FINAL PERFORMANCE REPORT

Spatial Ecology, Habitat Use and Angling Vulnerability in Muskellunges in Shabbona Lake: Implications for Management of a Recreational Fishery

John F. Bieber, Cory D. Suski

Department of Natural Resources and Environment Sciences
University of Illinois

Prepared for: U.S. Fish and Wildlife Service
Region 3 Federal Aid

F-202- R- 02
July 1, 2021-June 30, 2022

PROJECT F-202 R-2 FINAL REPORT

Project objective: The goal of this project is to provide information on potential mechanisms for angling vulnerability in Muskellunge that can define catch rates of Muskellunges in Shabbona Lake.

SUMMARY FOR REPORTING PERIOD: July 1, 2021-June 30, 2022

Job 1.1 Spatial ecology and movement patterns of Muskellunges in Shabbona Lake.

Objective 1: Over a period of 1 year, quantify the seasonal habitat use, movement and spatial distribution of Muskellunge in Shabbona Lake.

Progress: On April 26, 2022, 4 receivers were successfully recovered from Shabbona Lake, including one deployed on April 13, 2021 and 3 receivers deployed October 19, 2021. Following recovery, data were cleaned of false detections and time-corrected as per manufacturer protocols. This resulted in approximately 990,000 fish detections from the 4 receiver array, and each fish detection also was paired with a water temperature reading. Analyses of these data will quantify movement patterns, habitat use and patterns of thermal habitat use that will relate to angling vulnerability and provide insights into angler catch rates in Shabbona Lake.

Planned Direct Costs:	$0
Direct Costs:	$0

Job 1.2 Lure avoidance and hook learning

Objective: Over one year, define how hook avoidance and ‘learning’ influences capture rates of Muskellunge.

Progress:

Data collection and analysis for this Job is complete. A draft of the manuscript has been provisionally accepted at North American Journal of Fisheries Management. The entire draft of this manuscript is included at the end of this report. Here, we provide an overview of the methods, results, and key findings/outcomes from the study.

Planned Direct Costs:	$65,034
Direct Costs:	$65,034

Introduction

Angling has the potential to influence fish populations, both directly and indirectly. Specifically, angled fish are subjected to a host of challenges including hooking, exercise, and air exposure, and, in some cases, fish may experience initial or delayed mortality owing to the cumulative impacts of these stressors (Meka and Mccormick 2005). The loss of individual fish from the population can accumulate and lead to decreases in population size, which may occur even in situations where capture rates remain high (i.e., hyperstability) (Erisman et al. 2011).

Angling can also impart an indirect impact on fish populations by selecting for individuals with specific phenotypes that predispose that individual to capture. For example, work with common carp (*Cyprinus carpio*) has shown fish with bold and active personality traits are disproportionately captured over fish that are timid and sedentary, likely due to the foraging style of common carp whereby fish are actively swimming seeking benthic food items (Klefoth et al. 2017). Thus, over time, angling-vulnerable common carp that are bold and active can be removed from the population, either through harvest or incidental mortality, leaving sedentary timid individuals less likely to be captured, thereby reducing anger catch rates. More importantly, behavioral traits in fish are heritable and can relate to individual fitness, reproductive success and physiology (i.e., metabolic rate, hormonal physiology) (Cooke et al. 2007) through the pace of life framework (Réale et al. 2007). This means that the removal of fish with certain behavioral characteristics through angling can lead to an abundance of fish in a population that have lower reproductive output or lower metabolic rates, which, in turn, can reduce angler catch rates. As a result, owing to the possible changes to either angler catch rates or population-level parameters that can occur from the direct or indirect impacts of angling, it is critical to define the behavioral predictors of angling to inform managers of possible long-term changes to populations that can occur due to the impacts of anglers.

To that end, the goals of this study were to (1) define how behavioral and metabolic parameters drive capture in Muskellunge, and (2) quantify the potential for hook avoidance and 'learning' as it relates to capture of Muskellunge. Results will not only help identify factors that influence angler catch rates in the short term, but also will quantify possible long-term mechanisms that have influenced capture rates over the long term.

To accomplish this goal, we first conducted behavioral assays using hatchery-reared Muskellunge before stocking them into earthen ponds where they were targeted by anglers using conventional gear. A subset of uncaptured fish, along with all captured fish, were subsequently assayed for metabolic parameters. When combined, the results from this study highlight the behavioral axes that best predict angling vulnerability in Muskellunge, and ultimately inform the ways in which angling may be influencing populations of Muskellunge over time.

Methods

A total of 68 age – 0 Muskellunge were obtained from the Illinois Department of Natural Resources (IDNR) Jake Wolfe Memorial Fish Hatchery in Topeka, IL, on September 11, 2021 (mean total weight = 147.8 g ± standard deviation (SD) 24.8 g; mean total length = 310.2 mm ± SD 19.8 mm) and transported to the Aquatic Research Facility at the University of Illinois, Urbana, IL. Muskellunge were then assessed for behavioral phenotype, metabolic phenotype, and vulnerability to angling.

Behavior phenotype assessments consisted of standard 'open field' tests to quantify boldness, exploration, activity, and aggression using a 30 min trial broken into three 10 min segments (Koolhaas et al. 1999; Réale et al. 2007). All behavior assays were conducted between the hours of 0730 and 1800, September 16 – 20, 2021, within one of 4 identical indoor arenas that consisted of a 565 L (181 cm long × 65 cm wide) rectangular polyethylene stock tank filled with water to a depth of 20 cm that was isolated on all four sides with blackout curtains to avoid external stimuli. Behavioral arenas were divided into two distinct sections: a refuge zone and an open zone. The refuge zone comprised approximately one third of the tank area and contained gravel substrate along with one artificial aquatic plant. The refuge was separated from the remainder of the tank with a white plexiglass divider attached to pulley and was covered with a lid. The remaining two thirds of the stock tank was considered the open zone, and this zone was uncovered. The end of the open zone farthest from the refuge contained a matte grey plexiglass divider attached to a pulley that fully covered a 14 cm × 9 cm mirror mounted approximately 0.5 cm from the bottom of the tank in a position easily visible to the fish. Each arena was outfitted with a video camera (either a GoPro Hero 3 (GoPro, San Mateo California, USA) or a Sony Handycam CX405 (Sony Corp., Japan)) mounted above the tank on the refuge side. Following subsequent analyses, behaviors related to exploration and aggression were found to be related, and behaviors related to boldness and activity were found to be related.

Following the second behavioral trial, Muskellunge were haphazardly stocked into one of two 0.04 ha ponds (2 m deep × 24 m long×15 m wide) on October 2, 2021 (n = 34 per pond), along with approximately 500 Fathead Minnows for forage. Prior to stocking, both ponds were drained, vegetation was manually removed, and pond beds were permitted to air dry for 6 d. Following this 6 d period, ponds were refilled with municipal water, and given a 10 d period to dechlorinate; chlorine levels in the pond fell to under 1 ppm to prior to stocking. After stocking, Muskellunge were given one week to acclimate prior to commencement of angling trials. The fish stocked into the ponds did not differ in weight, length, or any of the principal component scores for behavior described below (*t*-tests, $t < -1$, $\mathrm{df} > 5$, $P > 0.1$). Angling in both ponds occurred from October 8, 2021, to November 11, 2021, with approximately 0.5 hr of effort applied to each pond during each angling session. To maximize captures over the course of the angling trials, a variety of lure types and angling techniques were used (e.g., varying speed of retrieval, different casting strategies, angling conducted at many times of the day). After the completion of angling, ponds were drained, and all fish were recovered. All captured, and an equal subset of non-captured fish, were set aside for the assessment of metabolic parameters.

Metabolic parameters consisted of standard metabolic rate (SMR), maximum metabolic rate (MMR) and aerobic scope (AS) while accounting for background respiration (Chabot et al. 2016). To quantify maximum metabolic rate, Muskellunge were exercised to exhaustion by tail grabbing in a small circular tank, a process that typically required 5 min (Suski et al. 2007). Once exhausted and unresponsive to additional tail pinches, Muskellunge were loaded into one of four static respirometry chambers (Loligo, Denmark) submerged in a temperature-controlled tank held at 11° C (a temperature that matched that of the outdoor holding tanks) where they remained overnight. Dissolved oxygen was measured utilizing a fiber-optic probe every 5 s throughout the measurement period and SMR was calculated utilizing the mean of the 5 lowest $\dot{M}O_2$ values throughout the overnight measuring period. MMR was defined as the single highest oxygen consumption value after exercise. Aerobic Scope (AS) was defined as the difference between MMR and SMR. Background respiration was quantified by running empty chambers before and after trials with fish and assuming a linear change in oxygen consumption (Redpath et al. 2010, Rodgers et al. 2016, Louison et al. 2018).

Results

A total of 7 behaviors were identified as repeatable. Utilizing these repeatable behaviors, 2 PCs were constructed with eigenvalues > 1 (Table 1). PC1 explained 44% of variance in the data and contained boldness and activity-related behaviors across both the pre-lure and lure sessions. Fish that received high PC1 scores spent a greater duration of time moving in the arena during the pre-lure phase and lure phase, moved a greater distance after the lure was introduced, and made more emergences from the shelter. PC2 explained 36% of the total variance and consisted of exploration and aggression-related variables. Fish that had high PC2 scores took a short amount of time to emerge from the shelter, spent a greater duration of time in the open at the outset of the trial, and spent a longer duration of time at the mirror (Table 1).

A total of 42 angler-hours was applied to the two ponds in 30 min increments across 35 days of angling. Capture tallies were highest on the first day when 4 fish were captured, and then declined in the following days (Figure 1). In total, 7 Muskellunge were captured across all angling sessions, resulting in a catch-per-unit effort (CPUE) of 0.167 Muskellunge per hour of angling. There were no recaptures over the 35 days of angling.

Analyses relating behavioral scores to capture (conducted on the full population of all Muskellunge that received behavioral testing) found four top models all containing PC2 and weight, highlighting the importance of PC2 for predicting capture (Table 2). When the influence of weight and PC2 were visualized, results showed that captured fish had a lower PC2 score relative to uncaptured fish (Figure 2A), and that captured fish were heavier than uncaptured fish (Figure 2B). Visualizing the interaction between weight and PC2 showed that fish more likely to be captured were heavier and had lower PC2 scores (Figure 2C). For the subset of fish that received metabolic testing, *t*-tests did not identify any significant differences between the captured and uncaptured groups.

Discussion

The capture of fish by hook-and-line angling can lead to incidental mortality that can directly influence fish communities by reducing population size. In addition, the removal of fish with certain traits, such as body size (growth rate), boldness, or metabolic parameters, can have indirect impacts on the composition of populations that can lead to declines in vulnerability, or possible long-term reductions in reproductive output. Gaining insight into traits that predispose fish to capture is valuable to both sustain angler satisfaction and can help with the long-term management of fish populations.

In the present study, Muskellunge that were larger, less exploratory, and less aggressive were preferentially captured relative to smaller more active fish; metabolism, boldness, and activity did not influence capture. Many other fish exhibit correlates of angling vulnerability based in behavioral or physiological traits. For example, angling vulnerability of Common Carp is predicted by boldness and activity (Klefoth et al. 2017), capture in Largemouth Bass is predicted by hormonal response to stress, while vulnerability in Bluegill is higher in more social individuals that also perform well in learning assessments (Louison et al. 2018). Muskellunge are a sedentary, sit-and-wait predator that lie motionless and use burst swimming to capture prey that ventures near. Therefore, the feeding ecology of Muskellunge would favor fish that are less exploratory and aggressive, and this feeding ecology therefore likely leads to increased capture of with these behavioral phenotypes.

In addition to behavior predicting capture, Muskellunge in the present study demonstrated evidence of learning that likely lead to hook avoidance and low capture rates. Several fish species have demonstrated learning in the context of angling, whereby fish ‘learn’ to avoid lures, even when not directly captured themselves (termed ‘social learning’) (Askey et al. 2006; Louison et al. 2018). Therefore, the low overall capture rate, despite the use of a variety of lures and angling styles, may have occurred due to social learning as Muskellunge developed a negative association with lures or the presence of anglers at the ponds. Past work has indicated Common Carp behave more cautiously in the presence of hooks when either directly hooked or see another fish hooked (Lovén-Wallerius et al. 2020). Furthermore, Wegner et al. (2017) showed that the presence of anglers at a fishing site likely contributed to declines in catch rates as fish ‘learn’ to avoid capture using stimuli such as boat noises or the sounds of anglers fishing. Past angling studies in these same ponds with Largemouth Bass and Bluegill have shown a similar decline in capture rates over time, but, (a) overall capture rates of Largemouth bass and Bluegill were higher than that of Muskellunge, and (b) capture rates of Largemouth Bass and Bluegill continued, albeit at low levels, over a protracted period of days or weeks, maintaining constant, low-levels of capture over time. While learning was not directly quantified in the present experiment, the steep decline in capture of Muskellunge across angling sessions, coupled with a complete absence of capture rates after a few angling sessions despite all fish being in the ponds, provides strong evidence that social learning is a factor contributing to the low capture of Muskellunge. Future work can perform more quantitative learning assessments with Muskellunge to test this hypothesis and the propensity for learning in Muskellunge. Together, data from this study show a strong propensity for Muskellunge to exhibit hook avoidance, even in the absence of direct capture.

Together, this study provides two mechanisms to explain why Muskellunge are difficult to capture. First, many years of sustained angling pressure could have resulted in a reduction in vulnerable phenotypes (i.e., fewer sedentary fish) and an abundance of non-vulnerable phenotypes (active fish) within a population; the predominance of non-vulnerable phenotypes can lead to low capture rates for a population. While the harvest of Muskellunges is likely currently low, incidental angling mortality can occur (i.e., deep hooking, thermal stress (Booth 2022, Jenkins 2022)) and harvest rates were presumably higher in the past. Incidental mortality may lead to mortality for vulnerable phenotypes, leaving a disproportionate number of non-vulnerable phenotypes in a population. Past work has suggested that vulnerability to angling is a heritable trait (Phillip et al. 2009). This means that a population that contains a disproportionate number of non-vulnerable parents could result in selection for non-vulnerable phenotypes in offspring, leading to declines in angling vulnerability and increase in angler effort over time. Selection for less vulnerable individuals could also impact population-level parameters such as the timing of maturation, growth rate and immune function through pace-of-life relationships, further eroding capture rates (Reale et al. 2007; Arlinghaus et al. 2017). Second, Muskellunge may be learning to avoid capture through mechanisms of social learning that occur even without fish being captured (van Poorten and Post 2005). Fish are capable of learning from prior experience of watching other individuals become captured, subsequently changing behavior to minimize risk of capture themselves (Loven-Wallerius et al. 2020). Therefore, in a lake with sustained angling effort, social learning can occur as individuals experience the capture of other fish, ultimately reducing capture rates. For Muskellunge in Shabbona Lake, these two factors (long-term selection against vulnerable phenotypes coupled with short-term angler avoidance through social learning) may combine and result in low angler catch rates.

Management Recommendations

Results of the present work indicate several recommendations to promote sustainable fisheries and/or increase angler catch rates. First, continuing to promote catch and release and best handling practices for Muskellunges is critical. Specifically, minimizing air exposure, reducing fight times, and angling when water temperatures are not so high as to induce mortality will maximize the survival of captured fish (Landsman et al. 2011; Jenkins 2022). By minimizing incidental mortality from angling events, the less aggressive and less exploratory

Muskellunge that are more vulnerable to angling will persist in the population and reproduce, ultimately preserving vulnerable phenotypes. Second, recent work with largemouth bass has shown that no-fishing protected areas have the potential to protect vulnerable phenotypes and provide an angling-free refuge for fish to avoid any angling stimuli and maintain catch rates over time (Twardek et al. 2017; Cooke et al. 2017). This management strategy chould be investigated in the future for Muskellunge, as the protection of vulnerable phenotypes may help sustain catch rates and populations. A refuge such as this may be challenging in a small, highly pressured lake such as Shabbona, but the potential for such a strategy to maintain catch rates is intriguing. Together, results from this study help provide valuable insights into the mechanisms responsible for capture in Muskellunge and highlight a possible target for management actions that can help sustain populations and support catch rates over time.

References

Arlinghaus, R., K.L. Laskowski, J. Alós, T. Klefoth, C.T. Monk, S. Nakayama, and A. Schröder. 2017. Passive gear-induced timidity syndrome in wild fish populations and its potential ecological and managerial implications. Fish and Fisheries 18: 360 - 373. https://doi.org/10.1111/faf.12176

Askey, P.J., S.A. Richards, J.R. Post, and E.A. Parkinson. 2006. Linking angling catch rates and fish learning under catch-and-release regulations. North American Journal of Fisheries Management, 26(4): 1020-1029.

Biro, P.A. and J.A. Stamps. 2008. Are animal personality traits linked to life-history productivity? Trends in Ecology & Evolution 23: 361–368. https://doi.org/10.1016/j.tree.2008.04.003

Booth, I.T., 2022. Evaluating Muskellunge (*Esox masquinongy*) catch-and-release mortality at elevated summer water temperature. Master's Thesis. West Virginia University.

Chabot, D., D.J. McKenzie, and J.F. Craig. 2016. Metabolic rate in fishes: definitions, methods and significance for conservation physiology. Journal of Fish Biology.88:1–9. https://doi.org/10.1111/jfb.12873

Cooke, S.J., C.D. Suski, K.G. Ostrand, D.H. Wahl, and D.P. Philipp. 2007. Physiological and behavioral consequences of long-term artificial selection for vulnerability to recreational angling in a teleost fish. Physiological and Biochemical Zoology. 80: 480–490. https://doi.org/10.1086/520618

Cooke, E.L., A.D. Wilson, C.K. Elvidge, and S.J. Cooke. 2017. Does capture method or the presence of aquatic protected areas influence the selective harvest of behavioural types in Largemouth Bass? Canadian Journal of Fisheries and Aquatic Sciences, 74(8): 1151-1157.

Erisman, B.E., L.G. Allen, J.T. Claisse, D.J. Pondella, E.F. Miller, and J.H. Murray. 2011. The illusion of plenty: hyperstability masks collapses in two recreational fisheries that target fish spawning aggregations. Canadian Journal of Fisheries and Aquatic Sciences. 68(10): 1705-1716.

Jenkins, P.I., 2022. Summer habitat use, home range, and effect of catch and release mortality on the trophy potential of Muskellunge,(*Esox masquinongy,* Mitchill, 1824), in a southern reservoir population. Master's thesis. West Virginia University.

Johansson, K., Sigray, P., Backström, T., & Magnhagen, C. (2016). Stress response and habituation to motorboat noise in two coastal fish species in the Bothnian Sea. In: Popper, A. N., & Hawkins, A. (eds.), The effects of Noise on Aquatic Life II, Advances in Experimental Medicine and Biology 875. Springer, New York, 513–521.

Klefoth, T., C. Skov, A. Kuparinen, and R. Arlinghaus. 2017. Toward a mechanistic understanding of vulnerability to hook-and-line fishing: boldness as the basic target of angling-induced selection. Evolutionary Applications, 10(10): 994-1006.

Koolhaas, J.M., S.M. Korte, S.F. De Boer, B.J. Van Der Vegt, C.G. Van Reenen, H. Hopster, I.C. De Jong, M.A.W. Ruis, and H.J. Blokhuis. 1999. Coping styles in animals: current status in behavior and stress-physiology. Neuroscience & Biobehavioral Reviews. 23: 925–935. https://doi.org/10.1016/S0149-7634(99)00026-3

Landsman, S. J., H.J. Wachelka, C.D. Suski, and S.J. Cooke. 2011. Evaluation of the physiology, behaviour, and survival of adult muskellunge (*Esox masquinongy*) captured and released by specialized anglers. Fisheries Research, 110(2), 377-386.

Louison, M.J., J.D. Jeffrey, C.D. Suski, and J.A. Stein. 2018. Sociable Bluegill, *Lepomis macrochirus*, are selectively captured via recreational angling. Animal Behaviour. 142: 129–137. https://doi.org/10.1016/j.anbehav.2018.06.013

Lovén Wallerius, M., J.I. Johnsson, S.J. Cooke, and R. Arlinghaus. 2020. Hook avoidance induced by private and social learning in common carp. Transactions of the American Fisheries Society. 149: 498–511. https://doi.org/10.1002/tafs.10246

Meka, J.M. and S.D. McCormick. 2005. Physiological response of wild Rainbow Trout to angling: impact of angling duration, fish size, body condition, and temperature. Fisheries Research. 72(2-3): 311-322.

Philipp, D. P., S.J. Cooke, J.E. Claussen, J.B. Koppelman, C.D. Suski and D.P. Burkett, (2009). Selection for vulnerability to angling in largemouth bass. Transactions of the American Fisheries Society, 138(1), 189-199.

Redpath, T.D., S.J. Cooke, C.D. Suski, R. Arlinghaus, P. Couture, D.H. Wahl, and D.P. Philipp. 2010. The metabolic and biochemical basis of vulnerability to recreational angling after three generations of angling-induced selection in a teleost fish. Canadian Journal of Fisheries and Aquatic Sciences. 67: 1983–1992. https://doi.org/10.1139/F10-120

Rodgers, G.G., P. Tenzing, and T.D. Clark. 2016. Experimental methods in aquatic respirometry: the importance of mixing devices and accounting for background respiration. Journal of Fish Biology. 88: 65–80. https://doi.org/10.1111/jfb.12848

Suski, C.D., S.J. Cooke, A.J. Danylchuk, C.M. O'Connor, M.A. Gravel, T. Redpath, K.C. Hanson, A.J. Gingerich, K.J. Murchie, and S.E. Danylchuk. 2007. Physiological disturbance and recovery dynamics of Bonefish (*Albula vulpes*), a tropical marine fish, in response to variable exercise and exposure to air. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology. 148: 664–673.

Twardek, W.M., C.K. Elvidge, A.D. Wilson, D.A. Algera, A.J. Zolderdo, S.C. Lougheed, and S.J. Cooke. 2017. Do protected areas mitigate the effects of fisheries-induced evolution on parental care behaviour of a teleost fish? Aquatic Conservation: Marine and Freshwater Ecosystems, 27(4): 789-796.

van Poorten, B. T., and J.R. Post. 2005. Seasonal fishery dynamics of a previously unexploited rainbow trout population with contrasts to established fisheries. North American Journal of Fisheries Management, 25(1), 329-345.

Wegener, M.G., H.L. Schramm, J.W. Neal, and P.D. Gerard. 2018. Effect of fishing effort on catch rate and catchability of largemouth bass in small impoundments. Fisheries Management and Ecology, 25(1), pp.66-76.

Table 1: Factor loadings and variance explained for principal components analysis on behaviors of N=68 muskellunge. Metrics include the repeatable behaviors that were measured across trials from Table 1, with respective trial phase in parentheses. The behavioral axis in which the behavior lies is defined in the Behavioral Axis column. Factors that loaded negatively (i.e., Refuge Emergence Time) are preceded with a hyphen (-).

Metric	Behavioral Axis	PC1	PC2
Frequency Leaving Shelter (Count)	Boldness	**0.665**	0.427
Total Time in Open Arena Before Lure(s)	Exploration	0.109	**0.953**
Refuge Emergence Time (s)	Exploration	-0.220	**-0.950**
Time Moving Pre-Lure (s)	Activity	**0.875**	0.223
Distance Moved During Lure(cm)	Activity	**0.908**	0.201
Proportion of Time at Mirror (Percentage)	Aggression	0.337	**0.657**
Time Mobile During Lure	Activity	**0.946**	0.147
Variance Explained		0.443	0.362
Cumulative Variance		0.443	0.805

Table 2: The 4 top models (those with a △AIC <2, shown in bold) that predict capture of muskellunge by anglers. All top models contain PC2 and weight, as well as models containing each variable individually. PC1 was not contained in any top model. PCs are shown in Table 1.

Model	K	Log Lik	AICc	ΔAIC_c
PC2 + Weight	**4**	**-18.97**	**44.32**	**0**
PC2 × Weight	**4**	**-18.499**	**45.6**	**1.28**
Weight	**3**	**-20.9**	**46**	**1.68**
PC2	**3**	**-20.93**	**46.05**	**1.73**
PC1+ PC2+ Weight	5	-18.9	46.44	2.12
Null Model	2	-22.54	47.14	2.82
PC1 + Weight	4	-20.88	48.13	3.81
PC1 + PC2	4	-20.93	48.24	3.92
PC1	3	-22.53	49.25	4.93
PC1 × PC2	4	-20.32	49.3	5.02
PC1 × Weight	4	-20.855	50.3	6.02
Full Model	9	-17.798	51.5	7.18

Figure 1: Number of Muskellunge captured per angling day. Angling occurred over a total 35 days, using a variety of lures and angling techniques.

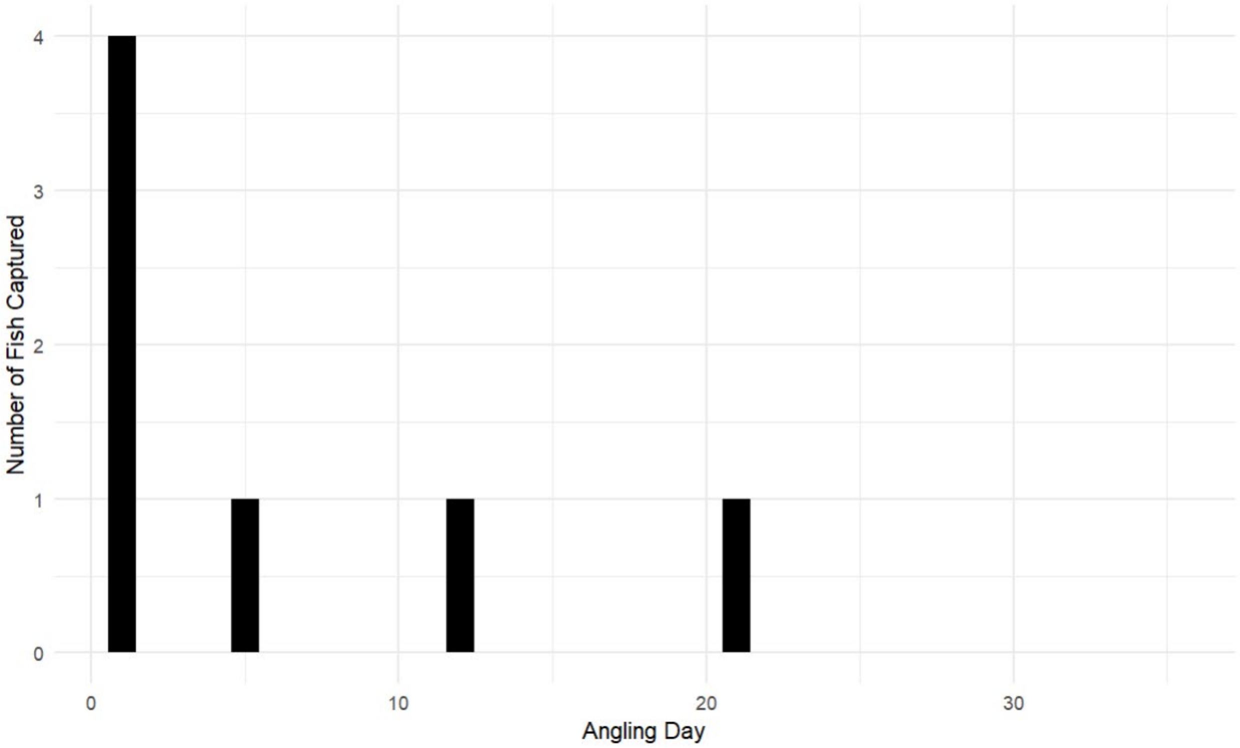
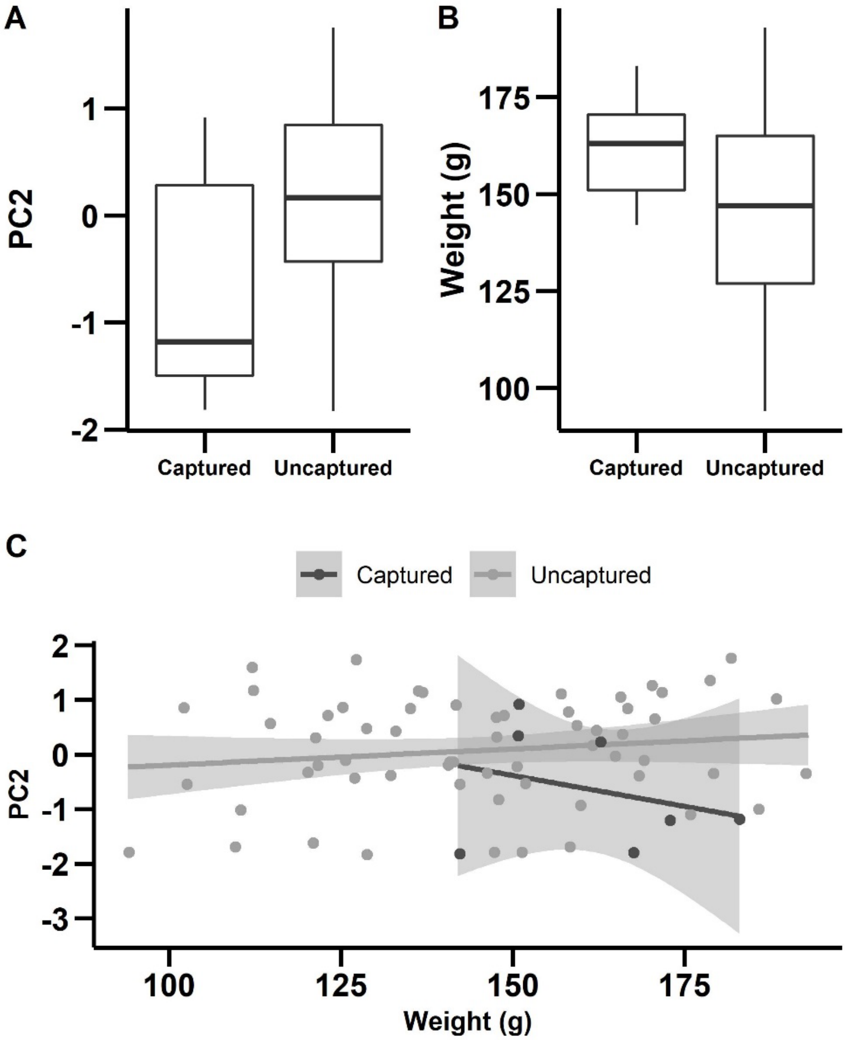


Figure 2: Figures visualizing the differences between captured and uncaptured Muskellunge. Panel A shows the PC2 (Aggression and Exploration) scores between captured and uncaptured fish. Panel B shows the weight (in grams) across captured and uncaptured fish. Panel C shows the interaction between PC2 and weight across captured and uncaptured fish. PC2 is described in Table 1.



Job 1.3 Food resources and capture rates

Objective: Over one year, compare angler capture rates of hatchery-sourced Muskellunge in experimental ponds with varying levels of available prey to define the role of food availability on the response of Muskellunges to angling lures.

Progress: This work will occur in the third year of this Project, in the final 2 quarters of 2022. To prepare for this study, research into methods necessary for food/hormone manipulations has been conducted. To date, four ponds at the INHS research site have been drained and prepared for fish holding, and communication with the Jake Wolfe Fish Hatchery has led to the scheduled delivery date of September 30, 2022 for 250 Muskellunge that will be used in this study. Behavioral arenas have been prepared for assays, hormone pumps have been delivered and preparations for this work are well underway.

Planned Direct Costs:	$0
Direct Costs:	$0

SUMMARY OF EXPENDITURES

TOTAL EXPENDITURES: *July 1, 2021-June 30, 2022*

Total Cost	$86,710
Federal Share	$65,034
State Share	$21,676

REPORT OF EXPENDITURES, July 1, 2021-June 30, 2022

Study 1.	
Job 1.1: Spatial ecology and movement patterns of Muskellunges in Shabbona Lake.	$0
Job 1.2: Lure avoidance and hook learning	$65,034
Job 1.3: Food resources and capture rates	$0
Total Cost	$65,034
Federal Share	$65,034
State Share	$21,676