oxygen concentrations varied from a top value of 11.54 mg/L during the spring session (P=0.32), stable concentrations during the summer (P=0.44) and a lowest value of 6.53 mg/L in the fall (P=0.06) without statistically significant trends between the seasons.

IV. DISCUSSION

The chlorophyll concentrations were at their highest in late summer and fall. The chlorophyll concentrations of Lake Bemidji peaked in the months of August and September. In a study of chlorophyll concentrations in 56 north temperate lakes, the first peak of the eutrophic lakes occurred during spring months of March and April, while a second peak appeared during August and September (Marshall and Peters 1989). The specific trends of chlorophyll concentrations can vary significantly between water bodies. Six lakes on Beaver Island on Lake Michigan and Lake Michigan proper were sampled for phytoplankton biomass using both plankton counts and fluorometry for ten of twelve months (Butts and Carrick 2017). All seven lakes had unique biomass profiles, while four of the sites in particular had unimodal peaks similar to the trend seen in Lake Bemidji.

The dissolved oxygen did not make any statistically significant changes during the three separate sessions as well as the overall study span. Normally during months with ice cover, the lack of primary production and high demand for oxygen depletes it to lower levels (Zdorovennova et al. 2021). The dissolved oxygen levels did not increase from ice to open water transition. Dissolved oxygen has its highest concentrations near the top waters and decreases with depth. However, only the upper two meters of the lake were tested for the study, meaning the entire water column is not considered. The temperature of the water inversely effects the oxygen content, with higher temperatures carrying less oxygen (Harvey et al. 2011). From June to August the water temperatures were at their greatest, but the dissolved oxygen observed did not greatly decrease.

In conclusion, the concentrations of chlorophyll collected in Lake Bemidji existed in small but noticeable concentrations during the month of March under ice cover, grew steadily throughout the spring when the ice was removed, peaked in late summer and early fall, then decreased along with the water temperatures. Therefore, the biomass of phytoplankton can be estimated to be at its highest point of the season in the turn from summer to fall.

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LONG TERM TRENDS IN MORTALITY RATES OF A SMALLMOUTH BASS POPULATION

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***Abstract*—Smallmouth bass *Micropterus dolomieu* are known as a popular sport fish for anglers. When a known smallmouth bass fishery appears to have a dwindling population, it raises questions about the population health. A common indicator of the health of the population is the mortality rate. By comparing mortality, conclusions can be made on whether smallmouth bass are dying at a different rate in the system over time. Therefore, the objective of this study was to see if there had been a significant change in smallmouth bass mortality over a span of thirty years in Round Lake (DOW:010204), Aitkin County, Minnesota. Smallmouth were sampled using Minnesota Department of Natural Resources standard gillnets, trap nets, and electrofishing gear following their procedures for a standard lake survey. Once data was collected, annual mortality was calculated. Catch curves were analyzed using regression analysis and graphed with 95% confidence intervals. There was not a significant trend in mortality rates through time (P = 0.37), and there was overlap of confidence intervals among years. Mortality ranged from 0.05 to 0.61 with a mean of 0.29 (SD = 0.20) over the years sampled. It appears the mortality rates reported in this study are similar to those previously published for smallmouth bass in similar systems.**

I. INTRODUCTION

Smallmouth bass *Micropterus dolomieu* have been found to have a relative annual mortality, due to natural cause and in an unexploited system, of about 0.16 (Reed and Rabeni 1989). Knowing the mortality gives a good measure of how healthy a population is in a system. If the mortality rate is too high, it can lead to extinction or a low abundance of fish in the system. If mortality is low, then the population may become stunted in growth with low variance in size. Knowing how changes in mortality can affect the structure or condition of fish populations is important for analyzing overall species health.

Since mortality is an important statistic for fish populations, it has been calculated for many different systems. In some systems smallmouth bass mortality has been recorded at higher levels than previously discussed, at around 0.3-0.4 (Beamesderfer and North 1998). This variability in mortality may also be related to productivity, water quality, type of habitat available, or prey abundance (Forney 1972; Coutant 1975). Another influence on mortality is how far north the system is, as it has been found that mortality rates are generally lower the farther north it is. This was theorized to be related to the lower average temperature (Beamesderfer and North 1998). Different studies have shown that high fishing pressure can lead to higher mortality rates due to angling mortality. This would be non-natural mortalities but is something to take into consideration in lakes or streams that receive heavy fishing pressure. All the variables mentioned influence mortality and can cause it to change over time in a system.

Mortality gives a relative answer to how much of the population is dying yearly and could be compared to see trends over time. The objective of this study was to compare mortality rates over multiple lake surveys done by the Minnesota DNR from 1988 to 2018. This was done to see if the perceived loss of smallmouth was truly due to an increase in mortality rates.

II. METHODS

This study was conducted on Round Lake (DOW:010204) located near Garrison, MN in Aitkin County. Round Lake is a 767-acre lake with a maximum depth of 125 ft. The study used a collection of lake survey data sets, from the Minnesota Department of Natural Resources. The surveys were from 1988 through 2018 and were conducted every five years.

Standard gillnets and trap nets were all used to collect smallmouth bass in the lake surveys. Gillnets were set at twelve locations around the lake and had five different mesh sizes. The mesh sizes were ¾, 1, 1 ¼, 1 ½, and 2 in. The trap nets were standard ¾ in double frame nets, and there were twelve set sites spread around the lake as well. The sites for all the sampling techniques remained the same for each of the individual gear types. The collecting each year was conducted within a work week or until all the sites had been set and worked. The exception to this was in 1993, when a population assessment was done. During the population estimate there was an increased effort to catch fish, with increased net sets and manpower.

Once the smallmouth bass were captured, total length and wet weight were recorded. If possible, otoliths and scales were taken from ten fish in every ten-millimeter length class for each survey. Otoliths and scales were later analyzed to calculate the age of each fish and relative growth rates. Otoliths were aged using the crack and burn method, and scales were aged by back calculating using a body-scale constant of 36 mm. Aging was done by Minnesota DNR fisheries specialists at the Aitkin office.

All analyses were done with program R (R Core Team 2023). Using von Bertalanffy's growth model (von Bertalanffy 1957) the aged fish were used to generate estimated ages of fish that were sampled and then released without aging structures being taken. A catch curve model was used to show the number of fish of each age that were caught. Then a regression analysis was done on the catch curve to determine mortality with a 95% confidence interval. This process of finding mortality was done for each year that the lake was surveyed. Once mortality was calculated for each of the survey years, a regression analysis was run to test for a significant trend in mortality rates through time.

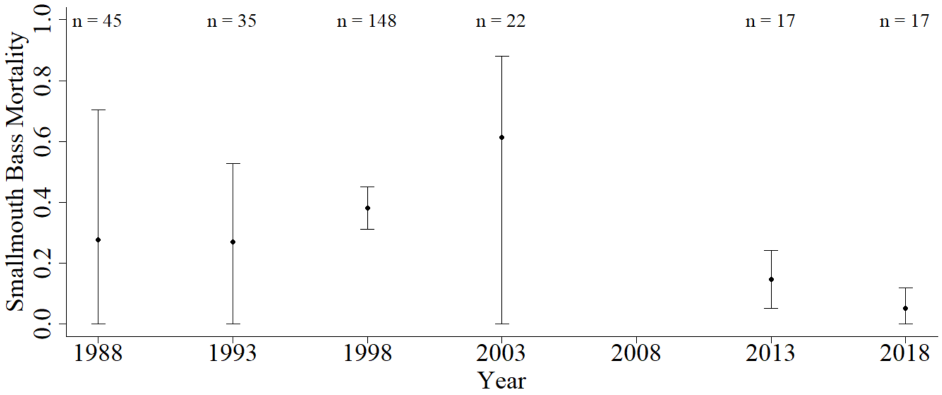

Fig. 1. Estimated smallmouth bass mortality calculated using a regression analysis with 95% confidence intervals. Collection years, shown on the x-axis, were between 1988 and 2018. Mortality is on the y-axis and ranges from zero, meaning no mortality, to one, meaning all fish have died.

III. RESULTS

The number of specimens collected each year ranged from 17 to 148. Overall, the smallmouth bass sampled ranged from 0 to 15 years old. Most fish were three or four years old. In 2008, there was no data recorded regarding age because of miscommunication on what fish structures were to be collected. Mortality ranged from 0.05 to 0.61 with a mean of 0.29 (SD = 0.20) over the years sampled. There was overlap among the confidence intervals (Figure 1). There was not a significant trend in mortality through time ($P = 0.37$). All individuals were graphed to create a historical growth curve (Figure 2). The maximum length of smallmouth bass was between 400 and 500 mm.

IV. DISCUSSION

The estimated average mortality for the system of 0.29 (SD = 0.20) falls almost exactly in the middle of the lowest and highest mortalities listed in literature of 0.16 and 0.40 (Beamesderfer and North 1998; Reed and Rabeni 1989). No trend was found in the recorded mortalities. However, in 2013 and 2018 the mortality was lower than the previous years. This may indicate a trend toward a change in mortality in recent years. The mortalities calculated for the last two years are close to the mortality, 0.16, calculated in a study of an unexploited system (Reed and Rabeni 1989). A decrease in the amount of fishing pressure on smallmouth bass could be a factor in this, and conducting a creel survey would further help to get an understanding of harvest mortality.

Smallmouth bass sampled in Round Lake reached quality lengths between two and six years of age and had a maximum length between 400 and 500 mm. The growth of smallmouth bass aligns with that found in literature. One study found that age at quality length, 280 mm, ranged from two to nine years for smallmouth bass (Beamesderfer and North 1998). A study done on smallmouth introduced into Nebraska lakes found that age seven smallmouth averaged 380 mm (Shall et al. 2016). Smallmouth at age seven in Round Lake averaged 424 mm. Growth of smallmouth bass and size at age seven indicate that Round Lake is a quality smallmouth fishery.

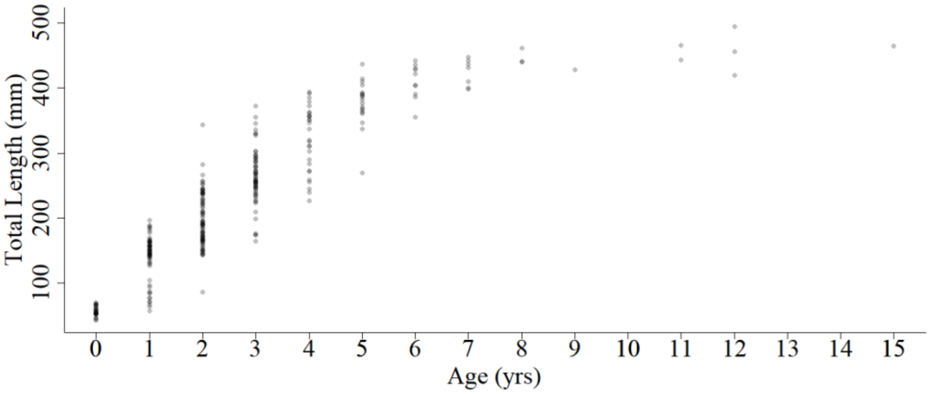

Fig. 2. Growth curve calculated using the von Bertalanffy method. Data was collected from 1988-2018. The data comprised of smallmouth bass ranging in age from zero to fifteen years, shown on the x-axis. The total lengths of each fish, in millimeters, was graphed on the y-axis.

During the last two years sampled, mortality rates were low which could potentially indicate the start of a trend. Future research should be done to further assess the mortality. If further sampling were to be done, it should be done at a higher level of consistency. The same sample gear should be used to capture all the specimens and not a combination of gear types. For optimal results of an accurate mortality estimate, it has been found that increasing sample size and at least ten fish per bin category is best (Coggins et al. 2013). The sample size achieved in 1998 of 148 fish and reaching ten fish per bin category should be used as goals for sample size in future years (Figure 1).

The perceived loss of smallmouth bass in Round Lake does not stem from a change in mortality. The smallmouth bass population has good growth rates and a quality size structure when compared with other smallmouth populations. Round Lake should continue to be monitored, to maintain the smallmouth fishery.

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THE EFFECTS OF LENGTH, WEIGHT, AGE, AND GENDER ON MERCURY CONCENTRATIONS IN BURBOT IN NORTH-CENTRAL MINNESOTA LAKES

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Abstract—**Burbot *Lota lota* in north-central Minnesota lakes have the potential to reach large sizes and consume large volumes of prey. This caveat may make burbot susceptible to higher rates of biocontamination, bioaccumulation and biomagnification. The objective of this study was to determine how changes in age, length, gender, weight, and lake affect total mercury concentrations in burbot. In this experiment 28 burbot were angled from three lakes: Cass (n = 17), Winnibigoshish (n = 4), and Bad Medicine (n = 7). Then tissue samples were taken from each fish and were lyophilized and homogenized. Homogenized tissue samples were analyzed by a Milestone TriCell Dual Beam Direct Mercury Analyzer (DMA-80evo) while following EPA protocol 7473. Average total mercury concentration was 0.1248 mg/kg (SD = 0.0717) in Cass Lake; 0.1022 mg/kg (SD = 0.0352) in Lake Winnibigoshish; and 0.0435 mg/kg (SD = 0.0176) in Bad Medicine Lake. Linear regression analysis using AIC scores were used to determine the effects of each variable on total mercury. The best supported model attributed changes in total mercury with changes in length, age, weight, and lake. It was found that as fish weight and length increase total mercury concentration increased. Furthermore, consumption advisory guidelines place burbot in 1-2 servings a week for safe consumption.**

I. INTRODUCTION

Mercury Hg is a dangerous aquatic contaminant that can significantly negatively impact human health (Rice et al. 2014). Mercury is most commonly found within contaminated fish, seafood, and wildlife (Rice et al. 2014). Mercury in aquatic systems is frequently found in two main forms, monomethylmercury $MeHg^+$, and environmental mercury or Hg_2^{2+} (Ullrich et al. 2001). Due to mercury's ability to bio-magnify and bioaccumulate, there is a need for state, federal, and tribal agencies to develop fish consumption advisory guidelines to ensure the safety and protection for their citizens.

Bioaccumulation is an issue for predatory fish species that have slower growth rates and live longer (Bentzen et al. 2016; Le Croizier et al. 2019). These are highly common phenotypic traits for burbot. Burbot are the only freshwater cod present in Minnesota and tend to be a slower growing, older, and benthic living fish species (Walther et al. 2022). Burbot are one of two species that have a circumpolar distribution (McPhail and Lindsey 1970). They often are used as a bioindicator of water quality and climate change (Stapanian et al. 2010). Similarly, burbot are frequently species of concern or endangered within their southern ranges with the rise of acidification, global warming, and aquatic pollution (Stapanian et al. 2010).

Since burbot generally have slow growth and potential to reach large lengths this makes them potential candidates for bioaccumulation and biomagnification. Additionally, burbot are widely sought after by anglers due to their white flakey meat with the frequent nickname being “poor man’s lobster”. Their common consumption by the public caused the need for a further analysis into total Hg concentrations in burbot. Therefore, the objective of this study was to determine the effects of length, weight, age, and gender on mercury concentrations in burbot in North-Central Minnesota lakes.

II. METHOD

Burbot were sampled from three lakes: Bad Medicine, Cass, and Winnibigoshish. Burbot were captured by conventional angling from the months of January until ice off during the 2023 ice fishing season. After landing, all burbot were euthanized by cranial concussion (Clark et al. 2012). Total number of burbot sampled were (n=28), with 22 males, and 6 females being captured.

Sample collection followed (US EPA 2000), and US Geological Survey (Scudder et al. 2008) sampling protocols. Measurements taken for each fish were total lengths (±1 mm), total weight (±1.00 g), sexual identification, and aging structures (otoliths) were recorded before collecting a ~30.00 g tissue sample. Skin-off tissue samples were taken on the left side anterior to the dorsal fin, while rolling the knife blade down the rib cage to limit bones from entering the tissue sample all while using a clean stainless-steel fillet knife. Additionally, diet contents were samples and preserved in 95% EtOH. Prey items were identified and taken to species. Tissue samples were rinsed with distilled and deionized water, weighed (wet weight) to the nearest 0.01 g, and placed in a clean sterile Whirl-Pak plastic bag. Whirl-Paks were labeled with Lake, Fish ID #, and gender. Tissue samples were transferred to a freezer (−20 °C) to be stored until lyophilization and homogenization. Tissue samples were lyophilized with a Harvest Right stainless-steel freeze dryer; approximately 24 hours of run time from frozen to a freeze-dried sample. Each sample was homogenized using porcelain mortar and pestles, weighed (± 0.01 g) for wet vs. dry weight conversions, and placed in 100 mL amber Boston vial.

Samples were analyzed using a Milestone TriCell Dual Beam Direct Mercury Analyzer (DMA-80evo) following EPA protocol 7473 (US EPA 2007). A 3-point calibration curve was developed using a serial dilution of a 1000 mg/kg Hg solution in 3% nitric acid. With the three standard solutions at concentrations of 0.9868, 0.09387, and 0.00958 mg/kg. The R^2 value of the calibration curve was found to be 0.9990. One DORM-4 sample, was used to verify EPA method 7473. All sample concentrations were converted from dry weight concentration to wet weight concentrations. Sample boats were brushed clean of ash and ran back through the DMA-80evo for sterilization after each sample run and stored in a new zip-sealed bag.

Following mercury analyzation linear regression analysis based on AIC scoring (Sakamoto et al. 1986) was completed to determine the affect the variables of age, length, weight, gender, and lake had on total mercury concentrations.

III. Results

Average total mercury was 0.1248 mg/kg (SD = 0.0717) in Cass Lake, 0.1022 mg/kg (SD = 0.0352) in Lake Winnibigoshish, and 0.0435 mg/kg (SD = 0.0176) in Bad Medicine Lake (Figure 1). Of the 29 burbot captured 17 were sampled from Cass Lake (2 females, and 15 males), 4 were sampled from Lake Winnibigoshish (2 females and 2 male), and 7 from Bad Medicine Lake (2 females and 5 males). AIC scores were calculated using total mercury as a function of age, length, lake, sex, and weight. As a result, 10 models were constructed based on a combination of these variables. AIC scores ranged from -95.85 and -61.46 with a maximum ΔAIC value of -34.39. Furthermore, R^2 values ranged from 0.000 to 0.7951 (Table 1). An additive model where mercury as a function of changes of lake, age, weight, and length produced the best AIC score and explained 79.51% of the variation in Hg concentration variability (Figure 2).

TABLE 1. MODELS USED TO PREDICT Hg CONCENTRATIONS IN BURBOT FROM BAD MEDICINE LAKE, CASS LAKE, AND LAKE WINNIBIGOSHISH.

Model	AIC	ΔAIC	R^2
Hg~Length+Weight+Lake+Age	-95.9	0	0.795
Hg~Age+Length	-92.3	-3.57	0.712
Hg~Length	-91.4	-4.45	0.681
Hg~Length+Weight+Lake	-91.1	-4.80	0.739
Hg~Length+Weight+Age	-90.4	-5.50	0.712
Hg~Length+Weight	-89.8	-6.03	0.685
Hg ~Weight	-87.9	-7.99	0.637
Hg~Age	-81.4	-14.5	0.543
Hg~Lake	-75.7	-20.1	0.479
Hg~Gender	-61.7	-34.2	0.199
Hg ~ 1	-61.5	-34.3	0.000

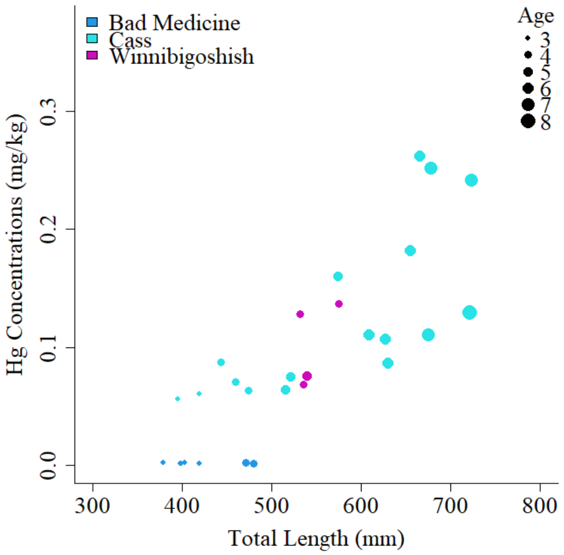

Fig. 1. Mercury concentrations (mg/kg) as a function of length (mm) from Bad Medicine Lake (blue), Cass Lake (green), and Lake Winnibigoshish (violet). Point sizes are weighted based on the age of individual burbot, larger points are older individuals. Burbot ages range from 3 to 8 years.

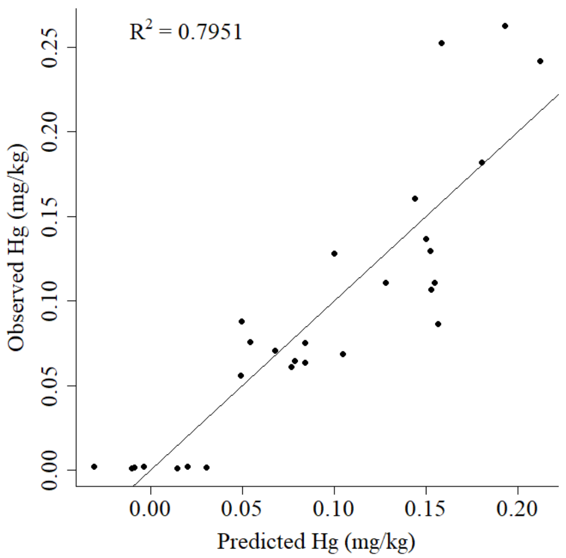

Fig. 2. Predictive model used to estimate Hg in burbot from Bad Medicine Lake, Cass Lake, and Lake Winnibigoshish. An additive model with four different variables length, age, weight, and lake was used to estimate Hg concentrations.

IV. DISCUSSION

The condition of burbot showed to be a major factor in total mercury accumulation. As burbot grew older, to longer lengths, and to heavier weights mercury concentrations increased dramatically. Fish require more calories and prey items to grow to these larger sizes which may contribute to mercury bioaccumulation leading to biomagnification (Kidd et al. 2012). Findings from the diet study suggested that prey items for burbot were low sources of mercury. Primary food sources were found to be crayfish, *Faxonius* sp. and other macroinvertebrates which are low in total mercury (Karmi et al. 2016). This allows for higher prey consumption with low risk of mercury accumulation for burbot. Besides diet and condition there may be other variables that also contribute to mercury accumulation in burbot.

Additionally, changes in the aquatic system had a significant effect on total mercury concentrations and bioaccumulation in burbot. Mercury is a biogeochemical that has a total maximum daily load of 0.2 mg/kg in fish tissue (MNPCA 2007). Two systems that were sampled within this study, Winnibigoshish and Cass are also connected by the Mississippi river which may contribute to possible mercury loading and lead to increased bioaccumulation. This is due to mercury being trapped in the sediment, and when the sediment is moved down stream during high water events sediment will load in exorheic systems. Furthermore, another discrepancy that may be affecting a difference in aquatic system is that the food web in each system may be slightly different at the benthic level. Burbot in all three systems may be selecting specific prey items more heavily than others resulting in different rates of bioaccumulation.

In contrast, this study suggests there is a drastic difference in mercury concentrations when compared to other Minnesota gamefish. More specifically when compared to mercury concentrations in northern pike *Esox lucius* and walleye *Sander vitreus.* For a point of reference, average mercury concentration in walleye with an average length of 380 mm was 0.268 mg/kg, and northern pike with an average of 560 mm had a mercury concentration of 0.320 mg/kg (MNPCA 2017). When these concentrations are compared to burbot at 533 mm average length mercury concentration were found to be 0.091 mg/kg. Based on these baseline averages northern pike had 3.5 times more mercury and 2.9 times more mercury in walleye. This makes burbot an excellent species for eating within mercury risk groups more specifically young children and pregnant women.

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A GUIDE TO OTOLITHS OF MINNESOTA FISHES

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***Abstract*—Investigations into the diet patterns of piscivores can provide crucial information on predator-prey relationships, population dynamics, and responses to changing ecosystems. However, digestive processes often remove or alter physical characteristics that are traditionally used to identify consumed fish. This problem has been addressed to some degree with advances in molecular technologies, although these methods can be costly and require specific training and equipment to do so. In contrast, bony structures such as otoliths, vertebrae, cleithra, and others frequently have morphologies that are unique among families, genera, and species. Because these structures are resistant to digestion, they can be used to identify prey fishes effectively and efficiently in varying states of digestion, if the investigator has access to reference specimens or photos from identified taxa. Although some reference materials for identifying bony structures are available, many are specific to a small number of species. This is especially true for otoliths, which are often more difficult to differentiate among species. To address this issue, we have compiled a photographic atlas of sagittal and astericus otoliths for fishes of Minnesota that have been identified in previous diet studies and during summer sampling within the state. In addition to photographs, this guide will provide insights on distinct morphological characteristics and key differences among similar species, making this a useful resource for investigations of piscivore diets in Minnesota and the surrounding area.**

I. INTRODUCTION

Fisheries managers often use diet studies from piscivores to quantify prey abundance, feeding interactions, habitat use and niche overlap between species (Chipps et al. 2007, Pierce et al. 1991). Identifying the contents of those diets can be very time consuming especially when fully intact specimens are not found, due to the quick digestion of soft tissue. As a result, hard structures such as otoliths, cleithra, vertebrae, scales, and pharyngeal teeth are often the only items left inside the stomachs. These structures consist of traits that aid in identification of the prey (Garman 1982; Holland-Bartels et al. 1990; Traynor et al. 2010).

Otolith shape and size vary heavily by species depending on body shape, habitat, and spawning practices, allowing for species identification, and making them especially beneficial to diet studies (Youssef. et al 2016). In a study in southern Georgia, otoliths proved helpful in the identification of species in predators' diets (Reid et al. 1996). Otoliths are hard calcium carbonate structures found in bony fishes (class Osteichthyes). These structures aid in the fish's ability to balance and hear. There are three pairs, sagittate (often the largest and main focus of this study), lapilli, and asterisci (certain sets extracted and photographed), that are found suspended inside a fluid filled sac near the inner ear (Secor et al. 1992). Otoliths are most commonly used as an ageing structure for fish as their annuli tend to be more accurate than other structures (e.g., scales or fin rays; Haglund et al. 2017). These accurate age estimates can influence management practices like stocking, size limits and harvest limits (Allen et al. 2010). Another concept otoliths are used for is microchemistry. Otolith microchemistry looks at the chemical composition and mineral accumulation inside the otolith. Often otoliths develop distinct trace elements to allow for analyses. This allows researchers to gauge environmental histories, diet, pollution exposer, movements, and habitat changes (Sturrock et al. 2015).

As the 21st century continues, otoliths are still being used for ageing, past history, movements and identification. Small photo inventories of otoliths exist, like the Lackman Labs online inventory of otoliths from mid-western species (bigmouthbuffalo.org/otolith/), but references for marine species are generally more common (Campana 2004). Recent studies have revealed morphological differences in shape and size of otoliths depending on geographic location of the species, which could provide difficulties for using them worldwide (Capoccioni et al. 2010). The objective of this study is to produce a photographic atlas of otoliths of Minnesota fishes to provide insight to future diet analyses and other research centered around otoliths.

II. METHODS

In this study, fish were collected by the Minnesota Department of Natural Resources (MNDNR), Minnesota Pollution Control Agency (MPCA), and by anglers. Fish were collected across the entire state of

Minnesota, including border waters Lake Superior and the Red River of the North. Fish captured by the MNDNR and MPCA were collected using standard surveying practices. These practices included gill netting, electrofishing (boat, mini-boom, and backpack), seining, and angling. Collected fish that were 300 mm total length (TL) or smaller were placed in voucher containers filled with 10% formalin until voucher containers could be washed with deionized water and then refilled with 70% ethanol. All fish over 300 mm TL were placed in bags and frozen until otoliths could be extracted.

Otolith extraction was the most time consuming and tedious part of this study. Representative fish were selected based on two main criteria: (1) specimens looked to have no abnormalities which could affect growth of hard structures and (2) specimens were older than age-0. Otoliths were extracted using the "through-the-gills" method for fish 100 mm TL or larger and the "between-the-eyes" method for fish smaller than 100 mm TL (Long and Grabowski 2017).

Extracted otoliths were placed into a scintillation vial filled with distilled water to ensure they would not dry out and crack or deteriorate prior to being photographed. Otoliths were photographed using an Olympus EP 50 digital microscope camera paired with an Olympus SZX10 microscope (Olympus Corporation, Tokyo). They were placed on their distal surface with their anterior end facing down, oriented to match their original location in the fish (i.e., the otolith to the left in the photo is the otolith from the left side of the fish; Campana 2004). A scale bar (2 mm long) was included on all photos to show relative size. Photos of otoliths were sorted into families and are placed accordingly in the guide.

III. RESULTS

Otoliths were collected from individuals representing 11 families, 37 genera, and 46 species. Similar to other structures, there were patterns in otolith morphology that were consistent within families and genera. Brief descriptions of the overall morphology for families and genera are listed below. Differences in morphology became more subtle with higher taxonomic resolution, but certain genera and species could still be differentiated. The descriptions and photographs below will provide a resource to identify specimens based on otolith morphology. Figure 1 shows general positioning of otolith inside a fishes head.

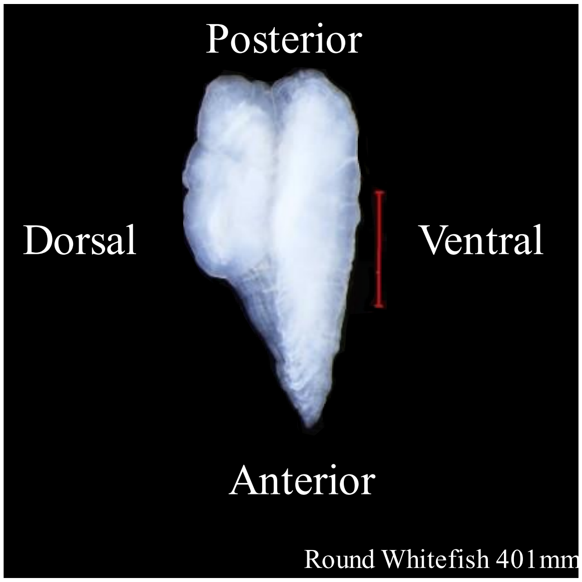

Figure 1. Positioning of otoliths inside the fish.

Amiidae

Otoliths can be characterized with an oval shape, with a wider posterior end and a narrower ventral end. Serrated edges surround the entire circumference of the otolith with deeper serrations on the posrior end. Only the bowfin *Amia ocellicauda* belongs to this family (Figure 2).

Catostomidae

Otoliths can be characterized by a circular to oval shape. Unlike the Amiidae, the circumference is much smoother along the edges of most species in the family, except for the white sucker *Catostomus commersonii*, where light serrations can be found. There are one to three projections extending from the ventral side of the otoliths depending on species (Figures 3-4).

Centrarchidae

Centrarchidae otoliths have two main shapes. Otoliths from *Ambloplites*, *Lepomis*, and *Pomoxis* generally have a wider oval shape with two lobes on the anterior end of the otoliths. The dorsal half is smoother and contains less severe serrations than the ventral half, and these three genera have relatively large otoliths compared to the size of the fish. *Micropterus* have a thinner, longer oval shape with visually sharper lobes compared to the other three genera. Serrations are found along most of the circumference, but smaller serrations are noted on the posterior end (Figures 5-8).

Cottidae

Cottidae otoliths have very smooth circumference with a unique oval shape. At the posterior end it is wide and there are two small lobes that appear very rounded. As you go farther to the anterior end it narrows down and comes to a rounded point. The two species collected within the Cottidae family are very similar in both shape and size (Figure 9).

Leuciscidae

This family was the largest sampled and recorded in this study. Luesciscidae otoliths are all very similar in shape and size. They appear to have a very round shape and rigid along the entire circumference. Certain genera have larger projections than others and the photos below will be very helpful in identification of species (Figures 10-15).

Esocidae

Of the two species collected from Esocidae both are from the genus *Esox* (Northern Pike *Esox lucius*, Muskellunge, *Esox masquinongy*). These otoliths have a very unique shape, unlike the other families. These otoliths have a wider, almost squared posterior end, narrowing down to a curved anterior end that comes to a point. Although both are very similar in shape and size both have unique attributes to allow for identification (Figures 16-17).

Gadiddae

Gadidae is another family that have otoliths with a unique shape. They are very large for the size of fish and are longer than they are wide. They have a very straight and smooth dorsal side, with a large gradually lobed and rigid ventral side. Both the posterior and anterior ends are rounded with the anterior end slightly sharper (Figure 18).

Hiodontidae

Only one species was collected in the study. The otoliths had a robust build to them with a unique shape. The shape resembles a heart with the dorsal side containing two rounded lobes, with a deep triangular cut in between them. The ventral side came down to a rounded point, with a small secondary lobe on the posterior edge of the otolith (photo from Long et al. 2021 was used for interpretation of otolith).

Ictaluridae

Two genera (*Amerius*, *Ictaluris*) were gathered from the Ictaluridae family. Both sets of otoliths recovered had a very round shape. *Amerius* otoliths seemed to have more and deeper serrations along circumference, with a small projection at the anterior end. *Ictaluris* had a smoother circumference although small serrations were noted, and the projection at the anterior end was larger and had a deeper ident (Figure 19).

Percidae

Four genera were collected in the family Pericdae, (*Ethostoma*, *Perca*, *Percina*, *Sander*) totaling six species. Overall, all have a relatively similar shape, looking like a compressed oval with a rounded anterior end and a lobe on the ventral side. *Etheostoma* and *Percina* have a smooth circumference, where *Perca* and *Sander* have a serrated circumference. *Percina* has a larger indent on the anterior side before the lobe, where *Etheostoma* is much more gradual and less noticed. Overall size will also help differentiate between genera (photo from Lackmann Otolith Lab used to interpret walleye otolith) (Figures 20-23).

Salmonidae

Three genera were collected in the family Salmonidae (*Coregonus, Onchorhyncus, Salvelinus*), all with a similar general shape. Consisting of a wider posterior end, narrowing down to pointed or rounded anterior end. *Coregonus* otoliths were very large for the size of fish and had a sharper point at the anterior end compared to other genera. *Onchorhyncus* otoliths varied the most in their genus ranging from very small to large and robust. *Salvelinus* otoliths had a much more gradually rounded posterior end than other genera in this family (Figures 24-34).

IV. DISCUSSION

In this study, a photographic inventory was created that documented morphological variations in the otoliths of the several families, genera and species present in Minnesota. Differences between morphology of otoliths are greatest at the family and genus levels, although differences between species are noted but less extreme. Even though differences at species level are not as drastic in certain species, the photographs should prove useful to differentiate between species of similar morphology that may be in question. Although otoliths can often be used for identification to species, their small size hinders their ability to be useful in all instances. In these cases, other structures such as otoliths, clithera, or pharyngeal teeth (Garmin 1982, Traynor et al. 2010) are likely more practical.

In the instance of extra specimens' additional sets of otoliths were pulled to see if there was variation amongst morphology. Although slight differences were noted, overall size was the biggest variation between the sets recovered. During the study, total length of the specimen that otoliths were recovered from was the only statistic recorded. Only measuring the total length of the specimen brought to question if there would be a difference in otolith morphology from male to females in the species. Many fish species are known to have sexual dimorphism. In a study looking at one species, *Oryzias dancena* (Indian Ricefish) it found a significant difference in many characteristics between sexes (Im et al. 2016).

Overall, otoliths are still and will continue to be a reliable asset to diet studies. Having the ability to identify partially digested prey inside stomachs down to families, genera, and species is beneficial to managers and researchers looking at predator-prey relationships and niche overlap. Although, additional studies are needed to see if there are variations in otolith morphology based on sex, geographical isolation and other factors that might influence difference in species.

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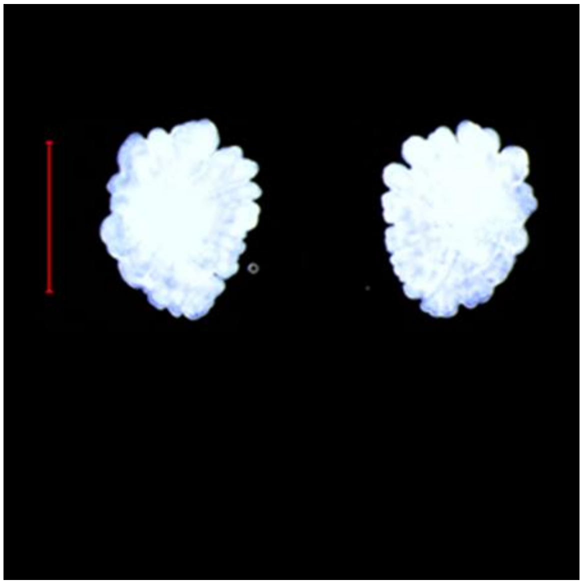

Figure 2: Bowfin (*Amia ocellicauda*) TL 220mm

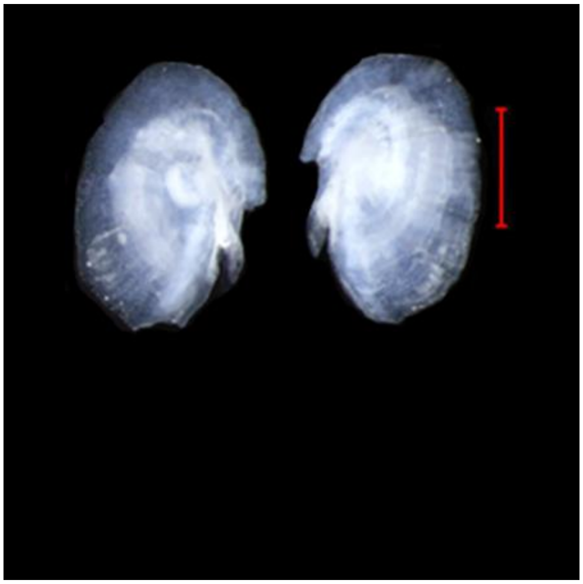

Figure 4: Shorthead Redhorse (*Moxostoma macrolepidotom)* TL 343mm

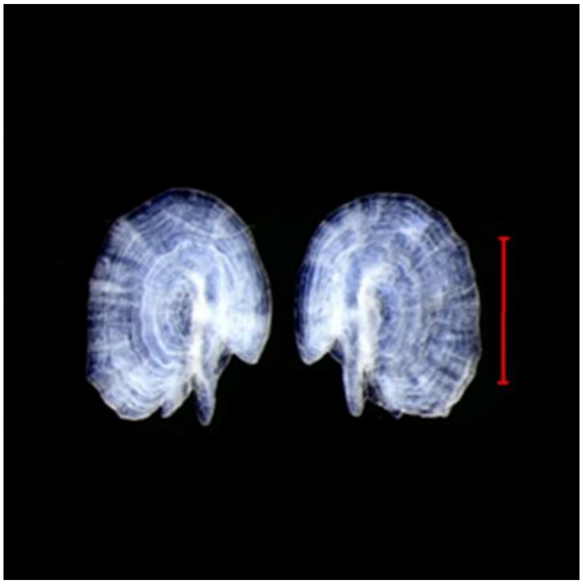

Figure 3: Longnose Sucker (*Catostomus catostomus*) TL 287mm

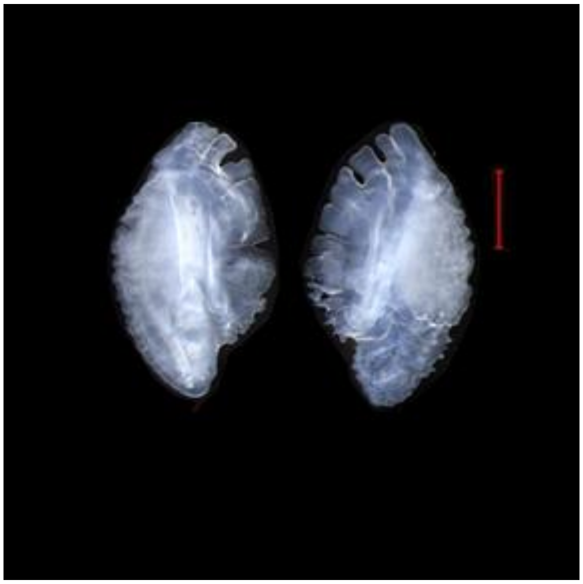

Figure 5: Rock Bass (*Ambloplites rupestris*) TL 197mm

Figure 6: Bluegill (*Lepomis macrochirus*) TL 221mm

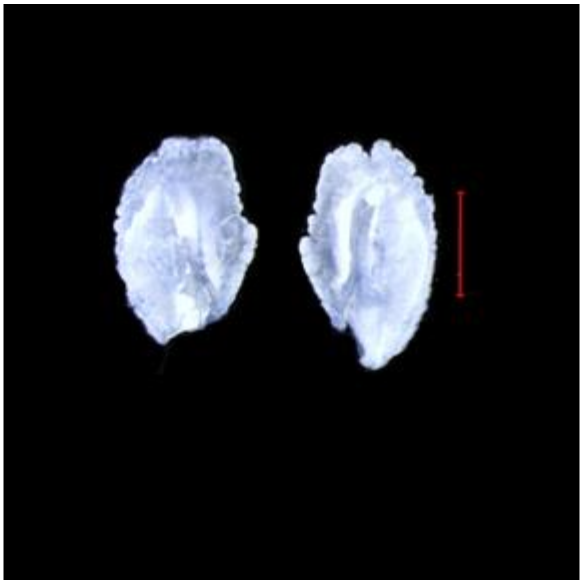

Figure 7: Green Sunfish (*Lepomis cyanellus*) TL 87mm

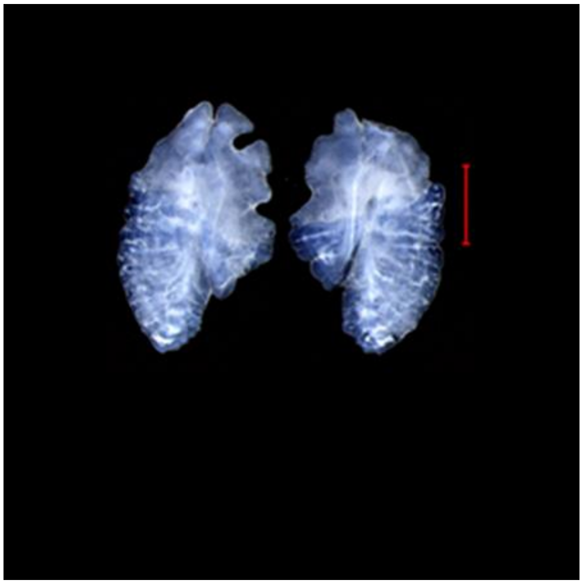

Figure 8: Pumpkinseed (*Lepomis gibbosus*) TL 177mm

Figure 9: Mottled Sculpin (*Cottus bairdii*) TL 120mm

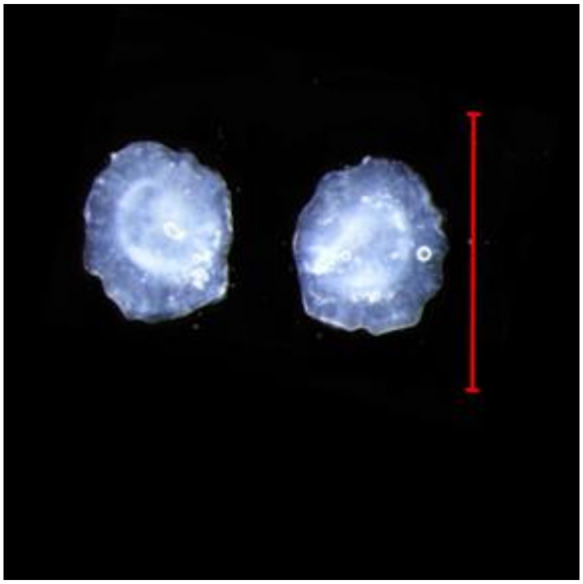

Figure 10: Central Stoneroller (*Campostoma anomalum*) TL 114mm

Figure 12: Common Shiner (*Luxilus cornutus*) TL 157mm

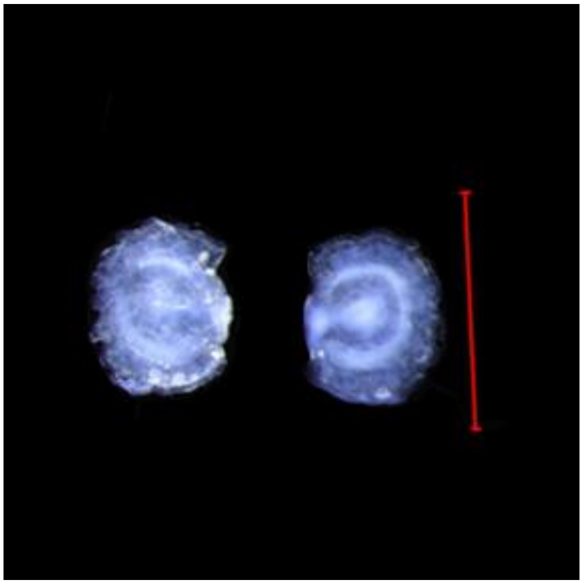

Figure 11: Spottail Shiner (*Notropis hudsonius*) TL 81mm

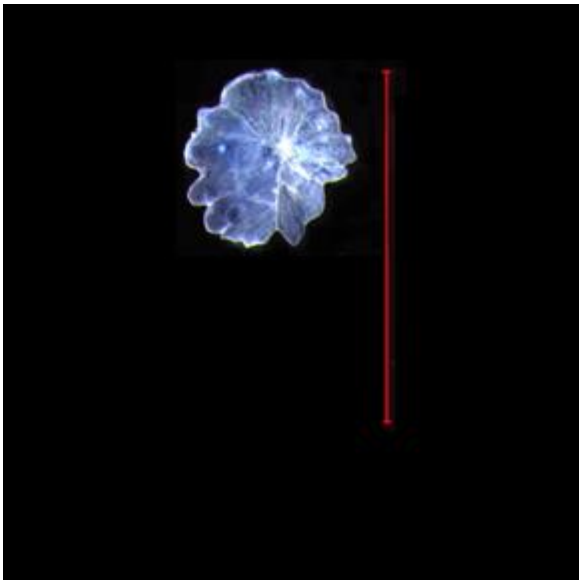

Figure 13: Blackchin Shiner (*Notropis heterodon*) TL 46mm

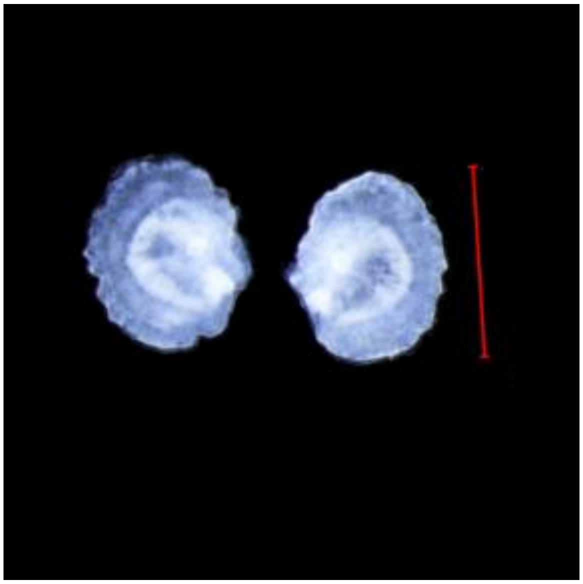

Figure 14: Hornyhead Chub (*Nocomis biguttatus*) TL 141mm

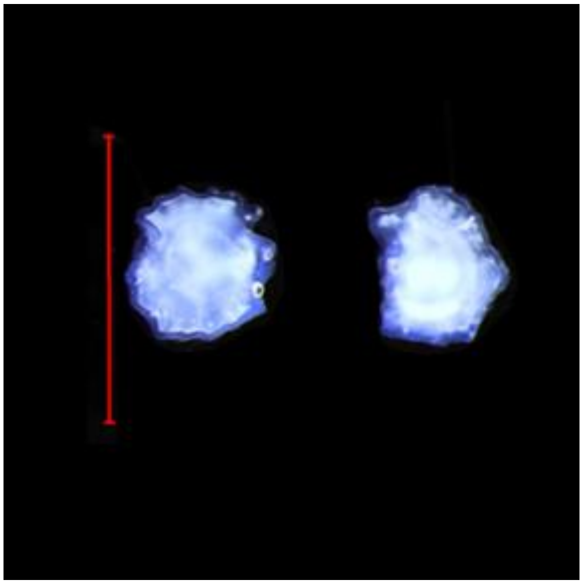

Figure 15: Bluntnose Minnow (*Pimephales notatus*) TL 81mm

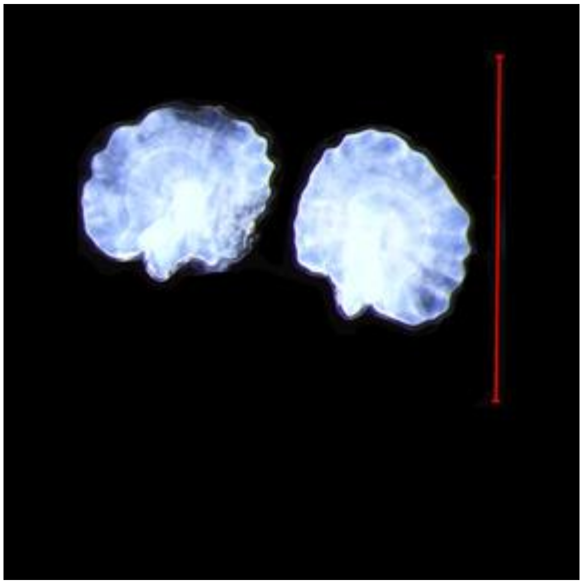

Figure 16: Longnose Dace (*Rhinichthys cataractae*) TL 93mm

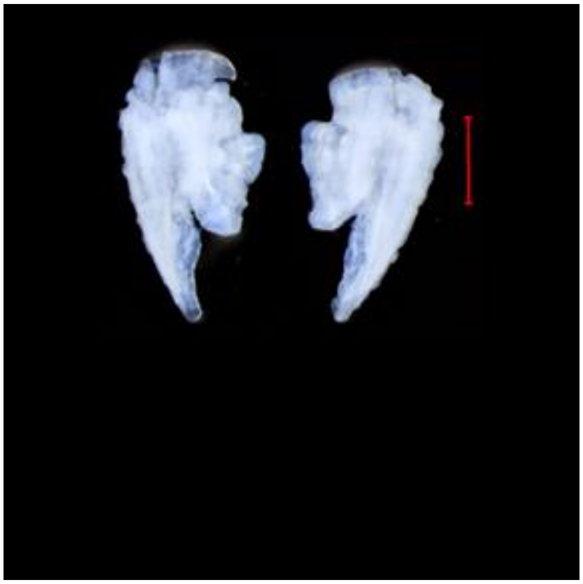

Figure 17: Muskellunge (*Esox masquinongy*) TL 701mm

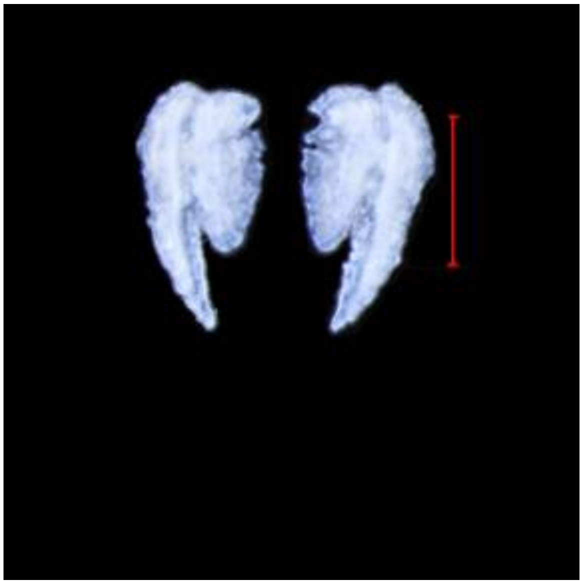

Figure 18: Northern Pike (*Esox lucius*) TL 171mm

Figure 20: Yellow Bullhead (*Ameiurus natalis*) TL 228mm

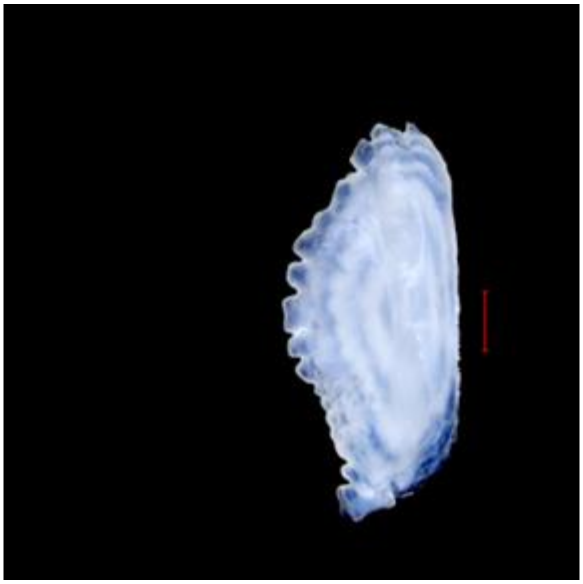

Figure 19: Burbot (*Lota lota*) TL 488

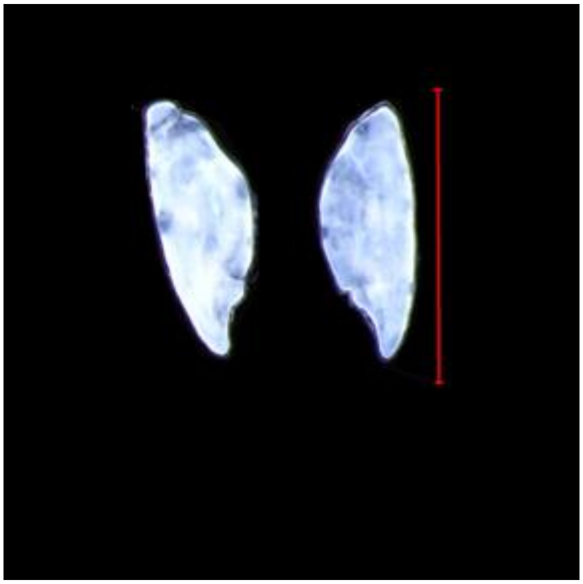

Figure 21: Johnny Darter (*Etheostoma nigrum*) TL 70mm

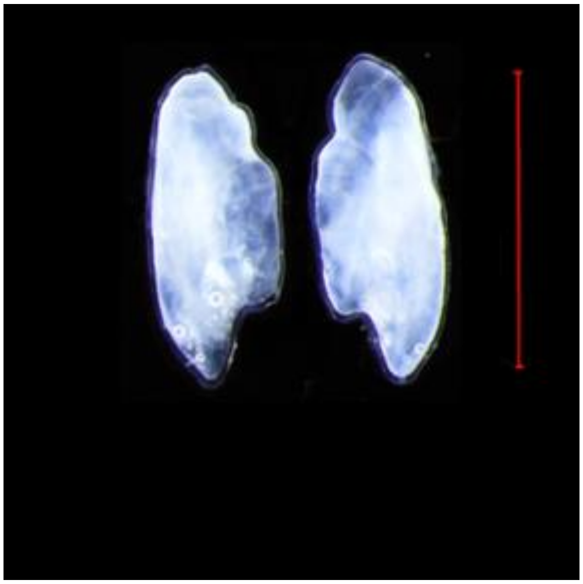

Figure 22: Rainbow Darter (*Etheostoma caeruleum*) TL 55mm

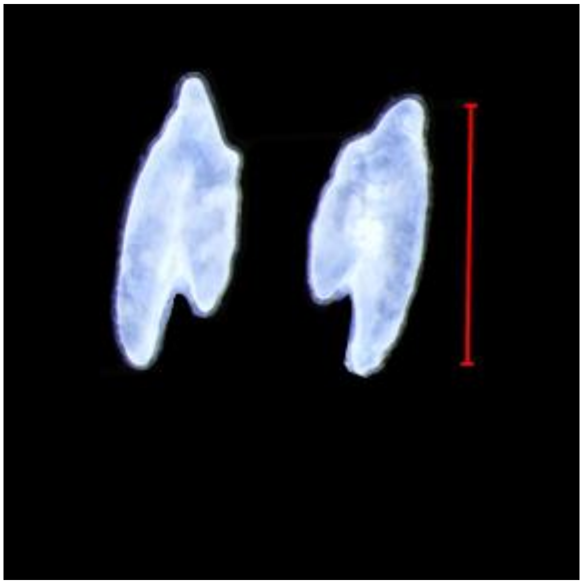

Figure 23: Blackside Darter (*Percina maculata*) TL 87mm

Figure 24: Logperch (*Percina caprodes*) TL 119mm

Figure 25: Bloater (*Coregonus hoyi*) TL 299mm

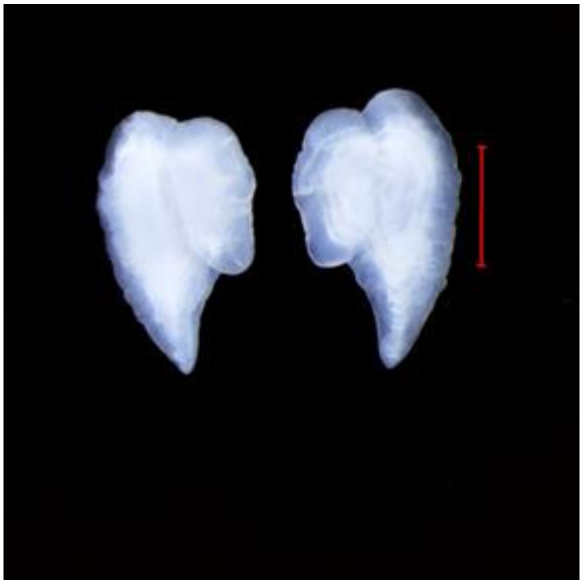

Figure 26: Kiyi (*Coregonus kiyi*) TL 205mm

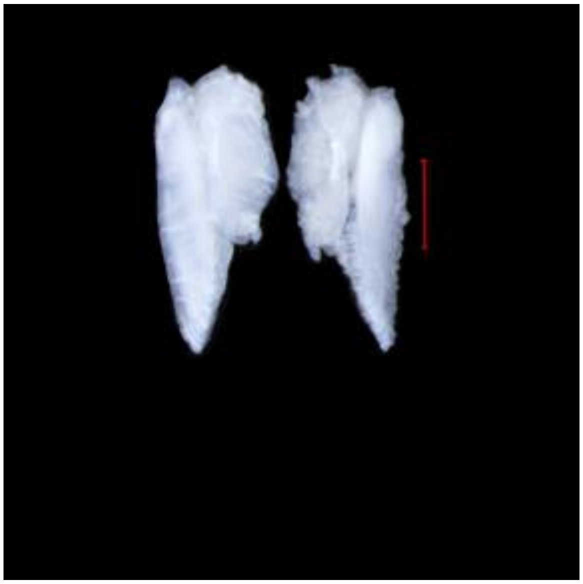

Figure 27: Lake Whitefish *(Coregonus clupeaformis*) TL 584mm

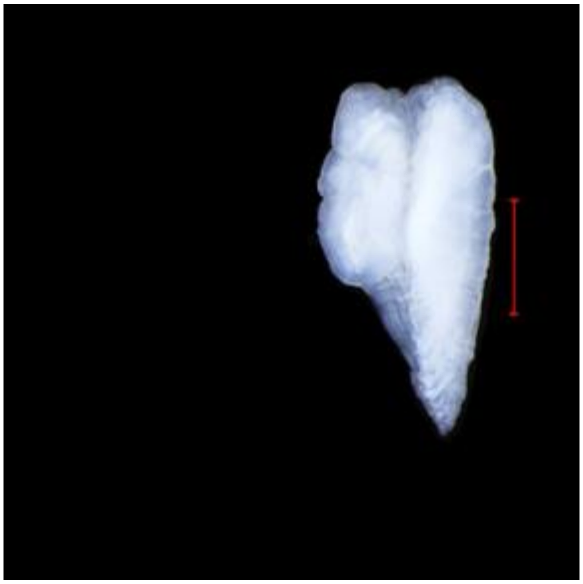

Figure 28: Round Whitefish (*Prosopium cylindraceum*) TL 401mm

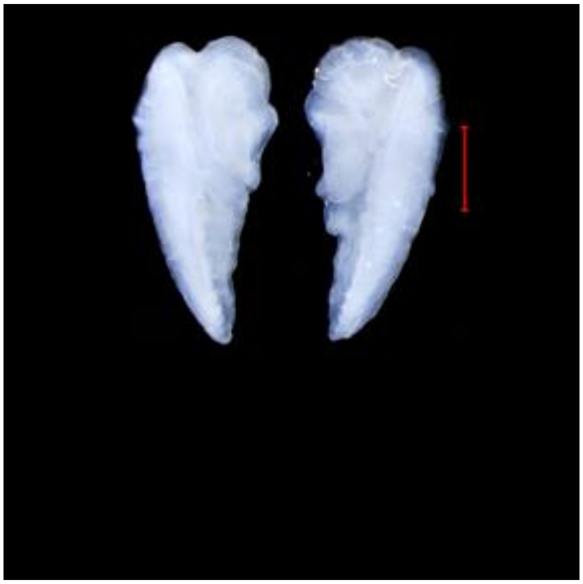

Figure 29: Tulibee Cisco (*Coregonus artedi*) TL 391mm

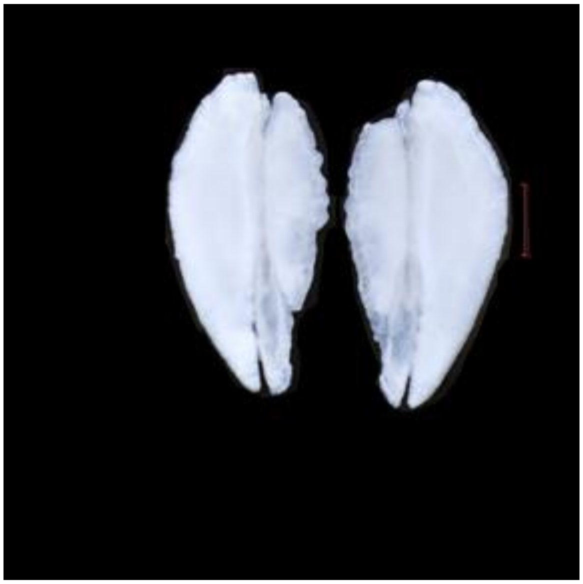

Figure 30: Chinook Salmon (*Oncorhynchus tshawytscha*) TL 698mm

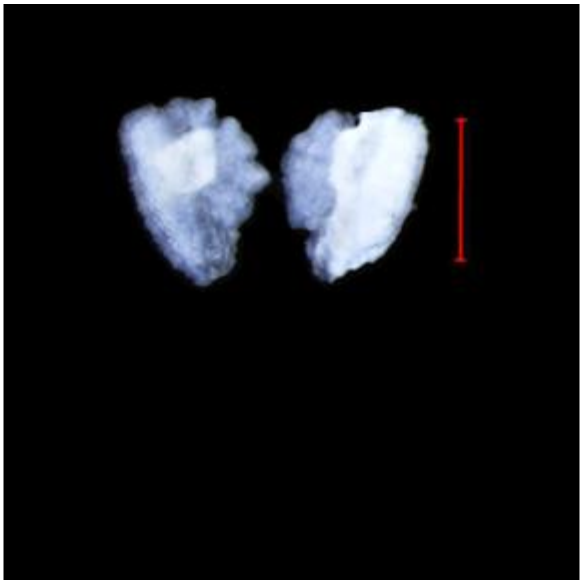

Figure 32: Pink Salmon (*Oncorhynchus gorbuscha)* TL 368mm

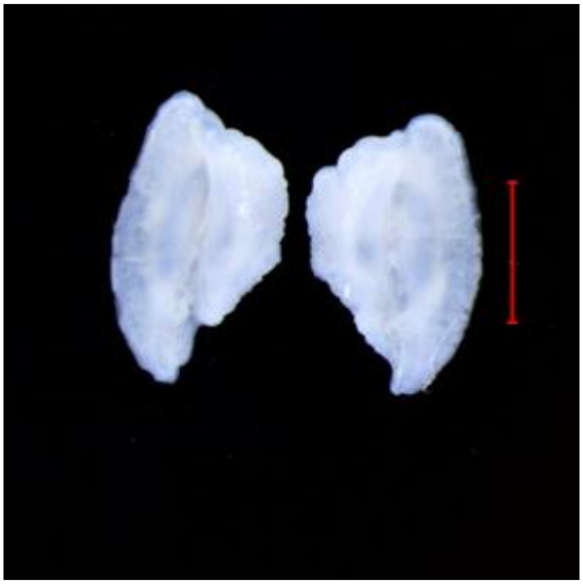

Figure 31: Coho Salmon (*Oncorhynchus kisutch*) TL 426mm

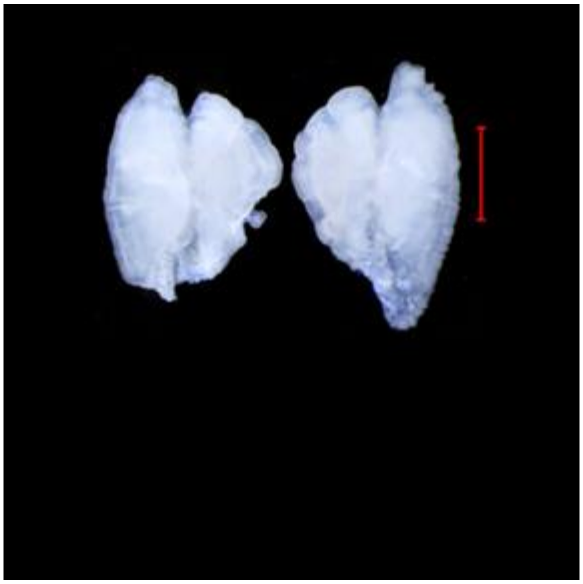

Figure 33: Rainbow Trout (*Oncorhynchus mykiss*) TL 377mm

Figure 34: Lake Trout (*Salvelinus namaycush*) TL 597mm

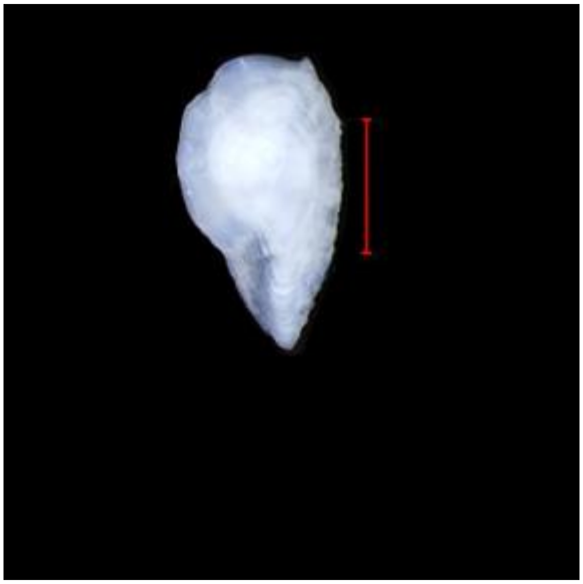

Figure 35: Siscowet Lake Trout TL 467mm

FILLET WEIGHT COMPARISON FOR BLUEGILL, BLACK CRAPPIE, AND YELLOW PERCH

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***Abstract*—Panfish, including bluegill *Lepomis macrochirus,* black crappie *Pomoxis nigromaculatus,* and yellow perch *Perca flavescens* are three sought-after species. Anglers often perceive a change in regulations as an attempt at limiting the amount of harvest. However, the goal of many regulation proposals is to increase the size structure of panfish, allowing anglers to achieve their ideal harvest with less fish. The primary objective of this study was to assess the relationship between panfish fillet weight and total length to estimate how many fillets would be needed to reach a harvest weight of 0.5 lbs. The secondary objective was to compare this relationship between ten West Central Minnesota lakes to previously published data from seven Wisconsin lakes. Minnesota fillet weights and yields were calculated from 360 bluegill, 167 crappie, and 108 yellow perch. Mean fillet yield was 36.5%, 42.3%, and 44.5% for bluegill, black crappie, and yellow perch, respectively. On average the fillet yield from Minnesota lakes was 10.72% greater than fillet yields from the previous research done in Wisconsin. In conclusion, fillet weight can be useful metrics for managers to generate harvest limits that allow anglers to reach the 0.5 lbs fillet goal.**

I. Introduction

Many panfish populations of historically high quality have seen declines in size structure in recent years (Lyons et al. 2017). Panfish are described as rock basses *Ambloplites* spp., sunfishes *Lepomis* spp., crappie *Pomoxis* spp., and yellow perch *Perca flavescens* (Lyons et al. 2017). With a lack of large individuals, anglers struggle to find adequate fisheries (Lyons et al. 2017). Continuous removal of large parental males alters the energy expense in the remaining towards gonadal development and reproductive activity (Jacobson et al. 2005). Having an abundant number of small fish affects the overall population's maturity, age, growth, and weight (Neuswanger et al. 2015). Decline in panfish size structure has inspired management attempts to increase biological and ecological qualities of aquatic systems (Jacobson et al. 2005).

Managers have addressed stunted populations with various techniques. Predatory species, such as walleye *Sander vitreus* and largemouth bass *Micropterus nigricans*, have been used to manage growth rates for stunted populations (Forney 1977). Predation reduces competition within the fish community to allow for yellow perch, black crappie *Pomoxis nigromaculatus*, and other panfish to reach a desirable harvest size (Forney 1977). Another technique involved the removal of colonial nests targeting egg and fry to manage bluegill *Lepomis macrochirus* reproduction (Neuswanger et al. 2015). Restrictions on daily bag limits attempt to combat overabundance of smaller fish by improving the size structure of panfish species. Under some conditions, the increase in fishery yield may be due to the size of fish harvested offsetting the reduction of fish being kept (Lyons et al. 2017).

Fish weight and yield can be used to communicate the tradeoffs between the harvest of a greater quantity of smaller fish versus fewer larger fish (Lyons et al. 2017). Total fishery yield, the estimated sum of the weights of all harvested fish, will sometimes be used by managers to compare the effects of various regulations (Lyons et al. 2017). The weight of edible fillets available to anglers from specific sizes would represent a better metric for communication of restrictive regulations (Lyons et al. 2017). The primary objective of this study was to assess the relationship of total fillet weight and total length among bluegill, black crappie, and yellow perch. A secondary objective was to compare the species from ten west central Minnesota lakes to seven previously studied Wisconsin lakes.

II. Methods

Bluegill, black crappie, and yellow perch were collected during the 2023 standard lake survey season. The season started in May 2023 and ended August 2023. Sampled lakes were from the west central Minnesota region including Barrett, Chippewa, Ida, Linka, Maple, Miltona, Moon, Page, Pomme de Terre, and Reno. Moon and Reno samples were collected in September 2023 from the standard fall panfish surveys.

Sampling methods included techniques outlined by the MNDNR standard survey which included standard gill nets, and standard fyke nets (MNDNR 2017). Gill and fyke nets were deployed and retrieved in 24 hours. The process was repeated to reach a total of 66 fyke net sets and 60 gill net sets for the summer sampling season. Sample size was subjected to opportunities from gill net mortalities and fyke net otolith extraction. A minimum standard length of quality fish was determined as 150 mm for bluegill and 200 mm for black crappie and yellow perch (Gabelhouse 1984).

Fish that were brought back to the office were re-measured using a standard measuring board down to the nearest millimeter. The total weight was measured in grams. Fillets were extracted by one experienced individual. The individual avoided, if not removed rib structures from fillet and any left-over skin. Belly meat was included on all fillets. A single fillet weight was then recorded and doubled for total fillet weight (TFW). Percent yield was then the calculated quotient from the total fillet weight by the total weight. Then multiplied by one hundred to be viewed as a percentage.

% Fillet yield= (TFW (g)/ Weight (g)) x 100

A table was then created to communicate the projected results to angling regulation by including the three species from both Minnesota and Wisconsin. Each fish species had increased total length measurements (TL) that would be obtained from a realistic combination of observed means. This was to display the total number of fish that would be needed to reach 0.5 pounds or 227 grams of fish fillet that would be produced from different TL (Lyons et al. 2017).

Data was summarized into species groups. The covariate total length (TL) was used to compare fillet yield among the three species. Fillet weight was estimated from fish TL for each species using a linear regression. The form was as: $\log_{10}$ (fillet weight) = $B_0 + B_1 \times \log_{10}$ (TL) where B_0 and B_1 are estimated coefficients (Lyons et al. 2017).

$$\log_{10} (\text{fillet weight}) = B_0 + B_1 \times \log_{10}(\text{TL})$$

III. Results

Data was collected from 360 bluegill, 167 crappie, and 108 yellow perch from ten west central Minnesota lakes. Samples were opportunistically collected from gill net mortalities and otolith extractions over the summer survey sampling period. Number of fish per species varied from sampling location.

Fillet weight for all three species had a strong, positive relationship to total length (Figure 1). For Minnesota and Wisconsin bluegill had the highest fillet weight at any given TL while yellow perch the lowest. Mean fillet yield for Minnesota was 36.5% for bluegill, black crappie was 42.3%, and yellow perch at 44.5% (Table 1). Minnesota demonstrated and increased fillet yield by 10.72% over Wisconsin mean fillet yield. The fillet yield of individual fish varied for Minnesota with minimum and maximum values differing by 25.24% for bluegill, 21.74% for black crappie, and 28.41% for yellow perch. While Wisconsin reported 34.6% for bluegill, 27.8% for black crappie, and 20.8% for yellow perch (Lyons et al. 2017).

TABLE 1. SUMMARY OF STATISTICAL FILLET YIELD FOR 2023 SUMMER SURVEY FOR WEST CENTRAL MINNESOTA BLUEGILL (BLG), BLACK CRAPPIE (BLC), AND YELLOW PERCH (YEP).

Species	Mean	SD	Minimum	Maximum
BLG	36.5	3.8	24.8	50
BLC	42.2	3.5	33.2	55
YEP	44.5	4.2	36.6	65

Minnesota bluegills, black crappies and yellow perch all had a slight yet significant negative correlation between fillet yield and TL (Figure 1). Where (Lyons et al. 2017) reported only significant negative correlation in black crappies for fillet yield to TL. In other words, Minnesota larger fish had a slightly lower fillet yield than respected smaller fish (Figure 1).

Estimating the effect of a reduced bag limit on TL, based off the findings of Repel (2015), West Central Minnesota would have an increase average of 219 mm with a range of 179 mm to 283 mm (Figure 2). While Lyons et al. (2017) reported an estimated TL after the regulation change of 194 mm, with a range of 168 to 237 mm (Figure 2). Realistic combinations of size and quantity would result in higher total weight of harvestable fillets from an increased bag limit (Table 2).

The maximum projected increase for bluegill would have a greater fillet weight if an angler were to keep 10 fish from a 10-fish bag limit (Table 2).

VI. Discussion

Minnesota fillet weight and yields were greater than the respective Wisconsin fillet data. Literature to support the assessment of fillet weight to TL relationship was difficult to find. Aquaculture often uses fillet yield measurement when fillet weight is known to manage stock (Lyons et al. 2017). Captive estimates of yellow perch in Rosauer et al. (2011) reported fillet yield of 34.6-35.2% which was less than the Minnesota mean fillet yield of 44.5%. The difference in estimates across studies could reflect populations condition, methods of filleting or both.

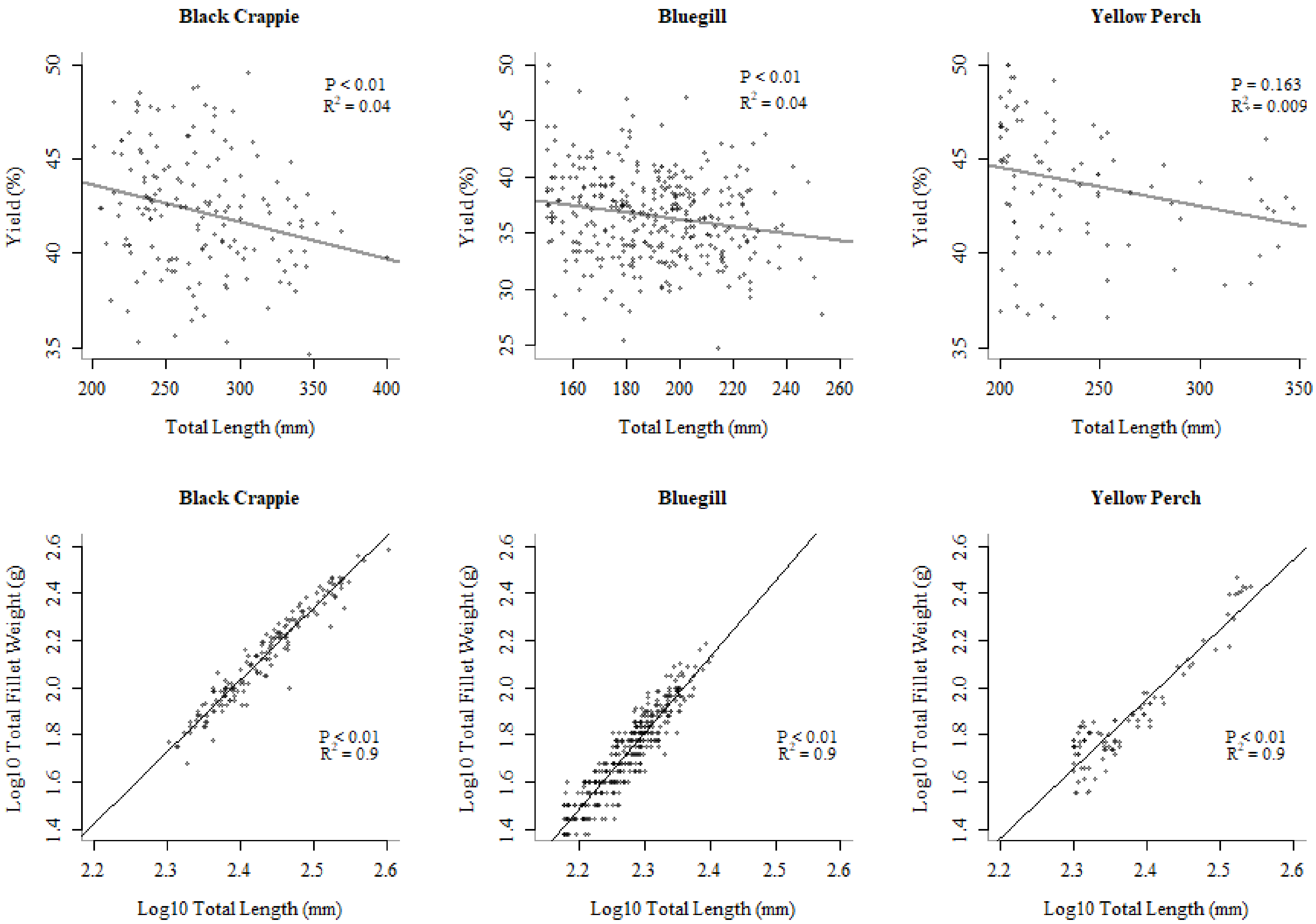

Fig. 1. The relationship of fish total length to fillet yield (top) and fillet weight (bottom) for bluegill, black crappie, and yellow perch from 2023 summer survey data for West Central Minnesota. Significant regression lines are shown. P values and R^2 values are shown for each graph.

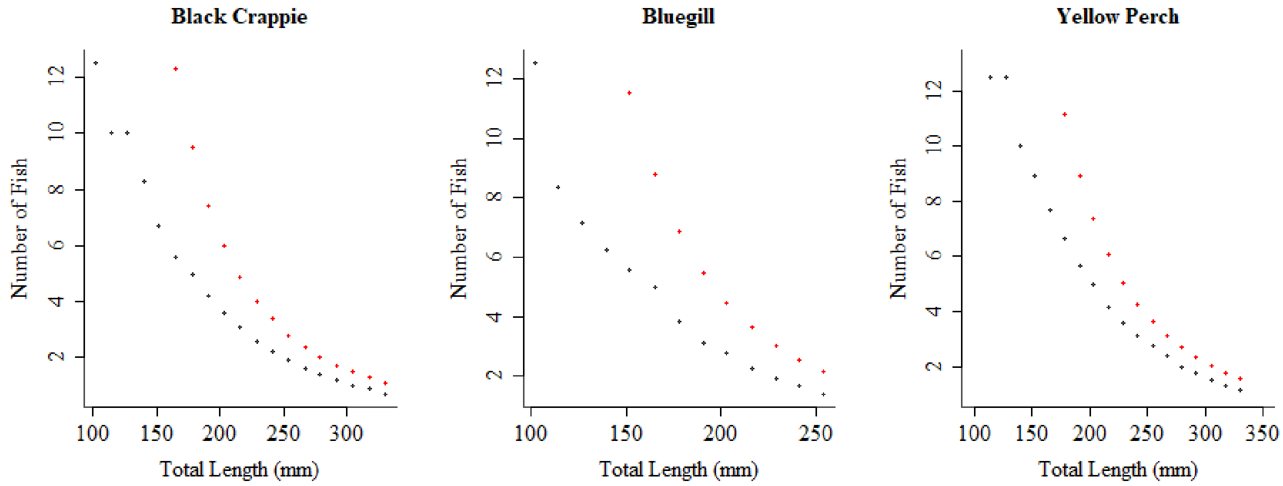

Fig. 2. Relationship of number of fish needed to reach the 0.5 lbs angling benchmark to total length (mm) for bluegill, black crappie, and yellow perch.

TABLE 2. NUMBER OF FISH FOR 0.5 LBS OF FILLET FOR BLUEGILL, BLACK CRAPPIE, AND YELLOW PERCH FROM 2023 SUMMER LAKE SURVEY FOR WEST CENTRAL MINNESOTA AND LYONS ET AL. (2017) WISCONSIN LAKES.

Species	5 in	6 in	7 in	8 in	9 in	10 in	11 in	12 in	13 in
$\text{Bluegill}_{\text{Minnesota}}$	7.1	5.6	3.8	2.8	1.9	1.4	N/A	N/A	N/A
$\text{Bluegill}_{\text{Wisconsin}}$	20.8	11.5	6.9	4.5	3.0	N/A	N/A	N/A	N/A
$\text{Black crappie}_{\text{Minnesota}}$	10	6.7	5	3.6	2.6	1.9	1.4	1	0.7
$\text{Black crappie}_{\text{Wisconsin}}$	N/A	16.2	9.5	6	4	2.8	2	1.5	1.1
$\text{Yellow perch}_{\text{Minnesota}}$	16.7	8.9	6.7	5	3.6	2.8	2	1.5	1.1
$\text{Yellow perch}_{\text{Wisconsin}}$	32.4	18.5	11.2	7.4	5	3.6	2.7	N/A	N/A

Applying fillet weight and fillet yield data can estimate the potential results of a reduced bag limit change. Bag limit reductions can increase the total weight of fillet if they lead to an increase average size of the population (Lyons et al. 2017; Jacobson 2005; Rypel 2015). It may take several years to obtain a population with an average total size increase have a bag limit reduction (Lyons et al. 2017; Jacobson 2005; Rypel 2015). The lake productivity may also influence fish condition. Lakes that are highly productive that are subject to more angling pressure are more likely to benefit from the regulation change (Lyons et al. 2017).

Methods used for filleting vary by experience and location. The variation of filleting techniques influence fillet weight and fillet yield data of any species at any size. The difference may come from the ability to limit bones in the fillets or leaving out belly meat. Equations or estimations trying to relate fillet weight to total length should be considered rough approximations due to the variability.

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RELATIONSHIP BETWEEN NORTHERN PIKE AND WALLEYE CPUE IN MINNESOTA LAKES

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***Abstract* – Northern pike *Esox lucius* and walleye *Sander vitreus* are both top predators in freshwater systems. Due to their predatorial nature, high populations of one species can prohibit populations of the other species from thriving, specifically northern pike foraging on walleye. This information is tracked by the Minnesota Department of Natural Resources through catch per unit effort (CPUE). CPUE data was gathered for all lakes in Beltrami County, Minnesota, and a regression analysis was done to test for a relationship between pike and walleye. It was found that the relationship between northern pike and walleye CPUE was significant (P = 0.02). As northern pike CPUE increased, walleye CPUE decreased. A relationship between both northern pike (P = 0.02) and walleye (P < 0.01) CPUE and lake size was also found. As lake size increased, walleye CPUE increased and northern pike CPUE decreased. Northern pike were found to be more abundant in smaller lakes, and walleye were more abundant in larger lakes.**

I. Introduction

Every ecosystem, terrestrial or aquatic, consists of a trophic pyramid that shows how energy is transferred by the organisms living in it. At the top of these pyramids are the predators in the system. Walleye *Sander vitreus* and northern pike *Esox lucius* are two of the most prominent predator species of fish in Minnesota. Northern pike, being the most widespread game fish in the state, are known to be highly aggressive and a popular target for anglers (Paukert et al. 2001).

Fish populations are often estimated by relative abundance and catch per unit effort (CPUE). Abundance is the total number of fish in a population or biomass collected over a specific period of time and space. Catch per unit effort is compared to abundance by being a measure of relative density of the fish population (Dunn et al. 2000).

Northern pike and Walleye occupy many of the same bodies of water and because of this, they share a lot of the same food sources. A study done in Minnesota shows that there is an overlap in walleye and northern pike diets by 33%-53% (Herwig et al. 2021). Part of this diet overlap includes walleye as prey. Walleye, like many other fishes, are known to exhibit cannibalism (Zhou 2017). Pike will also regularly consume walleye, especially during the spring and fall seasons (Ahrenstorff and Holbrook 2016).

Walleye fry and fingerlings are great forage for northern pike. Being that fry and fingerlings are usually what is stocked into systems with minimal or no natural walleye reproduction, pike can be quick to eat those small fish. This is why lakes with high northern pike CPUE usually cannot support much of a walleye population (Raabe et al. 2020). The objective of this study was to test for a relationship between northern pike and walleye CPUE in Minnesota lakes.

II. Methods

This study was based off gill net CPUE data of all lakes in Beltrami County, provided publicly by the Minnesota Department of Natural Resources (MNDNR 2023). There were 183 lakes in Beltrami County, Minnesota, 36 lakes had gill net data for both northern pike and walleye, only these lakes were used. Data was collected from these lake surveys alphabetically and recorded in an excel spreadsheet.

Surveys of these lakes took place at various times of the year, usually being spring through early fall. Surveys were only used if they have taken place since 2010. Gill nets were set on a one-day basis, though the survey itself may last a week or longer. Nets are set one morning and left in the water for 24 hours. Then they are retrieved at roughly the same time the following day to be processed. This is when lengths, weights, counts, and aging structures of fish are taken. CPUE is calculated by taking the total number of fish caught per species and dividing that number by the total number of nets set throughout the survey. CPUE of both northern pike and walleye were recorded for this study, along with which lake they were surveyed from and the size of that lake in acres.

Three separate regression analyses were performed. The first regression analysis was to directly test for a relationship between northern pike and walleye CPUE. The second and third regression tests were analyzing the potential relationship between total acreage of a lake and how that may influence CPUE of northern pike or walleye.

III. Results

Data was collected from 36 lakes in Beltrami County. Northern pike CPUE had a significant influence on walleye CPUE (P=0.016). As northern pike CPUE increased, walleye CPUE decreased (Figure 1). Northern pike CPUE significantly decreased as lake size increased (*P* = 0.02; Figure 2). Black Lake was 271 acres and had the highest CPUE of northern pike with 19.25 fish/net. Big Bass Lake was 337 acres and had the second highest CPUE of northern pike with 18.89 fish/net. Grant Lake was 214 acres and had the third highest CPUE of northern pike with 17.33 fish/net.

Walleye CPUE significantly increased in lakes of larger sizes (*P* < 0.01; Figure 3). Blackduck Lake was 2,711 acres and had the highest CPUE of walleye with 18.47 fish/net. Balm lake was 537 acres and had the second highest CPUE of walleye with 15.67 fish/net. Lake Bemidji was 6,596 acres and had the third highest CPUE of walleye with 13.67 fish/net.

IV. Discussion

The key finding of this study shows that northern pike CPUE has a significant negative relationship with walleye CPUE. A Wisconsin study on stocked walleye and their competition with other game fish found that not only do northern pike prey on juvenile walleye, but they also regularly compete with them for food (Fayram et al. 2005). These findings can be inferenced for Minnesota lakes as well. Suggesting the inverse relationship of northern pike and walleye abundance could be due to predation or the fact that northern pike are outcompeting walleye for food. Either result leads to an increase in natural mortality rates for walleye found in lakes with high abundance of northern pike.

The results also show opposite relationships between northern pike CPUE and walleye CPUE when compared to lake size. The correlation between lake size and walleye CPUE got stronger as lake size increased. This positive relationship was also found in a study on walleye abundance and lake surface area in northern Wisconsin (Nate et al. 2000). One factor found that could influence walleye recruitment in these smaller lakes is lack of spawning habitat (Moyle 1946; Kitchell et al. 1977). In order to spawn, walleye require gravel or cobble found on shorelines, mid-lake humps or reefs, point bars, or island shoreline (Bozek et al. 2011).

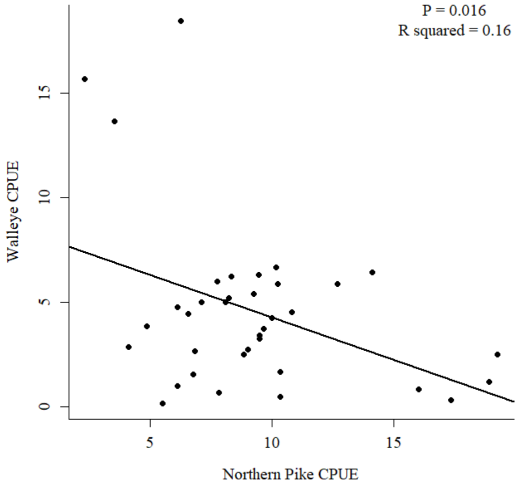

Fig. 1. Scatterplot depicting lakes in Beltrami County, Minnesota, and their respective northern pike and walleye CPUE values.

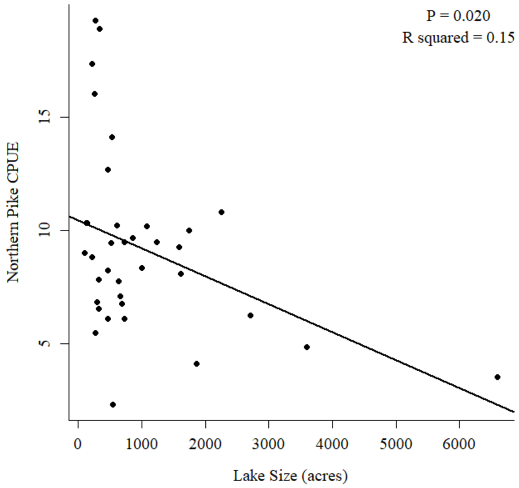

Fig. 2. Scatterplot depicting lakes in Beltrami County, Minnesota, plotted by size in acres and northern pike CPUE values.

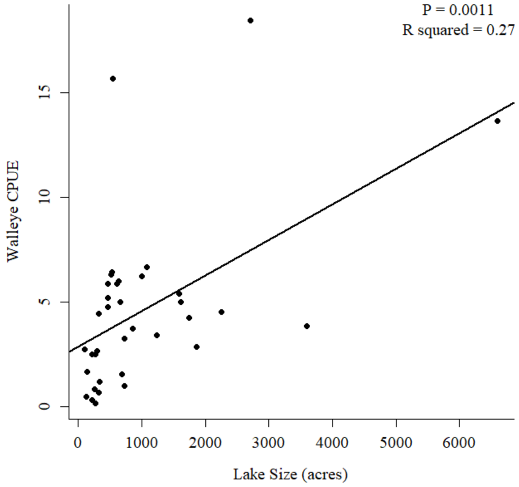

Fig. 3. Scatterplot depicting lakes in Beltrami County, Minnesota, plotted by size in acres and walleye CPUE values.

These types of habitats are not as common in small lakes as in large lakes because many smaller lakes have a higher littoral area, allowing the sun to reach the substrate, causing vegetation to grow with ease. However, these shallow, vegetation dense areas are ideal for northern pike spawning.

Northern pike generally spawn in shallow patches of flooded vegetation, preferably grasses and sedges, but other aquatic plants are used as well (Casselman and Lewis 1996). The recent introduction of zebra mussels into new bodies of water could also influence the ability of fish to spawn. Zebra mussels are filter feeders, feeding on phytoplankton suspended in the water column. In the absence of these phytoplankton, water clarity can increase. This improves the ability of the sun to penetrate to depths otherwise no sun light would reach, increasing plant growth, creating more habitat suitable for northern pike to spawn, and eliminating potential walleye spawning habitat.

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EFFECT OF WALLEYE FRY STOCKING ON FUTURE GILLNET CPUE

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Abstract**—Walleye *Sanders vitreus* for many states, is a key attractant of anglers from around North America. Due to immense popularity, management efforts have been conducted to maintain Walleye populations, especially in the form of stocking. The purpose of this study is to analyze the effect of Walleye fry stocking on gillnet catch per unit effort (CPUE). A total of 90 lakes were analyzed for this study within three defined regions of Minnesota, 30 from each region. The regions chosen for this study are the Minnesota Department of Natural Resources northern pike *Esox lucius* regulation regions which consist of the Southern, North-Central, and North-Eastern regions of the state. This is because each area has similar lake types ranging from prairie pothole lakes to Canadian shield lakes, which provides different habitat for Walleyes. Data collected from each lake consisted of CPUE, average fish weight (lbs), and stocking density (fry/littoral acre). There is little evidence to suggest that stocking density alone affects gillnet CPUE, however, there is evidence to suggest that gillnet CPUE is most effected by zone. Average weight had a very similar outcome where the best supported model was correlated with CPUE and zone.**

I. Introduction

Walleyes are an important species throughout North America for their role in recreational, commercial, and tribal fishing (Colby et al. 1979). While they are native to lakes and rivers of Canada and the northern United States, they have since been stocked throughout a large portion of the lakes and reservoirs within much of the United States (Porath and Peters 1997). Due to the Walleye being in such high demand, many agencies have made extensive stocking efforts to improve their fisheries.

Stocking of Walleye is necessary for the fisheries to be maintained due to natural reproduction being marginal in many lakes and reservoirs (Murphy et al. 1983). Lakes can be stocked in several ways including, fry, small fingerling, and large fingerling, which is largely based on the ecosystem of the waterway (Ellison and Franzen 1992). There is variation amongst different areas of the country due to several limiting factors in stocking of many fish species (Diana and Wahl 2008). The primary limiting factors for Walleye include habitat, forage abundance, and water chemistry (Fielder 1992).

This variability in results causes a need to understand how effective Walleye stocking is for a fisheries manager. It is important to understand this due to the massive economic benefits that come from producing Walleye in a fishery. Millions of dollars in revenue can be generated by their presence in a waterway (Fielder 1992). Currently, the most effective method of surveying Walleye abundance is the utilization of gillnets (Li et al. 2011).

The objective of this study is to determine the effects of Walleye stocking on future gillnet CPUE (catch per unit effort). Data from the Minnesota Department of Natural Resources (MN DNR) will be utilized to help collect the necessary data for this study.

II. Methods

The MN DNR "LakeFinder" webpage was the primary source of data collection for this project (MN DNR 2024). Within the database, there are stocking reports for any lake that has been stocked including stocking rate, average weight, and gillnet CPUE. CPUE is a quantitative method used by fisheries around the world (Maunder et al. 2006). In this study, CPUE is defined as the amount of Walleye caught per gillnet.

Fry stocking is historically conducted by the MN DNR at a rate of 1,000 fry/littoral acre. A littoral acre is defined as an acre that is less than 15 feet deep (MN DNR 2023). However, there can be variation in fry stocking densities. For example, Lake Andrusia in Beltrami County, Minnesota, is stocked at a density of 10,613 fry/littoral acre per year. This is due to several factors, with the main reason being that the lake is connected to the Cass Lake chain, which is a large Walleye fishery in Minnesota, creating a demand for a large Walleye population.

The lakes analyzed during this study are separated by the defined northern pike *Esox lucius* management areas in the state of Minnesota (North-central, North-east, and Southern). This is because, in general, the lakes defined by these regions of the state are similar in forage base, lake type, geological region, etc. For example, many of the lakes in the Northeast region are Canadian shield lakes that are low in productivity but provide cold-water refuge for prey species such as cisco *Coregonus artedi* and lake whitefish *Coregonus clupeaformis*. The differences in regions will allow for variation in lake types and areas of the state where Walleyes are stocked.

There were 30 lakes from the three described zones, totaling 90 lakes, that were selected based on stocking data availability, and the primary form of stocking was fry stocking. The specific lakes selected were those that are stocked with Walleye fry, lakes entirely within the state of Minnesota, and are <1,000 acres in size, with a few exceptions. All lakes selected had lake survey data from 2013-present day and data from the most recent lake survey was collected.

Lakes from every county in this study were selected in alphabetical order, following the criteria listed above. Lakes from the north-central region were selected starting from Beltrami County, where the starting 15 lakes were selected. No more than 15 lakes were taken from any county within this study. Counties targeted contained lakes that have known walleye fisheries such as Aitkin County, Itasca County, Hubbard County, etc. All lakes from the north-east zone came from the three counties within the zone (St. Louis; Lake; Cook). The southern zone has limited walleye fisheries that tend to be concentrated within certain counties, or primarily fingerling stocking. The primary counties that had walleye fry stocking were Freeborn, Rice, and Le Sueur.

Gillnet CPUE can be analyzed against average weight and stocking densities to create a linear regression model. Natural log transformation plots will be used for analysis over standard plots because it reduced problems with heterogeneity in variance and non-linearity within the plots (Leydesdorff and Bensman 2006). The Akaike Information Criterion (AIC) scores will be used to determine the best supported models where lower scores equate to higher support (Sakamoto et al. 1986). The predictor values represented in the models were average weight and CPUE, and the response values were CPUE and Density.

III. Results

The highest density of fry stocked was 10613.2 fry/littoral acre and the lowest density was 465 fry/littoral acre, with the average density for all lakes being 1309 fry/littoral acre (SD = 491.6). The highest average weight was a north-east zone lake at 5.12 lbs. and the lowest was also a north-east lake 0.64 lbs., with the average weight of 1.9 lbs. (SD = 1.3). across all zones (Table 1).

TABLE 1. AVERAGES FOR ALL DATA THROUGHOUT THE STUDY. AVERAGE WEIGHT (WT) PER WALLEYE, AVERAGE STOCKING DENSITY (FRY/LITTORAL ACRE), AND AVERAGE CPUE ARE SHOWN FOR EACH ZONE NORTH-CENTRAL = NC; SOUTHERN = S; NORTH-EAST = NE. NUMBERS SHOWN WITHIN PARANTHESES ARE REPRESENTATIVE OF STANDARD DEVIATIONS

Zone	x̄ Wt (lbs)	x̄ Density	x̄ CPUE
NC	2.1 (0.8)	1732.1 (2306.1)	4.2 (4)
S	2.3 (1.1)	769.7 (279)	10.6 (8.8)
NE	1.9 (1.3)	1425.2 (1014.8)	5.8 (5.4)

While the highest weight of fish in gillnets came from the north-east zone, the lowest weight also came from that same zone. The highest CPUE recorded came from the southern zone at 33.33, while the lowest CPUE came from the north-east zone at 0.22. The average CPUE for the north-central zone was 4.2 (SD = 4.0), 10.6 (SD = 8.8) for the southern zone, and 5.8 (SD = 5.4) for the north-east zone (Table 1).

The best supported model at explaining variation for average weight of fish included both ln(CPUE) and Zone (Table 2). When explaining variation in ln(CPUE), the best supported model included only zone as a factor (Table 3).

TABLE 2. LINEAR REGRESSION MODELS USED TO TEST FOR THE EFFECT OF CPUE AND ZONE ON AVERAGE WEIGHT OF WALLEYES IN MINNESOTA LAKES. THE BEST SUPPORTED MODELS WERE DETERMINED USING AIC SCORES (LOWER SCORES = MORE SUPPORT).

Formula	AIC	ΔAIC
ln(Avg.Weight)~ln(CPUE)+Zone	108.0	0
ln(Avg.Weight)~ln(CPUE)*Zone	109.6	1.7
ln(Avg.Weight)~ln(CPUE)	114.7	6.8
ln(Avg.Weight)~1	130.4	22.4
ln(Avg.Weight)~Zone	130.6	22.7

TABLE 3. LINEAR REGRESSION MODELS USED TO TEST FOR THE EFFECT OF STOCKING DENSITY AND ZONE ON GILL NET CPUE OF WALLEYES IN MINNESOTA LAKES. THE BEST SUPPORTED MODELS WERE DETERMINED USING AIC SCORES (LOWER SCORES = MORE SUPPORT).

Formula	AIC	ΔAIC
ln(CPUE)~Zone	274.6	0
ln(CPUE)~ln(Density)+Zone	275.9	1.3
ln(CPUE)~ln(Density)*Zone	278.9	4.3
ln(CPUE)~1	280.5	5.9
ln(CPUE)~ln(Density)	282.3	7.6

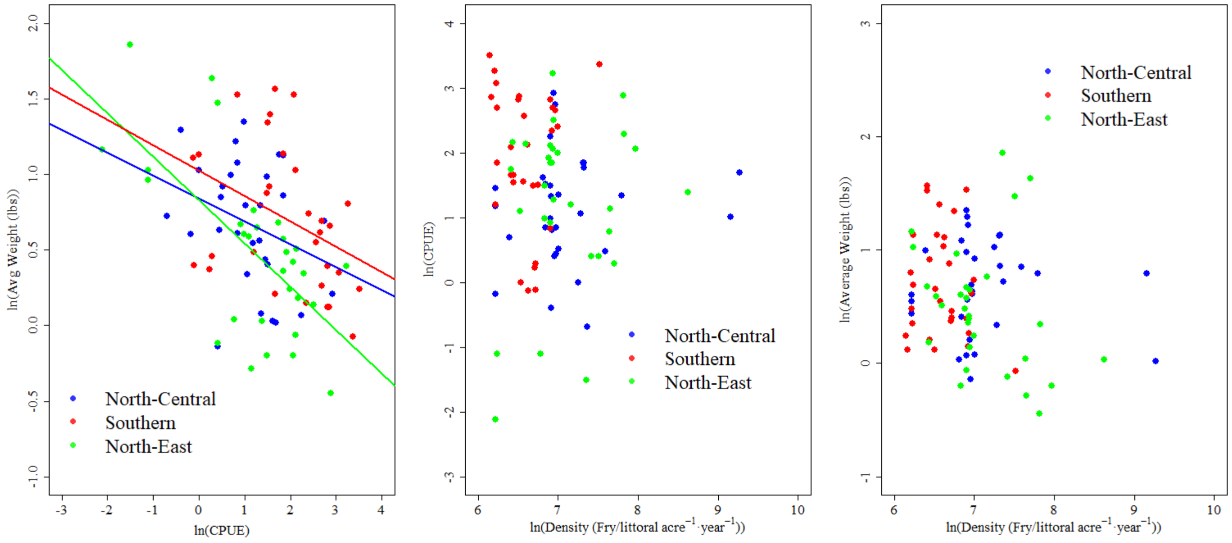

Fig. 1. Gillnet ln(CPUE) of Walleyes plotted against ln(Avg.Weight) and ln(Density) found in gillnets as well as ln(Avg.Weight) plotted against ln(Density). Blue dots indicate the north-central lakes; red dots indicate southern lakes; green dots indicate north-east lakes.

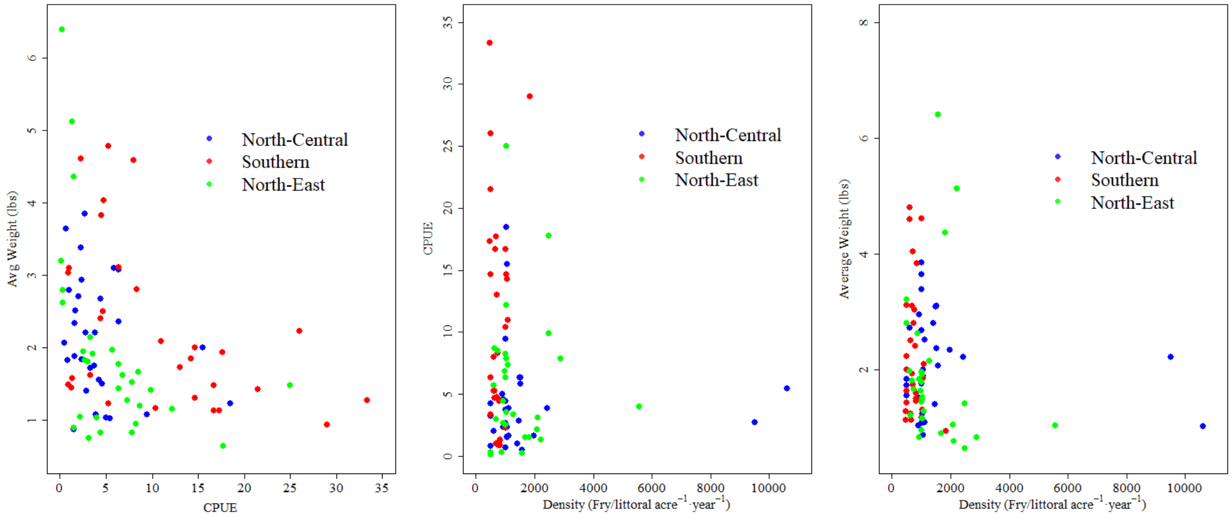

Fig. 2. Gillnet CPUE of Walleyes plotted against average weight (lbs) of individuals and density of fry stocked (Fry/littoral acre[1]). Blue dots indicate the north-central lakes; red dots indicate southern lakes; green dots indicate north-east lakes.

IV. Discussion

Over the range of stocking densities throughout this study, there is little evidence to suggest that stocking density directly affects gillnet CPUE. However, there is evidence to suggest that the zone in which the stocking occurs will influence gillnet CPUE. The southern lakes had on average the lowest stocking density at 769.8 (SD = 279), while also having the highest average CPUE at 10.6 (SD = 8.8) (Table 1). The most expected cause for this discrepancy between zones is the increased productivity of southern lakes, allowing for increased growth rates (Eddy and Carlander 1940). The north-central and north-east lakes had similar rates of stocking effectiveness in relation to future CPUE, this could be caused by numerous factors such as lake latitude, lake type, species present, etc.

There is evidence to suggest that average weight is significantly affected by zone and CPUE. The southern zone had the highest average weight of fish on average ~2.3 lbs. (SD = 1.1) while also having the highest CPUE on average at 10.62 (SD = 8.8), this is likely caused by the high productivity of southern Minnesota lakes in relation to their northern counterparts, allowing for plentiful forage and large size. The north-east and north-central zone had very similar results in weight (NC = ~2.12 lbs.; NE = ~1.92 lbs.) and CPUE (NC = ~4.23; NE = 5.75).

TABLE 4. LINEAR REGRESSION MODELS USED TO TEST FOR THE EFFECT OF STOCKING DENSITY AND ZONE ON AVERAGE WEIGHT OF WALLEYES IN MINNESOTA LAKES. THE BEST SUPPORTED MODELS WERE DETERMINED USING AIC SCORES (LOWER SCORES = MORE SUPPORT).

Formula	AIC	ΔAIC
ln(Avg.Weight)~ln(Density)	129.3	0
ln(Avg.Weight)~1	130.4	1.1
ln(Avg.Weight)~ln(Density)+Zone	130.5	1.2
ln(Avg.Weight)~Zone	130.6	1.4
ln(Avg.Weight)~ln(Density)*Zone	133.2	3.9

Based off the data, there is sufficient evidence to determine that stocking densities do marginally influence average weight. The average weight of fish does have a positive relationship with lower stocking densities, but there isn't a major discrepancy. The average weight per fish in the southern zone was 2.3 lbs (SD = 1.1) and the north-central zone was 2.1 lbs (SD = 0.8), while maintaining a large gap of 962.4 fry/littoral acre per year stocked on average. This would suggest that while there is an effect on average weight from fry stocking densities, it is very minimal.

There is evidence that suggest gillnet CPUE differs by zone. It should be noted that regional variance has a larger effect on gillnet CPUE than stocking densities. There is a variation of at least 1.5 fish per net on average between the zones, with the largest gap found between the southern zone at 10.6 CPUE (SD = 8.8) and the north-east zone at 4.2 (SD = 4). The likely candidate for this variation is the difference in zone productivity. The north-east zone is comprised of oligotrophic Canadian shield lakes whereas the southern zone is comprised primarily of prairie pothole, eutrophic lakes, with the north-central zone lying between the productivity levels.

It can be concluded that while stocking densities may not directly affect gillnet CPUE, it does have an influence when different areas are considered as a factor. This is not to say however, that fry stocking doesn't work. Even for the lakes that have lower numbers of fish, stocking is still an effective tool for managing specific fishes. If stocking were to be removed, this could potentially cause crashes in target fish populations.

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SPECIFIC MEASUREMENTS OF A YELLOW PERCH HEAD COMPARED TO THE TOTAL LENGTH

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***Abstract*—Yellow Perch *Perca flavescens* is a popular fish for harvesting in Minnesota. Because of this the Minnesota Department of Natural Resources survey populations with gill nets, however, some water bodies have Rusty Crayfish *Faxinous rusticus* that commonly consume most of the body leaving only the head to be accurately measured. The goal of this research was to see if there is a relationship between specific measurements of the head and the total length of the fish. The number of Yellow Perch sampled in this study was 72 and all came from Lake Bemidji in Minnesota during the month of October in 2023. All the fish collected were measured in millimeters using a digital caliper for the head measurements. The best relationship was using the measurement of the opercular bone (TL = 3.8137x + 2.0415; R^2 = 0.99). The measurement of the mouth was the second best (TL = 9.3343x + 15.992; R^2=0.99) and from the tip of the mouth to the eye was the worst relationship (TL= 13.142x + 8.9854; R^2=0.97). All relationships had a p value less than 0.01.**

I. Introduction

Yellow Perch *Perca flavescens* is a key species for many fisheries in Northern Minnesota, both for forage and harvest. Because of this, measuring the size structure is important to observe the health of the populations. However, there are many times where the only measurable part of the Yellow Perch is the head. Often this occurs because of Rusty Crayfish *Faxinous rusticus* that consume the body while the fish is caught in a gill net.

Studies have been conducted in Europe on European Perch *Perca fluviatilis* comparing operculum length to the total length of the fish and there was found to be a relationship between the two measurements (Machiels and Wijsman 1996). The study on European Perch was conducted to compare the size selective mortality of different cohorts so there was data from a few different years. This was done by measuring the opercular bones of the different cohorts and running a regression analysis. A similar study was conducted on Yellow Perch from Lake Mendota in Wisconsin (Bardach 1996) but only focused on the opercular bone and not any other measurements.

Unlike the study on European Perch, the goal of this study is to determine if there are multiple measurements on Yellow Perch that can be used if the rest of the body is unmeasurable. The measurements chosen were the distance from the tip of the mouth to the beginning of the eye socket, the total length of the mouth, and the distance from the tip of the mouth to the end of the opercular bone. The data from this research would be used to determine the best estimated total length of the perch if only the head is measurable.

II. Methods

The Yellow Perch for this study were sampled on Lake Bemidji using multi-mesh gill nets that were approximately 14.6 m long, 1.8 m high with various mesh sizes of 9.5, 12.7, 15.9, 19.1, 25.4, and 31.8 mm. The gill nets were set at six predetermined locations around the lake and Yellow Perch were sampled from 5 - 19 October 2023.

When a Yellow Perch was sampled, the total length was measured first with a bump board, then the distance from the tip of the mouth to the beginning of the eye socket, total length of the mouth, and the distance from the tip of the mouth to the end of the opercular bone were all measured with a digital caliper (Figure 1).

There was a total of 72 perch that were measured. The measurements were then entered into a table and a regression analysis was run to see if there was a correlation between the head measurements of the perch and the overall length.

III. RESULTS

There were 72 Yellow Perch collected that ranged from 84 to 248 mm in total length. All three of the relationships had a p value of less than 0.01 (Table 1). The relationships between the total length measurement were as follows, the tip of the head to the inside edge of the eye ranged in size from 5.72 to 18.74 mm and had an R^2 value of 0.97 (Figure 2). The total length of the mouth had a range of 7.27 to 25.00 mm and an R^2 value of 0.99 (Figure 3), and the length from the tip of the mouth to the edge of the opercular bone measured from 22.03 to 64.22 mm and had an R^2 value of 0.99 (Figure 4).

IV. DISCUSSION

Based off the data collected, the total length of a Yellow Perch can be extrapolated with a high degree of confidence by using measurements from the head morphology. Previous studies on other species, such as Red Drum *Sciaenops ocellatus* (Serafy et al. 1996), demonstrated this can be used on multiple different species. Like the study on Red Drum, all the measurements that were taken are good predictors of the total length of the Yellow Perch because the R^2 value of the measurements was between 0.97 and 0.99.

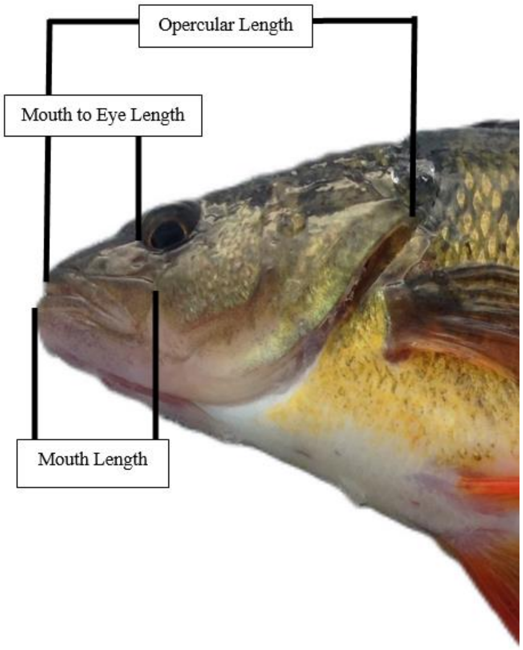

Fig. 1. Measurement taken of the Yellow Perch *Perca flavescens* head.

TABLE 1. RELATIONSHIPS AND R^2 VALUES OF THE OPERCULAR, MOUTH, AND EYE TO MOUTH MEASUREMENTS.

Measurement	Regression Equation	R^2 Value
Opercular	$y = 3.8137x + 2.0415$	0.99
Mouth Length	$y = 9.3343x + 15.992$	0.99
Eye to Mouth	$y = 13.142x + 8.9854$	0.97

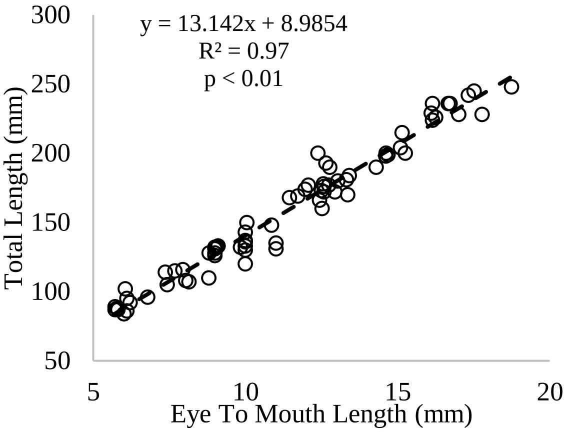

Fig. 2. Total length and distance from tip of mouth to inside of the eye regression analysis with R^2 and p value.

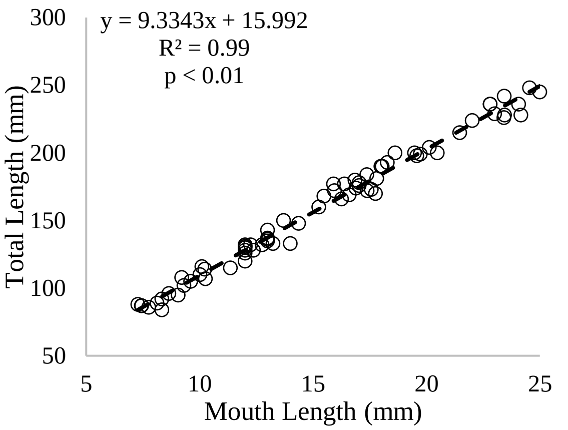

Fig. 3. Total length and mouth length regression analysis with R^2 and p value.

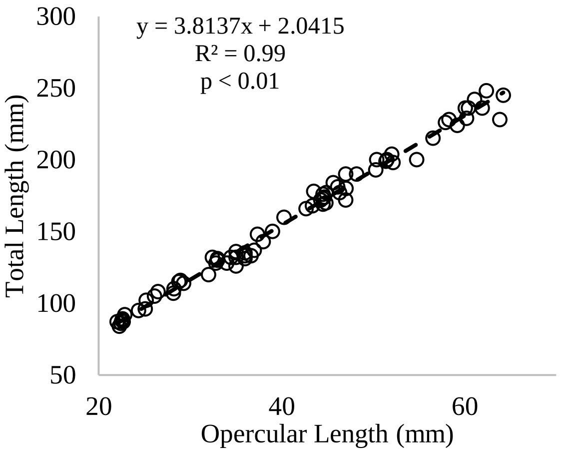

Fig. 4. Total length and opercular length regression analysis with R^2 and p value.

Since it was found that head measurements can be used to determine the total length of a Yellow Perch, this research found that the opercular bone is the most accurate measurement for extrapolating the total length. This supports the findings from Lake Mendota (Bardach 1955). The biggest difference between the two studies would be that different equations are formed from the data collected from different systems. This means that to have the most accurate data possible, if this was to be used on a system that was not Lake Bemidji the data might not be the most accurate.

This data can be used for size estimates of the Yellow Perch populations by using only the heads, whether they are the only measurable part or obtained from anglers after they utilize the fish. This would add more supplemental data for fisheries managers to use and get a better understanding of what the harvest and populations look like beyond the normal data that is collected. The Yellow Perch were only collected from Lake Bemidji but can be expanded upon by including Yellow Perch from other systems to get a more accurate measure for the species and form an equation that can be used on multiple lakes large and small.

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THE EFFECT OF *TRIAENOPHORUS CRASSUS* ON THE CONDITION OF *COREGONUS ARTEDI*

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***Abstract*—Cisco *Coregonus artedi* is, historically, the largest commercial fishery in the Great Lakes. The species is also important to commercial and recreational fisheries in inland lakes. Tapeworm *Triaenophorus crassus* larvae embed themselves into the flesh of Ciscoes, rendering the fish unmarketable to humans. *Triaenophorus crassus* is common in inland waters such as Leech Lake and Cass Lake, MN. One Canadian researcher has suggested that the parasite negatively affects the growth and weight of Ciscoes. Poor condition can reduce fecundity, leading to lower recruitment rates. This would mean a detrimental impact on not only individual fish, but the health of the entire population. The goal of this study was to determine whether a relationship exists between the severity of *T. crassus* infection and the condition of adult Ciscoes. Fish were sampled on Lake Bemidji, a medium sized mesotrophic lake, which represents inland Cisco habitat well. Both a standard weight equation and percent dry fillet weight were used to estimate fish condition. The severity of *T. crassus* infections were quantified by the number of cysts in relation to the wet weight (g) of muscular tissue on each specimen. Regression analyses suggested that both condition metrics were negatively correlated with the severity of *T. crassus* infection.**

I. INTRODUCTION

Cisco *Coregonus artedi* is a species of high ecological and economical importance in Canada and the Northern United States. The species serves as forage for apex predatory fishes in lakes it inhabits. Studies suggest they increase the trophy potential for Walleye *Sander vitreus* when available (Kaufman et al. 2009). Ciscoes are also vital to commercial fisheries. For example, when harvest peaked in the late 19th century there was an annual Cisco harvest of 9 million kilograms on Lake Michigan alone (Claramunt et al. 2019).

An issue for inland Cisco fisheries is that many inland lakes hold populations of pikes *Esox* spp. Ciscoes in such systems are susceptible to infections of parasitic tapeworms *Triaenophorus crassus* (Appendix A). The life cycle of *T. crassus* uses several intermediate hosts before maturing in the definitive host, a pike. The tapeworms release their eggs into the water from a pike's intestine in the spring when the fish spawns. The eggs develop into coracidia, a free-swimming form that is then consumed by copepods. Inside the copepod, the coracidium develops into a procercoid. If the infected copepod is consumed by a suitable planktivorous fish, in this case a Cisco, the procercoid moves through the intestinal wall and into the muscular tissue of the fish. It then develops into a plerocercoid. The immune system of the Cisco then forms large cysts around the plerocercoid. In high concentrations, the cysts render the fish unmarketable to human consumers. If the Cisco is eaten by *Esox* spp., the plerocercoid will mature into an adult in the intestine of the predator, completing the life cycle of the tapeworm (Lahnsteiner et al. 2009).

Mesotrophic lakes in Northwestern Minnesota provide an abundance of each organism required to complete the life cycle of *T. crassus*. Variable and occasionally severe infestations of these parasites have been observed in adult Ciscoes in Lake Bemidji. The effect of *T. crassus* in Ciscoes has not been extensively documented. Canadian studies suggest that severe *T. crassus* infestations reduce growth rates and weight of the affected Ciscoes (Miller 1945, 1952). If this relationship exists, it could potentially reduce the forage value of the fish. The objective of this study was to quantify concentrations of *T. crassus* and the effect they have on the condition of adult Ciscoes on Lake Bemidji.

II. METHODS

The Ciscoes used in this study were all captured from Lake Bemidji using standard angling equipment. Samples were collected from January 6th to February 9th, 2024. Upon capture, the fish were given an ID. Wet weight (g) and total length (mm) of the specimens were also recorded at this time. The specimens were then placed in bags labelled with the corresponding ID before being frozen for further analysis in the laboratory.

Fish were thawed for processing in the laboratory. Specimens were filleted and the total weight (g) of the fillets was recorded for each fish. Otoliths were also taken for aging at this time as well as the sex of each specimen. Fillets were then placed in aluminum pans for dissecting and drying. Cysts (Appendix A) were counted in each fillet and summed to obtain a total parasite count for each specimen. After counting, the fillets were retained in the drying pans which were then placed in an oven at 70° C. The fillets were left in the oven until their weight no longer decreased. At this point the dry weight (g) was recorded, and the specimens were discarded.

Two methods were used to compare the condition of specimens. The first was relative weight obtained by Equation 1, a standard weight equation developed for inland populations of Cisco (Fisher and Fielder 1998). The second method of condition estimation was a ratio between the wet and dry weights of the specimens' fillets. This allowed measurement of comparative lipid content between the specimens. Density of *T. crassus* was calculated as a ratio between total cysts and wet fillet weight. Regression analyses were performed for both condition estimates as well as for age in relation to density of *T. crassus* cysts. A regression was also used to assess the predictive capabilities of relative weight for percent dry fillet weight.

$$\log_{10}(W_w) = -5.716 + 3.289\log_{10}(L)$$

Equation 1: This equation was generated for inland populations of Cisco (Fisher and Fielder 1998). Wet weight (g) is represented by W_w and total length (mm) by L.

III. RESULTS

A total of 45 Cisco specimens were processed for this study, 9 males and 36 females. Ages ranged from 3 to 12 years, and every specimen was mature. Prevalence of *T. crassus* was 97.7%. Infection severity was highly variable, with abundances ranging from 0 to 28 cysts per fish ($\mu = 9$, $\sigma = 6.5$) and densities ranging from 0 to 178 cysts per kilogram (p/kg; $\mu = 38.9$, $\sigma = 32.0$). The highest mean abundance occurred in age 9 (12.7 cysts per fish) and the highest mean density in age 8 (54.3 p/kg). Condition estimates using standard weight ranged from 69 to 120 ($\mu = 90$, $\sigma = 9$). Dry weight retention ranged from 17.0% to 21.1% ($\mu = 18.9$, $\sigma = 1.1$).

When testing for relationships between parasite density and other metrics, a logarithm transformation was performed on the parasite density, which was positively skewed (Figure 5). This normalized the spread of parasite densities and yielded a more linear relationship between the variables (Figures 1, 2, 4 and 5).

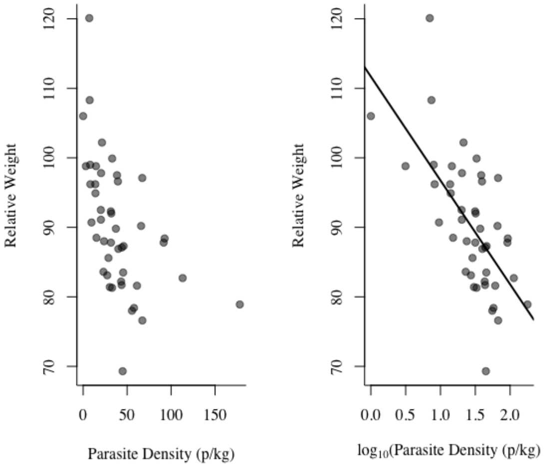

Fig. 1 (Left) The relationship between relative weight (*Wr*) and parasite density (*Triaenophorus crassus* cysts per kilogram of wet fillet weight, or p/kg) for Ciscoes *Coregonus artedi* captured from Lake Bemidji in 2024. (Right) The relationship between relative weight (*Wr)* and the $\log_{10}$ transformation of parasite density (*D*) for *C. artedi.* A regression analysis yielded the model ($Wr = -14.94(\log_{10}(D)) + 111.68$, $R^2 = 0.43$, $P < 0.001$).

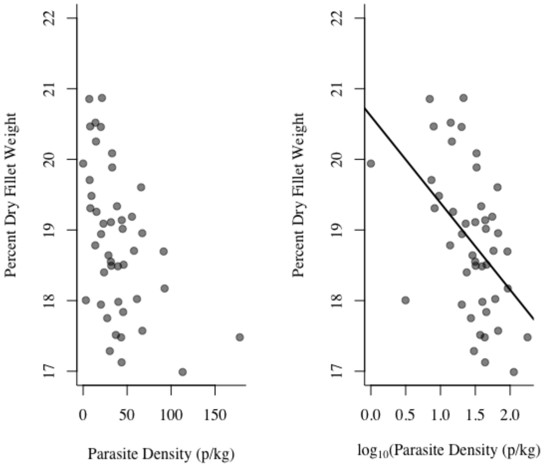

Fig. 2 (Left) The relationship between percent dry fillet weight and parasite density (*Triaenophorus crassus* cysts per kilogram of wet fillet weight, or p/kg) for Ciscoes *Coregonus artedi* captured from Lake Bemidji in 2024. (Right) The relationship between percent dry fillet weight (*Wd*) and the $\log_{10}$ transformation of parasite density (*D*). A regression analysis yielded the model ($Wd = -1.22(\log_{10}(D)) + 20.61$, $R^2 = 0.24$, $P < 0.001$).

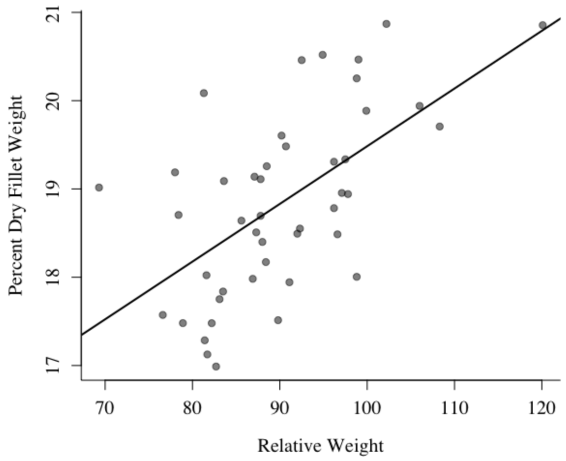

Fig. 3. The relationship between percent dry fillet weight (*Wd*) and relative weight (*Wr*) for Ciscoes *Coregonus artedi* captured from Lake Bemidji in 2024. A regression analysis yielded the model ($Wd = 0.065Wr + 12.947$, $R^2 = 0.36$, $P < 0.001$).

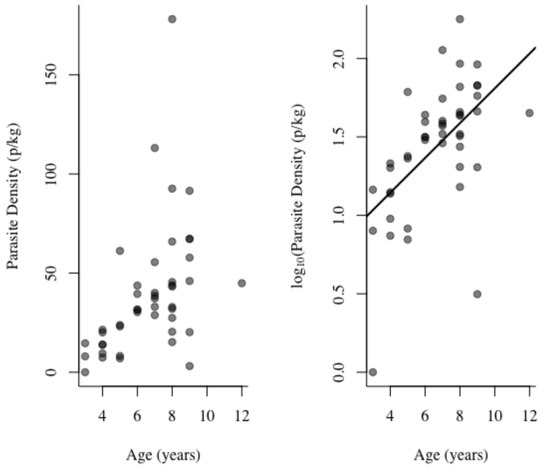

Fig. 4. (Left) The relationship between parasite density (*Triaenophorus crassus* cysts per kilogram of wet fillet weight, or p/kg) and the age (years) of Ciscoes *Coregonus artedi* captured from Lake Bemidji in 2024. (Right) The relationship between the $\log_{10}$ transformation of parasite density (D) and age (A). A regression analysis yielded the model ($\log_{10}(D) = 0.111A + 0.701$, $R^2 = 0.30$, $P < 0.001$).

IV. DISCUSSION

The primary finding in this study is that Cisco condition is negatively correlated with *T. crassus* infection severity. This is consistent with the findings of Miller (1945, 1952), whose studies suggest that Ciscoes infected heavily with *T. crassus* grow more slowly and are lighter when compared to less heavily infected specimens. The migration of *T. crassus* procercoids through the tissues of Cisco likely causes significant trauma to the fish. This necessitates metabolically costly immune responses and can reduce the host's lipid content (Timi and Poulin 2020). The preoccupation of the immune system with *T. crassus* leaves Cisco more vulnerable to other environmental or pathogenic stressors. The degradation of host condition and growth is an effect that has been documented in other fish tapeworms. It has been suggested that this is beneficial to the parasite as it increases the chance that the intermediate host is consumed by the definitive host (Barber et al. 2000).

A secondary finding is that percent dry fillet weight is significantly correlated with relative weight. This is supported by previous studies, which have found strong correlations between condition indices and lipid content in Ciscoes (Pangle and Sutton 2005). Some of the variation observed could be explained by inconsistency in filleting. Ciscoes, as with other Salmonids, do not store lipids homogenously throughout their muscular tissues. One area of high lipid concentration is directly beneath the skin. This could potentially cause variability since standard filleting is often inconsistent in the amount of tissue left on the skin.

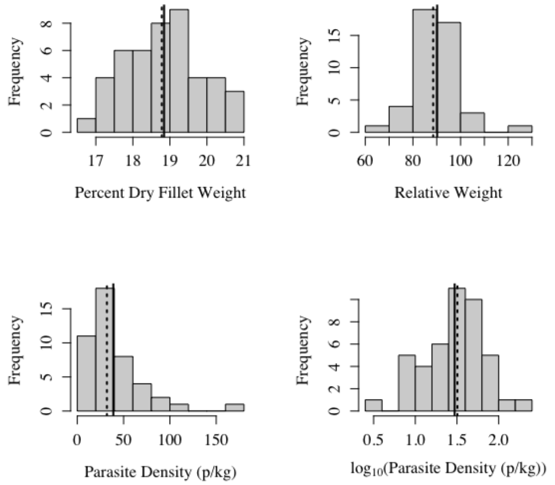

Fig. 5. These histograms show the distributions of percent dry fillet weight, relative weight, parasite density (*Triaenophorus crassus* cysts per kilogram of fillet weight, or p/kg), and the $\log_{10}$ transformation of parasite density for Ciscoes *Coregonus artedi* captured from Lake Bemidji in 2024. Mean is represented as a solid line, and median is displayed as a dotted line.

The severity of *T. crassus* infection was also significantly correlated with age. The trend has also been observed in previous studies. Miller (1952) found that *T. crassus* cyst abundance increases steadily from year 2 to 7 before stagnating or decreasing. This is attributed to the lifespan of *T. crassus* plerocercoids, which was estimated to be between 4 and 5 years. This was similar to what was observed in this study, though the age at highest abundance was slightly higher. This may be due to ecological differences between Lake Bemidji and the lakes studied by Miller (1952).

Prevalence of *T. crassus* in Ciscoes sampled in this study was high. The highest infection prevalence found by Miller (1952) was 93%. This may show that *T. crassus* is very successful in Lake Bemidji. Whether or not this is exceptional for lakes in Northwestern Minnesota is not yet known. An assessment of *T. crassus* prevalence in Ciscoes from other systems in the region would provide a more meaningful reference for this statistic.

The densities and abundances of *T. crassus* cysts observed in this study were highly variable. This is consistent with the findings of Miller (1952). Average abundances were the same as those observed in Ciscoes by Miller (1945) in Lesser Slave Lake ($\mu = 9$ cysts per fish). The range of ages in sampled Ciscoes could be a major cause of variability in infection severity. Another source could be individual feeding differences during spring and early summer, when *T. crassus* infested prey may be concentrated in shallow water. The variability of infection severity observed in this study is consistent with the findings of Miller (1952).

Another finding is that the relative weight of Ciscoes in Lake Bemidji is variable. The correlation between infection severity and relative weight may suggest that any variability in the former would cause the same effect in the latter. This could explain the wide range of relative weights observed in this study.

An important note in this study is that Ciscoes exhibit relatively high morphological diversity. This can induce variation in the effectiveness of standard weight equations in comparing specimens. This is most applicable when comparing Ciscoes from separate systems. A predictor of average relative weight is the fertility of the system. Populations in oligotrophic systems exhibit a lower average relative weight than those in mesotrophic systems. The standard weight equation used accounted for inland lakes including both oligotrophic and mesotrophic systems (Fisher and Fielder 1998). Because oligotrophic systems are included in the equation’s development, condition estimates for Ciscoes in mesotrophic lakes will be higher than is accurate. This could potentially explain why the condition estimates are relatively high for the specimens used in this study.

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APPENDIX A

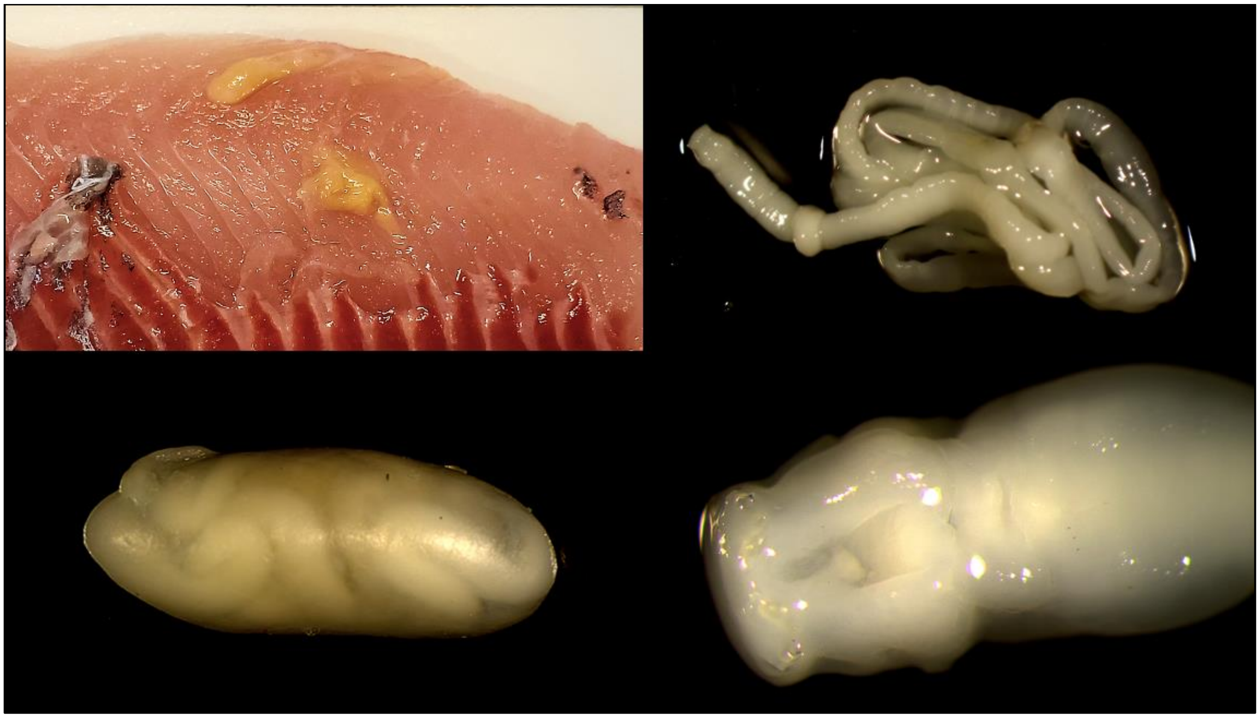

Figure A1: (Top-Left) Cysts of *Triaenophorus crassus* in the flesh of a Cisco *Coregonus artedi*. (Bottom-Left) A plerocercoid of *T. crassus* contained in a cyst. (Top-Right) A plerocercoid of *T. crassus*. (Bottom-Right) The scolex of a *T. crassus* plerocercoid. Each plerocercoid shown was found in Cisco specimens that were captured from Lake Bemidji in January and February 2024.

RELATIONSHIP BETWEEN FISHING HOURS AND NUMBER OF FISH HARVESTED FROM UPPER RED LAKE

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***Abstract*-Total hours fishermen spend fishing and total amount of fish harvested per year are some of the most important pieces of knowledge gained from creel surveys. They provide crucial information that assesses fisheries mortality and pressure. MN DNR uses their results from creel surveys to improve or impose regulations, and to maintain healthy fisheries. Based on results from similar studies, there is expected to be a positive relationship between hours fished and fish harvested. To determine the relationship between these two variables on Upper Red Lake, data from two years were selected when the variables were at their highest and lowest values, without regulation changes occurring. The results from this study were obtained using regression analysis on catch rates. The values from the catch rate analysis showed that fish per angler hour is dependent on the amount of effort put forth, but there are ultimately other variables influencing the overall outcome. This study could be expanded in the future to include questions regarding why anglers exhibit patterns of pressure in specific systems.**

I. INTRODUCTION

Walleyes are the most sought-after species on Upper Red Lake. Each year, during the creel open water survey, May-August, Upper Red Lake sees high fishing pressure. For example, anglers spent 142,126 hours fishing on Upper Red Lake in 2022. This was up approximately 12,000 hours from the previous year (2021). Almost all those fishing hours are spent targeting walleye. This pattern seems to be present regardless of if the fishing is good or bad (Kennedy 2022).

Harvest information from creel surveys is used to assess the health of recreational fisheries and inform fishery managers through interviews and counts of anglers. This allows managers to assess the effort, catch, and harvest of specific species in a system (Nieman et al. 2021). Over the years slot limits and size limits have changed as walleye size and number have increased. With increasing slot and size limits, more fishing hours are being spent on Red Lake (Kennedy 2022).

Using data from creel surveys, past studies have looked at the relationship between fish harvesting rates from anglers. One paper showed that harvest rates and time anglers spent fishing were correlated to anglers' decision to keep the fish that they kept. As an angler expends more energy and time fishing, the rate of harvest should decline (Hunt 2002). This coincides with the low fishing hours reported by creel surveys in early-late summer on Upper Red Lake.

Large lakes with high maximum sustainability yields are often viewed as being more resistant to overharvest. They can be overfished today due to anglers' ability to travel and take advantage of these situations (Parkinson 2004), especially during times of high catch rates. Upper Red Lake creel information shows that anglers travel and spend the most time fishing on the lake when harvest rates are thought to be, and typically are, the highest (Kennedy 2022). The reason anglers' hours reach such low rates towards the middle of the summer (June-Aug) on Upper Red Lake, is because catchability is at its lowest rate of the open-water season. So, anglers take advantage of better angling opportunities on lakes closer to the point of origin (Parkinson 2004).

The objective of this study is to test for a relationship between total hours fished and total rate of harvest, by using catch rate analysis from open-water creel surveys. As fishing pressure increases there seems to be an increase in the total amount of fish harvested, understanding this relationship better could help estimate fish harvest rates more accurately. Knowing more about the social responses by fisherman can benefit fishery managers by accounting for ecological dynamics and human dimensions in a system (Nieman et al. 2021). Is increased angling more of a sociological element or is it representative of actual higher harvest rates is the question this study is trying to answer.

II. METHODS

The Upper Red Lake area that falls under the jurisdiction of Minnesota is approximately 48,000 acres. The maximum depth on Upper Red Lake is 16 ft, with an average depth of 9 ft. East Upper Red Lake is managed by the Minnesota Department of Natural Resources, Division of Fisheries, in Bemidji, Minnesota (Kennedy 2022).

To examine for a correlation between total hours fished and amount of fish harvest from Upper Red Lake, data was retrieved from the Minnesota Department of Natural Resources (MN DNR). Creel survey reports were used from 2006-2015. 2015 was selected because it had the highest fishing hours and fish harvest without a regulation change. In 2006, fishing hours and harvest were the lowest without a regulation change occurring.

Creel surveys are done on Upper Red Lake each year to implement the Red Lake Fisheries Technical Committee’s Harvest Plan (Kennedy 2023). The survey implements a two-stage completed trips interview done by a creel clerk, who inquiries about the total fish caught and asks to measure species kept. The total hours spent fishing is also obtained by the creel clerk during the interview. Fishing hours selected, ranged from sunrise to sunset in the months May-September. Fish length data and amounts are computed to report total fish harvest rates.

Regression analysis was used to test for a relationship between total fish harvest rates and hours fished. The data was displayed on three separate graphs, one representing total fish harvest rates in 2015 and 2006, another representing total hours fished in both sample years studied, and the last one showing log-transformed data. The total hours spent fishing, and total fish harvest rates were calculated by the MN DNR and published in the Upper Red Lake Creel Report.

III. RESULTS

Catch rates varied from (C=0.12-1.8 fish/hr; Figure 1) in 2006, and (C=0.39-1.9 fish/hr; Figure 2) in 2015. The relationship between catch rate and fishing effort was tested using log-transformed data, which showed a significant relationship in 2006, but not in 2015 (Figure 3). The results showed inconsistent relationships between fish harvested and catch rates (Figure 3). Walleye harvests ranged from 898-17,450 fish per period (Figure 4). Fishing hours ranged from 2,713-81,141 (Figure 5) in 2006 and 2015.

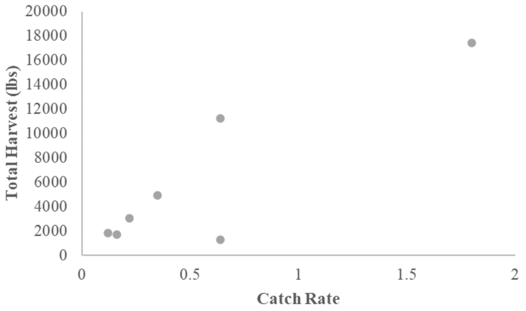

Fig. 1. Scatterplot of regression analysis figure between catch rates and number of walleyes harvested in 2006.

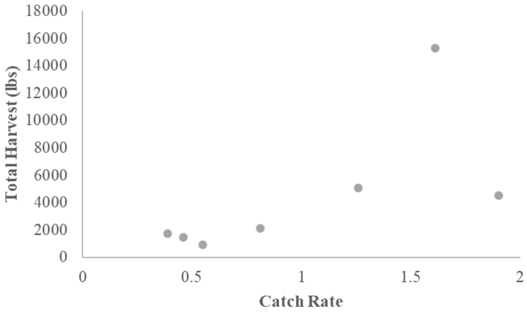

Fig. 2. Scatterplot of the regression analysis using catch rate and number of walleyes harvested in 2015.

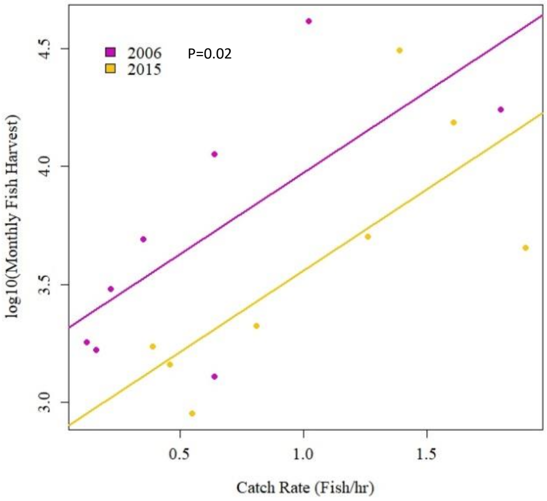

Fig. 3. Catch rate and fish harvest were log-transformed from regression analysis data, for the years 2006 and 2015.

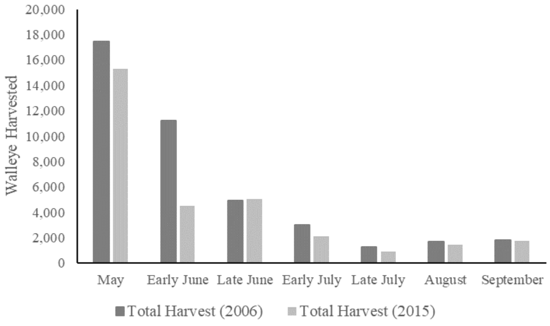

Fig. 4. Comparison of total walleye harvested on Upper Red Lake in 2006 and 2015

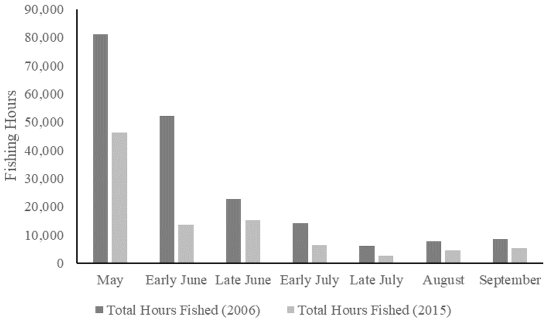

Fig. 5. Comparison of total fishing hours on Upper Red Lake in 2006 and 2015.

IV. DISCUSSION

Recreational fisheries, such as Upper Red Lake, must be managed carefully because they are social-ecological systems. Understanding of how humans can impact fisheries is one of the most important aspects gained from creel survey (Nieman 2021). Harvest amounts and fishing effort are obtained which assist fishery managers decisions in establishing slot limits and size limits. Testing how greatly these two variables influence each other, showed that catch rate is greatly dependent on fishing effort exerted. Determining why the fishing effort varies so greatly, when the catch rate stays relatively stable, is an important socio-ecological question fishery management should be asking today (Hunt 2002).

Annual harvest information from creel surveys is currently used to implement Harvest Plans in recreational fisheries (Kennedy 2023). In a time where human-environmental interactions are at an all-time high, creel surveys are being slowly adapted to inquire why anglers make certain decisions. Some examples could include questions regarding anglers' decisions to keep certain fish, or why they chose to exert certain amounts of effort (Nieman 2021).

Further inquiry is required to sustain fisheries in the future. Research into why anglers are fishing in patterns would help expand fisheries knowledge on how to better manage heavily pressured lakes and predict fishing pressure during certain periods of time. Creel surveys need to be adapted and changed to better answer critical aspects of social-economic relationships today (Nieman 2021).

ACKNOWLEDGEMENTS

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THE EFFECTS OF HABITAT CHARACTERISTICS AND LOCATION ON BROOK TROUT SIZE DISTRIBUTION

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***Abstract*—Adfluvial Brook Trout *Salvelinus fontinalis* are known to typically grow larger than riverine Brook Trout. The Kabekona River in Hubbard County, Minnesota exhibits suitable habitat for both fluvial and adfluvial Brook Trout populations. The objective of this study was to analyze the relationships between depth, stream width, canopy cover, water temperature, sediment size, and distance from Kabekona Lake on Brook Trout size distribution in the Kabekona River. Brook Trout (n=35) were angled from the Kabekona River from August 24 to September 26, 2023. Each fish was measured and released, with habitat metrics being recorded at time of release. ArcGIS was used to determine distance from Kabekona Lake for each Brook Trout, and linear regression analysis was used to determine if any of the habitat metrics showed correlation to Brook Trout size. Distance from Kabekona Lake had a significant effect on Brook Trout size ($P = 0.03$), with larger trout being captured closer to the lake. The trout size also increased as depth increased ($P = 0.02$). The information from this study could be useful to those seeking to improve stream habitat to enhance the size of Brook Trout.**

I. INTRODUCTION

Clear, cold lakes and ponds, often those that are oligotrophic, represent the optimal lacustrine (lake resident) Brook Trout habitat (Raleigh 1982). Riverine (fluvial) Brook Trout habitat is characterized by silt-free, rocky substrate in rifle–run areas with moderate flow (Raleigh 1982). Brook trout are often characterized with cool, spring fed groundwater (Raleigh 1982). Much of the ideal Brook Trout habitat is exhibited within the Kabekona River system. Adfluvial (spending time in lakes and rivers) and lacustrine Brook Trout are commonly called “coaster” Brook Trout (Becker 1983; Huckins et al. 2008). Coaster Brook Trout tends to grow larger than fluvial Brook Trout (Behnke et al. 2002).

Aside from migratory factors, there are habitat variances that can affect Brook Trout size as well. Brook Trout populations residing in water temperatures between 11 and 16 °C tend to experience optimal growth and survival (Raleigh 1982). Depth can also play a role in Brook Trout size as well. A Wyoming study found that larger Brook Trout were found in low gradients, meandering channels, and deep trench pools (Larschield and Hubert 1992). Large woody debris, boulders, and undercut banks have been described as key cover components for trout (Bjornn and Reiser 1991, Raleigh 1982). Large woody debris is considered excellent cover for Brook Trout. Undercover is any overhanging structure (trees, bushes, debris) above or in the river that trout will reside beneath. This habitat is also a crucial factor to Brook Trout survival. Moreover, pebble count data indicates that small boulders (12.8-25.6 cm) and larger are good sources of cover for Brook Trout as well.

The objective of this study was to analyze the relationships between depth, stream width, canopy cover, water temperature, sediment size, and distance from Kabekona Lake on Brook Trout *Salvelinus fontinalis* size distribution in the Kabekona River. This was done to analyze the effects of different habitats on the size of brook trout to better understand what the ideal habitat consists of to grow and support the largest brook trout possible.

II. METHODS

All Brook Trout captured in this study were caught with standard angling equipment. All fish were caught between 14 August and 26 September 2023. Once captured, each fish was measured with a tape measure in centimeters and released. At the time of release, each habitat metric was recorded. For location, each fish was given a waypoint in the OnX hunting app. This recorded latitude and longitude of the catch location. In the notes of the waypoint, length of the fish and habitat metrics were recorded. Depth was recorded using a tape measure from the bottom of the river to the surface and recorded in meters. Stream width was recorded by taking the distance from one side of the river to the other using a tape measure and recorded in meters. The canopy cover was taken by using a paper towel roll and pointing it at the sky and estimating a percentage of sky that is not obstructed by canopy. Water temperature was obtained using a thermometer and recorded in Celsius. Lastly, sediment size was calculated by walking heal-to-toe in a circle and measuring a pebble from the lake bottom with a tape measure in centimeters at every step. It is important to note that all habitat metrics were recorded where the fish bit the bait.

Once all data was collected, it was transferred to an Excel document. From there, regression analysis was run for depth, stream width, canopy cover, water temperature, and sediment size. A scatter plot was also created within excel for each of the habitat variables.

ArcGIS pro was used to digitize points that corresponded to the waypoints saved in OnX. The cut tool was then used to determine the distance from the lake to each site. Excel was then used to create a figure that represented Brook Trout size as a function of distance from the lake.

III. RESULTS

Habitat metrics were collected from 35 Brook Trout (12.7-29 cm (about 11.42 in) TL). This yielded 35 trout locations. Depth was recorded for each trout location, and it was found that trout size increased as depth increased (*P* = 0.02; Figure 1). Stream width was measured in meters at each location, but despite stream width generally getting wider near the lake, it was not significantly related to trout size (*P* = 0.08; Figure 2). Neither canopy cover (*P* = 0.34; Figure 3) nor water temperature (*P* = 0.88; Figure 4) was significantly related to trout size. Sediment size was recorded via pebble counts at each catch, but it was also not significantly related to trout size (*P* = 0.21; Figure 5). Distance from the lake was also recorded and it was found that trout size decreased as distance from the lake increased (*P* = 0.005; Figure 6).

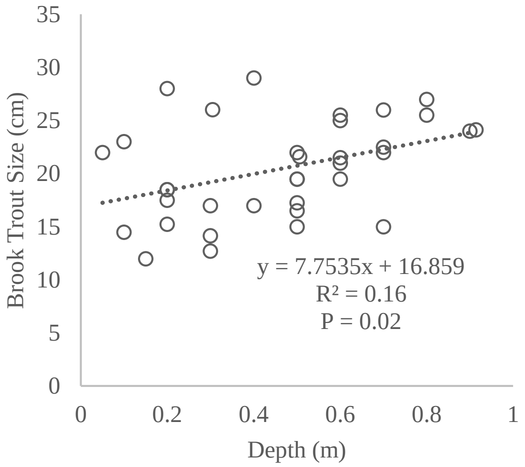

Fig. 1. Depth of catch location plotted against size of Brook Trout *Salvelinus fontinalis* in the Kabekona River. Fish were caught August through September 2023 (*P* = 0.016).

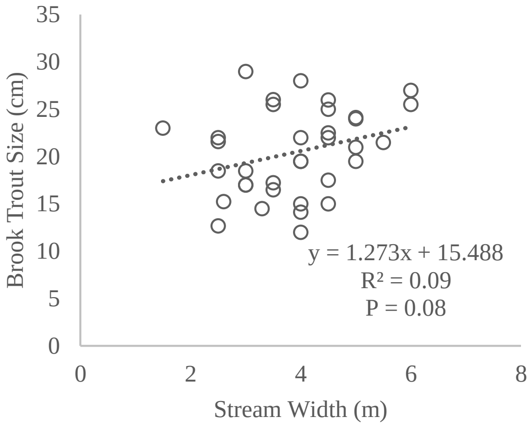

Fig. 2. Stream width plotted against size of Brook Trout *Salvelinus fontinalis* in the Kabekona River. Fish were caught August through September 2023 (*P* = 0.08).

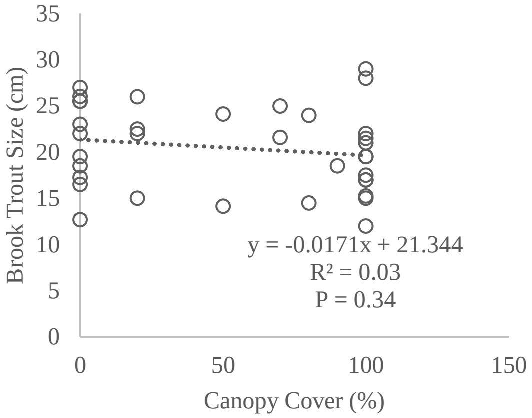

Fig. 3. Canopy cover % plotted against size of Brook Trout *Salvelinus fontinalis* in the Kabekona River. Fish were caught August through September 2023 (*P* = 0.34).

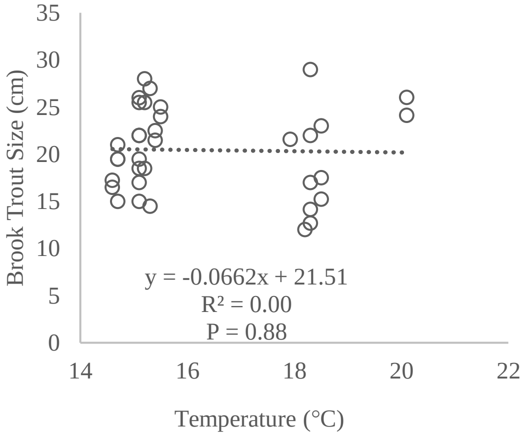

Fig. 4. Water temperature plotted against size of Brook Trout *Salvelinus fontinalis* in the Kabekona River. Fish were caught August through September 2023 (*P* = 0.88).

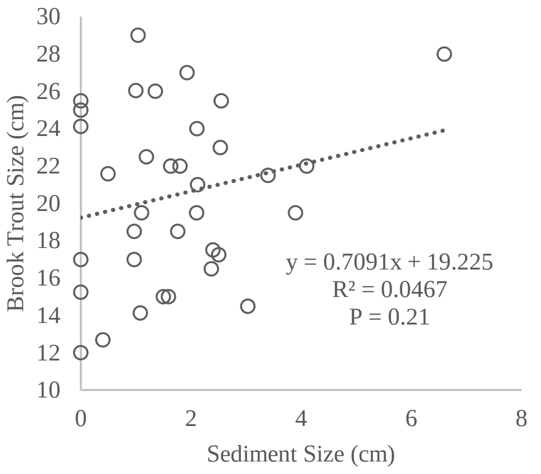

Fig. 5. Sediment size plotted against size of Brook Trout *Salvelinus fontinalis* in the Kabekona River. Fish were caught August through September 2023 (P = 0.21).

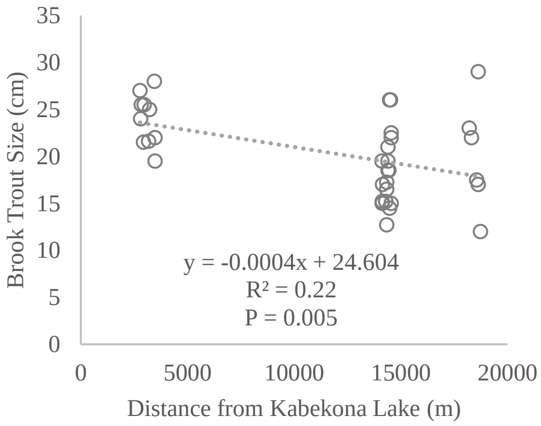

Fig. 6. Distance from Kabekona Lake plotted against size of Brook Trout *Salvelinus fontinalis* in the Kabekona River. Fish were caught August through September 2023 (P = 0.005).

IV. DISCUSSION

A key finding of this study showed that larger Brook Trout tended to reside closer to Kabekona Lake. Research from Lake Superior tributaries suggests that the average larger size in adult adfluvial trout is due to a habitat shift, where less energy is required to grow to larger sizes in lake environments (Kusnierz et al. 2009). This would suggest that the trout in this system travel in and out of the river, making them adfluvial. The presence of these fish would explain their larger size.

Another conclusion found in this study was that Brook Trout size increased with depth. This would make sense as larger trout tend to prefer living in deeper pools (Larschield and Hubert 1992). This relationship could also explain why trout are larger closer to the lake, as the river generally gets deeper downstream.

The results of this study suggest that depth and distance from the lake play a role in determining size of Brook Trout. Research suggests that juvenile Brook Trout do not exhibit differences in size, even though heterogenous habitat is present. The larger size in adult fish is often linked to growth in a lake environment (Kusnierz et al. 2009). This could explain why habitat metrics such as stream width, canopy cover, water temperature, and sediment size did not show any statistical significance in Brook Trout size. This study could be further looked into by increasing the sample size, including fish residing in Kabekona Lake.

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