Muskellunge (*Esox masquinongy*) Feeding Habits and Habitat Preferences in Lake St. Clair

By

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Abstract

Muskellunge (*Esox masquinongy*) are an economically and ecologically important species. Yet, our understanding of their feeding habits and habitat preference is limited and incomplete. This study addressed these shortcomings with muskellunge in Lake St. Clair. Muskellunge were captured by trolling on charter boats and electrofishing. Feeding habits were determined by comparing fish consumed to abundance of fish in the lake. Habitat preference was determined by spatially analyzing collected fish catch-per-unit-effort and lake conditions such as depth and submerged aquatic vegetation coverage. Overall, 167 muskellunge were sampled and 77% of them had empty stomachs. White bass (*Morone chrysops*) was the most common found prey species in their diet. Moronidae was the family composing the largest portion of their diet. Muskellunge were more abundant in water with greater depth. The entire lake appears to have suitable coverage of submerged aquatic vegetation with an average of 67%. In conclusion, muskellunge consumed small amounts of the main sport fish species in Lake St. Clair and likely have minimal impacts on those populations. The majority of Lake St. Clair has the preferred habitat for muskellunge and is likely to be a contributing factor to their large population.

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Table of Contents

Introduction

Muskellunge (*Esox masquinongy*) are apex predators (Mooradian and Shepherd 1973; Belusz and Witter 1986; Hanson 1986; Smith 1996; Bozek et al. 1999) and support a multi-million-dollar sport fishery (Menz and Wilton 1983; Younk and Cook 1992; Farrell et al. 2007). They have been shown to directly influence fish assemblages in many inland lakes (Tonn and Magnuson 1982). They are a highly targeted fish species because of their large size, sharp teeth, and the fight they put up when caught. Therefore, muskellunge are ecologically and economically crucial for the areas they inhabit. Muskellunge are found throughout the Great Lakes region and in the upper basin of the Mississippi River (Cook and Solomon 1987). Yet knowledge of their feeding habits (William 1961), and habitat preference (Dombeck 1986) are limited and incomplete.

There is a general lack of understanding of muskellunge's effect on other species. In particular, there is interest in their effect on sport fish, such as yellow perch (*Perca flavescens*), walleye (*Sander vitreus*), and northern pike (*Esox Lucius*), due to their consumption of these fish. Muskellunge are often blamed for perceived declines in other sport fish populations without any supporting evidence (MDNR 2012). Feeding habits of muskellunge have been studied in various lakes and rivers and the laboratory, but studies are limited due to the rare abundance of the fish and its importance to angling. Muskellunge appear to feed in the midwater region of lakes (Buss 1960) and show crepuscular feeding habits, most active in the early morning or late afternoon

(Cook and Solomon 1987). When actively feeding, they are ambush predators and do not pursue prey for long distances (Engstrom-Heg et al. 1986). Muskellunge in Ontario and Quebec were found to be generalist predators with yellow perch being the predominant prey species (Hourston 1952). Yellow perch were also the most commonly consumed prey species in lakes in northern Wisconsin, while white suckers (*Catostomus commersonii*) were second most abundant (Bozek et al. 1999). Muskellunge in New River, Virginia primarily consumed cyprinids, and catostomids, with smallmouth bass (*Micropterus dolomieu*) comprising a minor component of their diet (Brenden et al. 2004). In Tennessee streams, muskellunge were generalists and showed little preference toward any particular species (Parsons 2011). Some of these studies did not compare prey items to availability or abundance of prey species in the lake, so they could not make conclusions about prey selectivity.

Previous studies describing muskellunge feeding habits used a variety of methods for capturing muskellunge with varying success. Capturing muskellunge is difficult because they are solitary animals for most of the year, except while spawning, and are low in abundance, which makes collection difficult (Eddy and Underhill 1976). Bozek et al. (1999) captured 1,092 muskellunge in smaller inland lakes, using fyke nets, electrofishing, and angling over three years. Gammon and Hasler (1965) also used fyke nets, electrofishing, and angling to catch 220 muskellunge during a two-year period in small bog lakes. Fyke netting can lead to bias due to feeding while captured or delay in time of capture to time of retrieval of prey items leading to digestion post-capture (Breen and Ruetz 2006). Electrofishing is only effective in shallower water and a difficult capture method for muskellunge because of their avoidance behavior. Angling or trolling for muskellunge can be a more effective capture method than electrofishing because they are less likely to escape when hooked. However, this introduces bias of catching fish that are hungry because they are going after the bait and therefore they may have a higher frequency of empty stomachs than the overall population.

Historically, stomach contents were collected by dissection because muskellunge were harvested by anglers. Dissection ensures that all stomach contents are removed. More recently, most anglers follow a catch-and-release ethic making the previous method obsolete. Gastric lavage is a commonly used method for extracting stomach contents from muskellunge (Gammon and Hasler 1956; Bozek et al. 1999; Brenden et al. 2004; Parsons 2011; Kapuscinski et al. 2012). While it is often difficult to remove larger items by gastric lavage, fish can be returned to the lake alive.

In addition to feeding habits, it is important to understand muskellunge habitat preference because many populations of muskellunge have declined (Cook and Solomon 1987), and loss of critical habitat is considered to be a large contributor to this decline (Oehmcke et al. 1974; Trautman 1981). Studies of muskellunge habitat in the summer have shown strong preference for areas with vegetation, deeper water, and changes in contour (Dombeck et al. 1984; Miller and Menzel 1986; Strand 1986; Cook and Solomon 1987; Zorn et al. 1998; Rust et al. 2002; Diana et al. 2015). Many of these studies primarily focused on spawning sites and only marginally determined habitat preference during other times. Diana et al. (2015) did observe muskellunge habitat in the summer and found muskellunge were often suspended in 3-10 m of water over locations with bottom depths averaging 30 m in June and 40 m in August. *Chara spp*. was the dominant species of SAV in the spawning sites of muskellunge in Torch Lake (Diana et al. 2015). Cook and Solomon (1987) described an optimal percent cover of SAV as ranging between 25-75%, and believed completely covered bottom with SAV would reduce the foraging positions available and decomposing vegetation would deplete dissolved oxygen levels. At the opposite extreme, a lack of SAV would provide no foraging coverage necessary for them to prey on fish. Cook and Solomon (1987) and Valley et al. (2004) also found that extensive SAV interspersed with open water was important for muskellunge and the type of vegetation was also important. Cross and McInerny (2006) found that lakes with high diversity of plant species had the highest fish catch per effort of valued sport fish, while lakes with extensive coverage by a single plant species had the highest catch rates of benthic omnivores. Yet, understanding of non-spawning habitat requirements during adulthood is limited and incomplete (Dombeck 1986). Many studies on muskellunge habitat used radio or ultrasonic transmitters that were surgically implanted into the fish (Miller and Menzel 1986; Hanson and Margenau 1992; Diana et al. 2015). While these methods are good for tracking a single muskellunge's range of habitat, it is limiting in the number of muskellunge that can be followed and, therefore, not always representative of the population's habitat preference (Martyn and Etienne 2000). While these studies provide useful information on muskellunge, their findings may not be generalizable to all systems, because lakes have differing prey communities and differing abiotic factors influencing muskellunge habitat selection.

Despite their importance, there is limited information on diet and habitat preferences of muskellunge in Lake St. Clair (Bozek et al. 1999). Lake St. Clair supports one of the largest self-sustaining populations of muskellunge (Haas 1978), so they have the potential to heavily influence prey populations there. Therefore, it is important to understand why muskellunge are prevalent in Lake St. Clair and what their influence is on other fish populations, such as yellow perch, and walleye. This study was designed to address these shortcomings and potential impacts.

The objectives of this study were to: 1) determine prey species composition in adult muskellunge diets; 2) determine whether adult muskellunge in Lake St. Clair preferentially target certain prey species; 3) determine if muskellunge selectively feed on certain sizes of prey; 4) estimate habitat selected by adult muskellunge, using catch-per-unit effort of charter fishers; and 5) evaluate depth and presence of submerged aquatic vegetation as important habitat features selected by adult muskellunge.

My hypotheses include:

1) Adult muskellunge in Lake St. Clair are generalist feeders and their diet will reflect prey species abundance in the lake.

2) Catostomidae and Cyprinidae compose the majority of their diet because of their abundance in Lake St. Clair and in other diet studies.

3) Larger muskellunge select larger prey items.

4) Muskellunge select areas that are between 50-80% covered by submerged aquatic vegetation.

5) Muskellunge inhabit areas with a depth greater than three meters.

Study Site

Field work was conducted throughout Lake St. Clair on the U.S. and Canadian side and in the Detroit River near Belle Isle and Wyandotte (Figure 1). Fish were collected from May to September in 2014 and 2015. In the late 1800s, muskellunge supported a commercial fishery in the Great Lakes (Porter 1977; Crossman 1986), but over time this transformed into a recreational fishery. The fishery in Lake St. Clair generates over $36 million a year and is one of the most heavily recreationally fished areas in the Great Lakes (MacLennan et al. 2003). Smallmouth bass, walleye and yellow perch make up the majority of fish caught by recreational anglers in Lake St. Clair (Thomas and Wills 2015).

Lake St. Clair has biotic and abiotic characteristics that create a unique environment for muskellunge. It is not considered one of the Great Lakes, but it is a part of the Great Lakes system. It is large compared to other inland lakes that muskellunge occupy, but much smaller than any of the Great Lakes, with a surface area of 1,114 km^2 (Thomas and Haas 2012). It is relatively shallow lake with an average depth of three meters (Thomas and Haas 2012). Water flows in from Lake Huron through the St. Clair River, and out via the Detroit River into Lake Erie with a retention period of about seven days (Bolsenga and Herdendorf 1993). Therefore, the temperature of the lake is greatly influenced by Lake Huron (Bolsenga and Herdendorf 1993) and generally leads to cooler than expected temperatures in summer. This is especially true in the western portion of the lake, because water enters the lake through the St. Clair river channels that feed the western portion. Temperatures in that portion are lower by 2-4 degrees Celsius from the eastern side (Bolsenga and Herdendorf 1993). Submerged aquatic vegetation varies slightly year to year throughout the lake, but with a shallow depth and the recent invasion of zebra and quagga mussels increasing water clarity, submerged aquatic macrophytes have increased in abundance (Thomas and Haas 2012) and are present over most of the lake (Haas and Thomas 2012).

The fish community in Lake St. Clair is comprised of a mixture of warmwater and coolwater species and appears to favor an esocid-centrarchid community (Danzmann et al. 1992; MacLennan et al. 2003). Danzmann et al. (1992) described two categories of fish in the lake by their habitat: Centrarchidae associated with an abundance of aquatic vegetation; and Catostomidae, Percidae, and Sciaenidae associated with open water. There are over 61 species and 19 families of fish found in Lake St. Clair. Walleye, muskellunge, smallmouth bass, and northern pike are key predators that have sustained their populations despite various changes to the system throughout time (MacLennan et al. 2003). Over 13 years of survey data from the Lake St. Clair Fisheries Research Station, rock bass (*Ambloplites rupestris*) were the most dominant species in the survey (Thomas and Wills 2015). Other common species included channel catfish (*Ictalurus punctatus*), smallmouth bass, and northern pike (Thomas and Wills 2015). Community surveys of forage fish were dominated by yellow perch and spottail shiner (*Notropis hudsonius*) (Thomas and Wills 2015). Surveys of larger adult fish done by the Ontario Ministry of Natural Resources and Forestry's (OMNRF) Lake Erie Management Unit showed freshwater drum (*Aplodinotus grunniens*) and channel catfish to be the most commonly caught species, comprising 33 and 24% respectively (OMNRF 2015). Surveys of young-of-year fish by the OMNRF in Lake St. Clair showed spottail shiner, brook silverside (*Labidesthes sicculus*), and other cyprinids to be predominant.

Methods

Feeding habits were evaluated by comparing the relative abundance of species present in Lake St. Clair to species found in muskellunge stomach contents in order to determine if they selectively target certain species or are generalists. Muskellunge were mainly captured by trolling on charter boats to provide a large sample size. Prey items were removed by gastric lavage, so the muskellunge could be returned alive. Habitat preference was evaluated by comparing muskellunge capture points and locations fished by a charter boat over four years. Percent coverage of submerged aquatic vegetation and depth were evaluated to create a low resolution but geographically wide map of habitat availability.

Stomach contents were collected from muskellunge caught by trolling and electrofishing, as well as fish harvested and taken to a taxidermist. The Michigan Department of Natural Resources (MDNR) conducted electrofishing surveys in the spring of 2014 and 2015 for their annual egg take program, and stomach contents were removed from some of those fish. Electrofishing began around 2200 and lasted until 0200 in 2-3 meters of water. MDNR staff also electrofished in Anchor Bay of Lake St. Clair during daylight several times throughout summer 2015 and captured five muskellunge from which stomach contents were collected. Trolling was done by cooperating with charter fishers who began the first Saturday of June and continued until September in 2014 and 2015. During trolling six rods were fished with a variety of lures about one meter below the surface. The boat was driven at five km per hour in 3-6 m of water. Trolling occurred in daylight typically from 0800 to 1700.

Upon capture of a muskellunge, location was recorded using GPS, and fish were put into a holding tank to recover. Upon recovery, total length was measured to the nearest centimeter. Muskellunge were restrained for gastric lavage, using an electronarcosis device in order to reduce stress and ease handling. This device was a modification of Jennings and Looney's (1998) system, with a holding cradle made of PVC pipes and mesh. Two bare wires were positioned down the sides of the cradle with nine wires across the middle. All wires were attached to a 9-volt battery. A wet cloth was placed on the device, and fish were laid over that. This device caused the fish to lose equilibrium and the muscles to relax (Hudson and Johnson 2011). Stomach contents were then collected using gastric lavage. One person held the fish on the device and massaged the stomach, while another performed gastric lavage, using a modified version of the apparatus described by Crossman and Hamilton (1978). The apparatus used for gastric lavage was comprised of a 12-v bilge pump attached to a flexible hose and a battery. The bilge pump was placed in water, while the flexible hose was inserted in the mouth of the muskellunge. When the apparatus was turned on the muskellunge stomach filled with water dislodging contents inside, which were then regurgitated. Stomach contents were captured in a strainer. On several occasions pliers were used to remove larger food items. Stomach contents were saved in a Ziploc bag or plastic jars, submersed in ethanol, and labeled for later analysis in the laboratory.

Samples were analyzed at the Natural History Museum at the University of Michigan. Dr. Gerald Smith helped identify each sample to the lowest taxonomic level possible. Total length of food items was measured directly when possible or estimated by comparison to specimens of the same species. Partially digested prey items that could not be identified initially were later identified to lowest taxonomic level by comparison with museum specimens using bones such as the Weberian apparatus or cleithra (Traynor et al. 2010).

In order to evaluate prey selection, all of the samples collected in 2014 and 2015 were categorized to family because this was the lowest taxonomic group identified for all individual prey. Percent frequency was determined for each prey family found in muskellunge. A Chi-square test was used to compare observed prey families' occurrence in the diet to abundance of that family in Lake St. Clair. Prey abundance in Lake St. Clair was estimated from MDNR trap net surveys (Wills and Thomas 2014) and OMNRF trap net and beach seine surveys (OMNRF 2015). Alpha was set at 0.05 for all tests. A simple linear regression was used to test relationships between prey fish total length and muskellunge total length.

To determine habitat preference for muskellunge, I mapped catch-per-unit-effort (CPUE) of charter anglers throughout the lake as a proxy for muskellunge abundance in ArcGIS 10.3.1. This was compared to depth and percent cover of submerged aquatic vegetation (SAV). Depth data came from a bathymetry map available from Michigan Department of Technology, Management and Budget's geographic data library (www.mcgi.state.mi.us). Percent cover of SAV data came from MDNR hydro-acoustic surveys (Thomas and Haas 2003) and transformed by Great Lakes Aquatic Habitat Framework (glahf.org) to generate an estimated value of SAV across the entire lake from locations where SAV was sampled. The CPUE layer was developed with data obtained from a charter boat, on capture locations of muskellunge, and tracks of fishing effort during the muskellunge fishing seasons 2010-2014 in Lake St. Clair. A 1000 x 1000 m grid system was created to calculate CPUE values and compare them to depth and SAV. Average, maximum, and minimum values for percent cover of SAV were calculated for each grid cell, based on the 1,156 point values that were estimated per grid cell. Maximum and minimum values were compared to see if there were any noticeable differences between grid cells that may have had significant variation within the cell. Average depth was also created for each cell based on 4,489 values that were estimated per cell. A simple linear regression of muskellunge abundance per grid cell and its corresponding depth and SAV values was run to test for a relationship between muskellunge abundance and the two variables. A t-test was also done to compare SAV in areas fished versus areas not fished. R Studio (2015) was used to run statistical analysis with an alpha of 0.05.

Results

Overall 167 muskellunge were sampled and 77% of them had empty stomachs. A total of 40 individual prey were found across all muskellunge stomachs sampled, and all were fish. Two muskellunge contained two fish in their stomachs, and one muskellunge contained three fish. Three of the prey were too digested to identify, and two could only be identified to class (Actinopterygii); these were eliminated from diet analyses. The identified prey were from eight families. White bass (*Morone chrysops*) was the most commonly found prey species, with 8 out of 35 individuals, and Moronidae was the family most represented in muskellunge stomachs with 9 individuals. Catostomidae and Cyprinidae were the second most frequent families represented in the diet with eight individuals each (Table 1). In Lake St. Clair, Cyprinidae was the most common family and Centrarchidae was second most abundant (Figure 2).

There was a significant difference between prey species relative abundance and frequency of species in the diet (Figure 3) ($p < 0.05$). Moronidae comprised 26% of muskellunge diet but only 1.4% of the fish community in Lake St. Clair. White sucker was the second most common prey item found, but made up only 0.083% of fish community composition. Cyprinidae comprised 23% of the muskellunge diet and they made up 68% of the fish community in Lake St. Clair, while Sciaenidae composed 8% of the diet and only 0.08% of the fish community. Only a single yellow perch (Percidae) was found in a muskellunge, while they comprised 1.7% of the Lake St. Clair fish community. Only a single fish in the Esocidae family, which include northern pike, was found in muskellunge diet. Therefore, a total of 6% of muskellunge diet was comprised of families that contain the main sport fish. Total length of prey consumed was correlated with the total length of muskellunge ($P < 0.05$) (Figure 4). Prey fish ranged in size from 6-43% of muskellunge total length and the average prey items were 25% of the length of a muskellunge.

Muskellunge trolling occurred over most of the western and central areas of Lake St. Clair, excluding Anchor Bay, and CPUE was generally highest on the Canadian side in offshore locations (Figure 1). There were also some high CPUE areas along the southern portion of the lake (Figure 1). CPUE was significantly correlated with mean depth ($p < 0.05$), indicating selection of deeper portions of the lake by muskellunge. However, this correlation was rather weak ($r = 0.277$). The grid cell with the highest CPUE (0.21 fish per hour) had an average depth of 4.8 m. The average depth of all grid cells with a CPUE value above 0 was 4.5 m, and the average depth of grid cells that were fished in but had 0 CPUE was 2.7 m. There were no significant correlations between muskellunge CPUE and average, maximum, or minimum percent coverage of SAV. There was also no significant difference between the coverage by SAV in fished and unfished areas. The average percent cover for the area fished was 68% and the average percent cover for areas not fished was 66%.

Discussion

I found that muskellunge in Lake St. Clair selectively consumed certain fish at rates higher than predicted by their abundance in the lake, which does not support the hypothesis that muskellunge are generalist predators. Moronidae, Catostomidae, and Cyprinidae comprised the majority of muskellunge diet, which partially agrees with one of my hypotheses; although it was surprising to find Moronidae comprising such a large proportion of muskellunge diet. This suggests that the major sport fish in Lake St. Clair compose a minor part of muskellunge diet, and have little effect on these species populations. Muskellunge abundance showed no relationship with percent cover of submerged aquatic vegetation, yet SAV coverage did not vary widely throughout the lake, so there may not have been enough variance to detect a relationship. This may suggest that all of Lake St. Clair has favorable coverage of SAV and may be a supporting factor in their prevalence in this lake. This was unexpected and contradicts the hypothesis that muskellunge associate with higher coverage of SAV. Muskellunge abundance did increase with depth, as expected.

I found that muskellunge selectively foraged on Moronidae, Catostomidae, and Cyprinidae, which composed 26%, 23%, and 23% of the diet, respectively, for a total of 72% of all prey consumed (Figure 2). Catostomidae composed only 0.54%, and Moronidae only 1.4% of Lake St. Clair's fish community, so both are over represented in the diet and, therefore, selectively preyed upon. Other studies of muskellunge diet also found Catostomidae and Cyprinidae comprised the majority of muskellunge diet in lakes in Virginia, Quebec, and Ontario. (Harrison and Hadley 1979; Hanson 1986; Brenden et al. 1999). However, Moronidae was less frequently found to be common in other muskellunge diet studies, while much of the literature shows yellow perch as the most common species in their diet (Hourston 1952; Bozek et al. 1999). Moronidae were slightly more abundant in Lake St. Clair than Percidae and comprised 1.7% of the fish community, but were considerably more abundant in muskellunge diet (26%) than Percidae (3%). Esocidae also only composed 3% of the diet, so sport fish comprised only 6% of the diet. This suggests that sport fish are not a major component of their diet. Even though Cyprinidae composed a large component of muskellunge diet, it was less common in the diet compared to its abundance in Lake St. Clair, where 68% of the fish community is Cyprinidae. The discrepancy between the abundance of cyprinids in the lake and the diet may be due to the focus on adult muskellunge. Many cyprinid species are smaller in size and therefore more likely to be consumed by juvenile muskellunge. Brenden et al. (2004) found that the diet of muskellunge smaller than 800 mm consisted primarily of cyprinids.

Prey length averaged 25% of the muskellunge length and showed a positive relationship with muskellunge length as expected. Hess and Heartwell (1978) found similar results of a direct relationship between the size of the muskellunge and size of prey consumed. Bozek et al. (1999) also found similar results with prey length ranging from 6-47% of the muskellunge total length. Since muskellunge energy requirements increase as they increase in size, they may eat larger prey, although further investigation is needed to determine if energy requirements cause this change because larger muskellunge can also eat more prey. Their gape also increases in size as they grow, making them more capable of eating larger prey.

Muskellunge prefer habitat with 25-75% SAV coverage and 3-10 m depths, and Lake St. Clair has an average SAV coverage of 67%, with little variance across the entire lake, and an average depth of 3 m, indicating that most of the lake is within preferred SAV coverage and depth for muskellunge, which is likely a contributing factor to the large population and fishery. Muskellunge abundance during the summer increased with depth in Lake St. Clair. This was expected because many other studies found muskellunge to inhabit areas with deeper water in the summer. The area with the highest abundance of muskellunge in this study had an average depth of 4.8 m, compared to an average for the lake of 3.4 m. This is consistent with what several other studies found, such as Diana et al. (2015), who observed muskellunge suspended in 3-10 m of water. This is further supported by my results that showed areas where muskellunge were present had an average depth of 4.5 m, while areas that were fished but no muskellunge were caught had an average depth of 2.7 m. Oehmeke et al. (1974) found muskellunge usually remained in waters less than 4.5 m deep, but occasionally were found in depths of 15 m. In some lakes in Ontario, muskellunge inhabited areas 1.2-2.7 m deep in the summer (Minor and Crossman 1978), while tracked muskellunge in West Okoboji Lake, Iowa were mostly found in water 1.8-7.6 m deep (Miller and Menzel 1986). The average depth of Lake St. Clair is 3.4 m, so the entire lake is within the range of depths that muskellunge typically inhabit. Muskellunge may inhabit areas with deeper water in Lake St. Clair because larger prey may be found in these areas, as opposed to smaller prey species that seek cover in shallow vegetated areas (Harvey and Stewart 1991).

Average cover of submerged aquatic vegetation was not correlated with muskellunge abundance, which was unexpected. Becker (1983) found muskellunge inhabited vegetated areas during the day, and Miller and Menzel (1986) similarly found muskellunge to have strong allegiance to areas associated with vegetation. The percent cover of submerged aquatic vegetation in areas fished (68%), which are where fishermen expected to encounter muskellunge based on their previous experience, had similar SAV coverage to areas not fished (66%). SAV coverage is very similar across the entire lake, and the entire lake appears to have suitable SAV coverage for muskellunge. Cook and Solomon (1987) stated the optimum habitat would have extensive submerged aquatic vegetation ranging from 25-75% coverage interspersed with open water, a condition which is common in Lake St. Clair. Most studies on the relationship between SAV and fish abundance have found that intermediate levels of SAV promote high fish species richness and are optimal for growth and survival of all fish (Thomas and Haas 2012).

The type of vegetation is also important for muskellunge. Cross and McInerny (2006) found that lakes with high diversity of plant species had the highest CPUE of valued sport fish, while lakes with large coverage of a single plant species had the highest catch rates of benthic omnivores. Thomas and Haas (2012) found that muskgrass (*Chara spp*) is one of the main species found in the lake, and the lakes does have a high diversity of submerged aquatic vegetation.

There are several limitations that restrict the interpretation of the findings in this study. I was only able to collect a small number of stomach samples (35 identifiable diet specimens), which is very limited in determining diet composition of a large population of muskellunge with any significant meaning. One reason for the high proportion of empty stomachs was probably due to bias in the capture method, with angling leading to sampling more muskellunge with empty stomachs because of selection for hungry fish (Hayward et al. 1989). While this small sample size should still identify the commonly eaten species, it could miss less common ones and may also lead to particular species of prey being over or under-represented in the diet. Caution should be taken when interpreting these results, and further investigation is needed to support the findings that muskellunge mainly target Moronidae.

Another limitation is that the muskellunge abundance data was taken from a charter boat, and charter captains are experienced in finding muskellunge. This leads to bias in certain areas being fished more heavily than others, but CPUE corrects for this by adjusting catch to time spent in an area. Caution should be used when interpreting results such as the lack of a relationship with submerged aquatic vegetation, because charter fishers likely avoid heavily vegetated areas to prevent lures from fouling. Analysis of habitat selection may also be biased because the scale for spatial data was too coarse to detect small differences, particularly in submerged aquatic vegetation. Vegetation, CPUE, and abundance were evaluated for large cells (1000mx1000m), while a finer scale study may be able to detect differences in habitat selection. However, the difference between maximum and minimum coverage of submerged aquatic vegetation within a grid cell was only 5%, meaning each grid cell had fairly consistent coverage within it. SAV data also came from an average from 2007 to 2011, and SAV growth varies yearly.

Results from this study will be helpful in future management of the recreational fishery including muskellunge in Lake St. Clair. A crucial part to sustaining a lucrative recreational fishing industry is a comprehensive understanding of muskellunge diet and subsequent effects on fish populations. This study presents a baseline understanding of what muskellunge eat in Lake St. Clair and that their possible effect on sport fish populations may be minimal. In addition to knowledge of muskellunge impact on other species, management needs to know habitat requirements. Muskellunge occupied areas with depths ranging from 2-6 m and required large coverage of SAV on the bottom. These conditions are currently found throughout most of Lake St. Clair, so there is an abundance of suitable habitat, and this lake can serve as a model to other lakes trying to support muskellunge populations.

Tables:

Family	Lake St Clair Fish community	Muskellunge diet (number)	Muskellunge diet (percent)
Catostomidae	0.69	8	22.86
Sciaenidae	0.10	3	8.57
Ictaluridae	1.31	1	2.86
Centrarchidae	7.54	4	11.43
Moronidae	1.75	9	25.71
Cyprinidae	86.0	8	22.86
Percidae	2.08	1	2.86
Esocidae	0.55	1	2.86

Table 1: The number and percent of prey found in muskellunge stomachs and in surveys done in the summer of 2014 by the Ontario Ministry of Natural Resources and the Michigan Department of Natural Resources.

Figures:

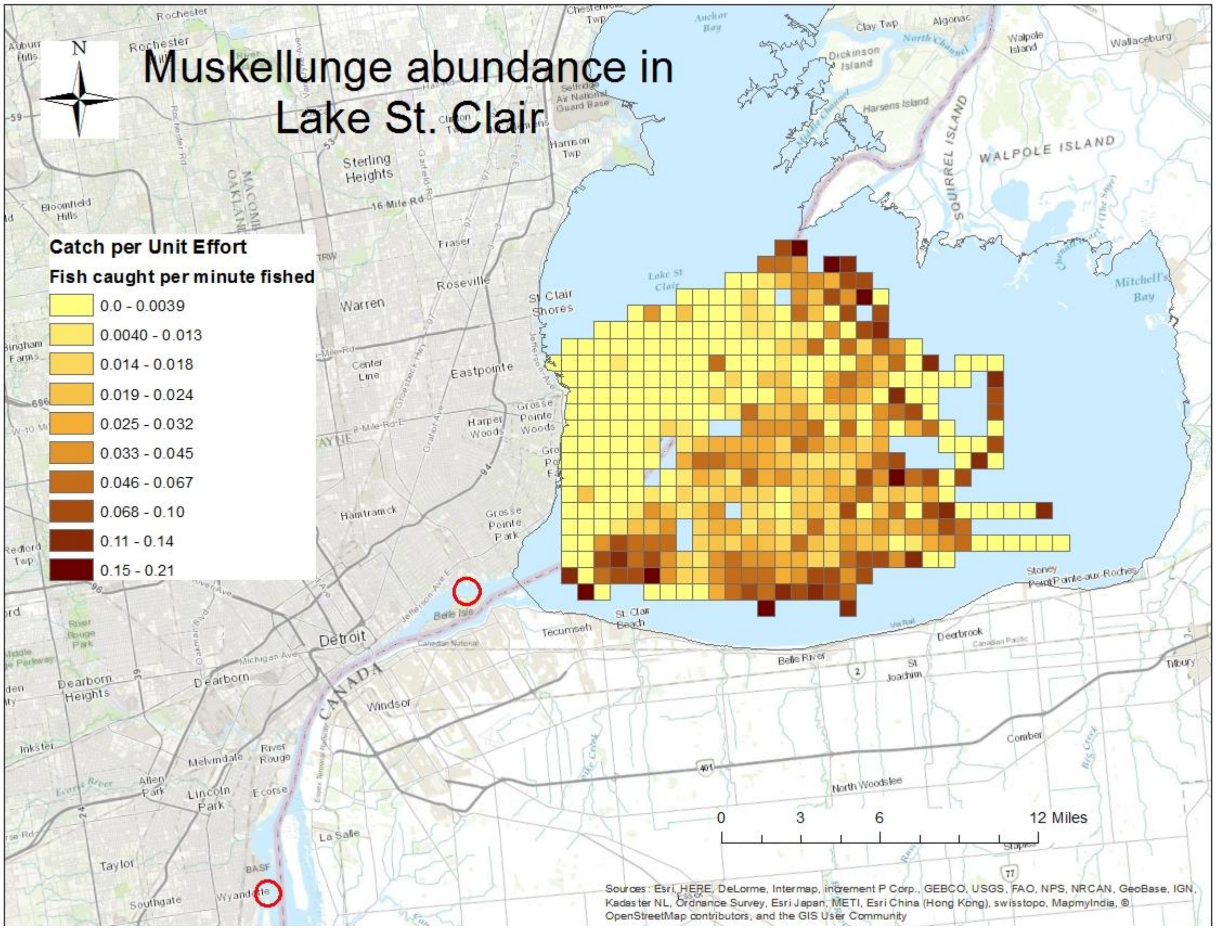

Figure 1: Map of catch per unit effort of muskellunge caught by charter fishing in Lake St. Clair. Red circles denote areas sampled in the Detroit River.

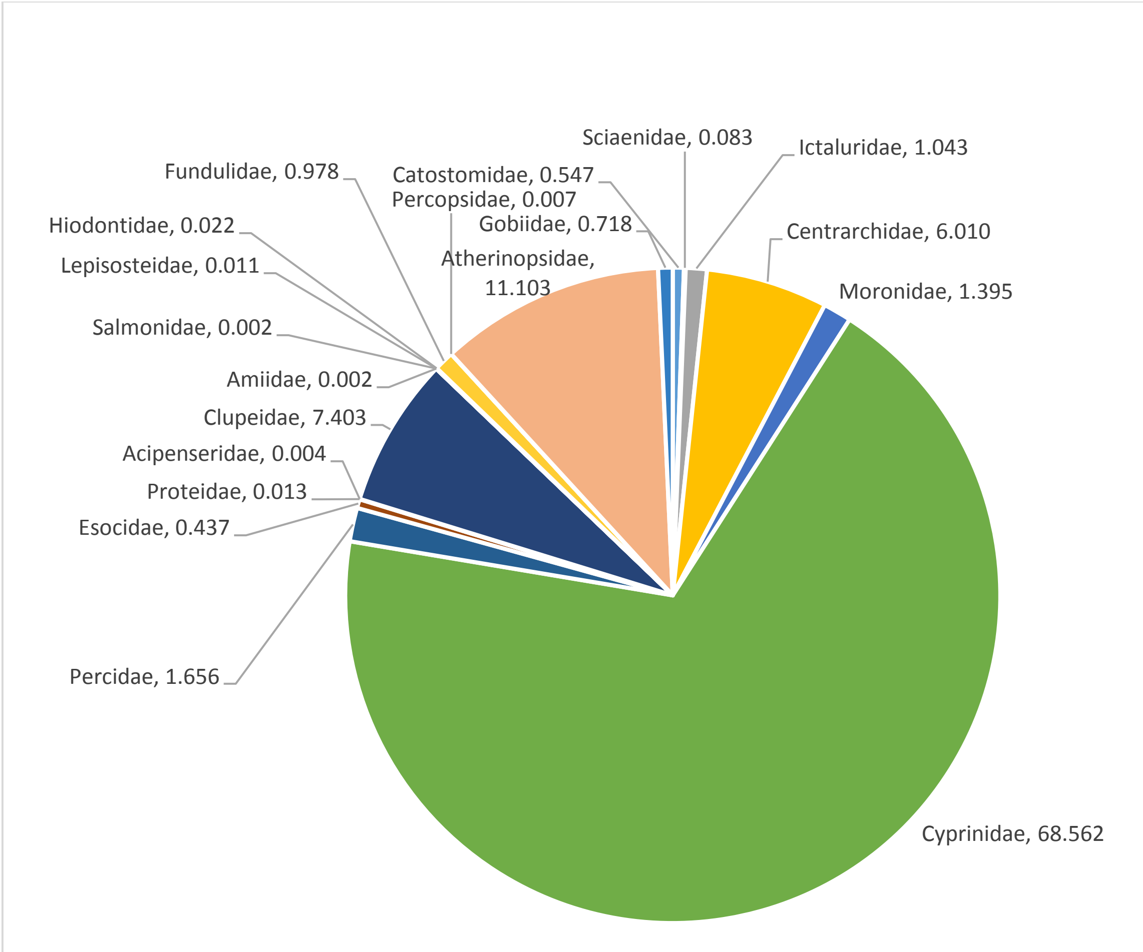

Figure 2: Percent composition of fish species by family for collections by MDNR and OMNR in Lake St. Clair in 2014.

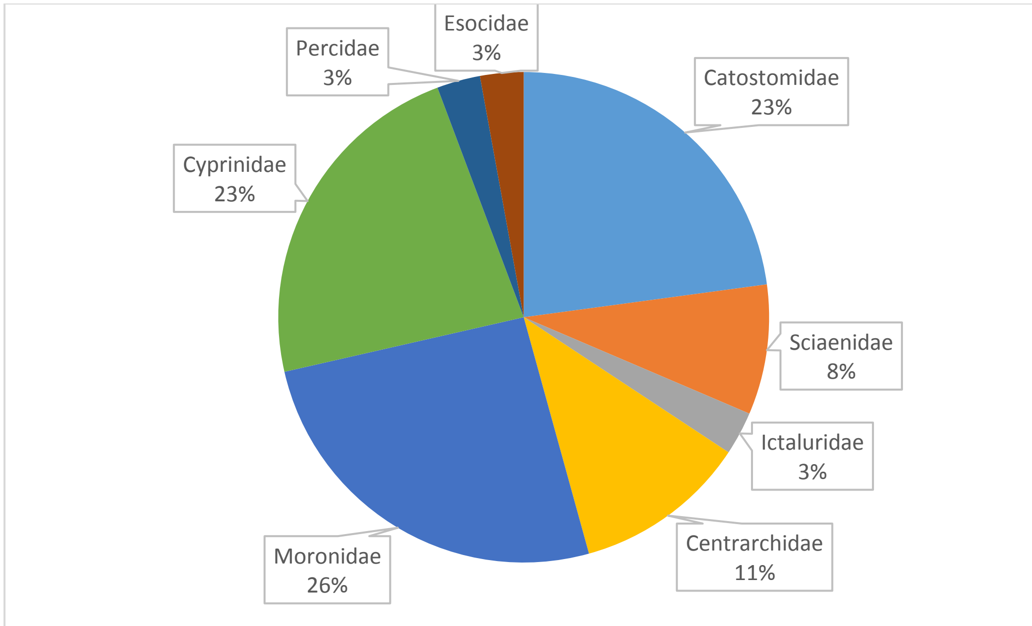

Figure 3: Percent composition of all prey families found in muskellunge sampled from 2014-2015 in Lake St. Clair.

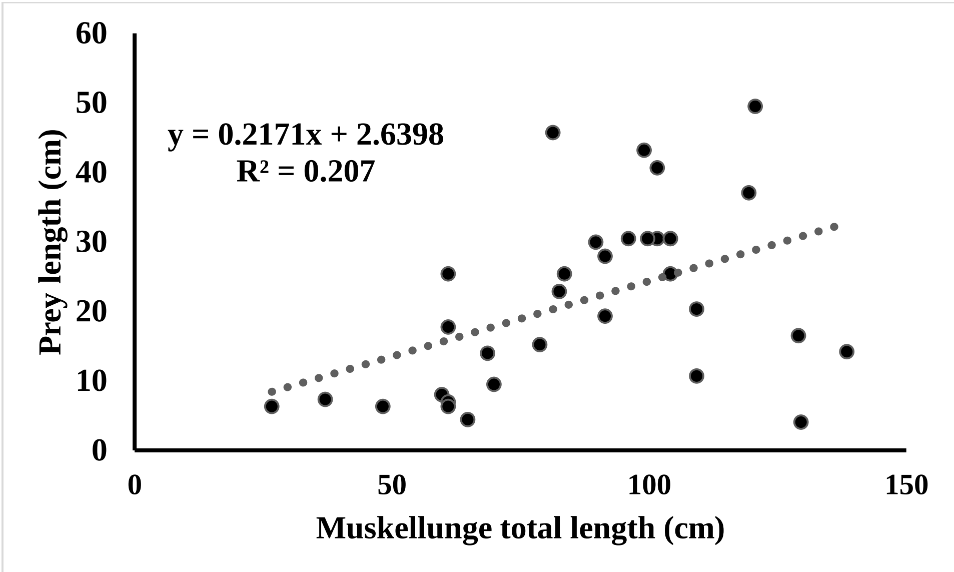

Figure 4: Length of prey consumed by corresponding sizes of muskellunge.

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