MOVEMENTS AND HABITAT SELECTION OF STOCKED AGE-1 MUSKELLUNGE IN EAGLE CREEK RESERVOIR

A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

BY NICHOLAS W. HAUNERT

ADVISOR: THOMAS E. LAUER

BALL STATE UNIVERSITY

MUNCIE, IN

MAY 2015

MOVEMENTS AND HABITAT SELECTION OF STOCKED AGE-1 MUSKELLUNGE
IN EAGLE CREEK RESERVOIR

A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
MASTER OF SCIENCE.

BY

NICHOLAS W. HAUNERT

ADVISOR: THOMAS E. LAUER

Committee Approval:

____ ______________

Committee Chairperson Date

____ ______________

Committee Member Date

____ ______________

Committee Member Date

Departmental Approval:

____ ______________

Departmental Chairperson Date

____ ______________

Dean of Graduate School Date

BALL STATE UNIVERSITY
MUNCIE, INDIANA
MAY 2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table Page

CHAPTER 2

ACKNOWELDGEMENTS

I thank the many Ball State students who assisted with tracking and recording data. I especially thank Sandra Clark-Kolaks of the Indiana Department of Natural Resources for her assistance with implanting radio tags and Jason Doll for statistical help. I also thank Dr. Thomas Lauer for his guidance and recommendations over the last two years. I thank the Indiana Department of Natural Resources for the use of their equipment and fish needed for my thesis. Additionally, I thank Ball State University for funding of this project. I finally thank my family and Amanda Greene for their help and support throughout my schooling.

Chapter 1: An evaluation of stocked Muskellunge in Eagle Creek Reservoir, Indianapolis IN.

Abstract - The goal of this study was to determine the effect of stocked Muskellunge on the fishery in Eagle Creek Reservoir. These fish have been stocked annually in Eagle Creek Reservoir since 2011 at a rate of one per acre to increase fishing opportunities and as an effort control the large population of Gizzard Shad. Experimental gill nets, trap nets, and nighttime electrofishing were used from 2012 to 2014 to evaluate the fishery. However, no Muskellunge were collected during the three years of sampling using these collection methods. In response to these findings, a telemetry project was created that would track age-1 Muskellunge in Eagle Creek Reservoir to determine their movements, home range sizes, and habitat selection. Tracking took place weekly from March to December 2014. The results of this study found that age-1 Muskellunge in Eagle Creek Reservoir displayed little movement and had small home range sizes during tracking. The Muskellunge strongly selected timber even though there was a limited amount of woody debris available in the reservoir. This study will allow managers to more closely evaluate the fishery and stockings in Eagle Creek Reservoir, as well as other fisheries with Muskellunge throughout North America.

Introduction

Eagle Creek Reservoir is a 546 hectare impoundment located on the northwest side of Indianapolis. This impoundment is used for fishing, recreational boating, and as a water supply for Indianapolis and Speedway. The Indiana Department of Natural Resources (IDNR) has a history of stocking predator fish species, such as Walleye (*Sander vitreus*) and Hybrid Striped Bass (*Morone saxatilis x M. chrysops*) in an attempt to provide better quality fishing and reduce the number of unwanted fish, specifically Gizzard Shad (Smyth 2008). Muskellunge (*Esox masquinongy*) have been stocked annually at a rate of one fish per acre since the fall of 2011 by the IDNR as an effort to provide trophy fishing and control the Gizzard Shad population. How well these age-1 Muskellunge are affecting the fishery in Eagle Creek Reservoir is unknown, as these “small” fish are rarely caught by anglers and have been difficult to catch using conventional fisheries assessment gear.

The original goal of this study was to determine how the stocked Muskellunge were affecting sport fishes in Eagle Creek Reservoir. The specific objectives included: 1) Determine whether the sport fishes in Eagle Creek Reservoir are the size typically desired by anglers 2) Determine the effect of introducing Muskellunge to control Gizzard Shad densities on the overall fishery of Eagle Creek Reservoir. It was hypothesized that many of the sport fish sizes would be less than desired by anglers. Additionally, it was hypothesized that the Muskellunge would improve the fishery in Eagle Creek Reservoir by reducing the Gizzard Shad densities.

Sampling of Eagle Creek Reservoir occurred in July 2012, May 2013, and July 2014. Sampling sites were those previously used by the Indiana Department of Natural Resources. The fish were collected using experimental gill nets, trap nets, and night DC electrofishing following

IDNR general lake survey protocol. Fish were collected, measured (mm) and returned to the water unharmed, when possible. The lengths of each species were used to calculate the Proportional Stock Densities (PSD) following Anderson (1976).

The results of this study (see attached data file) suggested the fishery in Eagle Creek Reservoir is poor. The fishery was dominated by undesirable fishes, such as Gizzard Shad and Common Carp (*Cyprinus carpio*). Largemouth Bass (*Micropterus salmoides*) populations were balanced and Bluegill (*Lepomis macrochirus*) populations were stunted in Eagle Creek Reservoir. However, there were no Muskellunge collected during all three years of sampling. The lack of Muskellunge during the surveys prevented the original objectives of this study to be reached. However, a new track was taken, with respect to the Muskellunge in the reservoir.

The new and current goal of this study was to improve the understanding of age-1 Muskellunge in Eagle Creek Reservoir. The specific objectives include: 1) Determine the movements of stocked age-1 Muskellunge in Eagle Creek Reservoir 2) Determine home ranges of stocked age-1 Muskellunge in Eagle Creek Reservoir during the spring, summer and fall 3) Determine the habitat selection and the amount of suitable habitat for age-1 Muskellunge in Eagle Creek Reservoir. I hypothesized that Muskellunge movements and home ranges would be greater during the spring and fall compared to summer because of limitations in habitat, specifically, dissolved oxygen and water temperatures. In addition, I hypothesized that the age-1 Muskellunge would select timber over the other physical habitat types found in the reservoir, as other known habitat preferences (e.g., rooted aquatic vegetation) are limited.

Telemetry was used to track stocked age-1 Muskellunge in Eagle Creek Reservoir in order to complete the new objectives. In 2013, 40 fish were held back from the intended fall stocking and kept at the East Fork State Fish Hatchery over winter. These individuals had radio tag transmitters surgically implanted (Hanson and Margenau 1992) in March 2014, then held for an additional two days in the hatchery to ensure recovery prior to stocking (Rogers and White 2007) by the IDNR. Tagged age-1 Muskellunge were tracked once a week from March to December 2014 following the methods of Bettoli et al. (1997). The principle inflow, Eagle Creek, was also monitored in the fall to track individuals that have moved upstream. Once a fish was located, the GPS location, water depth, and habitat type were recorded (Cooke et al. 2012). The habitat types include: artificial (e.g., boat ramps and docks), timber, vegetation, sand/muck, and boulders (Carline and Headrick 1993). Temperature and dissolved oxygen profiles were taken at the northern and southern halves of the reservoir using a HydroLab®. During the tracking period many of the age-1 Muskellunge disappeared from Eagle Creek Reservoir. However, some fish were tracked upstream of the reservoir in Eagle Creek, and one individual was found in a nearby gravel pit. The results of this study found that age-1 Muskellunge in Eagle Creek Reservoir displayed little movement and had small home range sizes during tracking. This lack of movement creates issues when using traditional fisheries equipment to sample sub-adult (age-1) Muskellunge when evaluating a fishery. The Muskellunge strongly selected timber even though there was a limited amount of woody debris available in the reservoir. This limited amount of preferred habitat could be restricting development of this fishery, thus causing displacement of fish upstream or be lost through competitive interactions.

The results of the study will help with the management and stocking of Muskellunge populations in this reservoir, but it may have larger inferences. There has been difficulty in capturing sub-adult muskellunge (e.g., age-1), although older (and larger) fish are more easily sampled (Pearson 2006). Hence, little is known about the movements and habitat selection of these juveniles (Hanson and Margenau 1992). This study may allow managers to more closely evaluate the fishery, despite the limitations of conventional fishery collection equipment. Ultimately, I will be improving our abilities to enhance the quality of this popular fish, not just in Indiana, but throughout its North American range.

References

Anderson, R. O. 1976. Management of small warm water impoundments. Fisheries 1:5-7. 26-28.

Bettoli P., J. Layzer, and M. Pegg. 1997. Movement of Saugers in the Lower Tennessee River Determined by Radio Telemetry, and Implications for Management. North American Journal of Fisheries Management 17:763-768.

Carline, R. and M. Headrick. 1993. Restricted Summer Habitat and Growth of Northern Pike in Two Southern Ohio Impoundments, Transactions of the American Fisheries Society 122:228-236.

Cooke, S., S. Hinch, M. Lucas, and M. Lutcavage. 2012. Biotelemetry and biologging. Pages 819-881 in A. Zale, D. Parrish, and T. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Hanson, D., and T. Margenau. 1992. Movement, habitat selection, behavior, and survival of stocked Muskellunge. North American Journal of Fisheries Management 12:474–483.

Pearson, J. 2006. Juvenile Muskellunge Electrofishing Assessments. Indiana Department of Natural Resources, Division of Fish and Wildlife, Indianapolis, IN.

Smyth, J. 2008. Evaluation of the fish community and walleye stockings at Eagle Creek Reservoir. Indiana Department of Natural Resources, Division of Fish and Wildlife, Indianapolis, IN.

Rogers, K. and G. White. 2007. Analysis of movement and habitat use from telemetry data. Pages 625-676 in C. Guy and M. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Chapter 2: Movements, home range, and habitat selection of stocked age-1 Muskellunge in Eagle Creek Reservoir.

Abstract - Muskellunge young-of-year were stocked in Eagle Creek Reservoir in the fall of 2011, 2012, and 2013 to provide a fishery unique to Central Indiana. However, some questions linger as to the efficacy of these stocked fish and their eventual fate. Therefore, the objective of this study was to define movements, seasonal home range sizes, and habitat selection of these fish to better manage the fishery. In March 2014, 40 age-1 Muskellunge provided by the Indiana Department of Natural Resources were implanted with radio transmitters and released, with tracking taking place once a week from March through December 2014. When fish were found, location and habitat metrics were noted. Most Muskellunge were found close to shoreline during tracking, as the fish showed small home ranges and displayed little movement. Fish movement was less during the summer compared to the fall and spring seasons, although not all fish were tracked during the entire study period. Some fish were tracked upstream of the reservoir in Eagle Creek, and one individual was found in a nearby gravel pit. Fish mortality could have been due to the large number of predatory birds may have preyed upon the Muskellunge. By November, 27 fish could not be located or were known dead. The Muskellunge that remained in the reservoir associated with timber and strongly avoided sand and muck. The amount of habitat where Muskellunge were found was limited to 22.4 hectares, or about 4.2 % of the surface area in Eagle Creek Reservoir. This limited amount of preferred habitat could be restricting development of this fishery, thus causing displacement of fish upstream or be lost through competitive interactions.

Introduction

Muskellunge (*Esox masquinongy*) are a popular sport fish that occur only in North America, being both ecologically and economically important to the fishery (Bozek et al. 1999; Stewart et al. 2014). Anglers enjoy Muskellunge due to their large sizes (Gillis et al. 2010) and the difficult “fight” they display when caught using a fishing rod and reel. Muskellunge are typically found in “cool” bodies of water throughout their natural range (Cole and Bettoli 2014). Anglers have many opportunities to target Muskellunge throughout Canada and as far south as the state of Tennessee in the U.S. (Wagner et al. 2007a; Cole and Bettoli 2014). However, many states have been introducing these fish to new or marginal environments because of their increasing popularity (Dombeck et al. 1984).

When Muskellunge are stocked in new waters, or where they are not reproducing, it is typically in response to increasing sport fishing opportunities (Cole and Bettoli 2014; Farrell et al. 2014). In addition, stocking Muskellunge may control densities of undesired fishes that are physically too large for other top predators to eat (Wagner et al. 2007a), ultimately improving the overall fishery (Knapp et al. 2012). Muskellunge stocking rates are not well defined, and vary throughout North America. The Indiana Department of Natural Resources (IDNR) typically stocks Muskellunge at a rate of five fish per acre when that number of fish are available (Pearson 2006), with rates in other states as low as 0.2 fish per acre (Wagner et al. 2007a). Although Muskellunge populations may be maintained by stocking throughout the Midwest, active management is often needed to assess success (Weeks and Hansen 2009).

Sampling bias exists for every type of fisheries sampling equipment (Brown et al. 2012), but catching sub-adult Muskellunge is difficult using traditional fisheries techniques (i.e. gill nets, trap nets, electrofishing). Younger fish have limited movements and remain close to shoreline (Hanson and Margenau 1992; Farrell et al. 2014) making passive collection techniques ineffective (Hubert et al. 2012). Active types of fisheries equipment, such as trawls and electrofishing, can be problematic in the shallow depths along shore (Hayes et al. 2012; Reynolds and Kolz 2012) where the age-2 and younger Muskellunge are often located. This gear bias precludes accurate enumeration and creates problems for managers when evaluating Muskellunge populations.

Radio telemetry is a tool researchers have used to answer many questions about freshwater fishes (Hockersmith and Beeman 2012; Knapp et al. 2012) and can be preferable to acoustic telemetry because of increased detection ranges and being able to track from the air, boat, or land (Koehn 2012). Radio telemetry has been used to evaluate movements, home ranges, habitat use, and behavior of several species of fishes (Knapp et al. 2012; Kuechle and Kuechle 2012), including Muskellunge (Cole and Bettoli 2014) where this method was used to determine stocking success (Hanson and Margenau 1992).

Muskellunge are often stocked into water systems to control densities of undesired fishes as they can feed on larger prey (Wagner et al. 2007a), such as Gizzard Shad (*Dorosoma cepedianum*). These prey are undesirable in most fisheries, as they compete or negatively interact with juvenile sport fishes (Dettmers and Stein 1996; Yako et al. 1996). Eagle Creek Reservoir, located in Indianapolis Indiana, has a large population of Gizzard Shad that were thought to have been stocked by anglers as baitfish into the water with the intention of improving the fishery. The Gizzard Shad population in this reservoir appears to be negatively affecting sport fish populations based on recent surveys (Haunert, unpublished data). Current piscivores in the reservoir, including Largemouth Bass (*Micropterus salmoides*) and Walleye (*Sander* vitreus) among other species, are unable to eat the larger specimens of Gizzard Shad, creating a size refuge for this prey. Moreover, chemical control is not a viable management option for controlling unwanted fish, as the reservoir serves as a water source for the cities of Indianapolis and Speedway. Hence, since 2011, Muskellunge have been stocked annually in Eagle Creek Reservoir in an effort to control the Gizzard Shad and to provide trophy fishing.

How the Muskellunge stocked in Eagle Creek Reservoir are affecting the recreational fishery is unknown. Sub-adult Muskellunge are rarely caught by anglers and are difficult to catch using conventional fisheries assessment gear, such as gill nets, trap nets, and electrofishing (Pearson 2006; Wagner and Wahl 2011). Without accurate catch rates in Eagle Creek Reservoir, management actions are difficult to make, particularly when coupled with a paucity of literature on the movements and home ranges of juvenile Muskellunge (Hanson and Margenau 1992; Wagner and Wahl 2011; Farrell et al. 2014).

Muskellunge movements and home ranges may be related to habitat type. These fish associate with and use timber habitat (Wagner et al. 2015) or vegetation (emergent or submerged) (Farrell et al. 2014) when available in a body of water. However, the amount of habitat typically used by Muskellunge in Eagle Creek Reservoir is unknown, and could be limiting the success of the Muskellunge fishery (Younk et al. 1996). An imbalance between the number of Muskellunge stocked and the available habitat can cause increased competition among the Muskellunge or other fishes (Wahl 1999; Eslinger et al. 2010). This competition may negatively influence the Muskellunge fishery (Wahl 1999), ultimately limit the success of the entire fishery and inhibit sound management decisions.

The goal of this study is to improve the understanding of age-1 Muskellunge in Eagle Creek Reservoir. My specific objectives include: 1) Determine the movements of stocked age-1 Muskellunge in Eagle Creek Reservoir 2) Determine home ranges of stocked age-1 Muskellunge in Eagle Creek Reservoir during the spring, summer and fall 3) Determine the habitat selection and the amount of suitable habitat for age-1 Muskellunge in Eagle Creek Reservoir. I hypothesized that Muskellunge movements and home ranges would be greater during the spring and fall compared to summer because of limitations in habitat, specifically, dissolved oxygen and water temperatures. In addition, I hypothesized that the age-1 Muskellunge would select timber over the other physical habitat types found in the reservoir, as other known habitat preferences (e.g., rooted aquatic vegetation) are limited.

Methods

Study area - Eagle Creek Reservoir is a 546 ha eutrophic impoundment located on the northwest side of Indianapolis, Indiana. The reservoir has a mean depth of 3.5 m and maximum depth of 16 m. Water clarity is low, with Secchi Disk readings rarely more than 1 m. The watershed for Eagle Creek Reservoir has a total area of 423 km² and the majority of the land-use is agriculture (Jacinthe et al. 2012). The reservoir was constructed in 1968 to serve as a flood control for Eagle Creek. Additionally, it is divided into a northern and southern half by the 56th Street causeway. Much of the immediate area surrounding the reservoir is a city park managed by the Indianapolis (Indy) Parks and Recreation. A portion of the southern half shoreline includes residential housing. The reservoir is also used for fishing, recreational boating, and as a water supply for the cities of Indianapolis and Speedway. The impoundment one public boat ramp with private storage and docking, along with a private sailing club. There is a 10 mph speed limit and a 10 hp limit for recreational boats.

Radio tag implantation - Forty age-1 Muskellunge were implanted with acoustical tags for this study. Fish were originally hatched at East Fork State Fish Hatchery in 2013 and reared at this facility until March 2014. At that time, fish were surgically implanted with Advanced Telemetry Systems (ATS) F1570 radio tag transmitters using aseptic techniques following Hanson and Margenau (1992). The average fish total length was 294 mm with an average weight of 120 g. Each radio tag weighed 3.1 g, which was within the guidelines for implantation that being less than the 5 % of the total body weight of the fish (Mulcahy 2003; Wagner et al. 2011). Tags had a stated battery life of 257 d, and each one had a unique frequency ranging from 150.022 to 150.801 MHz. Pulse rate was set at 30 pulses per minute to extend battery life to the expected time span of the study. Tag antennae were 20 cm long but were cut to approximately 10 cm to limit or eliminate abrasion or interference with anal and caudle fin movement. Surgical equipment, such as scalpels and needle holders, were sterilized before being used on each individual by submerging them in chlorhexidine solution. Using aseptic surgical techniques, fish were first anesthetized using electrical anesthesia (Sterritt et al. 1994) provided by the IDNR. A 10 mm incision was made on the posterior end directly below the pelvic girdle of each fish using scalpels with a size 15 blade (Wagner et al. 2011). Tags were then inserted into the abdomen and rested on the pelvic girdle of the fish with the antennae protruding out of the incision towards the caudal fin (Wagner et al. 2011). The incision was closed using one black monofilament 3-0 suture with a curved 24 mm reverse cutting needle. The age-1 muskellunge were held for two days in the hatchery following surgery to ensure recovery prior to stocking in Eagle Creek Reservoir (Rogers and White 2007). The fish were transported and stocked on the northern half of the reservoir by the IDNR on March 27, 2014 using routine IDNR hauling and stocking procedures.

Tracking procedures - The tagged age-1 Muskellunge in the reservoir were tracked once a week (Pegga et al. 1997) during daylight hours from March 28, 2014 to December 10, 2014 (Wagner and Wahl 2011) using an ATS R2000 scientific receiver with a frequency of 150.000-151.999 MHz and a directional antenna. The antenna for the receiver was mounted on PVC pipe, 2.5 m above the deck of the boat, which allowed for 360 degree movement. Tracking was done by following a pre-established pattern that encompassed the entire reservoir: one lap along the shore while stopping at specific locations, and an "X pattern" cross of the northern and southern halves of the reservoir (Figure 1; Cooke et al. 2012).

A six km stretch of Eagle Creek above the reservoir was monitored in October to track any individuals that had moved upstream. A canoe was launched in the town of Zionsville and I traveled downstream Eagle Creek until reaching the northern portion of the reservoir. The antenna for the receiver was held by hand and was approximately 1.5 m above the water surface.

When a fish was found and specifically located, several field variables were noted, including GPS location, water depth, and habitat type following Cooke et al. (2012). The locations of GPS points were recorded in UTMs with a Gamin® GPSMAP® 62s handheld unit, while the water depths were determined using a Humminbird® 110 Fishin' Buddy sonar fish finder. The habitat classifications included: artificial (e.g., boat ramps and docks), timber, vegetation, sand/muck, and boulders (Headrick and Carline 1993). The habitat type at each location was determined by visual inspection above the water surface, and from the sonar unit underwater. Temperature (°C) and dissolved oxygen profiles (mg/L) along with Secchi disk readings (m), wind direction, and wind speed (kph) were taken at specific locations at the 5 m depth on the northern half of the reservoir, and at the 8 m depth on the southern half of the reservoir using a HydroLab® during each week of tracking (Figure 1).

Nighttime tracking (between sunset and sunrise) was additionally performed each week in July. Nighttime tracking was done concurrently on the same dates as daytime tracking using the same sampling protocols.

Statistical Methods - The movement distances of age-1 Muskellunge were determined using the trajectories of fish relocations during the tracking period. Movements were calculated using the as.ltraj() function from the adehabitatLT package in R (Calenge 2006; R Core Team 2014). The distance (m) from the stocking site on March 27, 2014 and all relocations for each individual to December 10, 2014 were used for the analysis. The average movement distance for all of the fish tracked during each week were determined and compared to selected environmental variables which included season, Secchi disk readings, surface dissolved oxygen (mg/L), surface temperature (°C), water depth, wind direction, and wind speed. In order to perform statistical analyses and compare to the average weekly age-1 Muskellunge movements, the variables needed to be averaged for each week. Secchi disk readings, surface dissolved oxygen, surface temperature, wind direction, and wind speeds were averaged from data collected at the northern and southern depth profile locations each week. Lastly, the water depths in which the all age-1 Muskellunge were found was averaged in any given week. The average weekly movement distances were compared among spring (March 27 - June 20), summer (June 21 - September 21), and fall (September 22 - December 10) seasons. Additionally, daytime and nighttime movement distances differences for age-1 Muskellunge were determined and compared using the trajectories of fish relocations during the tracking period. Movements were calculated using the as.ltraj() function from the adehabitatLT package in R (Calenge 2006; R Core Team 2014).

Generalized linear models were used to assess the relationship between movement distances and environmental variables. Models from normal and gamma (link = log) distributions were evaluated because the data were continuous and the best model was selected based on the ΔAICc. The dredge() function from the MuMIn package in R was used to find the best model and combinations of parameters (environmental variables) in the model to determine what affected the average weekly movements distance (Barton 2014; R Core Team 2014). The gamma distributions model estimate of movement distances is in natural log and can be converted back to meters using the exp() function in R (R Core Team 2014). The model with the lowest AICc value was selected as the most parsimonious (best), however, if the ΔAICc for individual models were less than 2, they would be considered as equally plausible. Once the best distribution was selected, the modavg() function from the AICcmodavg package in R was run and the model-average estimate was determined for each parameter that affected the average weekly movements of the fish (Mazerolle 2015; R Core Team 2014).

The estimation of age-1 Muskellunge home range areas were determined using minimum convex polygons (Gillis et al. 2010; Wagner and Wahl 2011). Home range areas in hectares (ha) were calculated using the mcp() function from the adehabitatHR package in R (Calenge 2006; R Core Team 2014). The areas of the home ranges were determined individually for each age-1 Muskellunge, and were separated based on spring, summer, and fall seasons. Individuals needed to be tracked at least five weeks during each season in order to determine the home ranges. A generalized linear models with Normal, Poisson, and Negative binomial distributions were used to select a best model for comparing the differences in home range sizes between the three seasons, with the best model based on the ΔAIC. Poisson distribution can take on any positive real number (including 0) and all of the numbers in the data fit this requirement. Negative binomial distribution is sometimes used as an alternative to Poisson distribution, but it models overdispersed data and does not assume homoscedasticity.

Habitat survey - Habitat in Eagle Creek Reservoir was surveyed on December 10 and 11 of 2014. GPS locations were marked in UTMs using a Gamin® GPSMAP® 62s handheld GPS at sites along the entire shoreline in which the natural contour of the shoreline and habitat types changed throughout the reservoir where water depth was navigable by boat. Shoreline and open water habitat percentage was estimated for each type using visual information and a Lowrance® X96 Sonar Fishfinder from a boat between each GPS point marked. The habitat types were categorized as: artificial (e.g., boat ramps and docks), timber, vegetation, sand/muck, and boulders (Headrick and Carline 1993). Although these categories appear limited in scope, they represent fairly the types of physical habitat found in the reservoir. The distance between each of the GPS points marked was determined and the area (ha) for each habitat type was calculated using ArcGIS® (Fisher et al. 2012). The areas between GPS points for individual habitat types were then summed to determine the total area of each habitat type in the reservoir.

Habitat selection - Habitat selection of age-1 Muskellunge in Eagle Creek Reservoir were determined using Jacobs index (D) (Jacobs 1974), and is calculated as:

$$D = (r-p) / (r+p-2rp)$$

Where r is the proportion of a habitat type used based on its proportion in a Muskellunge's home range and p is the proportion of that same habitat type available in the reservoir. Jacobs index ranges from -1 (strong avoidance of a habitat type) to +1 (strong preference of a habitat type). Habitat selection was determined for each habitat type during the spring, summer, and fall seasons. The home ranges for each age-1 Muskellunge were calculated using the same methods as previously described. The area of each habitat type within the home ranges of the age-1 Muskellunge was determined using the Intersect tool (Analysis) in ArcGIS® (Fisher et al. 2012).

Results

The age-1 Muskellunge were tracked for 31 weeks from March 27 to December 10, 2014. A total of 319 tracking locations over the 260 day tracking period for all 40 fish was recorded (Figure 2). The number of fish being tracked decreased by half during the third week after stocking, while this number eventually declined to 11 fish after six weeks. Only three individuals were tracked every week for the entire tracking period. While searching, one fish was found in an adjacent gravel pit during the summer, while six fish were found in Eagle Creek above the reservoir in October. The fish found in the stream were tracked an additional week to confirm that they were alive and not dead. Additionally, four Muskellunge were tracked on shore and determined dead during the mouths of July and August. The specific loss of the other individuals was not known. Overall, Thirty-nine of the 40 individuals tagged were tracked at least once after stocking.

Thirty-nine fish were used to determine the average weekly movements of age-1 Muskellunge in Eagle Creek Reservoir. Average distances ranged from 21 to 1,076 m during the entire tracking period (Figure 3) and were influenced by several environmental variables. Water depth, dissolved oxygen, wind speed, season, and Secchi disk (Tables 1, 2) were the variables that were included in the most parsimonious model as described by AICc. Although not all variables were included in this model, several combinations of these four variables along with depth appeared to influence fish movement, as the top five models all had Δ AICc values < 2 (Table 1).

Interpreting how each environmental variable affected the average weekly movements of age-1 Muskellunge in Eagle Creek Reservoir can be quantified using the best models. All parameters were initially converted to meters from their natural log values produced in the

Gamma distributions (Table 3). First, when age-1 Muskellunge were found in deeper depths, their movement distance was greater. That is, fish found at deeper depths moved further than fish found in shallower waters. The model relationship was that for every meter increase in water depth, the fish moved an average of 2 m further (95% C.I. [0.98, 2.44]; Table 3). Second, the fish tended to have greater movement distances during periods of higher oxygen levels as opposed to lower levels. The movement distances increased by 2 m as dissolved oxygen concentration changed by one mg/L (95% C.I. [1.05, 2.32]; Table 3. In this example, if the dissolved oxygen level was 10 mg/L, the Muskellunge would travel 20 m on average. Additionally, the variation in dissolved oxygen levels from depth profiles were greater during the summer compared to the spring and fall (Figure 4). Third, age-1 Muskellunge moved greater distances when wind speeds were higher. The fish traveled 1.1 m for every kph increase in wind speed (95% C.I. [1.04, 1.12]; Table 3). Here, when the wind speed was 10 kph, the fish moved 11 m. Fourth, I found that season influenced movement distances. The average movement appeared to be highest during spring and fall (Figure 3), but no differences were detected in average movement between these two seasons. Spring and fall seasons were not used in any of the best models. In contrast summer was used and the fish moved an average of 1 m (95% C.I. [0.49, 1.67]; Table 3). Fifth, Secchi disk transparency was not as influential in determining the average movement distance although this variable was statistically significant. A Muskellunge would travel 0.38 m when the Secchi disk reading is 1 m in this case (95% C.I. [0.18, 0.82]; Table 3), although this small amount of movement may not be biologically important. Sixth, there was no significant difference between the average weekly movement distance and surface temperature or wind direction. Additionally, there was no difference in average weekly movement distance when comparing the day and night tracking times as fish locations and movements did not differ regardless of the time of day.

Overall, there were no statistical differences detected between home size and seasons. This lack of differentiation may be due to the low number of age-1 muskellunge used to evaluate season: 16 for spring, six for summer, and three fish for fall (Figures 6, 7, 8). The remaining 24 fish were not tracked at least five times during one of the seasons and were eliminated from consideration when creating the convex polygons. Home ranges tended to overlap less as the seasons progressed suggesting that the age-1 muskellunge located an area that had less competition and satisfied other biological needs. Many of individuals remained in the northern half of the reservoir and tended to avoid the southern half, regardless of each season. Additionally, some fish remained in the same area during the entire tracking period. For example, one individual remained in the same location for 10 weeks in the spring before moving again. The smallest seasonal individual home range area was 0.3 ha, with the largest was 220 ha. The average home range area for spring (78 ha), summer (12 ha), and fall (30 ha) did not differ, likely due to the large variation and small number of fish being tracked. Average summer home ranges were < 20% of the spring and < 50% of the fall home ranges. The negative binomial was the best distribution to describe the differences among seasons (Table 4).

Nearly 20.8 km of shoreline and 104 GPS locations were used for the habitat survey (Figure 9). Sand/muck made up 94.8 % of the habitat, while timber was the second most abundant at 3.0 %, followed by vegetation (1.2 %), boulders (0.7 %), and artificial (0.3 %; Table 5). Most of the non-sand/muck habitat was located along the shoreline and in portions of the more open water areas north of 56th street. The Muskellunge strongly avoided the sand/muck regardless of season, and strongly selected the timber during all three seasons (Table 6). The boulders and artificial habitat types were slightly avoided for all of the seasons by the age-1 Muskellunge and there was no strong avoidance or selection for vegetation (Table 6).

Discussion

Two of my three hypotheses for this study on Eagle Creek Reservoir were supported. First, average weekly movements of age-1 muskellunge were related to several environmental variables, those being water depth, dissolved oxygen, wind speed, season, and Secchi disk readings. Fish movement distances during the summer were lower compared to the spring and fall seasons and were similar to the movements displayed by the age-2 Muskellunge in nearby Illinois (Wagner and Wahl 2011). However, my second hypothesis, home range sizes of fish, did not differ among spring, summer, and fall seasons in contrast to the predictions. The small home ranges suggested that the age-1 Muskellunge were only using and traveling in limited areas throughout the reservoir. The third hypothesis was supported as I showed that age-1 Muskellunge in Eagle Creek Reservoir selected the timber (woody debris) over other habitat types. Based on the habitat selection by Muskellunge and the whole lake habitat survey, less than 5 % of the reservoir area provides usable habitat for Muskellunge.

Dissolved oxygen concentrations were a driving force in determining movement distances of age-1 Muskellunge in Eagle Creek Reservoir. Because dissolved oxygen is essential for aquatic organisms to survive, the observed distances seen during the summer would suggest that the reduction in dissolved oxygen below the thermocline was influencing movement. The amount of movement detected during the summer was so low that it could be considered biologically irrelevant. Thus, the influence of stratification would prevent the fish from traveling into deeper waters and force the fish to stay at shallower depths, minimizing movement. The age-1 Muskellunge in Eagle Creek Reservoir experienced this phenomenon as they appeared to remain close to shore in < 0.5 m of water during the summer compared to the spring and fall.

Younk et al. (1996) similarly found that adults in the Mississippi River tended to relate to shallower water during the summer.

Although temperature and dissolved oxygen stratifications often mirror each other in eutrophic lakes during the summer (clinograde profile; Cole 1994), water temperature had no effect on age-1 Muskellunge weekly movements. I suspect the large differences in the oxygen profiles were a greater influence on movement, particularly as the summertime temperature differential between the epilimnion and hypolimnion was not great (Figures 4, 5). Although other studies have shown temperature to be one of the largest influences on behavior of juvenile and adult Muskellunge (Wagner and Wahl 2007; Cole and Bettoli 2014), it does not appear to be the case in this study or the specific influence is being masked by dissolved oxygen.

There was an increase in age-1 Muskellunge weekly movement distances as wind speeds increased in Eagle Creek Reservoir. The higher wind speeds would push waves on shore and increase turbulence, ultimately, decreasing near-shore water clarity (Miller and Crowl 2006). Hence, wind speed and the associated water movement may not be the driving factor in Muskellunge movement distances, but rather, the associated increase in turbidity (Abrahams and Katterfeld 1997; Ranåker et al. 2012). Further, most fish were found close to the shoreline in less than 0.5 m of water throughout the tracking period and would be heavily affect by wave action. This physical displacement and constant shifting of water would make it difficult for the age-1 Muskellunge to remain close to shore, promoting fish movement to greater depths or alternative shoreline locations.

Movement distances of age-1 Muskellunge were inversely related to water clarity in Eagle Creek Reservoir. These small-sized fish are frequently consumed by, for example, the Great Blue Herons (*Ardea herodias*; Wahl et al. 2012) and Largemouth Bass. Limiting movement or remaining in one location would reduce predation risk (Wahl 1999; Wahl et al. 2012), particularly since the Eagle Creek Reservoir Muskellunge were found at water depths less than 1 m for most of the tracking period. Others have found similar results where fish predation is reduced as water clarity decreases (Abrahams and Katterfeld 1997; Ranåker et al. 2012). I suspect at some size threshold, Muskellunge would enter a predation refugia, being too large for any predators. Ironically, Muskellunge are also lie and wait piscivores and rely heavily on sight in order to locate prey (Wahl and Stein 1993). An increase in water clarity would facilitate their predation success.

Overall, age-1 Muskellunge in Eagle Creek Reservoir had small home range sizes and displayed little movement throughout the tracking period. Wagner and Wahl (2011) found that age-2 Muskellunge had a similar pattern in home range sizes as my study, that being home ranges were greatest in the spring and fall, with the smallest range in the summer. However, their mean home ranges were only half the size or smaller than when compared to this study. The Muskellunge in Eagle Creek Reservoir were able to travel greater distances because Eagle Creek Reservoir is 546 ha and Forbes Lake is 225 ha, thus potentially allowing Muskellunge to travel greater distances. For example, one fish in Eagle Creek Reservoir traveled the entire length of the reservoir throughout the spring season, which was around 5 km, ultimately created greater home range sizes.

Several potential reasons existed that caused the age-1 Muskellunge to be lost during the study. Over half the fish have left Eagle Creek Reservoir by the third week of the study, potentially traveling upstream, going through the dam into Eagle Creek, or dying from several possible reasons. Six individuals were found in the major tributary, Eagle Creek, during the fall season and were over 4.9 km above the northern most point of the reservoir. One individual traveled to the northern most point of the reservoir during the last two weeks of tracking and although a signal was given by the fish, I was unable to get close enough for a precise location. Also, one individual was found in a nearby gravel pit after a large rain event, potentially facilitating this movement. Fish located on the southern half of the reservoir appeared to travel towards the dam after large precipitation events that increased the reservoir water level, potentially causing Muskellunge to be flushed through the dam (Wolter et al. 2013; Stewart et al. 2014). Several of these fish were tracked by the dam one week, but were never found again. Although the configuration of the dam may not be comparable to similar structures in the Midwest, Muskellunge have been flushed through these dams, particularly during daylight hours (Wolter et al. 2013; Stewart et al. 2014). Unfortunately, tracking below the dam to confirm this movement of fish was not possible due to liability and private property restrictions. However, there have been numerous anecdotal accounts of anglers catching sub-adult sized Muskellunge below the dam.

Age-1 Muskellunge loss may also be due to natural or anthropogenic mortality. Four individuals were confirmed dead onshore during two consecutive weeks in August of 2014. These fish were found dead after a period of severe thunderstorms and heavy rains passed through the area. Some of the fish missing could have been preyed on by predators because these younger Muskellunge are vulnerable to predation (Margenau 1992; Wahl 1999; Wahl et al. 2012). Other causes of death could be due to complications from surgically implanting radio tags into their abdomens. However, I contend that this loss was minimal, as Wagner et al. (2007b) found that age-0 Muskellunge had high survival and tag retention rates when implanted with passive integrated transponder (PIT) tags. Deaths due to radio tag implantation were not observed while recovering at the hatchery or in the field during this study.

In Eagle Creek Reservoir, the age-1 Muskellunge were located close to the shoreline throughout tracking during all of the seasons. Wagner and Wahl (2011) and Farrell et al. (2014) also found that younger Muskellunge remained close to shore, had small movements, and limited home range areas. This behavior create problems trying to capture them using passive sampling equipment. Even sampling techniques like nighttime boat electrofishing would not be effective because many boats are unable to navigate at such shallow depths inhabited by these Muskellunge (Hayes et al. 2012; Reynolds and Kolz 2012). In contrast to juvenile fish, adult Muskellunge have large home ranges and movements (Weeks and Hansen 2009; Diana et al. 2014). Adult fish are able to travel greater distances because they are not as vulnerable to predation and environmental variables (i.e. wind speed) as sub-adult fish (Farrell et al. 2014). However, this movement also subjects them to increased vulnerability to conventional fisheries capture equipment (Weeks and Hansen 2009; Diana et al. 2014), particularly passive gear, such as trap and gill nets (Hubert et al. 2012). Furthermore, active fisheries collection equipment, may capture adults more readily because these fish are typically found at greater water depths where trawls and electrofishing are more effective (Weeks and Hansen 2009; Hayes et al. 2012; Reynolds and Kolz 2012). Thus, the low catch rates of juvenile fish resultant from the small home ranges and short movement distances may not represent the population abundances of these Muskellunge, creating management difficulties (Farrell et al. 2014).

Available habitat may be limiting the age-1 Muskellunge fishery in Eagle Creek Reservoir (Eslinger et al. 2010), as these sub-adult fish selected timber almost exclusively over all other habitat types throughout the study. The total reservoir surface area of generally accepted habitat types (timber and vegetation: Hanson and Margenau 1992; Wagner and Wahl 2011; Farrell et al. 2014; Wagner et al. 2015) for Muskellunge was only 4.2 % and was concentrated in the upper portion. My findings that fish selected timber only were slightly different than Hanson and Margenau (1992), Wagner and Wahl (2011), and Farrell et al. (2014) where Muskellunge preferred timber and vegetation. I suspect the difference is due to the type of vegetation that was found in Eagle Creek Reservoir, exclusively emergent-shore species, such as various species of smartweeds, that did not project far away from shore. The absence of submersed species may be problematic in my study as Muskellunge hunt for prey along submerged vegetation lines (Cooper et al. 2008). When vegetation began to emerge in Eagle Creek Reservoir during spring, some of the fish were tracked near vegetation for a couple of weeks. Hence, that may be why there was neither a strong preference nor strong avoidance of vegetation by the age-1 Muskellunge.

The preferred habitat of Muskellunge in Eagle Creek Reservoir was not evenly distributed or present throughout the entire reservoir. Timber in the northern half may come from the adjacent shoreline, or may move in from the tributaries. Much of this timber collects along the shoreline with the causeway restriction preventing it from moving into the southern half. The majority of timber in the southern half of Eagle Creek Reservoir is a result of trees falling from eroded banks. However, the few age-1 Muskellunge tracked in the southern half of the reservoir were usually under docks and other man-made objects, presumably due to the rarity of woody debris and vegetation. The lack of typical habitat in the center of the reservoir forces the age-1 Muskellunge to remain close to the shoreline, thus possibility increasing competition for the habitat (Wahl 1999). This competition could cause some fish to travel outside of the reservoir in the nearby streams (Wahl 1999; Eslinger et al. 2010). Because the age-1 Muskellunge have a strong preference for timber this fact may have caused the fish to remain in the same areas and short movement distances for the entire tracking period, as well as serving as protection from predators and an aid in hunting for prey (Eslinger et al. 2010; Wahl et al. 2012). The age-1

Muskellunge avoided the sand/muck, artificial, and boulder regardless of season even though they made up most of the available habitat in the reservoir, as these physical habitat components do not protect them from predators and provides a reason for avoidance (Margenau 1992; Wahl et al. 2012).

Management Implications

Stocked populations of Muskellunge need several years to mature (Margenau and AveLallemant 2000) before the fishery can be fully evaluated. Hence, early indications based on empirical data of age-1 fish may not be indicative of the eventual outcome. However, several observations provide some directives. First, the IDNR should stock the Muskellunge at the northern half of the Eagle Creek Reservoir in order to reduce the number of fish going through the dam in to Eagle Creek (Wolter et al. 2013; Stewart et al. 2014). This stocking location choice would also place newly stocked fish near the most preferred physical habitat type. Second, the main constraining factor that may inhibit the establishment of the fishery would be the amount preferred habitat in the reservoir (Wagner et al. 2015), specifically woody debris. Manipulations of habitat, e.g., adding fish attractors such as brush piles (Summerfelt 1999), should be considered. Increasing the amount of habitat by adding brush piles promotes the fishery in habitat depauperate waters (Wahl 1999; Sass et al. 2006; Eslinger et al. 2010). Olson et al. (1998) concluded that larger amounts of habitat in a lake increased the size and growth of Bluegill (*Lepomis macrochirus*) and Largemouth Bass, thus creating higher numbers and increasing angler satisfaction. This increasing of habitat could also be applied for Muskellunge in Eagle Creek Reservoir as it would provide protection from predators and ambushing points in order to capture prey. However, brush pile location should be carefully considered, that is, located with respect to the depth of thermocline formation during the summer (Summerfelt

1999). Eagle Creek Reservoir has steep inclined banks and few gradual inclining areas along its shoreline. Third, in order to increase vegetation in Eagle Creek Reservoir, the amount of Common Carp (*Cyprinus carpio*) need to be reduced. The Common Carp in the reservoir are likely preventing macrophyte development because they increase the turbidity of the water, sheltering light penetration and constraining the aquatic vegetation (Miller and Crowl 2006). Unfortunately, reducing or eliminating Common Carp would likely require chemical control that would be expensive and potentially prohibitive give the size of the reservoir, the large drainage basin, and the use of the reservoir as a water supply. Fourth, the amount of available forage may also be a limiting factor for newly stocked or juvenile Muskellunge. Gizzard Shad make up the majority of the diet for Muskellunge in other reservoirs throughout the Midwest (Wahl and Stein 1993) and it is plausible the same predator-prey scenario exists at Eagle Creek Reservoir. Although the Gizzard Shad do produce notable year classes in the reservoir (Haunert, unpublished data), these year classes are not consistent from year to year. Given the other piscivores in the reservoir, including Largemouth Bass and Walleye, are also preying on the age-0 Gizzard Shad and reducing the available forage, age-1 Muskellunge may be competing for a limited food resource. Fifth, traditional fishery equipment do not typically capture sub-adult Muskellunge, as they are unable to be used in areas were the smaller fish are found (Hayes et al. 2012; Reynolds and Kolz 2012). Other fisheries equipment and techniques should be considered in order to collect the sub-adult fish. For example, seines have been used in many studies to collect juvenile Muskellunge in some lakes (Farrell and Werner 1999). However, seines might be difficult to use in Eagle Creek Reservoir as there is a large amount of woody debris along shore where the age-1 Muskellunge were usually found. Sampling in this timber close to shore could create potential issues by getting snagged in the seine, thus preventing Muskellunge from being sampled by allowing them to escape. Sixth, management actions may need to be expanded beyond the reservoir into the nearby streams as the fish have been tracked and many anglers have reported catching Muskellunge in the adjacent waterways. Weeks and Hansen (2009) also found that in the Manitowish Chain of Lakes adult Muskellunge traveled throughout all of the lakes in the system using connecting waterways. They suggested that the entire Manitowish Chain of Lakes should be managed instead of one individual lake (Weeks and Hansen 2009). These management actions could include simply creating easier public access sites in order for anglers to use the potential Muskellunge fishery in the nearby streams.

The results of the study will not only help with the management and stocking of Muskellunge populations in this reservoir, but it may have larger inferences. There has been difficulty in capturing age-1 Muskellunge, although older (and larger) fish are more easily sampled (Pearson 2006). Hence, little is known about the movements, home ranges, and habitat selection of age-1 fish (Hanson and Margenau 1992). This study may allow managers to more closely evaluate the fishery, despite the limitations of conventional fishery collection equipment. Subsequently, I hope to facilitate management activities at an earlier age than previously has been demonstrated. Ultimately, this study will improve our ability to enhance the quality of this highly popular fish, not just in Indiana, but throughout its North American range.

References

Abrahams, M. and M. Katterfeld. 1997. The role of turbidity as a constraint on predator-prey interactions in aquatic environments. Behavioral Ecology Sociobiology 40:169-174.

Barton, K. 2014. MuMIn: Multi-Model Inference. R package version 1.12.1. http://CRAN.R-project.org/package=MuMIn.

Brown, M. L., M. S. Allen, and T. Douglas Beard, Jr. 2012. Data management and statistical techniques. Pages 15-77 in A. Zale, D. Parrish, and T. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Bozek, M. A., T. M. Burri, and R. V. Frie. 1999. Diets of muskellunge in northern Wisconsin lakes. North American Journal of Fisheries Management 19:258-270.

Calenge, C. 2006. The package adehabitat for the R software: a tool for the analysis of space and habitat use by animals. Ecological Modelling 197:516-519.

Cole, G. A. 1994. Textbook of limnology, 4th edition. Waveland Press, Inc, Long Grove, Illinois.

Cole, A. J. and P. W. Bettoli. 2014. Thermal ecology of subadult and adult muskellunge in a thermally enriched reservoir. Fisheries Management and Ecology 21:410-420.

Cooke, S. J., S. G. Hinch, M. C. Lucas, and M. Lutcavage. 2012. Biotelemetry and biologging. Pages 819-881 in A. Zale, D. Parrish, and T. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Cooper, J. E., J. V. Mead, J. M. Farrell, and R. G. Werner. 2008. Potential effects of spawning habitat changes on the segregation of northern pike (*Esox lucius*) and muskellunge (*E. masquinongy*) in the Upper St. Lawrence River. Hydrobiologia 601:41-53.

Dettmers, J. M. and R. A. Stein. 1996. Quantifying linkages among gizzard shad, zooplankton, and phytoplankton in reservoirs. Transactions of the American Fisheries Society 125:27-41.

Diana, J. S., P. Hanchin, and N. Popoff. 2014. Movement patterns and spawning sites of muskellunge *Esox masquinongy* in the Antrim chain of lakes, Michigan. Environmental Biology of Fishes 1-12.

Dombeck, M. P., B. W. Menzel, and P. N. Hinz. 1984. Muskellunge spawning habitat and reproductive success. Transactions of the American Fisheries Society 113(2):205-216.

Eslinger, L. D., D. M. Dolan, and S. P. Newman. 2010. Factors affecting recruitment of age-0 muskellunge in Escanaba Lake, Wisconsin, 1987-2006. North American Journal of Fisheries Management 30:908-920.

Farrell, J. M., K. L. Kapuscinski, and H. B. Underwood. 2014. Fine scale habitat use by age-1 stocked muskellunge and wild northern pike in an upper St. Lawrence River bay. Journal of Great Lakes Research 40:148-153.

Farrell, J. M. and R. G. Werner. 1999. Distribution, abundance, and survival of age-0 muskellunge in the Upper St. Lawrence River nursery bays. North American Journal of Fisheries Management 19:309-320.

Fisher, W. L., M. A. Bozek, J. C. Vokoun, and R. B. Jacobson. 2012. Freshwater aquatic habitat measurements. Pages 101-162 in A. Zale, D. Parrish, and T. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Gillis, N. C., T. Rapp, C. T. Hasler, H. Wachelka, and S. J. Cooke. 2010. Spatial ecology of adult muskellunge (*Esox masquinongy*) in the urban Ottawa reach of the historic Rideau Canal, Canada. Aquatic Living Resources 23:225-230.

Hanson, D. A., and T. L. Margenau. 1992. Movement, habitat selection, behavior, and survival of stocked Muskellunge. North American Journal of Fisheries Management 12:474–483.

Hayes, D. B., C. P. Ferreri, and W. W. Taylor. 2012. Active fish capture techniques. Pages 267-305 in A. Zale, D. Parrish, and T. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Headrick, M. R. and R. F. Carline. 1993. Restricted summer habitat and growth of northern pike in two southern Ohio impoundments. Transactions of the American Fisheries Society 122:228-236.

Hockersmith, E. E., and J. W. Beeman. 2012. A history of telemetry in fishery research. Pages 7-19 in N. S. Adams, J. W. Beeman, and J. H. Eiler, editors. Telemetry techniques: a user guide for fisheries research. American Fisheries Society, Bethesda, Maryland.

Hubert, W. A., K. L. Pope, and J. M. Dettmers. 2012. Passive capture techniques. Pages 223-266 in A. Zale, D. Parrish, and T. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Jacinthe, P. A., G. M. Fillippelli, L. P. Tedesco, and R. Raftis. 2012. Carbon storage and greenhouse gases emission from a fluvial reservoir in an agricultural landscape. Catena 94:53-63.

Jacobs, J. 1974. Quantitative measurement of food selection. A modification of the forage ratio and Ivlev's electivity index. Oecologia 14:413-238.

Knapp, M. L., S. W. Mero, D. J. Bohlander, D. F. Staples, J. A. Younk. 2012. Fish community responses to the introduction of muskellunge into Minnesota lakes. North American Journal of Fisheries Management 32:191-201.

Koehn, J. D. 2012. Designing studies on acoustic or radio telemetry. Pages 21-44 in N. S. Adams, J. W. Beeman, and J. H. Eiler, editors. Telemetry techniques: a user guide for fisheries research. American Fisheries Society, Bethesda, Maryland.

Kuechle, V. B. and P. J. Kuechle. 2012. Radio telemetry in fresh water: the basics. Pages 91-137 in N. S. Adams, J. W. Beeman, and J. H. Eiler, editors. Telemetry techniques: a user guide for fisheries research. American Fisheries Society, Bethesda, Maryland.

Margenau, T. L. 1992. Survival and cost-effectiveness of stocked fall fingerling and spring yearling muskellunge in Wisconsin. North American Journal of Fisheries Management 12:484-493.

Margenau, T. L. and S. P. AveLallemant. 2000. Effects of a 40-inch minimum length limit on muskellunge in Wisconsin. North American Journal of Fisheries Management 20:986-993.

Mazerolle, M. J. 2015. AICcmodavg: Model selection and multimodel inference based on (Q)AIC(c). R package version 2.0-2. http://CRAN.R-project.org/package=AICcmodavg.

Miller, S. A. and T. A. Crowl. 2006. Effects of common carp (*Cyprinus carpio*) on macrophytes and invertebrate communities in a shallow lake. Freshwater Biology 51:85-94.

Mulcahy, D. M. 2003. Surgical implantation of transmitters into fish. Institute for Laboratory Animal Research Journal 44:295-306.

Olson, M. H., S. R. Carpenter, P. Cunningham, S. Gafny, B. R. Herwig, N. P. Nibbelink, T. Pellett, C. Storlie, A. S. Trebitz, and K. A. Wilson. 1998. Managing macrophytes to improve fish growth: a multi-lake experiment. Fisheries 23:6-12.

Pearson, J. 2006. Juvenile muskellunge electrofishing assessments. Indiana Department of Natural Resources, Division of Fish and Wildlife, Indianapolis, IN.

Pegga, M. A., P. W. Bettolia, and J. B. Layzera. 1997. Movement of saugers in the lower Tennessee River determined by radio telemetry, and implications for management. North American Journal of Fisheries Management 17:763-768.

R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Ranåker, L., M. Jönsson, P. Anders Nilsson, and C. Brönmark. 2012. Effects of brown and turbid water on piscivore-prey fish interactions along a visibility gradient. Freshwater Biology 57:1761-1768.

Reynolds, J. B. and A. L. Kolz. 2012. Electrofishing. Pages 305-362 in A. Zale, D. Parrish, and T. Sutton, editors. Fisheries techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Rogers, K. and G. White. 2007. Analysis of movement and habitat use from telemetry data. Pages 625-676 in C. Guy and M. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Sass, G. G., J. F. Kitchell., S. R. Carpenter, T. R. Hrabik, A. E. Marburg, and M. G. Turner. 2006. Fish community and food web responses to a whole-lake removal of coarse woody habitat. Fisheries 31:321-330.

Sterritt, D. A., S. T. Elliott, and A. E. Schmidt. 1994. Electrical anesthesia for immobilizing adult coho salmon in freshwater. North American Journal of Fisheries Management 14(2):453-456.

Stewart, H. A., M. H. Wolter, and D. H. Wahl. 2014. Laboratory investigations on the use of strobe lights and bubble curtains to deter dam escapes of age-0 muskellunge. North American Journal of Fisheries Management 34:571-575.

Summerfelt, R. C. 1999. Lake and reservoir habitat management. Pages 285-320 in C. C. Kohler and W. A. Hubert, editors, Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Wagner, G. N., S. J. Cooke, R. S. Brown, and K. A. Deters. 2011. Surgical implantation techniques for electronic tags in fish. Review in Fish Biology and Fisheries 21:71-81.

Wagner, C. P., M. J. Diana, and D. H. Wahl. 2007a. Evaluation of growth and survival of different genetic stocks of muskellunge: implications for stocking programs in Illinois and the Midwest. Annual Progress Report 1-66.

Wagner, C. P., M. J. Jennings, J. M. Kampa, and D. H. Wahl. 2007b. Survival, Growth, and Tag Retention in age-0 muskellunge implanted with passive integrated transponders. North American Journal of Fisheries Management 27: 873-877.

Wagner, C. P. and D. H. Wahl. 2011. Movement, home range and habitat selection of stocked juvenile muskellunge, *Esox masquinongy*, in Forbes Lake, Illinois: exploring the effects of latitudinal origin. Fisheries Management and Ecology 18:482-496.

Wagner, C. P. and D. H. Wahl. 2007. Evaluation of temperature-selection differences among juvenile muskellunge originating from different latitudes. The Muskellunge Symposium: a memorial tribute to E. J. Crossman 79:85-98.

Wagner, C. P., M. J. Weber, and D. H. Wahl. 2015. Structure complexity influences littoral coarse woody habitat selection by juvenile muskellunge. North American Journal of Fisheries Management 35:14-19.

Wahl, D. H. 1999. An ecological context for evaluating the factors influencing muskellunge stocking success. North American Journal of Fisheries Management 19:238-248.

Wahl, D. H., L. M. Einfalt, and D. B. Wojcieszak. 2012. Effect of experience with predators on the behavior and survival of muskellunge and tiger muskellunge. Transactions of the American Fisheries Society 141:139-146.

Wahl, D. H. and R. A. Stein. 1993. Comparative population characteristics of muskellunge (*Esox masquinongy*), northern pike (E. *lucius)*, and their hybrid (*E. masquinongy X E. lucius*). Canadian Journal of Fisheries and Aquatic Sciences 50:1961-1968.

Weeks, J. G. and M. J. Hansen. 2009. Walleye and muskellunge movement in the Manitowish Chain of Lakes, Vilas County, Wisconsin. North American Journal of Fisheries Management 29:791-804.

Wolter, M. H., C. S. DeBoom, and D. H. Wahl. 2013. Field and laboratory evaluation of dam escapement of muskellunge. North American Journal of Fisheries Management 33:829-838.

Yako, L. A., J. M. Dettmers, and R. A. Stein. 1996. Feeding preferences of omnivorous gizzard shad as influenced by fish size and zooplankton density. Transactions of the American Fisheries Society 125:753-759.

Younk, J. A., M. F. Cook, T. J. Goeman, and P. D. Spencer. 1996. Seasonal habitat use and movements of muskellunge in the Mississippi River. Minnesota Department of Natural Resources Investigational Report 449.

Figures

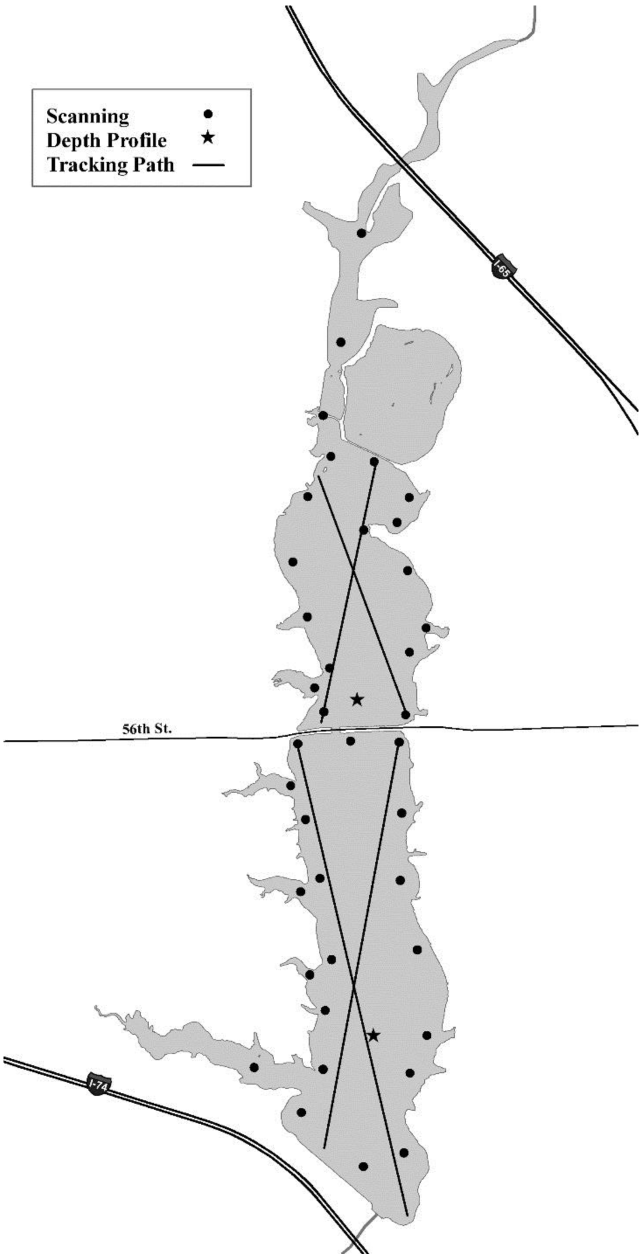

Figure 1. Scanning locations, depth profile, and tracking paths used to track age-1 Muskellunge in Eagle Creek Reservoir during 2014.

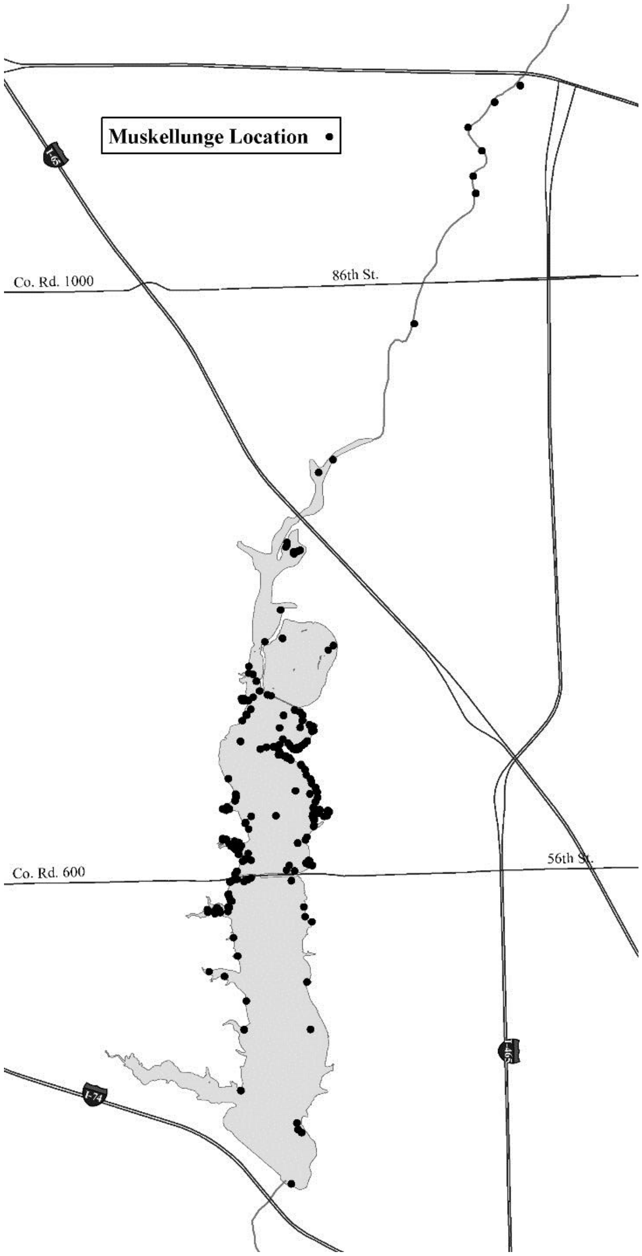

Figure 2. Tracking locations of age-1 Muskellunge in Eagle Creek Reservoir during 2014.

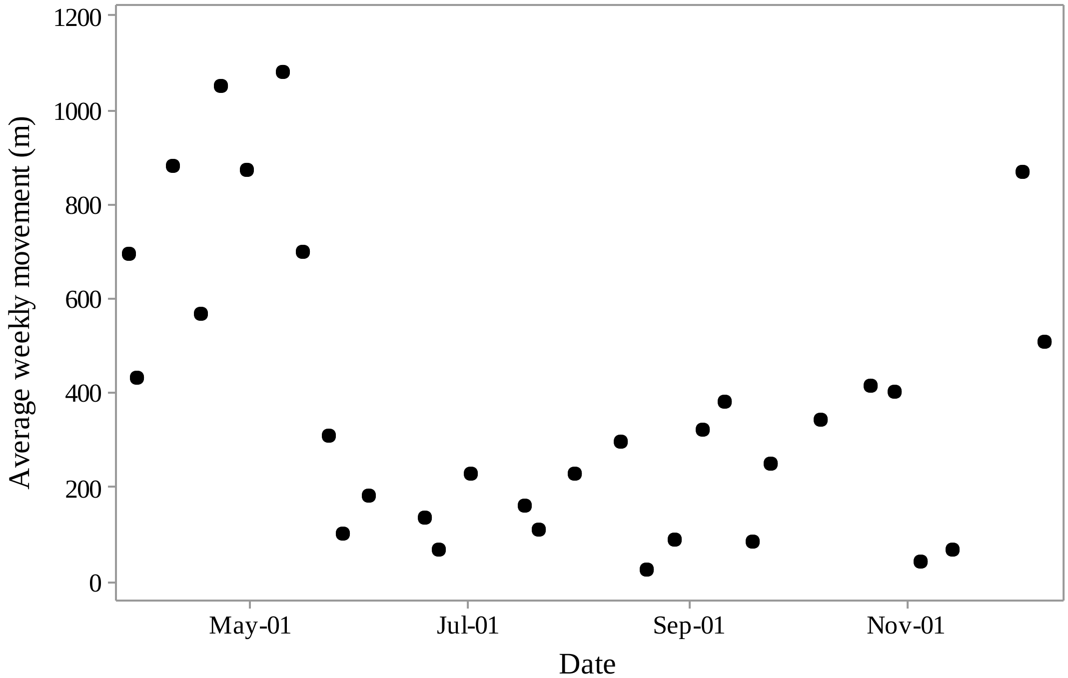

Figure 3. Change in average weekly movement of age-1 Muskellunge throughout the tracking period on Eagle Creek Reservoir during 2014.

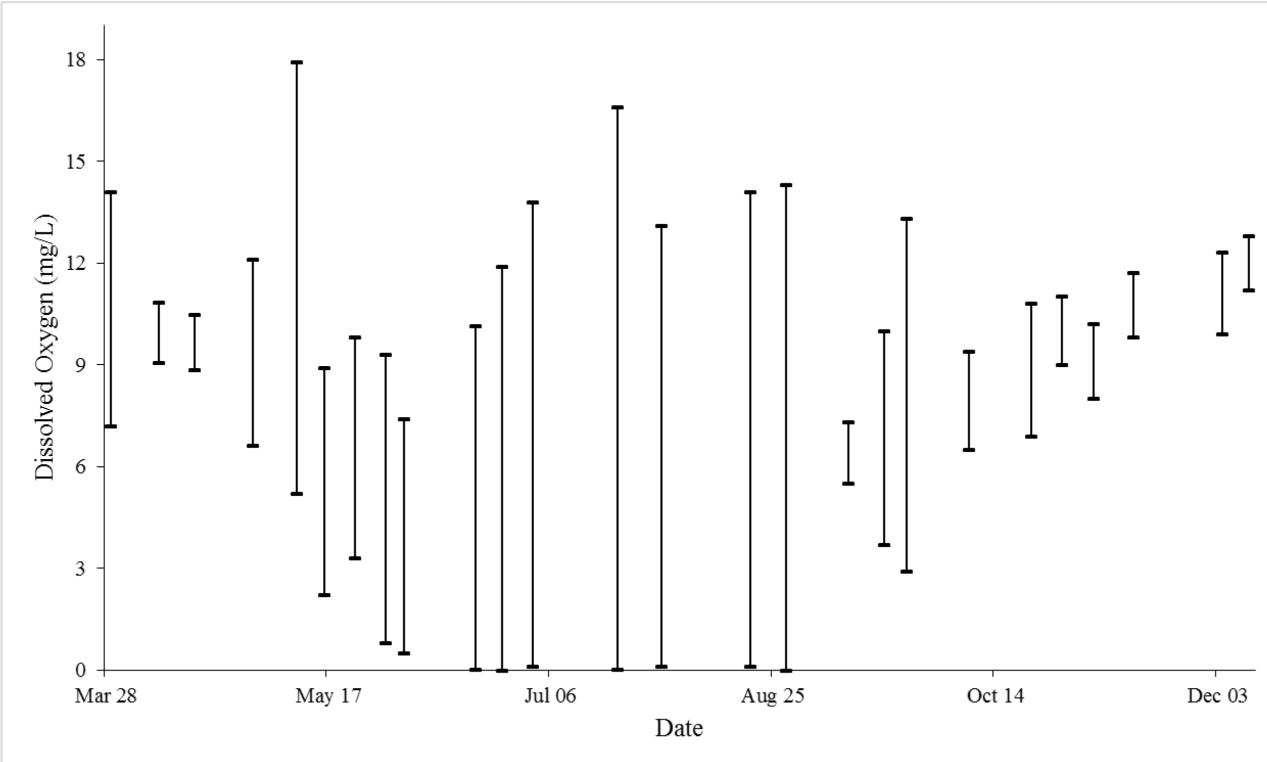

Figure 4. Ranges of dissolved oxygen concentrations (mg/L) from depth profiles in Eagle Creek Reservoir during 2014.

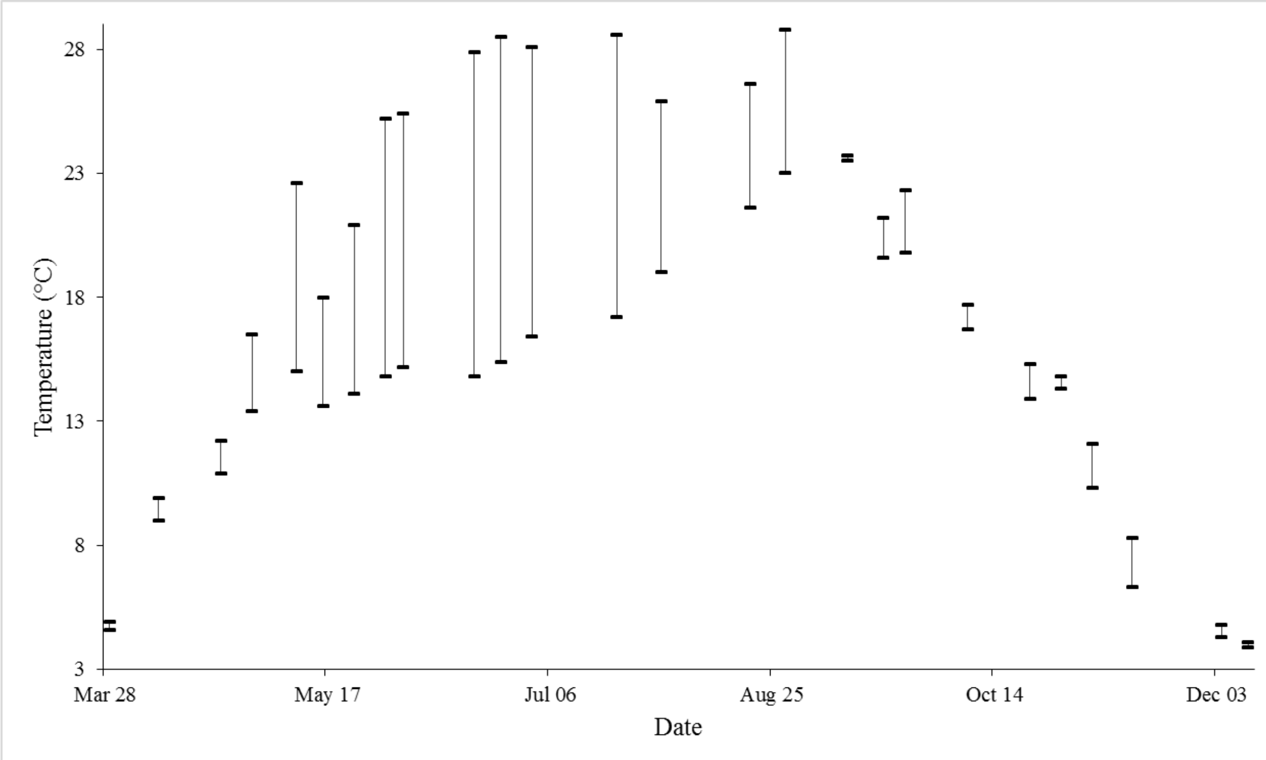

Figure 5. Ranges of temperature (°C) from depth profiles in Eagle Creek Reservoir during 2014.

Figure 6. Home ranges of age-1 Muskellunge represented in Eagle Creek Reservoir during the spring of 2014 (N=16).

Figure 7. Home ranges of age-1 Muskellunge represented in Eagle Creek Reservoir during the summer of 2014 (N=6).

Figure 8. Home ranges of age-1 Muskellunge represented in Eagle Creek Reservoir during the fall of 2014 (N=3).

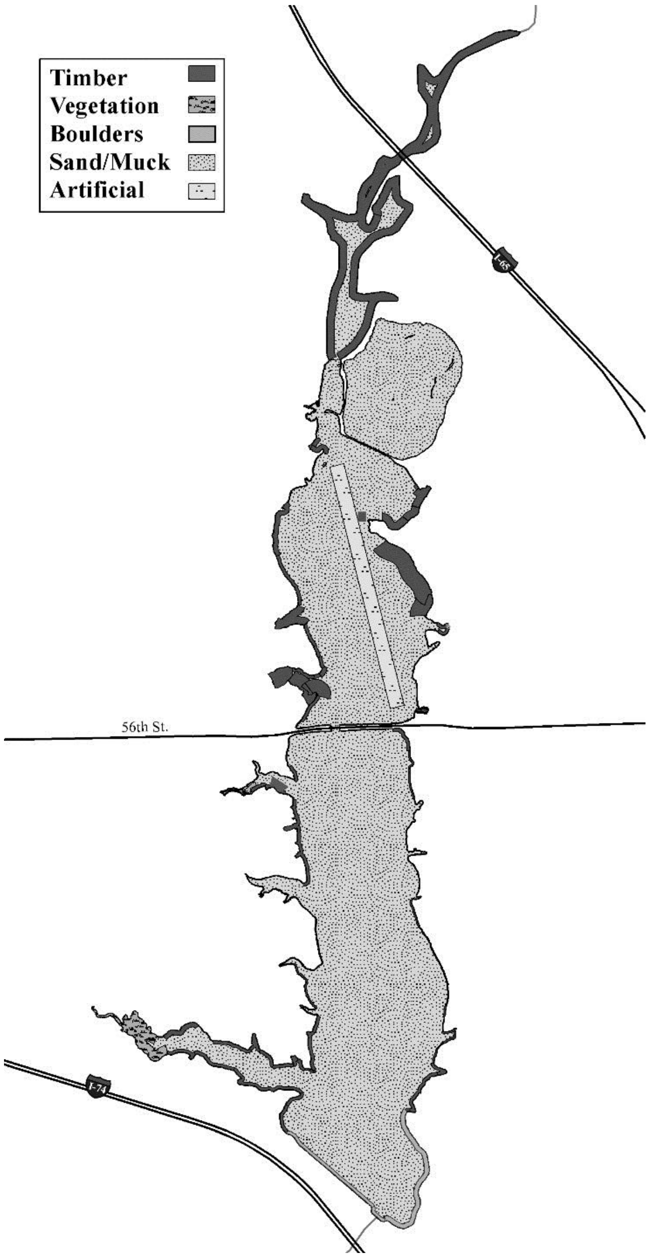

Figure 9. Map of habitat types in Eagle Creek Reservoir during 2014.

Tables

Table 1. Best models of Gamma distributions based on AICc values for determining environmental effects on the average weekly movements (natural log) of age-1 Muskellunge in Eagle Creek Reservoir.

Intercept	Season	Secchi (m)	DO (mg/L)	Temp. (°C)	Water Depth (m)	Wind Direction	Wind Speed (kph)	ΔAICc
3.26	+	-0.85	0.18	NA	NA	NA	0.08	0.00
3.15	+	NA	0.13	NA	NA	NA	0.07	0.67
3.11	NA	-1.11	0.17	NA	0.49	NA	0.07	0.94
2.74	+	-0.91	0.16	NA	0.36	NA	0.08	1.58
3.42	NA	-1.09	0.20	NA	NA	NA	0.08	1.72

Table 2. Best distribution for comparing average weekly movements (m) of age-1 Muskellunge and environmental variables based on AIC values.

Distribution	AIC	ΔAIC
Gamma	421.37	0.00
Normal	438.25	16.88

Table 3. Model-average estimate (natural log) of each parameter effect on the average weekly movements of age-1 Muskellunge in Eagle Creek Reservoir for the best models from the Gamma distribution.

Parameter	Model-Average Estimate	95% Confidence Intervals
Water Depth	0.43	-0.02, 0.89
Dissolved Oxygen	0.17	0.05, 0.28
Wind Speed	0.08	0.04, 0.11
Season - Summer	-0.1	-0.72, 0.51
Secchi Disk Reading	-0.97	-1.74, -0.2

Table 4. Best models for comparing home range areas (ha) during spring, summer, and fall seasons for age-1 Muskellunge based on AIC values.

Distribution	AIC	ΔAIC
Negative binomial	229.27	0.00
Normal	289.85	60.58
Poisson	1866.16	1636.90

Table 5. Amount of each habitat type in Eagle Creek Reservoir during 2014.

Habitat type	Area (ha)	Percentage
Timber	16.1	3
Vegetation	6.26	1.2
Boulders	3.77	0.7
Sand/Muck	518.51	94.8
Artificial	1.67	0.3

Table 6. Habitat selection of age-1 Muskellunge in Eagle Creek Reservoir during 2014 based on Jacobs index.

Habitat type	Spring	Summer	Fall
Timber	0.17	0.51	0.58
Vegetation	-0.28	-0.25	0.03
Boulders	0.25	-0.76	-0.32
Sand/Muck	-0.99	-0.99	-0.99
Artificial	0.14	-0.6	-0.54