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Effective Tandem Hoop Net Sampling Effort for Evaluation of Channel Catfish Populations in Reservoirs

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EFFECTIVE TANDEM HOOP NET SAMPLING EFFORT FOR EVALUATION OF CHANNEL CATFISH POPULATIONS IN RESERVOIRS

By

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THESIS ABSTRACT

Channel Catfish *Ictalurus punctatus* have an important role in Arkansas's commercial and recreational fisheries. This importance promoted sampling strategy investigations for obtaining information that assist with future management decisions. My study focused on determining effective sampling effort and sample size requirements needed for detecting changes in relative abundance within Channel Catfish populations, and explored relationships between catch per unit effort (CPUE) and reservoir habitat characteristics. My study was conducted during the spring of 2014 in six reservoirs (Lake Nimrod, Lake Overcup, Lake Catherine, De Queen Lake, Lake Erling, and Lake Columbia). General stock assessments consisting of length frequency distributions, growth rates, and mortality rates were also conducted for each reservoir. Sampling involved setting 16 tandem hoop net sets during April, May, and June in each reservoir. Mean CPUE (fish/tandem hoop net set) ranged from 1.9 (SD, 2.1) to 355.9 (SD, 137.2). Lake Erling's CPUE was the greatest, while Lake Catherine's CPUE was the lowest. In addition, catch rates were influenced primarily by water temperature. Shallow reservoirs had higher CPUE than deep reservoirs for each month sampled. In addition, the CPUE of each reservoir's lower section (closer to the levee) was less than the upper section during April. However, both sections were equal during May and June. Due to April's low catch rates, only May and June's CPUE were used to determine effective sample sizes. The greatest mean back-calculated length-at-age for Channel Catfish sampled occurred in Lake Overcup, while the greatest mean length-at-capture occurred in Lake Columbia. Growth rates were also significantly different between reservoir types for back-calculated ages two, four, five, and seven. Finally, shallow reservoir types displayed higher mortality rates than deep reservoirs. Sample size simulations were conducted to

determine the number of sets necessary to detect 10% to 50% changes in relative abundance at an alpha of 0.05 and 0.10 and power of 0.95 and 0.80. Simulations revealed CPUE assessments ineffective at describing populations without also assessing age and growth data and length frequency distributions. Furthermore, angler surveys and harvest estimates could be a potential alternative to CPUE for evaluating a population’s relative abundance.

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THESIS INTRODUCTION

Channel Catfish *Ictalurus punctatus* are an important United States (U.S.) fishery both commercially and recreationally. This has occurred due to the values placed on the commercial farming, harvesting, and angling of Channel Catfish. Commercially, the fishery exists as a high profit expenditure in several southeastern states; and among these states, Mississippi continues to lead in the commercial farming of Channel Catfish.

Its recreational value is the result of increasing popularity within the angling community (Arterburn et al. 2002). Data from surveys have shown that 26% of the nation's anglers fish for catfish (Reitz and Travnichek 2006), with Arkansas anglers devoting up to 18% of angling effort exclusively towards Channel Catfish. These commercial and recreational values have resulted in high exploitation and extensive research of Channel Catfish (Vokoun and Rabeni 1999), while also leading to the species increased range throughout the continental United States.

The species extended range has greatly been aided by the stocking of many state waters. The stocking of Channel Catfish is meant to both introduce the species into newly man-made impoundments and supplement existing populations. Due to the commercial and recreational value of Channel Catfish, it exists naturally and through stocking in most public bodies of water throughout the United States. In addition, many states implement similar stocking procedures of 25 catfish 200 to 250 mm in length per acre. However, there are some states such as Arkansas, which have modified stocking procedures.

Arkansas's stocking procedure consists of stocking either yearling or catchable size Channel Catfish based on the biologist's objectives (Olive et al. 2015). Normally, yearlings (individuals 175 to 230 mm in length) are stocked in large reservoirs where immediate catch is not important (Olive et al. 2015). However, when the immediate catch of stocked fish is desired, catchable-sized (individuals 330 to 380 mm in length) are stocked (Olive et al. 2015). By implementing this procedure, it ensures that there is an effective solution for any stocking objective.

Typically, the key factor in determining Channel Catfish stocking objectives is relative abundance. Relative abundance is the number of fish caught per unit of effort and is useful at detecting changes in a population over time (Gerow 2007). However, this population descriptor can only be estimated correctly through the use of adequate sampling effort.

In chapter one, the objective focuses on the methods that can be used to determine the recommended sampling effort for a specific sampling gear when targeting Channel Catfish. Sampling effort was estimated by power analyses. Power analyses are useful at determining the sampling effort needed to detect a change in a population's relative abundance while also accounting for gear bias.

In chapter two, the objective focuses on evaluating the population descriptors, age and growth, size structure, and mortality, while also determining how each is affected by a reservoir's physical and ecological characteristics. These abiotic and biotic characteristics have been shown in studies to have various effects on population descriptors (Hayes et al. 1999), which in turn, can influence management decisions for a

reservoir's Channel Catfish population (Sokal and Rohlf 1995; Kuklinski and Boxrucker 2008.

Recreational management decisions for Channel Catfish are difficult to determine, due to a lack of information and a difficulty in obtaining representative samples to describe a population (Michaletz and Dillard 1999; Brown 2007). In order to resolve these issues, my study was conducted to evaluate the current Arkansas Game and Fish Commission (AGFC) sampling protocol used to assess Channel Catfish populations. I determined how reservoir, reservoir type, reservoir section, and sampling month each affected population assessments and sampling effort.

By using power analyses, I was able to determine the required sampling effort needed to detect 10% to 50% changes in relative abundance with alpha (α) of 0.05 and 0.10 and power (1-β) of 0.90 and 0.80. This, in turn, helped me to determine if CPUE assessments are effective at describing populations relative abundance. As a result, AGFC and other fisheries biologists will be able to more effectively deal with sampling bias in their pursuit to make scientifically, justified management recommendations for Channel Catfish populations.

REFERENCES

Arterburn, J. E., D. J. Kirby, and C. R. Berry Jr. 2002. A survey of angler attitudes and biologist opinions regarding trophy catfish and their management. Fisheries 27(5):10-21.

Brown, Z. 2007. Current trends in catfish sampling techniques and information needs. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 61:6-9.

Gerow, K. G. 2007. Power and sample size estimation techniques for fisheries management: Assessment and a new computational tool. North American Journal of Fisheries Management 27:397-404.

Hayes, D. B., W. W. Taylor, and P. A. Soranno. 1999. Natural lakes and large impoundments. Pages 589-622 *in* C. C Kohler and W. A. Hubert, editors Inland Fisheries management in North America, 2^{nd} edition. American Fisheries Society, Bethesda, Maryland, USA.

Kuklinski, K. E., and J. Boxrucker. 2008. Catfish angling and harvest statistics with an emphasis on trophy blue catfish management in Oklahoma. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 62:149-153.

Michaletz, P. H., and J. G. Dillard. 1999. A survey of catfish management in the United States and Canada. Fisheries 24(8):6-11.

Olive, J., J. Barnett, J. Miller, B. Batten, and J. Quinn. 2015. Standard sampling methods for channel, blue, and flathead catfish in Arkansas waters. Pages 19-21 *in* Arkansas Game and Fish Commission: Arkansas Catfish Management Plan 2^{nd} edition. Arkansas Catfish Plan.

Reitz, R. A., and V. H. Travnichek. 2006. Examining the relationship between species preference and catfish angler demographics, angling behavior, and management opinions. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 60:145-151.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry. Freeman, New York.

Vokoun, J. C., and C. F. Rabeni. 1999. Catfish sampling in rivers and streams: a review of strategies, gears and methods. Pages 271-286 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm Jr., and T. Coon, editors. Catfish 2000: Proceedings of the International Ictalurid Symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

CHAPTER 1

EFFECTIVE SAMPLING SIZE AND EFFORT FOR TANDEM HOOP NETS IN ASSESSING CHANNEL CATFISH RELATIVE ABUNDANCE IN RESERVOIRS

INTRODUCTION

Catch per unit effort (CPUE) is an index of relative abundance and can be directly proportional to the abundance of a population (Harley et al. 2001; Tsuboi and Endou 2008). Fisheries biologists use this descriptor to detect changes in relative abundance within a population of fish. This makes CPUE a valuable asset to fisheries biologists when assessing a population (Gerow 2007). These assessments can then aid biologists in determining management plans for existing populations. However, CPUE can complicate a management plan due to its dependency towards a gear's catchability (Tsuboi and Endou 2008).

A gear's catchability may be influenced by size selectivity, fish behavior, and environmental factors (Colombo et al. 2008). Due to this, different gears can produce different estimates for the same population descriptors resulting in different conclusions about the population (Colombo et al. 2008). The different gears used to sample Channel Catfish *Ictalurus punctatus* populations include gill nets (Hanson 1986; Stevenson and Day 1986; Wilde 1995; Howell and Betsill 1999; Mitzner 1999; Santucci et al. 1999), electrofishing (Santucci et al. 1994, 1999; Dudash and Heidinger 1996, and tandem hoop nets (Michaletz and Sullivan 2002; Flammang et al. 2011; Richters and Pope 2011). With these methods, biologists have reported various degrees of success for CPUE, size structure, age and growth, and mortality rates (Colombo et al. 2008).

Among the different gears used, tandem hoop nets have been found to be the most effective for sampling Channel Catfish in reservoirs (Sullivan and Gale 1999; Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009; Flammang et al. 2011). Tandem hoop nets display higher, more consistent catch rates with less bias than most other methods including gill nets (Sullivan and Gale 1999; Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009; Flammang et al. 2011). Tandem hoop nets also display low mortality rates (Sullivan and Gale 1999). However, the effectiveness of tandem hoop nets can be influenced by several factors including size selectivity, habitat, and fish behavior. Tandem hoop nets are size selective toward individuals ≥ 250 mm in length (Sullivan and Gale 1999; Michaletz 2001; Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009; Flammang et al. 2011). This results in a misrepresentation of the size structure of individuals ≤ 250 mm in length within the population (Sullivan and Gale 1999; Michaletz 2001; Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009; Flammang et al. 2011).

Tandem hoop nets also produce higher catch rates when used during the spring and summer seasons (Jackson and Jackson 1999). This may be attributed to Channel Catfish inhabiting shallower portions of a reservoir during the spring and summer season (Fischer et al. 1999). The capture success of tandem hoop nets has also been shown to increase by 600% when bait is used, as opposed to no bait being used (Sullivan and Gale 1999). The bait used typically being soy cakes or waste cheese logs (Carter 1954; Pierce et al. 1981; Robinson 1994).

Finally, adequate soak times and a reduction in escaping fish can also improve capture success and sampling effectiveness. By restricting the second cod throat end and

allowing a minimum soak time of 48 hours, higher catch rates can be achieved with 85% of the fish captured being retained until net retrieval (Neely and Dumont 2001; Porath et al. 2011). Coincidentally, most gear bias can usually be countered by using the appropriate sampling effort or sample size to ensure the gear provides enough sampling data to effectively assess a population.

Power analyses provide a useful way to determine an appropriate sampling effort for a population or location. Power analysis is a statistical method used to determine the probability of detecting an effect in the population (Gerow 2007; Guy and Brown 2007). Many biologists tend to rely on personal experience to determine sampling effort; however, an effective sampling effort is actually dependent upon the targeted species, gear and techniques, sampling location, and environmental variability (Gilliland 1987; Miranda 1993; Anderson and Neumann 1996; Vokoun et al. 2001; Miranda 2007). Due to these variables, power analyses and sampling effort evaluation have become increasingly important to fisheries biologists for assessing population descriptors such as CPUE (Gerow 2007).

Currently, when using tandem hoop net sets to assess a fish population, the number of sets used is determined by reservoir size. Evidence supports the use of four sets for water bodies ≤ 20 ha, six sets for water bodies 20 - 60 ha, eight sets for water bodies > 60 ha, and 16 sets for water bodies 550 - 1,200 ha (Richter and Pope 2011; Stewart and Long 2012). The Arkansas Game and Fish Commission (AGFC), however, recommends four sets for water bodies < 50 ha, eight sets for water bodies 50 - 200 ha, 16 sets for water bodies 200 - 810 ha, and 32 sets for water bodies 810 - 4,050 ha (Olive

et al. 2015). Unfortunately, any variables that influence sampling effort can affect these recommendations, resulting in an increase or decrease in sampling effort.

Typically, small populations, shorter sampling times, larger sampling areas, and assessments that detect small changes require a greater number of samples and sampling effort (Miranda 2007). On the contrary, large populations, longer sampling times, smaller sampling areas, and assessments that detect large changes within a population may require fewer samples or less sampling effort (Miranda 2007). This validates the use and potential of power analyses to aid in effective sampling.

The goal of my study was to use power analyses to evaluate current tandem hoop net sampling effort for Channel Catfish populations in Arkansas reservoirs. This goal was achieved by 1) evaluating how reservoir characteristics affected the number of sets required, 2) determining if season or spatial location of nets influenced capture rates, and 3) evaluating if sampling effort could be extrapolated across reservoirs throughout the state for conducting stock assessments of Channel Catfish populations.

METHODS

Study Sites

The study was conducted on Lake Nimrod, Lake Overcup, Lake Catherine, De Queen Lake, Lake Columbia, and Lake Erling (Figure 1.1). Each reservoir ranged in size from 415 - 2,833 ha and were selected based on reservoir size (< 3,000 ha), depth, benthic substrate, and consultation with AGFC biologists. Each reservoir was categorized as either shallow or deep.

Shallow reservoirs, which consisted of Lake Erling, Lake Overcup, and Lake Columbia, were characterized by a sand and/or silt benthic substrate. Lake Overcup is a

415 ha reservoir that was constructed in 1963 on Overcup Creek in Conway County, Arkansas near the city of Morrilton, Arkansas. Lake Columbia is a 1,214 ha reservoir and was constructed by the AGFC in 1986 along Beech Creek in Columbia County, Arkansas. Lake Erling is a 2,333 ha reservoir that was constructed during the 1950's in Lafayette County, Arkansas as a water source for the International Paper Company. It was formed from the construction of the Percy Cobb Dam built on the Codcaw Creek.

Deep reservoirs, which consisted of Lake Nimrod, De Queen Lake, and Lake Catherine, were characterized by a rocky/large substrate bottom. Lake Nimrod is a 1,437 ha reservoir and located in the Quachita Mountains. It was constructed in 1942 on the Fourche LaFave River at the border of Perry and Yell Counties, Arkansas. Lake Nimrod is also the oldest United States Corporation of Engineers' reservoir in Arkansas. Lake Catherine is an 18 km long, 850 ha reservoir located in Hot Springs County, Arkansas. It was impounded during the 1920's by the Quachita River's Remmel Dam. It is the third reservoir of a series, downstream from Lake Quachita and Lake Hamilton. De Queen Lake is a 680 ha reservoir constructed in 1977 on the Rolling Fork River in Sevier County, Arkansas. It was also created and is under the maintenance of the U.S. Corps of Engineers.

All six reservoirs were also stocked annually and considered good Channel Catfish fisheries by AGFC biologists. Additional reservoir characteristics are listed in Table 1.1.

Field Methods

Each reservoir was divided into two sections (upper and lower; Figure 1.2) and each section was sampled once a month with eight tandem hoop net sets per section. This

resulted in a sampling effort of 16 sampling sets a month. The lower section was characterized as the half of the reservoir containing a dam or levee, while the upper section was characterized as the half of the reservoir containing the water source. Sampling was conducted monthly during April, May, and June of the year 2014, and all fish captured were identified to species and tallied. In addition, total length (TL; mm) was recorded for every Channel Catfish caught.

The tandem hoop net setup consisted of connecting three single hoop nets in a series through the use of a 5 cm stainless steel ring tied to three 3 m long nylon rope leads. All three leads were attached to the front hoop of each individual single hoop net and connected with a stainless steel snap to the next net in the series to form a tandem hoop net series (Sullivan and Gale 1999; Figure 1.3). As describe by Flammang et al. (2011), each single hoop net was 4.30 in length and constructed of size #15 twine with 3.81 cm bar-mesh netting. In addition, each single hoop net contained eight fiberglass hoops. The front hoop opening had a diameter of 0.76 m while the remaining seven hoops each had a diameter of 0.57 m. In addition, a zip tie was used to restrict the second cod end throat by clasping it 15 - 20 cm from the last knot located on the lead line (Flammang et al. 2011; Figure 1.4).

Sampling locations were determined by randomly selecting from a set of shoreline section markers used by the AGFC when determining sites for electrofishing. The shoreline section markers were spaced 600 m apart around the perimeter of each reservoir. For situations where a reservoir shoreline was not marked, GIS Arc Map was used to create a map of the reservoir and plot out random locations for each net set.

When setting each series, a highly visible float was attached to a six-meter-long nylon lead rope connected to the first hoop of the first net. Also, to prevent a series from shifting out of position, three anchors were attached to leads with the leads, in turn, attached to the first hoop of the first and second net and the cod end of the third net. In addition, each net in the series was baited with approximately 1.5 kg of waste cheese logs to increase capture rate and success. The waste cheese was placed into a nylon mesh bag and attached with a zip tie to the last hoop net of each net in the series.

As suggested by Flammang et al. (2011), each net was set parallel to the shoreline and between one and three meters deep to ensure a position above the thermocline. In addition, dissolved oxygen was measured with a YSI-55 meter at each set location to ensure that each location had a dissolved oxygen measurement of ≥ 5 mg/L. Each set was then allowed to soak for 72 hours before retrieval.

Along with dissolved oxygen, GPS coordinates, water depth, substrate type, water clarity, and water temperature were also recorded at each sample location. A Speedtech SM-5 Depthmate portable sounder was used to measure water depth, and a YSI-55 meter was used to measure water temperature (°C). A ponar grab sampler was used to collect small substrate, which was identified as silt (0.0058 - 0.0626 mm), sand (0.626 - 2 mm), or gravel (> 2 mm), while larger substrate was identified by shoreline composition. Finally, a Secchi disk was used to measure water clarity (mm) on the shaded side of the boat.

Data Analyses

Mean monthly Channel Catfish CPUE (fish/tandem hoop net set) and standard deviation were calculated along with log^{10} transformed CPUE + 1 for each reservoir

section and reservoir sections pooled. Catch per unit effort was 1 + $\log^{10}$ transformed to account for nets with no Channel Catfish collected.

The relationship among mean monthly CPUE was tested to determine if one month's CPUE could be used to predict a different month's CPUE. I used the program SAS (SAS Institute Inc. 2011) to perform linear regression analyses to determine if there was a relationship among each month sampled.

Mean CPUE was compared between reservoir types, reservoir sections, and among months sampled. I used SAS (SAS Institute Inc. 2011) to perform a repeated measures ANOVA at a significance level of $\alpha = 0.05$ to determine if any significant difference occurred among these factors.

The relationship between CPUE and water quality variables were also tested. I used SAS (SAS Institute Inc. 2011) to perform a Pearson's correlation and multiple simple linear regressions to determine if there was a relationship between the variables and CPUE. The variables tested consisted of water depth, water temperature, dissolved oxygen, and water clarity. The simple linear regressions were performed on both pooled reservoir data and reservoir data separated by type. In addition, each r^2 was categorized as either weak (< 0.35), moderate (≥ 0.35 - .075), or strong (≥ 0.75).

Effective sampling effort was calculated from $\log^{10}$ transformed CPUE + 1 data by performing power analyses. Sampling effort was calculated for four different changes in Channel Catfish relative abundance (10%, 20%, 30%, and 50%) and for four different combinations of alpha and power (0.05, 0.10; 0.05, 0.20; 0.10, 0.10; 0.10, 0.20). The equation $n = 2(z_\alpha + z_\beta)^2\,(s^2/d^2)$ developed by Snedecor and Cochran (1989) was used to calculate the number of net sets required to effectively sample a reservoir: n = the number

of samples needed; z_α = alpha; z_β = power (1 - β); s = standard deviation of the mean CPUE; and d = the detectable effect size as an absolute number. The effective sampling effort for each reservoir was calculated for each month sampled, first with sections separate and then with sections pooled.

RESULTS

The total number of Channel Catfish captured was 9,346. Catch per unit effort ranged from 0 - 580 fish per set. Average water conditions for set locations recorded for each month are presented in Table 1.2. Depth sampled ranged from 0.90 to 6.30 m deep. Warmest water temperatures recorded for April, May, and June were 22°C, 27°C, and 30.40°C, respectively.

CPUE Comparisons Among Months

Linear regressions were conducted to test if April's CPUE could predict May's and June's CPUE, and if May's CPUE could predict June's. April's CPUE was shown to be able to predict both May's and June's CPUE, while May's CPUE showed the ability to predict June's CPUE (Figures 1.5a - 1.5c).

Since sampling months were not independent of one another and multiple measurements were taken from a single set of reservoirs, a repeated measures ANOVA analysis was conducted to test how CPUE differed among months sampled, reservoir type, and reservoir section. Reservoir type (F (1,80) = 33.79; $P < 0.001$), month (F (2,160) = 50.88; $P < 0.001$), month x reservoir type (F (2,160) = 13.27; $P < 0.001$), and month x section (F (2,160) = 13.33; $P < 0.001$) were all shown to significantly affect CPUE. Shallow reservoirs produced higher CPUE than deep reservoirs during April, May, and June with mean CPUE ranging from 2.06 - 355.94 Channel Catfish per month

(Table 1.3, Figure 1.6a). Deep reservoirs only produced a range of CPUE from 0 - 51.38 Channel Catfish per month. In addition, the upper reservoir section produced a higher mean CPUE than the lower section during the month of April, while mean CPUE was equal between sections for May and June (Figure 1.6b). This trend between sections could be due to similar factors, which resulted in shallow reservoirs displaying greater CPUE then deep reservoirs.

Reservoir Regression Analyses

Simple linear regressions were used to test the relationships between CPUE and the water condition variables recorded. Each regression was performed with pooled CPUE data and a single predictor. All regressions ran revealed a significant effect on CPUE ($P < 0.01$; Figures 1.7 and 1.8); however, the r^2 value for each regression was weak (< 0.14). Correlations were also performed between each variable. Temperature was significantly affected by depth ($P = 0.03$). Dissolve oxygen was significantly affected by both depth ($P = 0.03$) and temperature ($P < 0.01$) (Table 1.4).

Similar regressions and correlations (Figures 1.9 and 1.10; Table 1.5) were also performed with reservoir data pooled by type. For pooled deep reservoir data, water temperature showed a significant effect on CPUE ($P < 0.01$; Figure 1.9b). For pooled shallow reservoir data, both water temperature and dissolved oxygen showed a significant effect on CPUE ($P < 0.01$; Figures 1.11 and 1.12; Table 1.6).

Power Analyses

Power analyses were used to run sample size simulations. Eight hundred and sixty-four simulations were conducted to determine the sample sizes and effort needed to

effectively sample at each significance criteria (0.05, 0.10; 0.05, 0.20; 0.10, 0.10; 0.10, 0.20) and detection rates (10%, 20%, 30%, and 50%).

The simulations revealed a decrease in sampling effort (number of sets required) from April to May for all reservoirs sampled (Tables 1.7 - 1.12). This indicated that statistical power varied among months. In addition, required sampling effort varied between reservoir types and sections. Shallow reservoir sampling effort estimates decreased from April to May, followed by an increase from May to June. Sampling effort estimates for deep reservoirs except De Queen Lake showed a continued decrease from April to June (Table 1.7). De Queen Lake showed a decrease in required sampling effort from April to May, and an increase from May to June.

When separating reservoir sections' CPUE data, simulations ran with shallow reservoir lower section data showed a decrease in required sampling effort from April to May, and an increase from May to June (Table 1.8). CPUE for lower sections in deep reservoirs showed no distinct patterns regarding sampling effort estimations.

Lake Nimrod showed a decrease in required sampling effort from April to June (Table 1.7). De Queen Lake showed a decrease in required sampling effort from April to May and an increase from May to June (Table 1.11). Lake Catherine showed an increase in required sampling effort from April to May, and a decrease from May to June (Table 1.12). Independently, the lower sections of each reservoir, except Lake Catherine and Lake Nimrod, showed a decrease in required sampling effort from April to May, and an increase from May to June. Lake Catherine showed an increase in required sampling effort from April to May, and a decrease from May to June, while Lake Nimrod showed a decrease from April to June.

Simulations ran with shallow reservoir upper section CPUE data showed a decrease in the required sampling effort from April to May proceeded by an increase from May to June. However, deep reservoir upper section data showed no distinct patterns across sampling periods. Independently, each reservoir, except Lake Nimrod, showed a decrease from April to May, and an increase from May to June within their upper section. Lake Nimrod showed a decrease from May to June (Table 1.9). Unfortunately, no April to May simulations were ran for De Queen Lake due to zero catches.

Independently, each reservoir shallow section displayed a smaller required sampling effort than its lower section during the month of April and May, except for De Queen Lake. Conversely, the month of June displayed no particular trend regarding required sampling effort, possibly due to there being fewer sets that showed zero catches.

DISCUSSION

The main goal when sampling is to obtain a sample with the least amount of effort that can still accurately and precisely describe a population (Bodine et al. 2013). A descriptor that works well for describing a population is a change in that population's relative abundance. This change in relative abundance is often determined by CPUE assessments.

The reason fisheries biologists use CPUE to measure population change is because of its correlation with population density (Michaletz and Sullivan 2002; Flammang et al. 2011). Unfortunately, the use of CPUE based assessments can add unnecessary complications to management decisions and objectives due to catchability and CPUE not being mutually independent of each other (Tsuboi and Endou 2008).

This lack of mutual independence has been shown in different field studies even though catchability is predicted to be constant within a population model (Peterman and Steer 1981). In these cases, catchability was either density-dependent (Peterman and Steer 1981; Bannerot and Austin 1983; Shardlow et al. 1985; Shuter et al. 1998; Post et al. 2002) or showed no relationship (Hansen et al. 2000; Newby et al. 2000; Pierce and Tomcko 2003).

Catchability can also be dictated by gear types. This is why biases such as low catch rates and misrepresentative sampling data have continued to plague fisheries biologists when attempting to describe a Channel Catfish population (Michaletz and Dillard 1999; Brown 2009). Furthermore, these sampling inadequacies were the result of biologists having limited knowledge of appropriate sampling gears and methods. As a result, many agencies have taken the initiative of developing their own sampling standards within their agencies (Bodine et al. 2013). However, their standards are usually developed without extensive scientific guidance (Bodine et al. 2013). In addition, the majority of sampling gear studies have focused more on how to increase catch rates instead of potential gear biases and precision (Bodine et al. 2013). This has resulted in gear bias being the main constraint of fisheries biologists (Michaletz and Dillard 1999).

In order to counter gear bias, biologists have to account for any factors that may affect catchability during sampling. In my study, the factors tested consisted of set depth, water temperature, dissolved oxygen, and water clarity. Each of these factors were shown to affect CPUE for pooled data among all the reservoirs. In addition, among those factors, temperature showed the greatest effect on CPUE for deep and shallow reservoirs, in which warmer water temperatures (23 - 24°C) resulted in a higher CPUE.

Deep reservoir CPUE steadily increased as sampling continued into June. This pattern in CPUE was shown to correlate with the rising water temperature, and assumed to be related to spawning time. Since deep reservoirs warm slower, it could be assumed that spawning occurs later than in shallow reservoirs.

Shallow reservoir CPUE increased into May, and is also assumed to be correlated with spawning activity. However, as sampling proceeded into June, dissolved oxygen levels began to affect CPUE. Since a negative relationship was seen between temperature and dissolved oxygen, it was concluded that an additional reason besides spawning time contributed to CPUE as temperature rose. This reason was that increasing water temperature also led to lower oxygen levels in shallower water causing a reduction in CPUE later into the sampling season.

Upper and lower reservoir sections also displayed patterns, which were observed among reservoir types. Upper sections showed increases into May, followed by decreases into June. This pattern is also assumed to be related to temperature and its interaction with dissolved oxygen. Lower sections, however, saw a steady increase similar to deep reservoirs, and was assumed to be influenced by temperature. Unfortunately, April was the only sampling period that revealed a significant difference in CPUE between reservoir sections. This means that only April would benefit from singling out the upper reservoir section to sample based on water variables. However, if biologists do take this into consideration, sampling effort could be reduced for the month of April or early season sampling, in general, to allow for more efficient sampling.

Power Analyses

Power analyses demonstrated that describing a Channel Catfish population through the use of CPUE assessments would not be feasible. The feasibility issues arose due to exceedingly large required sampling efforts and no known populations to test true gear effectiveness. Previous studies indicated that a known population is required to determine a gear’s accuracy in estimating population parameters (Bodine et al. 2013).

An effective way to deal with unknown populations is by performing feasibility studies. Power analyses ran during a feasibility study can help biologists determine how much sampling effort would be necessary to effectively sample and describe a population (Gerow 2007). Once the sampling effort is estimated, whether or not it will be feasible can then be determined.

Many of the reservoirs sampled in my study demonstrated that effective assessments would require a large number of sets, which may not be feasible. In addition, the specific sampling effort needed varied based on effect size and significance level. This is because an increase in power leads to an increase in sample size (Gerow 2007), and the calculation of power needed to detect statistical differences is directly affected by precision (Quinn and Keough 2002). The effect size has been categorized in previous studies as small, medium, and large or 20%, 50%, and 80% changes in the population, respectively (Cohen 1998; Bryant et al. 2004). In these studies, a small effect size was described as a manager’s specific interest in changes in abundance, while a large effect size was the largest effect size able to accurately detect a change (Gerow 2007). So depending on a biologists goals, the number of sets required can change.

CONCLUSION

Although CPUE assessments is typically used to assess a population, the results from my study and others show that unless a population is known, CPUE assessments must be used in conjunction with other population characteristics. In addition, catch rates may not always correlate well to abundance, since all gears have potential biases. This means that relying solely on CPUE assessments to evaluate Channel Catfish populations could lead to mismanagement and an unbalanced fishery. As a solution, CPUE assessments should be combined with other statistical assessments such as length frequency distributions, condition, and age and growth when describing a Channel Catfish population.

For this study, relative abundance was affected by both temperature and dissolved oxygen depending on reservoir type. Shallow reservoirs provided greater catch rates than deep reservoirs, and relative abundance was shown to be the greatest when water temperatures were between 21.4 - 24.6°C. Unfortunately, deep reservoirs did not reach these temperatures until later in the sampling season. In addition, reservoir section CPUE only differed significantly during April. This means sampling techniques may vary based on reservoir type.

Power analyses provided an effective way to estimate sampling effort and demonstrated that sampling effort could not be extrapolated across reservoirs, but would be best used as a preliminary method for sampling. This way, significance levels for the power analyses could be altered depending on the biologist’s goals. Reservoirs that are managed yearly or frequently could be tested by using more strenuous criteria such as an alpha of 0.05, a power of 0.90 - 0.80, and a 10% change in relative abundance while less

frequently managed reservoirs could be tested by using less rigorous criteria. This would help at identifying what sampling effort would be required to effectively obtain enough samples to estimate abundance assessments.

Not only should these results prove useful for biologists, there are some additional measures that biologists can take to sample more effectively. First, I would recommend that biologists conduct feasibility studies for performing power analyses. By performing power analyses, biologists will be better able to determine what and if the sampling effort is both financially viable and efficient (Gerow 2007). These power analyses would need to be conducted with at least eight sets and during the most productive sampling periods. If the estimated sampling effort is too large, which occurred for deep reservoirs, additional assessments should be made to help completely describe the population. These assessments should include age and growth analyses, length frequency distributions, and creel surveys. Second, I recommend sampling when the water temperature is 21.4 - 24.6°C, which may be May or June depending on reservoir type. This water temperature range produced the highest relative abundance, and as a result, may reduce sampling efforts. Finally, I propose that biologists focus on areas which consistently produce fish when sampling. By reducing the number of sets which sample zero fish, better population parameter estimates can be obtained.

REFERENCES

Anderson, R. O., and R. M. Neumann. 1996. Length, weight, and associated structure indices. Pages 447- 482 *in* B. R. Murphy and D. W. Willis editors. Fisheries Techniques 2nd edition. American Fisheries Society, Bethesda, Maryland.

Bannerot, S. P., and C. B. Austin. 1983. Using frequency distributions of catch per unit effort to measure fish-stock abundance. Transactions of the American Fisheries Society 112:608-617.

Bodine, K. A., D. E. Shoup, J. Olive, Z. L. Ford, R. Krogman, and T. Stubbs. 2013. Catfish sampling techniques: Where we are now and where we should go. Fisheries 38(12):529-546.

Brown, Z. 2009. Current trends in catfish sampling techniques and information needs. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 61(2007):6-9.

Buckmeier, D. L., and J. W. Schlechte. 2009. Capture efficiency and size selectivity of channel catfish and blue catfish sampling gears. North American Journal of Fisheries Management 29:404-416.

Bryant, M. D., J. P. Caouette, and B. E. Wright. 2004. Evaluating stream habitat survey data and statistical power from southeast Alaska. North American Journal of Fisheries Management 24:1353-1362.

Carter, E. R. 1954. An evaluation of nine types of commercial fishing gear in Kentucky Lake. Transaction of the Kentucky Academy of Science 15:56-80.

Cohen, J. 1998. Statistical power analysis for the behavioral sciences. Lawrence Erlbaum, Hillsdale, New Jersey.

Colombo, R. E., Q. E. Phelps, J. E. Garvey, and R. C. Heidinger. 2008. Gear-specific population demographics of channel catfish in a large Midwestern river. North American Journal of Fisheries Management 28:241-246.

Dudash, M., and R. C. Heidinger. 1996. Comparative survival and growth of various size channel catfish stocked into a lake containing largemouth bass. Transactions of the Illinois State Academy of Science 89:105-111.

Fischer, S. A., S. E. Stephen, and E. D. Aragon. 1999. Movements and habitat use of channel catfish and blue catfish in a small impoundment in Missouri. American Fisheries Society Symposium 24:239-255.

Flammang, M. K., R. D. Schultz, and D. N. Cashatt. 2011. Utility of tandem hoop nets for indexing channel catfish structure and growth. American Fisheries Society Symposium 77:545-555.

Gerow, K. G. 2007. Power and sample size estimation techniques for fisheries management: Assessment and a new computational tool. North American Journal of Fisheries Management 27:397-404.

Gilliland, E. 1987. Evaluation of Oklahoma's standardized electrofishing in calculating population structure indices. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 39(1985):277-287.

Guy, C. S., and M. L. Brown, editors. 2007. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Hansen, M. J., T. D. Beard, and S. W. Hewett. 2000. Catch rates and catchability of walleyes in angling and spearing fisheries in northern Wisconsin lakes. North American Journal of Fisheries Management 20:97-106.

Hanson, W. D. 1986. An evaluation of catfish populations which are maintained by annual stocking. Missouri Department of Conservation, Federal Aid in Sport Fish Restoration, Project F-1-R-34, Study I-23, Job 2, Final Report, Jefferson City.

Harley, S. J., R. A. Myers, and A. Dunn. 2001. Is catch-per-unit-effort proportional to abundance? Canadian Journal of Fisheries and Aquatic Sciences 58:1760-1772.

Howell, M. H., and R. K. Betsill. 1999. Evaluation of different sizes of advanced channel catfish fingerlings stocked in small Texas impoundments. Pages 461-465 *in* Irwin et al. (1999).

Jackson, J. R., and D. C. Jackson. 1999. Macrohabitat use by catfishes in a Southern United States floodplain-river ecosystem. American Fisheries Society Symposium 24:215-222.

Michaletz, P. H. 2001. Evaluation of channel catfish sampling methods in small impoundments. Missouri Department of Conservation, Federal Aid in Sport Fish Restoration, Project F-1-r-50, Study I-36, Job, Jefferson City.

Michaletz, P. H., and J. G. Dillard. 1999. A survey of catfish management in the United States and Canada. Fisheries 24(8):6-11.

Michaletz, P. H., and K. P. Sullivan. 2002. Sampling channel catfish with tandem hoop nets in small impoundments. North American Journal of Fisheries Management 22:870-878.

Miranda, L. E. 1993. Sample sizes for estimating and comparing proportion-based indices. North American Journal of Fisheries Management 13:383-386.

Miranda, L. E. 2007. Approximate sample sizes required to estimate length distributions. North American Fisheries Society 136:409-415.

Mitzner, L. 1999. Assessment of maintenance-stocked channel catfish populations in Iowa lakes. Pages 467-474 *in* Irwin et al. (1999).

Neely, B. C., and S. C. Dumont. 2011. Effect of soak duration on precision of channel catfish catch with baited, tandem hoop nets. American Fisheries Society Symposium 77:557-561.

Newby, J. R., M. J. Hansen, S. P. Newman, and C. J. Edwards. 2000. Catchability of walleyes to angling in Escanaba Lake, Wisconsin, 1980-1995. North American Journal of Fisheries Management 20:873-881.

Olive, J., J. Barnett, J. Miller, B. Batten, and J. Quinn. 2015. Standard sampling methods for channel, blue, and flathead catfish in Arkansas waters. Pages 19-21 *in* Arkansas game and fish commission: Arkansas catfish management plan 2nd edition. Arkansas Catfish Plan.

Peterman, R. M., and G. J. Steer. 1981. Relation between sport-fishing catchability coefficients and salmon abundance. Transactions of the American Fisheries Society 110:585-593.

Pierce, R. B., and C. M. Tomcko. 2003. Variation in gill-net and angling catchability with changing density of northern pike in a small Minnesota lake. Transactions of the American Fisheries Society 132:771-779.

Pierce, R. B., D. W. Coble, and S. Corley. 1981. Fish catches in baited and unbaited hoop nets in the upper Mississippi River. North American Journal of Fisheries Management 1:204-206.

Porath, M. T., L. D. Pape, L. K. Richters, K. L. Pope, and M. A. Pegg. 2011. Influence of throat configuration and fish density on escapement of Channel catfish from hoop nets. American Fisheries Society Symposium 77:563-571.

Post, J. R., M. Sullivan, S. Cox, N. P. Lester, C. J. Walters, E. A. Parkinson, A. J. Paul, L. Jackson, and B. J. Shutter. 2002. Canada's recreational fisheries: the invisible collapse? Fisheries 27(1):6-17.

Quinn, G. P., and M. J. Keough. 2002. Experimental designs and data analysis for biologists. Cambridge University Press, New York.

Richters, L. K., and K. L. Pope. 2011. Catch of channel catfish with tandem-set hoop nets and gill nets in lentic systems of Nebraska. 77:573-580 *in* P.H. Michaletz and V.H. Travnichek, editors. Conservation, ecology, and management of catfish: the second international symposium. American Fisheries Society Symposium 77, Bethesda, Maryland.

Robinson, J. W. 1994. Sampling procedures to capture flat head catfish and channel catfish in the Missouri and Mississippi Rivers. Missouri Department of Conservation, Sport Fish Restoration Project F-I-R-43, Study S-30, Job I, Final Report, Columbia.

Santucci, V. J., D. H. Wahl, and T. W. Storck. 1994. Growth, mortality, harvest, and cost-effectiveness of stocked channel catfish in a small impoundment. North American Journal of Fisheries Management 14:781-789.

Santucci, V. J., Jr., D. H. Wahl, and D. F. Clapp. 1999. Efficiency and selectivity of sampling methods used to collect channel catfish in impoundments. Pages 317-328 *in* Irwin et al. (1999).

SAS Institute Inc. 2011. Base SAS® 9.3 Procedures Guide. Cary, NC: SAS Institute Inc.

Shardlow, T., R. Hilborn, R. M. Peterman, G. J. Steer, and M. J. Bradford. 1985. Density dependent catchability coefficients. Transactions of the American Fisheries Society 114:436-440.

Shuter, B. J., M. L. Jones, R. M. Korver, and N. P. Lester. 1998. A general life history based model for regional management of fish stocks: the inland lake trout (*Salvelinus namaycush*) fisheries of Ontario. Canadian Journal of fisheries and Aquatic Sciences 55:2161-2177.

Snedecor, G. W., and W. G. Cochran. 1989. Statistical methods. Iowa State University Press, Ames Iowa.

Stevenson, F., and R. E. Day. 1986. An evaluation of channel catfish populations in Ohio impoundments. Ohio Department of Natural Resources, Federal Aid in Sport Fish Restoration, Project F-29-R-20 to R-25, Study 14, Final Report, Columbus.

Stewart, D. R., and J. M. Long. 2012. Precision of channel catfish *Ictalurus punctatus* catch estimates using hoop nets in Oklahoma reservoirs (> 200 ha). North American Journal of Fisheries Management 32:1108-1112.

Sullivan, K. P., and C. M. Gale. 1999. A comparison of channel catfish catch rates, size distributions, and mortalities using three different gears in a Missouri impoundment. American Fisheries Society Symposium 24:293-300.

Tsuboi, J., and S. Endou. 2008. Relationships between catch per unit effort, catchability, and abundance based on actual measurements of salmonids in a mountain stream. Transactions of the American Fisheries Society 137:496-502.

Vokoun, J. C., C. F. Rabeni, and J. S. Stanovick. 2001. Sample-size requirements for evaluating population size structure. North American Journal of Fisheries Management 21:660-665.

Wilde, G. R. 1995. Gill net sample size requirements for temperate basses, shads, and catfishes. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 47(1993):588-595.

Table 1.1. - Characteristics of sampled reservoirs.

Reservoir Characteristics					
Reservoir	Reservoir Type	Size (ha)	Substrate	Major Fish Species	Daily Channel Catfish Bag Limit
Overcup	Shallow	415	Silt	Channel Catfish, Crappie, Largemouth Bass, Bluegill	10
Erling	Shallow	2,833	Sand, Silt, Clay	Channel Catfish, Crappie, Largemouth Bass, Bluegill, Redear Sunfish	10
Columbia	Shallow	1,214	Sand, Silt, Clay	Channel Catfish, Flathead Catfish, Crappie, Largemouth Bass, Bluegill, Pickerel, Gar, Bowfin	10
Nimrod	Deep	1,437	Sand, Silt, Gravel, Cobble, Boulder	Channel Catfish, Crappie, Largemouth Bass, Bluegill	10
Catherine	Deep	785	Sand, Silt, Gravel, Cobble, Boulder	Channel Catfish, Flathead Catfish, Crappie, Largemouth Bass, Walleye, Sauger, Saugeye, Bluegill	10
De Queen	Deep	680	Sand, Silt, Clay, Gravel, Cobble, Boulder	Channel Catfish, Crappie, Largemouth Bass, Bluegill, Walleye, Spotted Bass, Hybrid Striped Bass	10

Table 1.2. - Average reservoir water conditions and Channel Catfish relative abundance.

	Depth (m)		Temperature (^{o}C)		Dissolved oxygen (mg/L)		Turbidty (m)		CPUE [c]	
Reservoir	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
April										
Catherine [b]	1.4-3.1	2.4	12.7-20.2	16.7	9.5-12.3	10.8	0.7-2.0	1.2	0.0-15.0	2.9
Columbia [a]	1.2-2.8	2.2	17.0-22.0	20.4	n/a	n/a	1.0-2.4	1.7	0.0-10.0	2.1
DeQueen [b]	1.0-4.3	2.2	14.1-17.9	16.3	0.9-6.9	3.4	0.3-1.9	1.1	0.0-1.0	0.1
Erling [a]	1.7-2.6	1.9	16.0-17.6	16.9	na	na	0.6-1.1	0.7	45.0-231.0	129.4
Nimrod [b]	2.0-4.2	2.8	15.2-17.4	16.3	7.0-9.9	8.6	0.7-1.0	0.9	0.0-38.0	8.3
Overcup [a]	1.0-2.5	1.6	15.2-17.1	16.0	8.2-9.6	9.0	0.4-0.7	0.6	0.0-27.0	4.7
May										
Catherine [b]	1.2-3.5	2.1	15.4-21.7	17.5	8.0-11.9	10.8	0.6-2.8	1.3	0.0-7.0	1.9
Columbia [a]	1.2-2.4	1.9	22.0-25.0	23.8	n/a	n/a	1.2-1.9	1.6	1.0-52.0	23.8
DeQueen [b]	0.9-2.9	2.0	22.1-27.0	23.9	2.8-6.7	4.3	0.9-1.9	1.3	1.0-44.0	9.0
Erling [a]	1.3-2.5	1.8	19.4-24.8	23.1	2.3-6.9	4.6	0.6-0.8	0.6	122.0-580.0	355.9
Nimrod [b]	4.0-6.3	5.0	18.0-22.3	20.3	6.3-8.4	7.5	0.3-0.6	0.4	0.0-51.0	11.8
Overcup [a]	1.0-3.1	1.8	22.4-25.4	23.8	5.5-9.7	8.2	0.5-0.7	0.6	4.0-144.0	58.2
June										
Catherine [b]	1.4-2.9	2.3	16.8-27.1	21.8	8.8-12.8	10.4	0.4-1.5	1.0	0.0-24.0	6.6
Columbia [a]	1.6-3.0	2.3	29.0-30.0	29.3	n/a	n/a	1.2-1.7	1.5	0.0-41.0	8.8
DeQueen [b]	1.4-3.2	1.9	28.7-30.4	29.7	1.5-3.1	2.3	0.4-1.6	1.3	0.0-27.0	7.0
Erling [a]	0.9-2.5	1.7	26.7-28.7	27.6	1.1-3.4	2.5	0.4-0.8	0.6	47.0-380.0	197.3
Nimrod [b]	2.3-4.3	3.2	23.8-28.6	26.4	6.4-10.0	8.6	0.7-1.0	0.9	9.0-121.0	51.4
Overcup [a]	1.1-2.9	1.8	22.8-27.9	25.8	5.8-10.3	7.5	0.5-0.9	0.6	1.0-55.0	27.3

[a] Shallow reservoirs.

[b] Deep reservoirs

[c] Number of fish per tandem set.

Table 1.3. - Mean and standard deviation of relative abundance from tandem hoop net sets for each reservoir, reservoir type, and reservoir section each month during the spring of 2014.

		CPUE					
		Lower		Upper		Pooled	
Reservoir type	Reservoir	Mean	SD	Mean	SD	Mean	SD
		April					
Deep	Catherine	3.0	5.3	2.9	2.7	2.9	4.1
	De Queen	0.1	0.4	0.0	0.0	0.1	0.3
	Nimrod	0.8	2.1	15.8	12.4	8.3	11.6
	Pooled	1.3	3.4	6.2	9.9	3.8	7.7
Shallow	Columbia	0.4	0.5	3.8	3.4	129.4	61.2
	Erling	126.6	60.2	132.1	66.2	2.1	2.9
	Overcup	0.1	0.4	9.3	9.1	4.7	7.8
	Pooled	42.4	69.3	48.4	70.9	45.4	77.5
	Grand Mean	21.8	52.8	27.3	54.4	24.6	53.4
		May					
Deep	Catherine	1.4	2.4	2.3	2.4	1.9	2.1
	De Queen	5.9	4.3	12.1	14.1	9.0	10.5
	Nimrod	6.4	8.5	17.1	17.4	11.8	14.3
	Pooled	4.6	10.4	10.5	11.6	7.5	10.9
Shallow	Columbia	22.1	17.9	25.4	17.9	23.8	17.8
	Erling	400.6	111.2	311.3	153.0	355.9	137.2
	Overcup	29.3	22.1	87.1	43.9	58.2	44.9
	Pooled	150.7	193.8	141.3	156.2	146.0	174.2
	Grand Mean	77.6	156.6	75.9	130.2	76.8	143.2
		June					
Deep	Catherine	10.8	7.3	2.5	4.9	1.9	2.1
	De Queen	5.1	6.0	8.9	9.1	7.0	7.7
	Nimrod	45.0	29.3	57.8	38.8	51.4	33.9
	Pooled	20.3	24.3	23.0	33.9	20.1	29.2
Shallow	Columbia	11.0	14.6	6.5	12.8	8.8	13.5
	Erling	120.6	51.5	274.0	103.2	197.3	111.7
	Overcup	21.8	17.3	32.8	15.0	27.3	16.6
	Pooled	51.1	59.2	104.4	136.0	77.8	107.2
	Grand Mean	35.7	47.2	63.7	106.5	48.9	83.1

Table 1.4. - Pearson's correlation showing the relationship between pooled 1 + log[10] transformed CPUE data from tandem hoop net sets and water condition variables recorded from pooled reservoir data during the spring of 2014.

Variable	CPUElog	Depth	Temp	DO	Turbidity
CPUElog	1.0000	-0.18204[a]	0.32544[b]	-0.35187[b]	-0.37112[b]
Depth		1.0000	-0.12926[a]	0.15693[a]	-0.0604
Temp			1.0000	-0.50011[b]	0.1062
DO				1.0000	0.0249
Turbidity					1.0000

[a] *P* <0.001
[b] *P* <0.0001

Table 1.5. - Pearson's correlation showing the relationship between pooled 1 + log[10] transformed CPUE data from tandem hoop net sets and water condition variables recorded from pooled deep reservoir data during the spring of 2014.

Variable	CPUElog	Depth	Temp	DO	Turbidity
CPUElog	1.0000	0.1312	0.48253[b]	0.0131	-0.1090
Depth		1.0000	-0.1197	0.0666	-0.41466[b]
Temp			1.0000	-0.4027[b]	0.0878
DO				1.0000	-0.1351
Turbidity					1.0000

[a] *P* <0.001
[b] *P* <0.0001

Table 1.6. - Pearson's correlation showing the relationship between pooled 1 + log[10] transformed CPUE data from tandem hoop net sets and water condition variables recorded from pooled shallow reservoir data during the spring of 2014.

Variable	CPUElog	Depth	Temp	DO	Turbidity
CPUElog	1.0000	-0.22571[a]	0.1253	-0.69067[b]	-0.51852[b]
Depth		1.0000	0.0943	0.0030	0.38861[b]
Temp			1.0000	-0.62681[b]	0.1632
DO				1.0000	-0.0229
Turbidity					1.0000

[a] *P* <0.001
[b] *P* <0.0001

Table 1.7. - Sample sizes calculated per month and section for Lake Nimrod by using power analyses. Catch rates recorded in the study from 2014 were used in the equation $n = 2(z_{\alpha} + z_{\beta})^{2} (s^{2} / d^{2})$ as a predictor to determine samples sizes for future sampling. Detection rates for population abundance consist of 10% and 20% with four different combinations of alpha and power (α; β).

	Sample size (α; β)											
	Pooled				Lower section				Upper section			
Percent change	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]
April												
10%	2073	1583	1497	1085	13736	10486	9920	7191	413	316	298	216
20%	518	396	374	271	3434	2621	2480	1798	103	79	75	54
May												
10%	709	541	512	371	1806	1379	1304	946	164	125	119	86
20%	177	135	128	93	452	345	326	236	41	31	30	21
June												
10%	79	61	57	42	80	61	58	42	88	67	64	46
20%	20	15	14	10	20	15	15	11	22	17	16	12

[a] Alpha; Power =Alpha is the significance level; Power is the likelihood of an effect being seen.

Table 1.8. - Sample sizes calculated per month and section for Lake Overcup by using power analyses. Catch rates recorded in the study from 2014 were used in the equation $n = 2(z_{\alpha} + z_{\beta})^{2} (s^2 / d^2)$ as a predictor to determine samples sizes for future sampling. Detection rates for population abundance consist of 10% and 20% with four different combinations of alpha and power (α; β).

	Sample size (α; β)											
	Pooled				Lower section				Upper section			
Percent change	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]
April												
10%	2090	1596	1510	1094	13736	10486	9920	7191	294	225	213	154
20%	523	399	377	274	3434	2621	2480	1798	74	56	53	39
May												
10%	112	86	81	59	132	101	96	69	34	26	24	18
20%	28	21	20	15	33	25	24	17	8	6	6	4
June												
10%	157	120	113	82	296	226	213	155	43	33	31	22
20%	39	30	28	21	74	56	53	39	11	8	8	6

[a] Alpha; Power =Alpha is the significance level; Power is the likelihood of an effect being seen.

Table 1.9. - Sample sizes calculated per month and section for Lake Erling by using power analyses. Catch rates recorded in the study from 2014 were used in the equation $n = 2(z_\alpha + z_\beta)^2 (s^2 / d^2)$ as a predictor to determine samples sizes for future sampling. Detection rates for population abundance consist of 10% and 20% with four different combinations of alpha and power (α; β).

	Sample size (α; β)											
	Pooled				Lower section				Upper section			
Percent change	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]
April												
10%	23	18	17	12	22	17	16	12	27	21	20	14
20%	6	4	4	3	6	4	4	3	7	5	5	4
May												
10%	9	7	7	5	4	3	3	2	14	10	10	7
20%	2	2	2	1	1	1	1	1	3	3	2	2
June												
10%	30	23	22	16	19	15	14	10	22	16	16	11
20%	8	6	5	4	5	4	3	2	5	4	4	3

[a] Alpha; Power =Alpha is the significance level; Power is the likelihood of an effect being seen.

Table 1.10. - Sample sizes calculated per month and section for Lake Columbia by using power analyses. Catch rates recorded in the study from 2014 were used in the equation $n = 2(z_\alpha + z_\beta)^2 (s^2 / d^2)$ as a predictor to determine samples sizes for future sampling. Detection rates for population abundance consist of 10% and 20% with four different combinations of alpha and power (α; β).

	Sample size (α; β)											
	Pooled				Lower section				Upper section			
Percent change	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]
April												
10%	1547	1181	1117	810	3270	2497	2362	1712	417	318	301	218
20%	387	295	279	203	818	624	590	428	104	79	75	55
May												
10%	305	233	220	160	345	264	249	181	305	233	220	160
20%	76	58	55	40	86	66	62	45	76	58	55	40
June												
10%	839	641	606	439	615	470	444	322	1205	920	870	631
20%	210	160	152	110	154	117	111	81	301	230	218	158

[a] Alpha; Power =Alpha is the significance level; Power is the likelihood of an effect being seen.

Table 1.11. - Sample sizes calculated per month and section for De Queen Lake by using power analyses. Catch rates recorded in the study from 2014 were used in the equation $n = 2(z_{\alpha} + z_{\beta})^{2} (s^2 / d^2)$ as a predictor to determine samples sizes for future sampling. Detection rates for population abundance consist of 10% and 20% with four different combinations of alpha and power (α; β).

	Sample size (α; β)											
	Pooled				Lower section				Upper section			
Percent change	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]
April												
10%	27472	20972	19840	14382	13736	10486	9920	7191	.	.	.	.
20%	6868	5243	4960	3596	3434	2621	2480	1798	.	.	.	.
May												
10%	331	252	239	173	159	121	114	83	474	362	342	248
20%	83	63	60	43	40	30	29	21	118	90	86	62
June												
10%	713	545	515	373	860	656	621	450	631	481	455	330
20%	178	136	129	93	215	164	155	113	158	120	114	83

[a] Alpha; Power =Alpha is the significance level; Power is the likelihood of an effect being seen.

Table 1.12. - Sample sizes calculated per month and section for Lake Catherine by using power analyses. Catch rates recorded in the study from 2014 were used in the equation $n = 2(z_{\alpha} + z_{\beta})^{2} (s^2 / d^2)$ as a predictor to determine samples sizes for future sampling. Detection rates for population abundance consist of 10% and 20% with four different combinations of alpha and power (α; β).

	Sample size (α; β)											
	Pooled				Lower section				Upper section			
Percent change	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]	0.05;0.1[a]	0.1;0.1[a]	0.05;0.2[a]	0.1;0.2[a]
April												
10%	1604	1225	1159	840	2912	2103	2223	1525	939	678	717	492
20%	401	306	290	210	728	526	556	381	235	170	179	123
May												
10%	1252	956	904	656	4968	3588	3792	2601	840	607	642	440
20%	313	239	226	164	1242	897	948	650	210	152	160	110
June												
10%	919	701	663	481	202	146	155	106	5997	4331	4578	3140
20%	230	175	166	120	51	37	39	26	1499	1083	1145	785

[a] Alpha; Power =Alpha is the significance level; Power is the likelihood of an effect being seen.

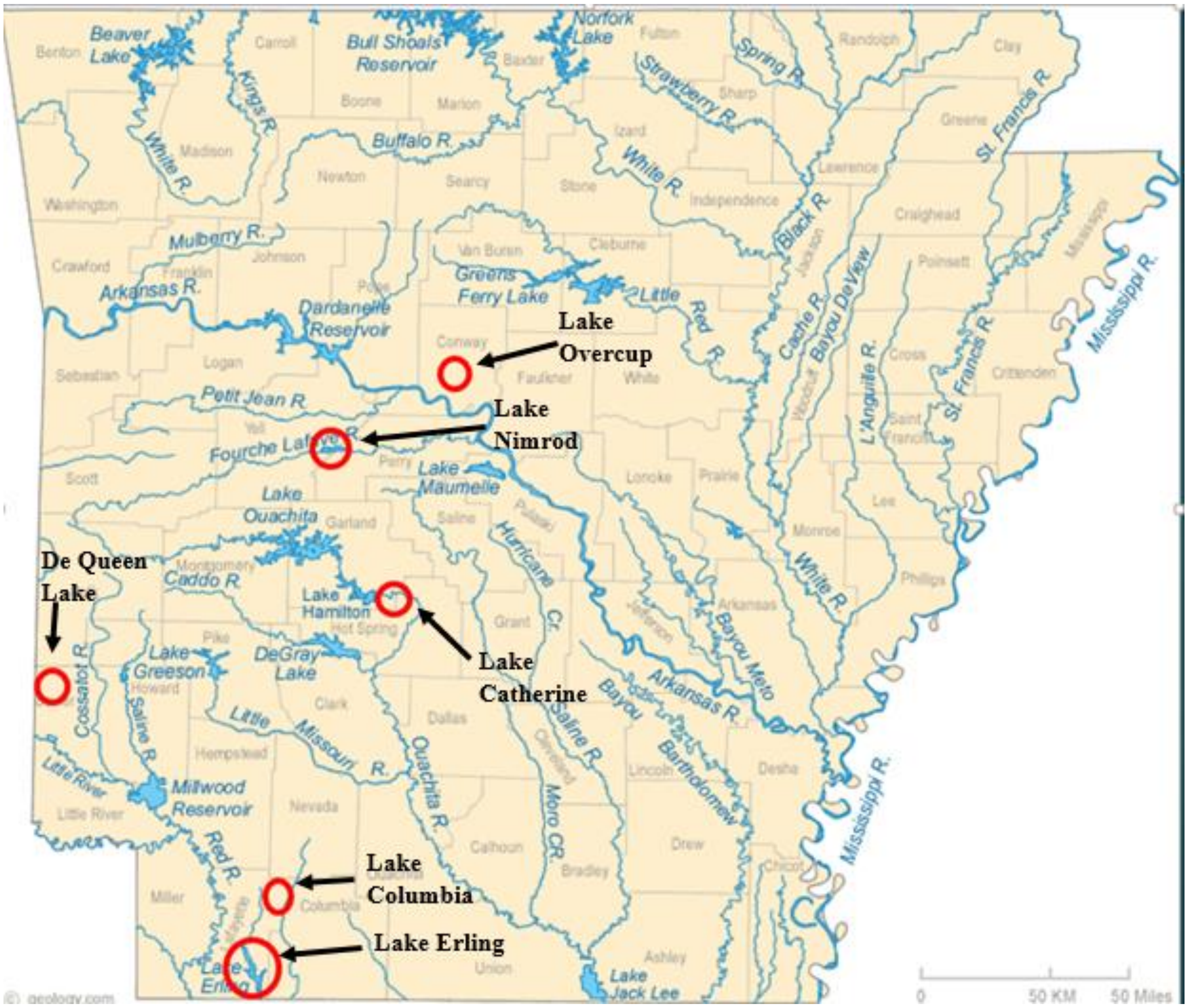

Figure 1.1. - Reservoirs sampled in the study to assess effective tandem hoop net sample size.

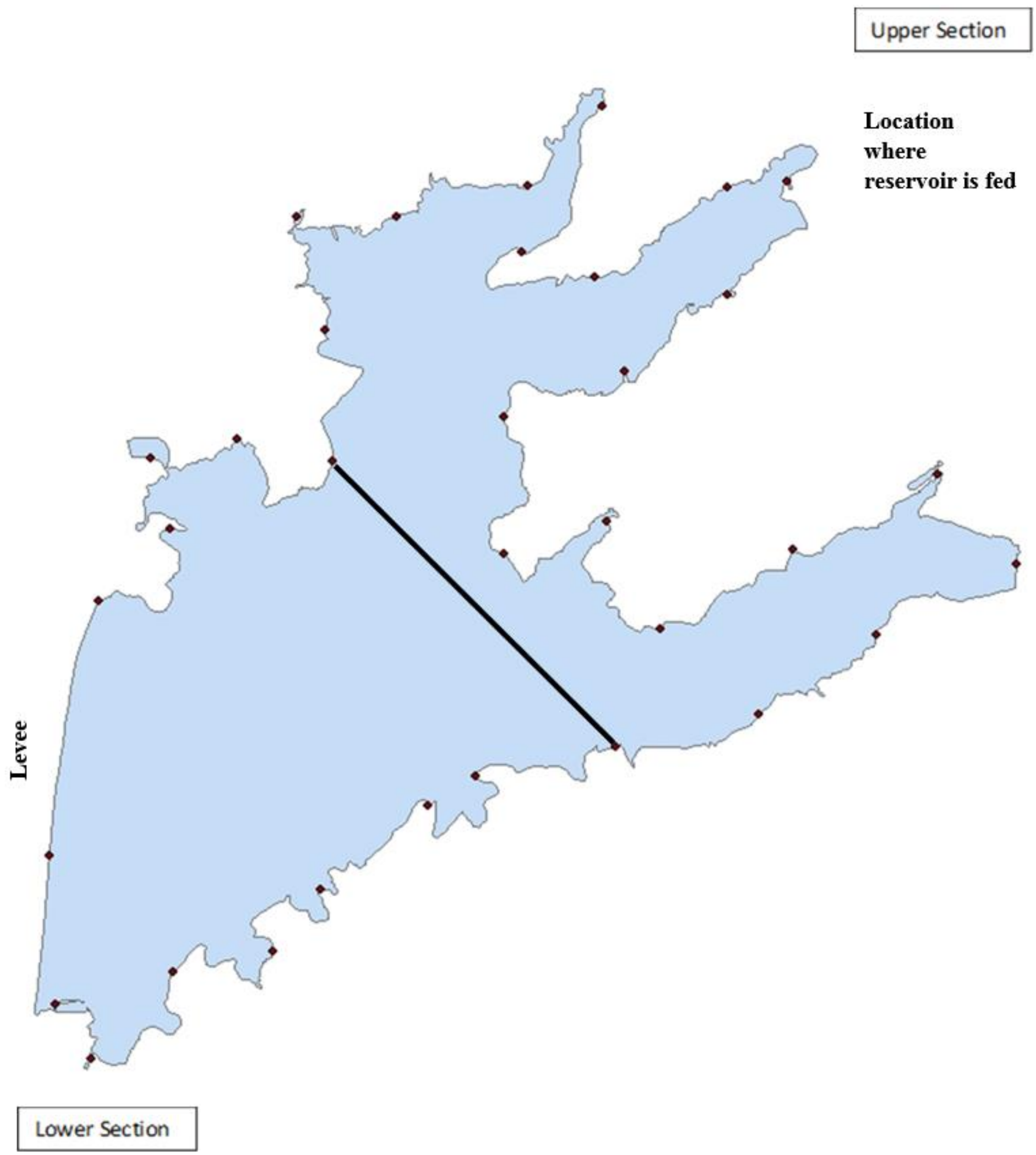

Figure 1.2. - A map of Lake Overcup demonstrating how the reservoirs in the study were divided to create a lower and upper section for sampling and analyses. The points labeled represent AGFC electrofishing markers that were used to randomly select tandem hoop net set locations.

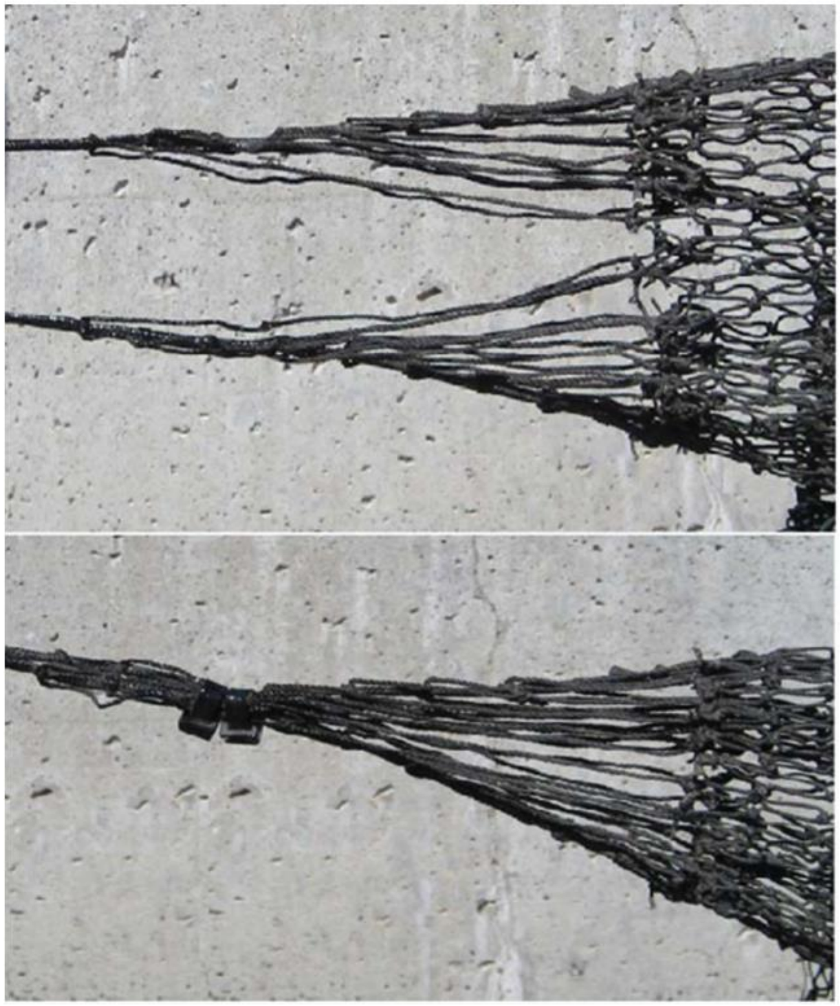

Figure 1.3. - Image from study performed by Flammang et al. (2011) showing where second cod end was restricted to reduce escapement of Channel Catfish.

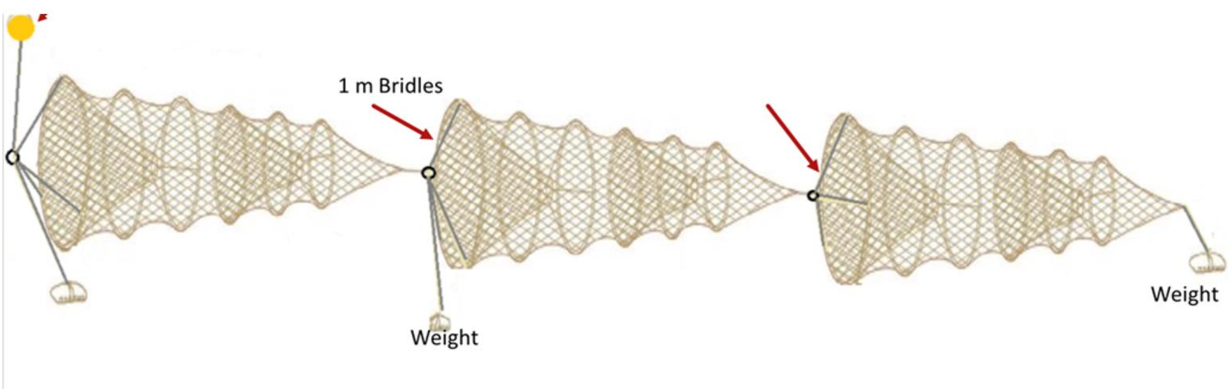

Figure 1.4. - A diagram demonstrating tandem hoop net configuration as described by Sullivan and Gale (1999).

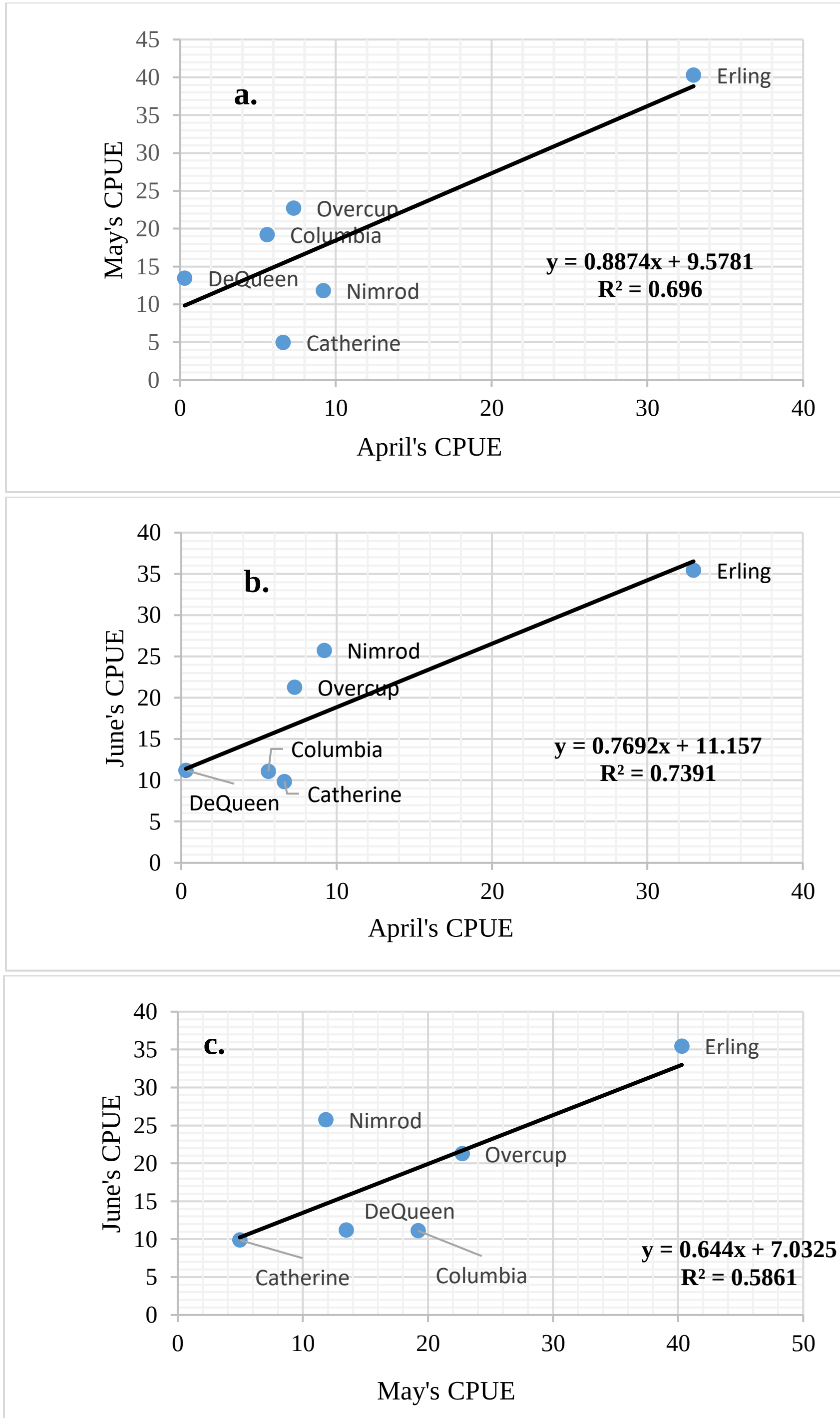

Figure 1.5. - Regressions performed by using **(a)** April's catch rates from tandem hoop net sets to predict May's catch rates from tandem hoop net sets, **(b)** April's catch rates from tandem hoop net sets to predict June's catch rates from tandem hoop net sets, and **(c)** May's catch rates from tandem hoop net sets to predict June's catch rates from tandem hoop net sets for the spring of 2014.

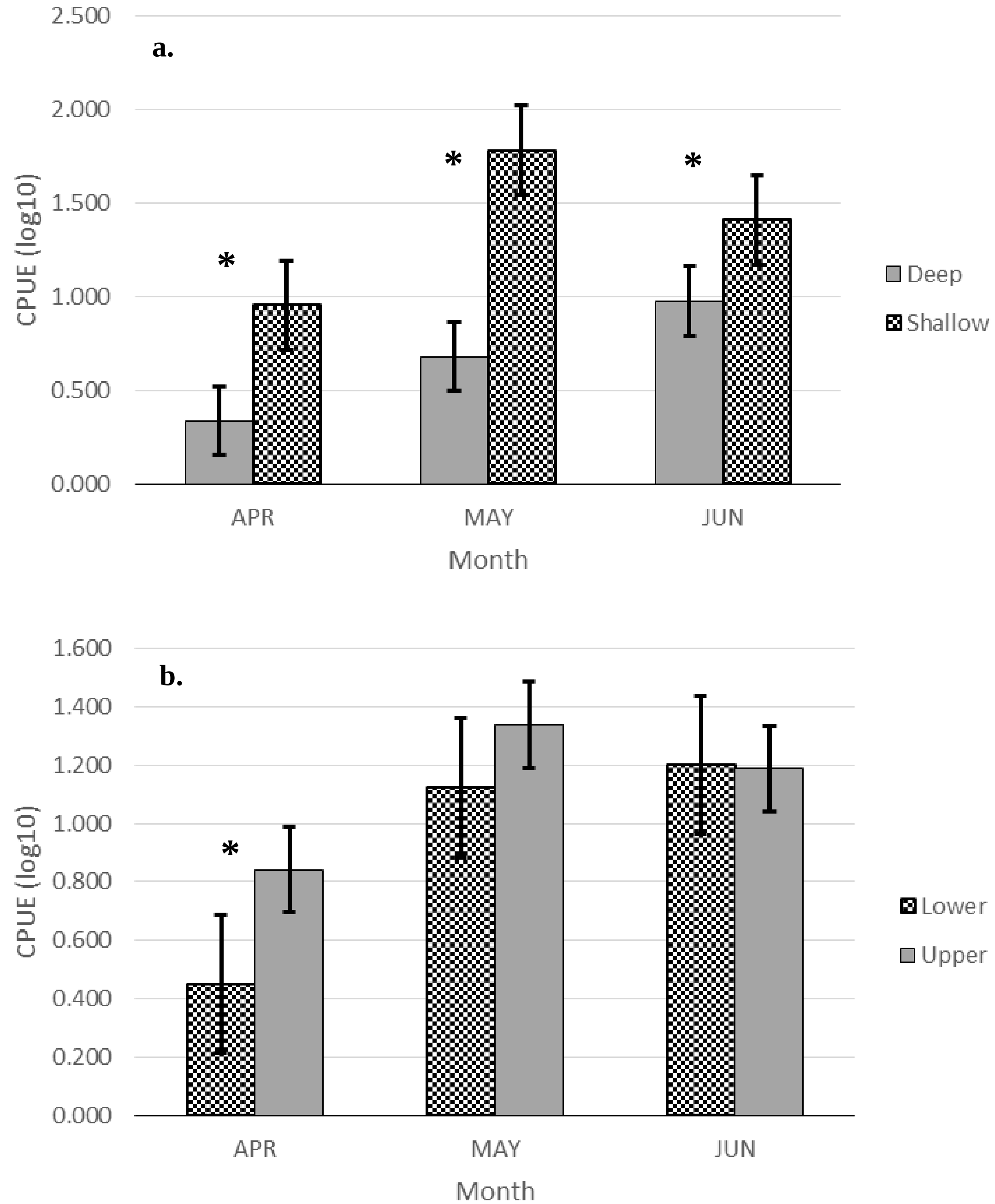

Figure 1.6. - CPUE comparison of **(a)** shallow and deep reservoir types and **(b)** lower and upper reservoir sections for April, May, and June of 2014. Comparisons with * were significant at $\alpha = 0.05$.

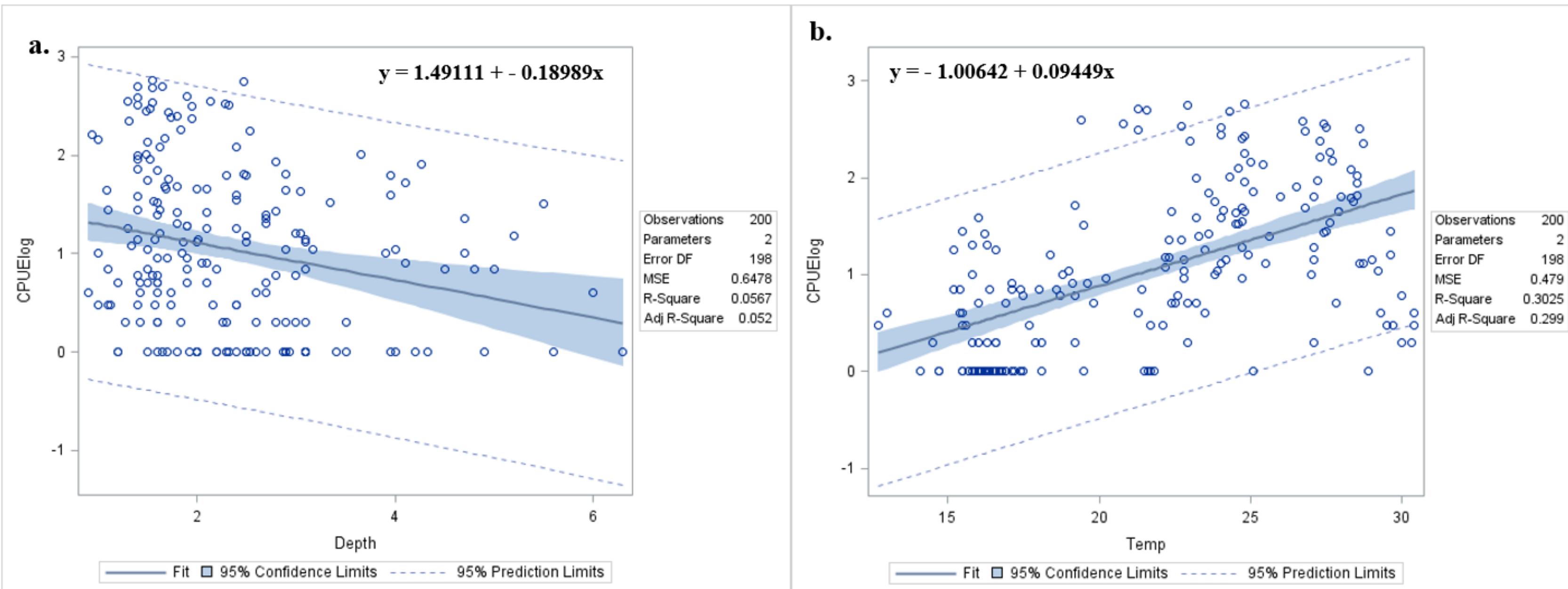

Figure 1.7. - Regressions of pooled log^{10} transformed + 1 CPUE data from tandem hoop net sets and the predictors **(a)** water depth (m) and **(b)** water temperature (°C) of reservoirs pooled for the spring of 2014.

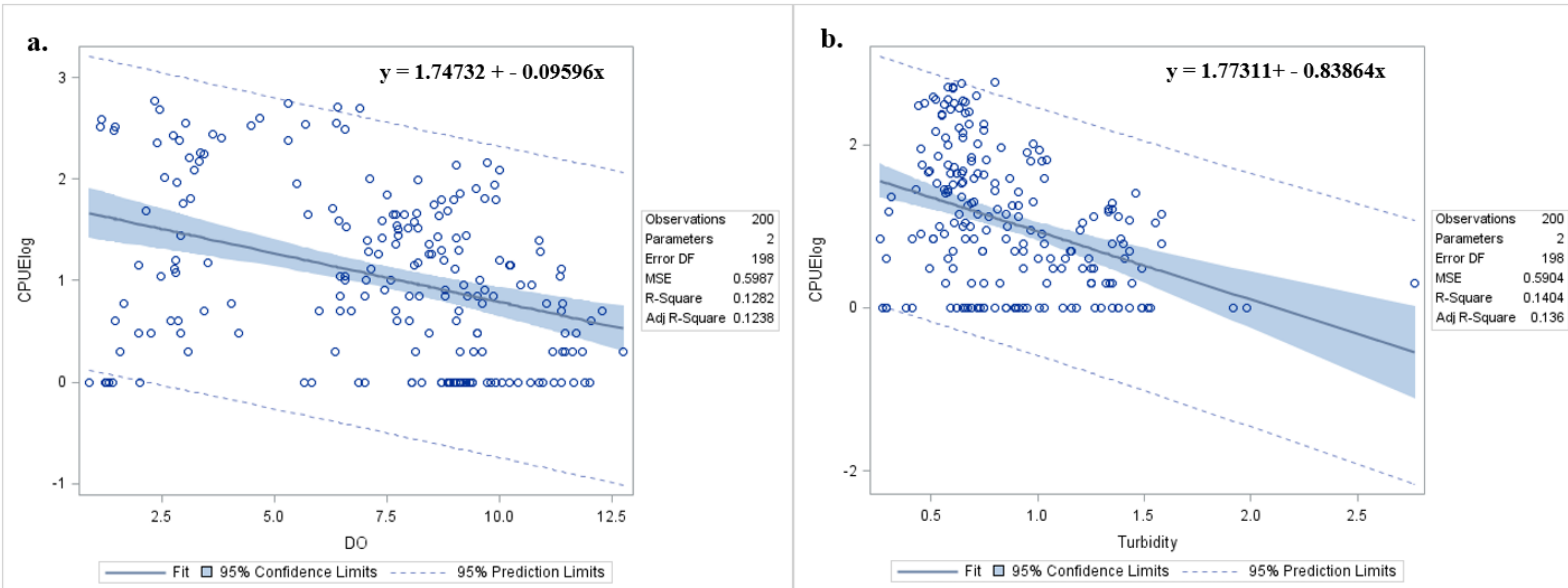

Figure 1.8. - Regressions of pooled log[10] transformed + 1 CPUE data from tandem hoop net sets and the predictors **(a)** dissolved oxygen (mg/L) and **(b)** turbidity (cm) of reservoirs pooled for the spring of 2014.

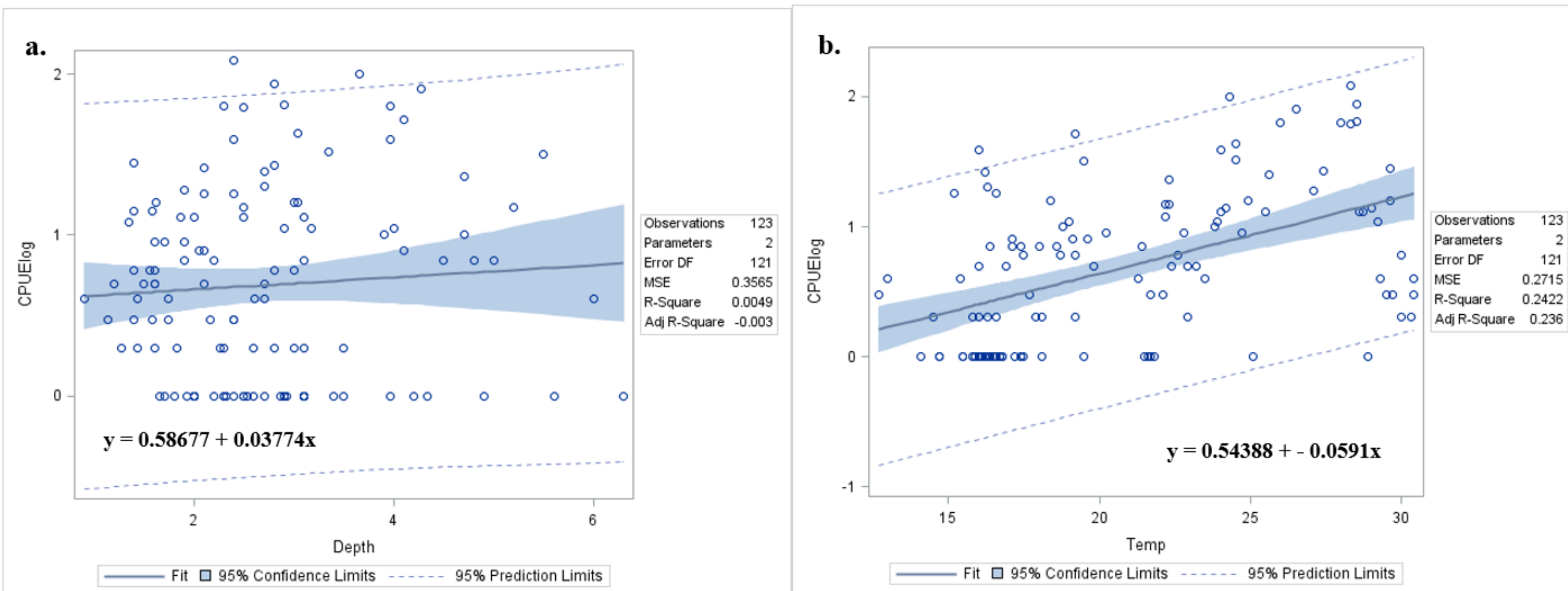

Figure 1.9. - Regressions of pooled log^{10} transformed + 1 CPUE data from tandem hoop net sets and the predictors **(a)** water depth (m) and **(b)** water temperature **(°C)** of deep reservoirs pooled for the spring of 2014.

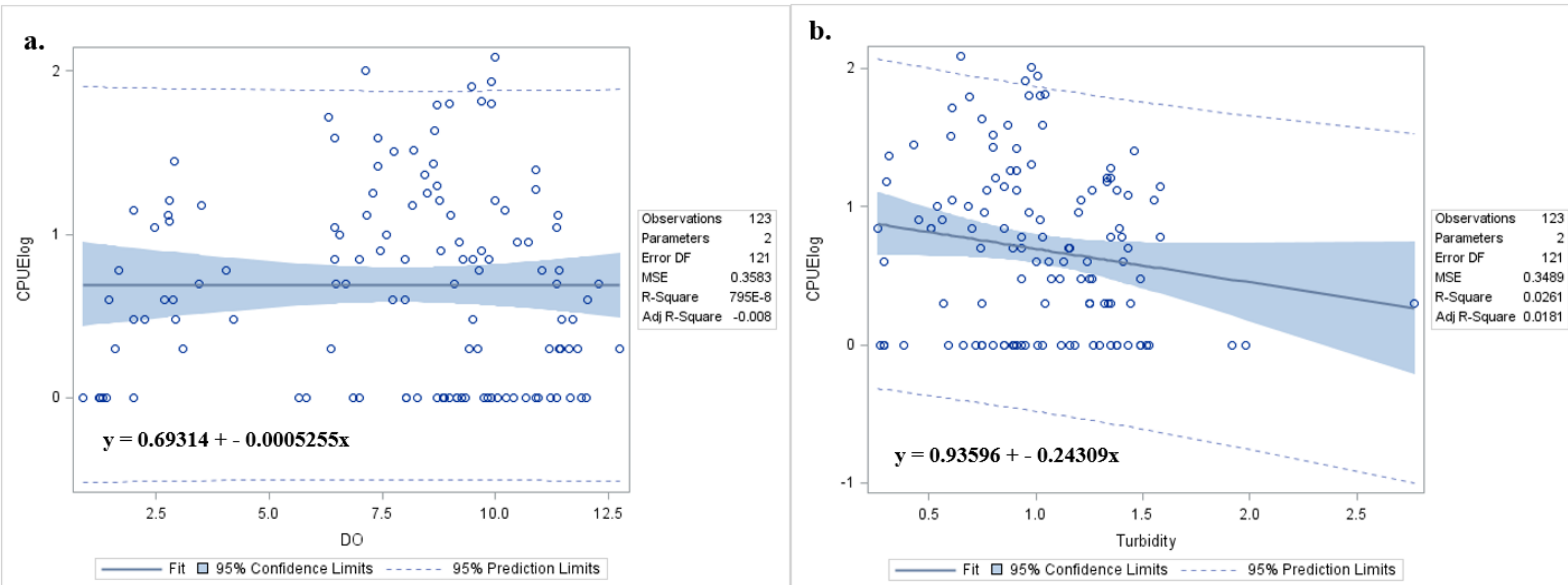

Figure 1.10. - Regressions of pooled log[10] transformed + 1 CPUE data from tandem hoop net sets and the predictors **(a)** dissolved oxygen (mg/L) and **(b)** turbidity (cm) of deep reservoirs pooled for the spring of 2014.

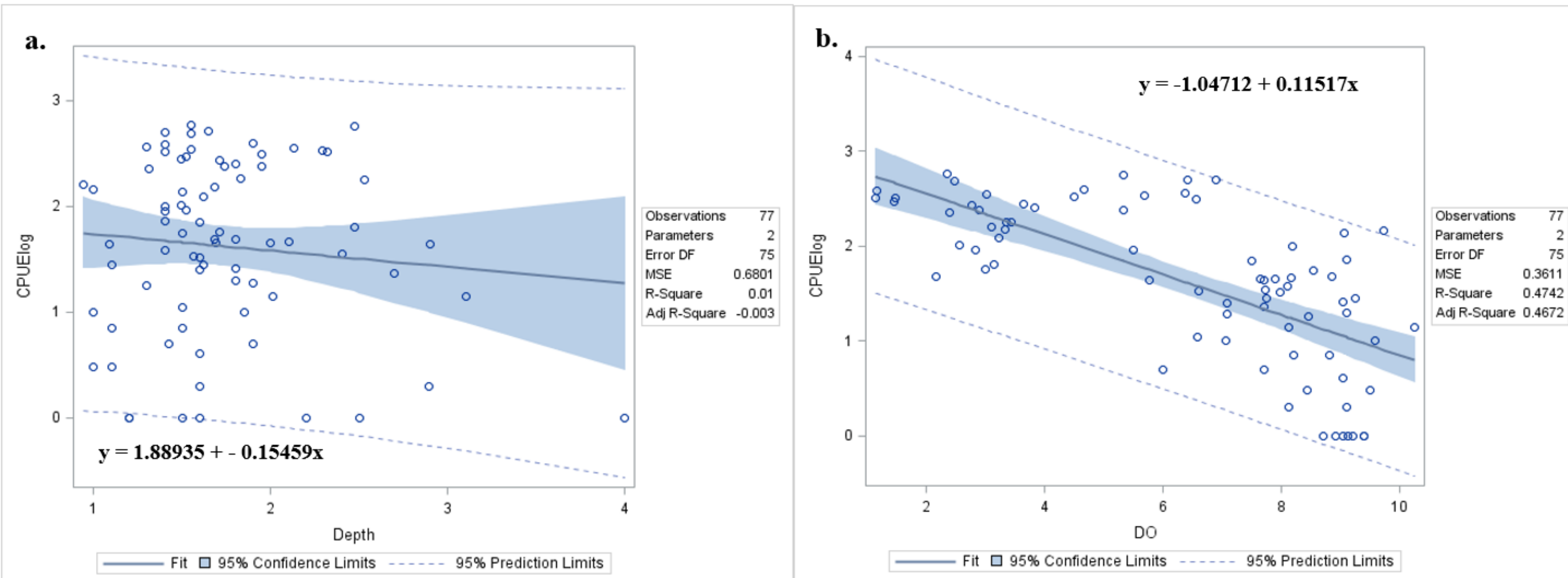

Figure 1.11. - Regressions of pooled log^{10} transformed + 1 CPUE data from tandem hoop net sets and the predictors **(a)** water depth (m) and **(b)** water temperature (°C) of shallow reservoirs pooled for the spring of 2014.

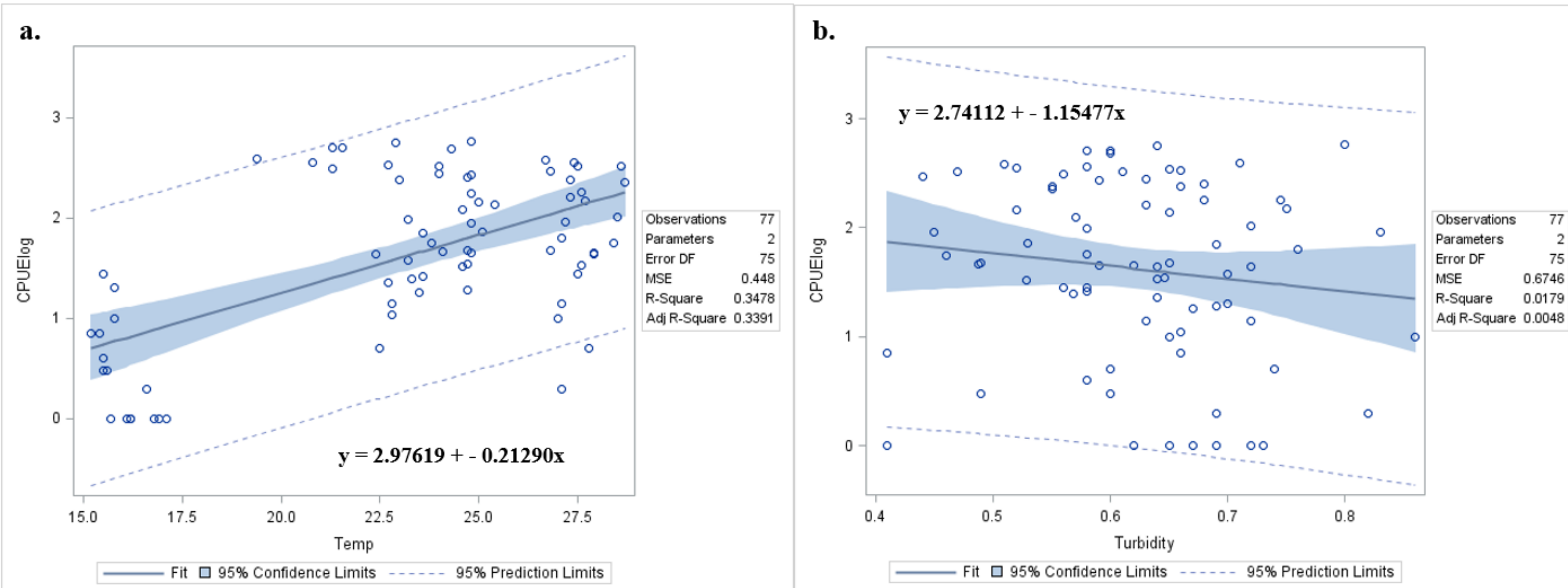

Figure 1.12. - Regressions of pooled log^{10} transformed + 1 CPUE data from tandem hoop net sets and the predictors **(a)** dissolved oxygen (mg/L) and **(b)** turbidity (cm) of shallow reservoirs pooled for the spring of 2014.

CHAPTER 2

EVALUATION OF CHANNEL CATFISH STOCK ASSESSMENTS IN ARKANSAS RESERVOIRS

INTRODUCTION

Channel Catfish *Ictalurus punctatus* are one of the most sought after fish species, both commercially and recreationally in the Midwest and Southeastern United States (Vokoun and Rabeni 1999; Colombo et al. 2008). Surveys from 2011 showed that 22.8 million anglers fished lakes, reservoirs, and ponds spent an average of 16 days fishing (U.S. Department of Interior et al. 2011). Of the 22.8 million anglers, 26% were shown to have spent an average of 14 days in the pursuit of Channel Catfish (Reitz and Travnichek 2006; U.S. Department of Interior et al. 2011). It was also stated that Channel Catfish ranked as the third most preferred sport fish in Missouri and Iowa (Weithman 1991). Among other fish species, preference towards Channel Catfish was shown to be 22% (Flammang and Schultz 2007), while Channel Catfish in Arkansas encompassed 18% of the total angling effort (Olive et al. 2015).

Due to angler popularity, Channel Catfish are managed and stocked in many reservoirs and smaller bodies of water to effectively maintain current populations and aid recruitment. Wellborn (1984) suggested stocking 25 fingerlings 200 - 250 mm in length per 0.40 ha when stocking impoundments containing other fish species such as Largemouth Bass *Micropterus salmoides*. Arkansas stocking procedures, however, consist of stocking either yearling or catchable size Channel Catfish (Olive et al. 2015).

Yearling Channel Catfish typically range from 175 - 230 mm in length, while catchable sized Channel Catfish range from 330 - 380 mm in length.

Yearling sized Channel Catfish are stocked in impoundments where the main objective does not include the immediate catch of stocked fish (Olive et al. 2015). Channel Catfish, however, are often stocked as catchable sized fish in various bodies of water throughout the state of Arkansas. Specifically, three catchable sized Channel Catfish per acre (0.40 ha) for lakes < 1,000 acres (404.69 ha) in size and one catchable Channel Catfish per acre (0.40 ha) for lakes > 1,000 acres (404.69 ha) in size are stocked in Arkansas Game and Fish Commission (AGFC)-owned lakes and impoundments (Olive et al. 2015). In addition, it's recorded that 400,000 catchable sized Channel Catfish have been stocked in Arkansas waters between the years 2009 and 2014 (Olive et al. 2015).

Although stocking is one aspect of management, many states did not historically manage for Channel Catfish populations intensively (Michaletz and Dillard 1999). The change came about due to the increasing popularity of fishing for Channel Catfish. As a result, Channel Catfish are now an important fish species in at least 32 states, managed in at least 34 states, and commercially fished in at least 28 states (Michaletz and Dillard 1999; Heidinger 2000; FAO 2003). Unfortunately, commercial harvesting has declined since the 1980s, while recreational fishing has continued to increase (Michaletz and Dillard 1999; Heidinger 2000; FAO 2003).

Due to the growing popularity towards channel catfishing, agencies began focusing more of their attention towards the management of Channel Catfish populations (Michaletz and Dillard 1999; Rachels and Ashley 2002). These new management practices, however, required accurate and reliable data (Arterburn et al. 2002; Brown 2007). Unfortunately, improvements in the management of Channel Catfish populations continues to be a slow process due to the difficult task of obtaining representative

samples that accurately describe a reservoir's population (Brown 2007). In addition, management decisions which typically require information on common population descriptors, tend to be based off single sampling methods and can result in contradicting estimates when compared against other methods (Sokal and Rohlf 1995; Colombo et al. 2008; Kuklinski and Boxrucker 2008). Furthermore, most of the difficulties that occur in management arise due to the lack of information on existing populations. Therefore, in order to obtain this information and determine management objectives, effective sampling protocols are needed.

Traditionally, Channel Catfish sampling occurs during the spring season and is performed near the shoreline. Large single hoop nets are primarily used for riverine sampling, while reservoir systems are typically sampled with tandem hoop nets (Gerhardt and Hubert 1989; Pugibet and Jackson 1991; Holland and Peters 1992; Stopha 1994; Robinson 1999; Sullivan and Gale 1999; Vokoun and Rabeni 1999; Michaletz and Sullivan 2002; Jackson 2004; Flammang et al. 2011; Richters and Pope 2011) and gill nets (Hanson 1986; Stevenson and Day 1986; Mitzner 1989, 1999; Wilde 1995; Howell and Betsill 1999; Santucci et al. 1999; Sullivan and Gale 1999). Electrofishing is, however, often used in both systems (Jacobs and Swink 1982; Santucci et al. 1994, 1999; Dudash and Heidinger 1996; Vokoun and Rabeni 1999). Unfortunately, gear bias can occur among all these methods due to fish behavior, seasonal influences, and size selectivity.

Fortunately, there have been several studies on combating gear bias. The studies investigated the variation in catch rates among hoop nets (Michaletz and Dillard 1999), baited versus unbaited hoop nets (Hanson 1986; Stevenson and Day 1986; Yeh 1977),

and set times (Robinson 1999). These studies also examined the selectivity and biases of each specific method (electrofishing, gill nets, and hoop nets) used during the research.

Electrofishing can be divided into two methods: high current (AC) and low current (DC). Both methods of electrofishing have been used in various sampling studies (Jacobs and Swink 1982; Santucci et al. 1999; Vokoun and Rabeni 1999) with differences in efficiency and selectivity occurring between both methods (Heidinger et al. 1983; Reynolds 1996; Santucci et al. 1999). Both methods also suffer from gear bias pertaining to size selectivity. This bias occurs due to Channel Catfish length groups responding differently to the strength and type of electric current being used (Justus 1994). As a result, electrofishing can produce inaccurate estimates of size structure and abundance varying by current type (Santucci et al. 1999; Vokoun and Rabeni 2001). For instances, high frequency electrofishing can produce high catch rates of individuals ≤ 250 mm in length enabling it to accurately represent the size structure of small Channel Catfish ≤ 250 mm in length within a population (Michaels and Williamson 1982; Santucci et al. 1999; Vokoun and Rabeni 2001). However, in order to determine the size structure of individuals > 250 mm in length, gill nets or hoop nets are needed.

Experimental gill nets have been used in past studies to sample for Blue Catfish *Ictalurus furcatus* and Channel Catfish along with making comparisons against other sampling gears (Mitzner 1989; Holland and Peters 1992; Sullivan and Gale 1999; Evans et al. 2011; Bodine et al. 2013). Generally, this method is more effective during periods when fish activity is high (Hubert 1996). In addition, most of this technique's gear bias occurs due to size selectivity influenced by mesh size (Holland and Peters 1992). Unfortunately, this bias can affect the validity of length frequency distributions and size

structure assessments. In order to counter this bias and develop accurate representations, studies performed in small Iowa impoundments suggested obtaining data from a minimum of 20 gill net pulls (Mitzner 1989).

Gill nets have also been shown to suffer from high mortality rates. This primarily occurs during long set times. Due to the occurrence of high mortalities, preference towards hoop nets for sampling Channel Catfish populations has continued to increase.

Single hoop nets and tandem hoop nets are used in riverine and reservoir habitats, respectively, to sample for Channel Catfish. An advantage to using hoop nets is the ability to return fish back to the water alive and relatively unharmed. This results in lower mortalities than gill nets (Sullivan and Gale 1999).

In riverine systems, studies performed with single hoop nets have shown that larger hoop nets produced higher catch rates than smaller nets (Flammang and Schultz 2007). Alternatively, tandem hoop nets use three single hoop nets attached to one another in a series, and are more effective at sampling Channel Catfish in reservoirs.

Tandem hoop nets are reported as having catch rates similar to gill nets while being more consistent between sets with less size bias (Sullivan and Gale 1999; Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009). This results in an accurate representation of the size structure of fish ≥ 250 mm in length that exist in a population (Sullivan and Gale 1999; Michaletz 2001; Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009; Flammang et al. 2011). In addition, catch rates and efficiency can be further increased by the use of different baits while simultaneously reducing effort (Sullivan and Gale 1999; Michaletz 2001; Michaletz and Sullivan 2002; Buckmeier and Schlechte 2009; Flammang et al. 2011). Unfortunately, the net and mesh dimensions of a

hoop net can affect the length of catfish captured (Jackson and Jackson 1999). In addition, gear bias can also be influenced by sampling effort, sampling season, and the by-catch of non-target species.

The number of tandem hoop net sets used and the soak time for sampling can both influence catch rates, and is dependent on the size of the water body and the targeted fish population. Both larger reservoirs and low abundance populations require more sets to accurately sample a population. Evidence supports the use of four sets of nets for water bodies ≤ 20 ha, six sets for water bodies 20 to 60 ha, and eight to nine sets for water bodies > 60 ha to accurately sample a population (Richters and Pope 2011). Net soak time usually varies between 24 - 72 hours with 48 - 72 hours being preferred (Neely and Dumont 2011). In addition, studies provide evidence of longer soak times resulting in greater catch rates than shorter soak times (Neely and Dumont 2011); however, in order for a fish to be caught, it must be retained in the net until retrieval (Porath et al. 2011).

Even though longer soak times have the potential to increase escape rates, the restriction of the second cod throat of a net, has been shown in studies to significantly reduce the number of fish escaping (Flammang et al. 2011). This method has reported up to 85% of the fish captured being retained (Porath et al. 2011).

Both season and bait have also been shown to have an effect on capture efficiency. Evidence supports higher catch rates of Channel Catfish in the spring and summer seasons (Jackson and Jackson 1999). Similarly, a Missouri study indicated May through June was an optimum time to sample for Channel Catfish (Michaletz and Sullivan 2002). This can be attributed to Channel Catfish being located in shallow

portions of a reservoir, 4.5 m or less, in the spring and early summer making their capture through the use of tandem hoop nets more effective (Fischer et al. 1999).
Independent of the season, the use of bait in hoop nets has been shown to increase capture success by as much as 600% when compared to non-baited hoop nets (Sullivan and Gale 1999). Common baits used include soy cakes and waste cheese logs (Carter 1954; Harrison 1954; Mayhew and Mitzner 1969; Mayhew 1972, 1973; Helms 1973; Pierce et al. 1981; Hubert and Schmitt 1982; Robinson 1994). However, between the two baits, soybean cakes have been shown to be more effective during summer sampling (Flammang and Schultz 2007).

Tandem hoop nets can also result in turtle mortalities, which typically occurs in impoundments where there are large turtle populations. In addition, longer set times can lead to a higher mortality rate in turtles (Sullivan and Gale 1999). Subsequently, this can potentially cause a decrease in capture effectiveness of tandem hoop nets (Michaletz and Sullivan 2002).

Due to the differences in selectivity across gears and sampling methods, there is a need for the standardization of sampling methods used for Channel Catfish population assessments. Over the years, the Arkansas Game and Fish Commission (AGFC) has continued to put forth effort towards creating uniform sampling protocols. Currently, there are standard sampling methods for Channel Catfish in reservoirs, which consist of using tandem hoop nets; however, an official standardized protocol has yet to be established. With the development of a standardized sampling protocol, fisheries biologists will be better able to deal with the variability that occurs among sampling

techniques and reservoirs. This will, as a result, aid in a biologist's ability to make scientifically justified management recommendations for Channel Catfish populations.

The goal of my study was to evaluate the current AGFC sampling protocol used for assessing Channel Catfish populations in reservoirs. Unfortunately, a reservoir's characteristics can affect how a reservoir is sampled, and how effective the sampling will be for the population. There may be times where more effort is required or the reservoir is not accessible. These characteristics can even play a role in the fishes' behavior. Due to this, I evaluated how reservoir characteristics affected Channel Catfish stock assessments and what changes could improve managing Channel Catfish populations in reservoirs. This goal was achieved through: 1) the implementation of stock assessments (age and growth, size structure, mortality, catch per unit of effort (CPUE), and proportional size distribution (PSD)) from tandem hoop net data to assess each reservoirs' Channel Catfish population with the hope of improving the management protocol currently being used, and 2) the observation of whether reservoir characteristics affected Channel Catfish growth and mortality rates to further aid in the improvement of managing Channel Catfish fisheries.

METHODS

Study Sites

The study was conducted on Lake Nimrod, Lake Overcup, Lake Catherine, De Queen Lake, Lake Columbia, and Lake Erling (Figure 2.1). Each reservoir ranged in size from 415 - 2,833 ha and were selected based on reservoir size (< 3,000 ha), depth, benthic substrate, and consultation with AGFC biologists. Using this criteria, each reservoir was also divided into two categories (shallow and deep).

Shallow reservoirs, which consisted of Lake Erling, Lake Overcup, and Lake Columbia, were characterized by a sand and/or silt benthic substrate. Lake Overcup is a 415 ha reservoir that was constructed in 1963 on Overcup Creek in Conway County, Arkansas near the city of Morrilton, Arkansas. Lake Columbia is a 1,214 ha reservoir and was constructed by the AGFC along Beech Creek in Columbia County, Arkansas in 1986. During the 1950's, Lake Erling is a 2,333 ha reservoir that was constructed in Lafayette County, Arkansas as a water source for the International Paper Company. It was formed from the construction of the Percy Cobb Dam built on the Codcaw Creek.

Deep reservoirs, which consisted of Lake Nimrod, De Queen Lake, and Lake Catherine, were characterized by a rocky/large substrate bottom. Lake Nimrod is a 1,437 ha reservoir and located in the Quachita Mountains. It was constructed on the Fourche LaFave River at the border of Perry and Yell Counties, Arkansas in 1942. Lake Nimrod is also the oldest United States Corporation of Engineers' reservoir in Arkansas. Lake Catherine is an 18 km long, 850 ha reservoir located in Hot Springs County, Arkansas. It was impounded during the 1920's by the Quachita River's Remmel Dam. It is the third reservoir of a series, downstream from Lake Quachita and Lake Hamilton. De Queen Lake is a 680 ha reservoir constructed on the Rolling Fork River in Sevier County, Arkansas in 1977. It was also created by and is under the maintenance of the U.S. Corps of Engineers.

All six reservoirs were also stocked annually, and considered good Channel Catfish fisheries by AGFC biologists. Additional reservoir characteristics are listed in Table 2.1.

Field Methods

Each reservoir was divided into two sections (upper and lower; Figure 2.2), and each section was sampled once a month with eight tandem hoop net sets per section. This resulted in a sampling effort of 16 sampling sets a month. The lower section was characterized as the half of the reservoir containing a dam or levee, while the upper section was characterized as the half of the reservoir containing the water source. Sampling was conducted monthly during April, May, and June of the year 2014, and all fish captured were identified to species and tallied. In addition, total length (TL; mm) was recorded for every Channel Catfish caught.

The tandem hoop net setup consisted of connecting three single hoop nets in a series through the use of a 5 cm stainless steel ring tied to three 3 m long nylon rope leads. All three leads were attached to the front hoop of each individual single hoop net, and connected with a stainless steel snap to the next net in the series to form a tandem hoop net series (Sullivan and Gall 1999; Figure 2.3). As described by Flammang et al. (2011), each single hoop net was 4.30 in length and constructed of size #15 twine with 3.81 cm bar-mesh netting. In addition, each single hoop net contained eight fiberglass hoops. The front hoop opening had a diameter of 0.76 m, while the remaining seven hoops each had a diameter of 0.57 m. In addition, a zip tie was used to restrict the second cod end throat by clasping it 15 - 20 cm from the last knot located on the lead line (Flammang et al. 2011; Figure 2.4).

Sampling locations were determined by randomly selecting from a set of shoreline section markers used by the AGFC when determining sites for electrofishing. The shoreline section markers were spaced 600 m apart around the perimeter of each

reservoir. For situations where a reservoir shoreline was not marked, GIS Arc Map was used to create a map of the reservoir and plot out random locations for each net set.

When setting each series, a highly visible float was attached to a six-meter-long nylon lead rope connected to the first hoop of the first net. Also, to prevent a series from shifting out of position, three anchors were attached to leads with the leads, in turn, attached to the first hoop of the first and second net and the cod end of the third net. In addition, each net in the series was baited with approximately 1.5 kg of waste cheese logs to increase capture rate and success. The waste cheese was placed into a nylon mesh bag and attached with a zip tie to the last hoop net of each net in the series.

As suggested by Flammang et al. (2011), each net was set parallel to the shoreline, and between one and three meters deep to ensure a position above the thermocline. In addition, dissolved oxygen was measured with a YSI-55 meter at each set location to ensure that each location had a dissolved oxygen measurement of ≥ 5 mg/L. Each set was then allowed to soak for 72 hours before retrieval.

Along with dissolved oxygen, GPS coordinates, water depth, substrate type, water clarity, and water temperature were also recorded at each sample location. A Speedtech SM-5 Depthmate portable sounder was used to measure water depth, and a YSI-55 meter was used to measure water temperature (°C). A ponar grab sampler was used to collect small substrate, which was identified as silt (0.0058 - 0.0626 mm), sand (0.626 - 2 mm), or gravel (> 2 mm), while larger substrate was identified by shoreline composition. Finally, a Secchi disk was used to measure water clarity (mm) on the shaded side of the boat.

Aging

Pectoral spines were removed from the first 10 Channel Catfish collected per 25 mm length group from each reservoir for age and growth analyses. The procedure required dislocating the left pectoral spine by firmly holding the spine against the fish's body, before finally rotating the spine counter-clockwise with a pair of pliers to detach the spine (Mayhew 1969). This procedure would result in a puncture-like wound which would later heal (Michaletz 2005). The spines collected were then stored in coin envelops to dry and later cleaned and sectioned (Nash and Irwin 1999).

Pectoral spines are primarily used to age Channel Catfish instead of otoliths because studies have shown them to be more accurate (Sneed 1951; Marzolf 1955; Mayhew 1969; Turner 1982; Buckmeier et al. 2002). In addition, the use of the pectoral spine allows individuals to be released after capture (Olive 2004; Boxrucker and Kuklinski 2006; Barabe 2009). There are, however, some drawbacks to using pectoral spines for aging.

One drawback consists of the loss of annuli as fish age due to the central lumen expanding (Marzolf 1955; Muncy 1959; Mayhew 1969; Hesse et al. 1976). Another is annuli can be harder to see in older fish resulting in a 50 - 65% agreement rate between or among readers (Nash and Irwin 1999). This is caused by annuli merging together in older and slower growing fish making the process of aging more difficult. In order to alleviate this problem, two sections, the basal recess and the articulating process, are cut from the spine.

The basal recess section was used to age the individual fish while the articulating process section was used for age conformation. The articulating process section is used

for age confirmation due to its ability to remain intact throughout the fish's life (Olive et al. 2011). This helps to lower the chance of early annuli being lost or missed during aging (Olive et al. 2011).

A Buhler Isomet 1000 precision saw with a 15 HC wafering blade was used to cut spine sections. Spine sections from fish ≥ 300 mm in total length were cut to a thickness of approximately 0.6 mm while spine sections from fish < 300 mm in total length were cut to a thickness of approximately 0.8 mm. This ensured the section would not break from being cut or handled. Once cut, both sections were placed between two glass microscope slides and mounted together using clear scotch tape. Each slide was then labeled with an identification number, sample location, and the specimen’s total length.

Spine sections were viewed under an Olympus S261 microscope at 10 x 0.67 - 4.5 magnification and a Schott ACE1 light source. A Coolpix 4300 digital camera with a Coolpix MDC Nikon lens attachment was used to capture an image of the spine section before storing to a SD card. The images were then used to assign an age to each fish. Age assignment required two readers to count the number of annuli present to ensure validity, but if a consensus could not be reached between readers, the fish was removed from the sample. Once the ages were determined, each image was uploaded to an imaging program called Image J. Image J was developed at the National Institutes of Health by Wayne Rasband. The program was used to estimate back-calculated lengths at age for each fish by measuring the distance between the focus and each annulus.

Data Analyses

Relative Abundance

Relative abundance analyses in this chapter focused solely on fish collected during the May sampling period. This was due to analyses conducted in Chapter 1 that determined May produced the highest CPUE among months sampled. Mean monthly CPUE (Channel Catfish per tandem hoop net set) and standard deviation were calculated for reservoir sections separate and pooled. In addition, comparisons of CPUE were made among reservoirs for both month and reservoir section. These comparisons were performed through the use of a two-way ANOVA, and conducted by using the program Statistical Analysis System (SAS) (SAS Institute Inc. 2011). Differences in CPUE among reservoirs were determined by conducting lsmeans tests with a significance level of 0.05. Additional detailed analyses for CPUE were evaluated and discussed in Chapter 1.

Size Structure

Length frequency histograms for both monthly and pooled distributions were constructed for each reservoir. To determine if each reservoirs' length frequency distributions were significantly different from one another, a Kolomogrov-smirnov two sample test with a significance level of 0.05 was conducted. This analysis was also performed by the program SAS (SAS Institute Inc. 2011).

Proportional size distribution (PSD), quality (PSD-Q), preferred (PSD-P), and memorable (PSD-M), were calculated for each lake. Proportional size distribution is the number of fish greater than or equal to a specific length divided by the number of fish greater than or equal to stock length (Anderson and Neumann 1996; Guy et al. 2007).

Stock, quality, preferred, and memorable lengths for Channel Catfish were defined as 280, 410, 610, and 710 mm, respectfully (Gabelhouse 1984).

Age and Growth

The program Fisheries Analysis and Modeling Simulator (FAMS; Slipke and Maceina 2014) was used to create an age-length key by assigning ages to all the fish sampled based on estimated lengths. FAMS is a statistical software used to analyze data collected from a fish population. In addition, the length groups for age assignment were based on 25 mm length groups.

The Dahl-Lea method (Dahl 1909; Lea 1910) was used to measure annuli and transform estimates into back-calculated lengths at age. The Dahl-Lea method is modeled as $L_i = ((S_i{*}L_c)/S_c)$: L_i = length when annulus formed; S_i = scale radius when annulus formed; L_c = total length at capture; S_c = total scale radius (spine, in this case) at capture (Dahl 1909; Lea 1910). The Dahl-Lea method was chosen over the Frasier-Lee method due to catfish having spines from the moment they are born.

The von Bertalanffy model (von Bertalanffy 1951) was used to calculate the growth parameters $L\infty$, k, and t_0. The model $L_t = L\infty\ (1\text{-}e^{-k\,(t-\,t_0)})$ encompasses L_t = length at time; $L\infty$ = asymptotic length; k = growth coefficient; and t_0 = time at zero (von Bertalanffy 1951). FAMS was used to calculate both mean back-calculated growth rates and length-at-capture growth rates. Individual reservoir growth rates were then linearized and an analysis of covariance (ANCOVA) was used to perform comparisons. In addition, the determining of whether reservoir or reservoir type had a significant effect on growth rates were performed in the program SAS (SAS Institute Inc. 2011) by conducting an ANCOVA test where alpha was set to 0.05.

Differences per age groups among reservoirs were tested by conducting mean back-calculated age comparisons. These comparisons were performed in the program SAS (SAS Institute Inc. 2011) by using multiple one-way Welch's ANOVA tests. A significance level of 0.05 was chosen when performing these comparisons and a Tukey's pairwise test was used to identify differences.

The factors, reservoir, fish age, and any interactions were tested to detect if any factors affected growth, and if growth rates differed among reservoirs. An ANCOVA was used to perform these tests by comparing linearized growth rates. In addition, a general linear means (GLM) test was also performed to determine if environmental factors such as reservoir type affected growth. For the GLM test, a significance level of 0.05 was used to evaluate if there was a significant effect on growth by reservoir type. The growth rate for each back-calculated age was then compared independently between reservoir types by using a non-parametric one-way ANOVA with a significance level of 0.05.

Mortality

Total annual mortality (*A*) was calculated for each reservoir through the regression of linearized catch curves by using SAS software (SAS Institute Inc. 2011). First, the number of fish in each age group was calculated and $\log^{10}$ transformed. Next, the age groups and transformed count data were modeled by using least squares regression. When modeling the regression, age one fish was not included due to gear bias occurring because of size selectivity. Finally, both weighted and unweighted regressions were performed. Weighted regressions took into account any gear bias associated with the sampling gear.

Instantaneous mortality (*Z*) was transformed to annual mortality (*A*) by the following equation: $A = 1 – e^{-z}$ (Bettoli and Miranda 2007). The slopes of each reservoir's catch-curve regression were used to compare instantaneous mortality rates for each reservoir by using a GLM test. Differences between reservoir pairs were determined by using lsmeans tests and a significance level of 0.05.

RESULTS

Channel Catfish produced the highest percent composition of individual species in the majority of the reservoirs sampled; followed by Bluegill *Lepomis macrochirus* and White Crappie *Pomoxis annularis* (Table 2.2a - 2.2c and 2.3a - 2.3c). By-catch of non-target species were not recorded for Lake Columbia, De Queen Lake, and Lake Erling. Lake Erling produced the greatest catch rates of Channel Catfish and Lake Catherine produced the lowest catch rates. The warmest average water temperatures occurred during the month of June (Table 2.4). In addition, silt and clay was the predominant substrate in shallow reservoirs. Deep reservoirs had a greater substrate diversity and were primarily composed of silt, gravel, and larger substrate (Table 2.5).

The relative abundance between reservoir types and reservoir sections for the month of May were compared by using a two-way ANOVA test. The test results showed significant effects on CPUE by reservoir type (GLM Reservoir type, Section, Interaction: F (1, 1, 1) = 78.35, 1.56, 0.02, P = < 0.01, 0.21, 0.88). In addition, lsmeans tests showed higher relative abundance in shallow reservoirs compared to deep reservoirs and in upper sections of reservoirs compared to lower sections (Figure 2.5; Table 2.6).

Size Structure

Length frequency distributions were created for each reservoir and compared. Lake Nimrod displayed the greatest range in sampled fish lengths (Figure 2.6a - 2.6f) and produced the largest Channel Catfish sampled. Variable year class strength was detected for every reservoir except for Lake Erling. A Kolmogrov-smirnov two-sample test was used to compare length frequency distributions among the six reservoirs. The test showed a significant difference ($P < 0.05$) for each comparison (Table 2.7).

Proportional size distribution was the greatest in De Queen Lake at 58% (Table 2.8). In addition, the pooled average length at age percentiles of the fish sampled were greater than the national growth standards published by W. A. Hubert (1999a) (Table 2.9).

Aging

Mean back-calculated age comparisons among age groups were calculated using one-way Welch's ANOVAs with Tukey's pairwise tests for comparisons. There were significant differences ($P < 0.05$) for all ages except seven ($P = .26$) (Figure 2.7a - 2.7g).

The von Bertalanffy equation for each reservoir was calculated from back-calculated lengths (Table 2.10 - 2.15). The fastest growth (k) and largest time at zero (t_0) occurred in Lake Overcup while the greatest asymptotic length ($L\infty$) occurred in Lake Catherine (Table 2.16; Figure 2.8 - 2.13). The slowest growth and smallest t_0 occurred in Lake Catherine, while the shortest asymptotic length occurred in Lake Overcup.

Linearized historic growth rates (slope of the growth coefficient) derived from each reservoir were compared by using an ANCOVA test. Test results showed significant effects on growth by reservoir, age, and age*reservoir interaction (GLM Reservoir, Age,

Interaction: *F* (5, 1, 5) = 12.31, 449.94, 25.10, *P* = < 0.01, < 0.01, < 0.01). Thus, it was determined that the linearized historic growth rate of at least one reservoir differed from another (Figure 2.14).

Environmental Effects on Growth by using Mean Back-Calculated Lengths

Fish age, reservoir, and the interaction term (age*reservoir) accounted for a significant proportion of variation in growth (GLM Age, Reservoir, Interaction: *F* (5, 5, 25) = 39.52, 5.18, 9.96, *P* = < 0.01, < 0.01, < 0.01). The length at capture growth rate of Channel Catfish was the fastest in Lake Columbia. The same process was also performed to compare reservoir types.

The model indicated that both age and the interaction between reservoir type and age accounted for a significant proportion of variation in Channel Catfish growth within each reservoir composition type (GLM Age, Reservoir Type, Interaction: *F* (7, 1, 7) = 41.44, 0.01, 4.66, *P* = < 0.01, 0.92, < 0.01). Due to the interaction between reservoir type and back-calculated age, growth for each back-calculated age was compared independently between reservoir types. There was no significant difference in growth between reservoir types for back-calculated ages one (*F* (1, 833) = 0.85, *P* = 0.36), three (*F* (1, 564) = 2.19, *P* = 0.14), and six (*F* (1, 58) = 2.30, *P* = 0.13). However, there was a significant difference in growth between reservoir types for back-calculated ages two (*F* (1, 758) = 9.18, *P* < 0.01) and seven (*F* (1, 15) = 5.37, *P* < 0.05) where deep reservoirs showed greater growth than shallow reservoirs and ages four (*F* (1, 327) = 12.08, *P* < 0.01) and five (*F* (1, 158) = 13.84, *P* < 0.01) where shallow reservoirs showed greater growth than deep reservoirs.

Mortality

Weighted annual mortality for each reservoir consisted of 50% for Lake Catherine, 41% for Lake Columbia, 39% for De Queen Lake, 56% for Lake Erling, 52% for Lake Nimrod, and 70% for Lake Overcup (Table 2.17). Shallow reservoirs tended to show higher mortality rates than deep reservoirs.

The slopes of each reservoir's catch-curve regression, which consisted of an Age*Lake interaction from all six reservoirs were compared amongst each other with results showing that there were no significant differences among the slopes (mortality rates) (GLM Age, Reservoir, Interaction: F (1, 5, 5) = 139.93, 2.62, 1.59, P = < 0.01, 0.05, 0.20.

DISCUSSION

Population characteristics are used to help develop and evaluate fishery management plans. These estimated characteristics often include relative abundance, size and age structure, growth, condition, and mortality. It is these characteristics that help fisheries biologists determine the productivity of a reservoir, current or potential problems, and the outcomes of implemented management plans.

Relative Abundance (CPUE)

Analyses in chapter one indicated that relative abundance varied by month. Through observations of the data and analyses performed, I found that May was the best time (month) to conduct relative abundance assessments on Arkansas reservoirs. Based on this finding, only May's CPUE data was used for analyses performed in this chapter.

May displayed the highest relative abundance for most of the reservoirs sampled. In addition, relative abundance was also found to be positively related to water

temperature with the most productive water temperatures ranging from 21.8 - 26.4 °C. I believe these water temperatures may have triggered a photoperiodism response in the different reservoirs' Channel Catfish population. This response could have, in turn, prompted the movement of fish into shallower depths and aided in the tandem hoop nets' effectiveness. This theory is further supported by my analyses that indicated shallower, upper reservoir sections produced greater CPUE than the deep, lower sections of the reservoirs. There were also differences in the relative abundance that occurred between reservoirs types.

In Chapter 1, it was indicated that water temperature was directly correlated to reservoir type, and shallow reservoirs had higher relative abundance than deep reservoirs. This was based on the assumption that shallow reservoirs had warmed faster than deep reservoirs resulting in later spawning times for deep reservoirs. From that assumption, I concluded that gear placement may have also been a factor influencing catch rates. Due to gear placement, the catch rates of Channel Catfish may have increased as fish move into warmer, shallower water to spawn. Conversely, deep reservoirs may have shown lower catch rates due to this transition occurring later in the season because the water temperature warmed slower.

Another plausible explanation is that the productivity of the environment played a role in the relative abundance of Channel Catfish sampled. Due to reservoirs succumbing to fluctuations in hydrology, temperature, and nutrient inputs (Quist et al. 2003), some reservoirs are more productive than others, which affects relative abundance. This has been shown in several studies focusing on fish populations and environmental variables (Mitzner 1991; Putman et al. 1995; Rutherford et al. 1995; Wildhaber et al. 2000;

Tomcko and Pierce 2001; Paukert et al. 2002; Durham et al. 2005). In these studies, environmental characteristics such as reservoir size, depth, chemical composition, and forage abundance (Winemiller et al. 2000; Bartram et al. 2011) were all shown to affect both productivity and relative abundance. This independently or in conjunction with natural recruitment could contribute to the different variations seen in CPUE between reservoirs and reservoir types such as large populations occurring where there is high productivity (Winemiller et al. 2000; Bartram et al. 2011).

In addition, Winemiller et al. (2000) stated that chlorophyll *a* is positively related to fish abundance and condition. Because shallow reservoirs have large quantities of vegetative structure (standing timber, falling logs, and debris), they may have a greater primary production. Coincidentally, this may occur in conjunction with large, naturally reproducing populations.

Channel Catfish typically use structures such as hollow logs, root structures, burrows, and mud bottoms for spawning sites (Brown 1942; Harlan and Speaker 1956; Marzolf 1957; Davis 1959; Lawler 1960; Deacon 1961; Geibel and Murray 1961; Sigler and Miller 1963; Stickney 1971; Weeks 1972; Van Eeckhout 1974; Nickum 1976). These structures not only provide potential spawning sites, but also protection from predators (Shipman 1977). However, some deep reservoirs lack a lot of vegetative structure resulting in higher predation or harvest on stocked and naturally spawned fish. This exploitation along with the possibility of lower productivity could result in a lower relative abundance. However, there is also the possibility that use of tandem hoop nets was not effective at sampling deep reservoirs and, as a result, the actual productivity and recruitment could have been equal to or greater than shallow reservoirs.

Finally, the gear used displayed biased towards fish ≥ 250 mm in length. This makes it difficult to gather reliable data to assess young of the year individuals, especially since Stevens (2013) found that recruitment rises when reservoirs have a moderate discharge. This means there could be a higher naturally occurring population of Channel Catfish than assumed in Lake Catherine, Lake Nimrod, and De Queen Lake, since each reservoir has a dam that frequently releases water. If so, each reservoir could have a greater total population than represented by the sampling data.

Size Structure

Analyses indicated that length frequency distributions were significantly different among reservoirs. Length frequency distributions, however, failed to accurately represent every length class present in the population. Individuals ≤ 250 mm in length were misrepresented due to size selectivity issues, while larger sized individuals > 650 mm in length were misrepresented due to a lower number of individuals within the population. Consequently, this gear bias also affects other analyses such as PSD calculations and mortality rate estimations.

Shallow reservoirs were shown to have a higher PSD than deep reservoirs, which could be influenced by factors such as supplemental stocking and naturally occurring reproduction. These factors affect year class structure within a reservoir's population by influencing yearly cohorts (Broach 1967; Keith 1971; Mosher 1999; Michaletz et al. 2005; Michaletz 2009). Therefore, average sized peaks could be associated with stocking or naturally occurring reproduction and large peaks could be the result of both occurring at the same time.

Since reservoir fish populations are influenced by factors such as hydrology, nutrient load, and temperature changes (Quist et al. 2003), events that influence productivity can also influence a population's year classes. Studies performed by both Buck (1956) and Lawler (1960) linked high turbidity and slow growth together for Channel Catfish. It has also been hypothesized and stated that reservoir hydrology, temperature, and discharge rates and frequency along with rainfall amounts can influence reproduction in Channel Catfish populations (Helms 1975; Holland-Bartels and Duval 1988; Hubert 1999b; Kwak et al. 2010). Although direct correlations have not been discovered between spawning time and year class, it has been observed that a delayed spawn can increase year class strength within a population (Stevens 2013).

A study performed by Stevens (2013) focused on recruitment between two reservoir types: tributary-storage reservoirs and main stem reservoirs. Tributary-storage reservoirs showed similar hydrology characteristics to the deep reservoirs in my study, while main stem reservoirs were similar in hydrology to the shallow reservoirs in my study. Both tributary-storage and deep reservoirs experienced frequent water changes along with high retention times, while both main stem and shallow reservoirs experienced stable water levels with low retention times. The results of Stevens (2013) study showed that reservoirs succumbing to frequent water changes saw pulses in recruitment, while reservoirs with stable water levels saw a more consistent recruitment pattern. Tributary-storage reservoirs also displayed recruitment pulses that were correlated with average rainfall levels (Stevens 2013).

Natural reproduction and year class strength also can be affected by predation. In reservoirs, which are quality Largemouth Bass fisheries, good years in productivity for

Largemouth Bass could potentially affect natural recruitment, and thus create weak year classes of Channel Catfish. Krummrich and Heidinger (1973) reported Channel Catfish < 127 mm typically saw greater mortality due to predation from Largemouth Bass than individuals ≥ 127 mm in length. In addition, Wellborn (1984) stated that when stocking a body of water with Channel Catfish, individuals should be 200 - 250 mm in length to prevent predation from Largemouth Bass.

Age and Growth

Analyses revealed that Lake Overcup had the greatest mean back-calculated growth rate, while Lake Columbia had the greatest length-at-capture growth rate. Lake Catherine, however, showed both the lowest mean back-calculated growth rate and length-at-capture growth rate. This proposes the ideal that shallow reservoirs had faster growth rates than deeper reservoirs. Unfortunately, when mean back-calculated length comparisons were running among the reservoirs, no significant difference was seen within the age groups one through six. A difference between reservoir types was seen, however, when a comparison of mean length-at-capture among reservoirs were performed.

Normally, mean back-calculated lengths are used for most growth analyses due to its ability to account for outliers in the sample population. Mean length-at-capture, however, can be beneficial for detecting if short-term environmental changes have affected the growth rate of a population. Analyses performed to compare mean length-at-capture revealed that reservoir type did have a significant effect on growth for ages two, four, five, and seven. Age one individuals showed no significant differences possibly due

to not being fully recruited to the gear. However, the differences that were seen between reservoir types could have resulted from various environmental factors.

Generally, the growth of Channel Catfish is assumed to be greater in shallow, highly productive reservoirs (Cole et al. 1991; Mosher 1999; Shoup et al. 2007; Michaletz 2009). This trend was shown to be true for Lake Overcup and Lake Columbia, both of which were labeled shallow reservoirs. Each shallow reservoir in the study was shown to warm up faster and have higher average water temperatures, which supported faster growth. There are also several studies that have shown both abiotic and biotic factors (Hayes et al. 1999) such as water temperature and depth (Andrews and Stickney 1972; Durham et al. 2005), water velocity, cover (Putman et al. 1995), geographical location and climate (Carlander 1969; Hubert 1999; Durham et al. 2005), inter and intraspecific competition, population density (Finnell and Jenkins 1954; Michaletz 2009), resource availability (Mosher 1999; Shoup et al. 2007; Michaletz 2009; Bowen et al. 1991), and biological productivity (Hall and Jenkins 1952) to all influence the growth rates of Channel Catfish in reservoirs.

Temperature has, however, been the most important factor believed to influence growth because of its ability to affect a fish's metabolic processes (Kitchell et al. 1977; Brett and Groves 1979; Boisclair and Leggett 1989b). The second most important factor thought to influence growth, however, is density-dependent interactions such as food availability (Bowen et al. 1991). Coincidentally, highly productive reservoirs are thought to have a greater density of macroinvertebrates, and as a result, promote faster growth (Mosher 1999). Therefore, shallow reservoirs in this study may have experienced faster growth rates due to factors, such as more productive algae bloom, warmer waters, less

occurrences of turnovers, and so forth. This may explain why Channel Catfish in shallow reservoirs showed greater growth than Channel Catfish from deep reservoirs. Unfortunately, Channel Catfish in shallow reservoirs can also exhibit stunted growth due to high population densities or overstocking.

Previous studies have shown both faster growth rates with lower densities (Michaletz 2009) and slower growth rates with higher densities (Hubert 1999; Mitzner 1999; Mosher 1999). These findings showed that overstocking Channel Catfish could result in poor fish condition and slow growth (Hill 1984; Mitzner 1999; Mosher 1999) while stocking fewer fish could result in faster growth (Michaletz 2009). This, along with other factors such as low productivity, may provide insight to periods when shallow reservoir Channel Catfish populations display slower growth than deep reservoir populations.

Subsequently, the cases where decreased growth rates were found in impoundments where Channel Catfish were regularly stocked was due to intraspecific competition (Hall and Jenkins 1952; Finnel and Jenkins 1954; Cole et al. 1991; Mosher 1999; Shoup et al. 2007). Intraspecific competition has been shown to affect Channel Catfish growth predominately during the first three years of life regardless of habitat (Hall and Jenkins 1952; Finnell and Jenkins 1954; Michaletz 2009). However, this generally tends to occur more in reservoirs with high rates of stocking or natural spawning (Finnell and Jenkins 1954; Mitzner 1990; Michaletz 1998; Stevens 2013).

Alternatively, density-dependent factors have been shown to play a bigger role on Channel Catfish growth than previously thought, and is greatly influenced by intraspecific competition (Michaletz 2009). This all occurs under the assumption that a

large population of fish can cause an overexploitation of a reservoir's resources and result in slower growth rates (Michaletz et al. 2005). In addition, competition can occur from several other fish species and potentially impact Channel Catfish growth. This is possible since Channel Catfish share a similar diet to other fish species during both their juvenile and adult stages (Stevens 2013). A Channel Catfish's diet can, however, change throughout the seasons (Stevens 2013). In addition, Stevens (2013) discovered that the growth of younger individuals was affected more by intraspecific competition, while older individuals were affected more by lake productivity.

The Channel Catfish sampled in deep reservoirs may have displayed slower growth due to lower productivity caused by cooler water temperatures. Unfortunately, Durham et al. (2005) failed to find any relationship between fish growth and lake productivity or depth. Mosher (1999), however, assumed that a highly productive lake was more likely to have higher food resources thus influencing growth.

The large substrate composition may also be less than suitable habitat for Channel Catfish, which could affect growth. Although, studies have provided evidence that Channel Catfish prefer foraging in littoral habitat. This means a high volume of littoral habitat; a characteristic of deep reservoirs could possibly result in faster growth (Carlander 1977; Edds et al. 2002; Shoup et al. 2007).

Finally, Channel Catfish growth can be affected on the statewide, regional, and national scales by the length of the growing season (Durham et al. 2005), and an impoundment's location and climate (Hubert 1999). In my study, the Channel Catfish showed faster growth in reservoirs centrally located in the state. This occurred whether the reservoirs were shallow or deep; however, the growth rates decreased as the locations

of reservoirs became more southern. This was similar to Durham et al. (2005), which showed a variation in growth as they sampled throughout Texas. Other studies (Carlander 1969), however, showed faster growth the more south a body of water was located in a region or state.

In the Durham et al. (2005) study, the growth of fish in both northern and southern most portions of the state displayed slower growth. Channel Catfish sampled from the northern reservoirs were theorized to have suffered from a short growing season (Durham et al. 2005), while southern reservoirs were theorized to have suffered from high summer water temperatures (Andrews and Stickney 1972; Kilambi et al. 1971). It is also thought that available resources could be a confounding factor when relating the length of the growing season to Channel Catfish growth (Hall and Jenkins 1952; Finnell and Jenkins 1954; Durham et al. 2005). Based off these studies, Lake Catherine's low growth rates could have been related to elevation.

Mortality

The greatest mortality occurred in Lake Overcup, while the lowest mortality occurred in De Queen Lake. In addition, the results from comparing the reservoirs' catch-curve slopes showed no significant differences among each reservoir. Since mortality is dependent on various factors such as individual and population health, insufficient resources, exploitation, predation, and stocking, reservoirs displaying higher mortality rates could have suffered from any of these factors.

It has also been shown that natural mortality can increase, and PSD can decrease when stocking rates are increased (Michaletz 2009). This is because as relative abundance increases, factors such as condition, growth, and size structure can decrease

due to density-dependent effects (Biro et al. 2003; Miranda and Bettoli 2007; Michaletz 2009). Mortality rates can also increase when dissolved oxygen levels decrease usually occurring when there has been a mixing of the thermocline. This means low oxygen levels can occur in both reservoir types. Shallow reservoirs can exhibit low oxygen levels due to increasing water temperature, while deep reservoirs can exhibit low oxygen levels due to a mixing of the thermocline.

CONCLUSION

My study presented several important findings that may be useful for fisheries managers and biologists. One was that sampling in May or when the water temperature is 23 - 24°C could potentially provide the best catch data for a Channel Catfish population. June was determined as the second best month to sample. This means an increase in the effectiveness of gear and a reduction of effort required can be achieved by simply sampling during an optimum time of the year. It could also prove beneficial to sample deeper reservoirs later than shallow reservoirs due to differences in the rates that the water temperature changes. Secondly, the use of CPUE assessments alone to describe a population would not be feasible for biologists due to the amount of effort required. Other assessments would be needed to accurately describe a reservoir's Channel Catfish population. Third, assessment data, especially growth, CPUE, and mortality, displayed some variation between reservoir types. This prevents biologists from making generalized statements about a reservoir based on another reservoir's data. In my study, shallow reservoirs typically saw greater relative abundance and mortality while growth rates varied between and among reservoir types. Finally, length classes showed no pattern related to reservoir types; however, length frequency distributions in conjunction with

growth rates and CPUE could help determine if a reservoir requires stocking (Shipman 1977).

These results show that several factors including angler's expectations have to be taken into consideration when performing assessments and determining management goals for a fishery. One of the most important management decisions made by biologists from assessment data is whether or not a reservoir should be stocked. This decision is one that managers not only have the most control over, but also produces one of the biggest impacts on a fishery.

Even though, stocking is the easiest management tool used to alter a population's relative abundance, it can also have drawbacks. This means some considerations have to be taken into account before plans to stock or change stocking rates are determined. These considerations may include: what the current relative abundance are, what is the size structure of the population, how fertile is the reservoir, and what are the anglers' expectations for the fishery.

Determining relative abundance and year classes can also identify naturally spawned cohorts, and if the population is suffering from stunted growth. This assessment, however, should be performed using both tandem hoop nets, high-frequency electrofishing, and creel surveys to get the best picture of a reservoir's Channel Catfish size structure. In addition, growth rates and patterns should be identified to ensure if a reservoir is productive enough to support the current or planned population size. When looking at the growth of a population, reservoir type, location and geography, food abundance, angler harvest, and population size structure should be used to form a detailed understanding of the fishery's productivity. This will help in determining what results

management objectives will have and if they are obtainable. Finally, angler's expectations can be used to further determine what route a Channel Catfish fishery should take, and if it is being achieved. If angler preference is a trophy Channel Catfish fishery, a highly productive reservoir that contains a greater proportion of larger individuals should be the goal. Conversely, if there is a preference for subsistence fishing, a fishery where there is a large population of slow growing, but catchable size Channel Catfish would be more appropriate.

Future Studies

Population modeling programs found within software such as FAMS are an effective method for combining acquired data and angler expectations to determine if desired results can be achieved from management goals. This would provide AGFC biologists with and evaluation of a plan's effectiveness. Furthermore, future AGFC biologists' research and management goals should consist of: 1) How does location specifically affect Channel Catfish growth in Arkansas reservoirs and how it could be used to determine stocking rates, 2) What specifically determined whether shallow or deep reservoirs displayed higher growth rates during certain years, 3) How can determining Channel Catfish diet aid in growth assessments, and 4) Determining young of year relative abundance for stocking rate adjustments and future management goals.

REFERENCES

Anderson, R. O., and R. M. Neumann. 1996. Length, weight, and associated structure indices. Pages 447-482 *in* B. R. Murphy and D. W. Willis editors. Fisheries techniques 2nd edition. American Fisheries Society, Bethesda, Maryland.

Andrews, J. W., and R. R. Stickney. 1972. Interactions of feeding rates and environmental temperature on growth, food conversion, and body composition of channel catfish. Transactions of the American Fisheries Society 101:94-99.

Arterburn, J. E., D. J. Kirby, and C. R. Berry Jr. 2002. A survey of angler attitudes and biologist opinions regarding trophy catfish and their management. Fisheries 27(5):10-21.

Barabe, R. 2009. Stock assessment of flathead catfish in the Pascagoula River after the passage of Hurricane Katrina. Master's thesis. Mississippi State University, Mississippi State.

Bartram, B. L., J. E. Tibbs, and P. D. Danley. 2011. Factors affecting blue catfish populations in Texas reservoirs. Pages 187-197 *in* P. H. Michaletz and V. H. Travnichek, editors. Conservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Bettoli, P. W., and L. E. Miranda. 2007. Mortality. Pages 229-277 *in* C.S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Biro, P. A., J. R. Post, and E. A. Parkinson. 2003. Density-dependent mortality is mediated by foraging activity for prey fish in whole-lake experiments. Journal of Animal Ecology 72:546-555.

Bodine, K. A., D. E. Shoup, J. Olive, Z. L. Ford, R. Krogman, and T. Stubbs. 2013. Catfish sampling techniques: where we are now and where we should go. Fisheries 38(12):529-546.

Boisclair, D., and W. C. Leggett. 1989b. Among-population variability of fish growth: III. Influence of fish community. Canadian Journal of Fisheries and Aquatic Sciences 46:1539-1550.

Bowen, S. H., D. J. D'Angelo, S. H. Arnold, M. J. Kewiry, and R. J. Albrecht. 1991. Density-dependent maturation, growth, and female dominance in Lake Superior lake herring (*Coregonus artedii*). Canadian Journal of Fisheries and Aquatic Sciences 48:569-576.

Boxrucker, J., and K. Kuklinski. 2006. Abundance, growth, and mortality of selected Oklahoma blue catfish populations: Implications for management of trophy fisheries. Proceedings of the Annual Conference Southeastern Fish and Wildlife Agencies 60:152-156.

Brett, J. R., and T. D. D. Groves. 1979. Physiological energetics. Fish Physiology, Vol. VIII (Hoar, W. S., Randall, D. J., and Brett, J. R., editors), Pages 279-352. New York: Academic Press.

Broach, R. W. 1967. Arkansas' catchable channel catfish program. Proceedings of the Southeastern Association of Game and Fish Commissioners 21:8 (mimeograph).

Brown, L. 1942. Propagation of the spotted channel catfish (*Ictalurus lacustris punctatus*). Transactions of the Kansas Academy of Science 45:311-314.

Brown, Z. 2007. Current trends in catfish sampling techniques and information needs. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 61:6-9.

Buck, H. D. 1956. Effects of turbidity on fish and fishing. Oklahoma Fish Laboratory Report No. 56:57.

Buckmeier, D. L., E. R. Irwin, R. K. Betsill, and J. A. Prentice. 2002. Validity of otoliths and pectoral spines for estimating ages of channel catfish. North American Journal of Fisheries Management 22:934-942.

Buckmeier, D. L., and J. W. Schlechte. 2009. Capture efficiency and size selectivity of channel catfish and blue catfish sampling gears. North American Journal of Fisheries Management 29:404-416.

Carlander, K. D. 1969. Handbook of freshwater fishery biology. Iowa State University Press, Ames. Page 752.

Carlander, K. D. 1977. Handbook of freshwater fishery biology, Vol. 2. Ames, IA: Iowa State University Press.

Carter, E. R .1954. An evaluation of nine types of commercial fishing gear in Kentucky Lake. Transaction of the Kentucky Academy of Science 15:56-80.

Cole, R. A., R. A. Deitner, R. J. Tafanelli, and G. A. Desmare. 1991. Habitat, fish community and stocking effects on channel catfish stock density, growth, and harvest in New Mexico warm-water reservoirs. Pages 79-91 *in* Warmwater Fisheries Symposium, Scottsdale AZ, General Tech. Rept., RM-207, Rocky Mountain Forest and Range Experiment Station, Forest Service, USDA, Fort Collins, CO.

Colombo, R. E., Q. E. Phelps, J. E. Garvey, R. C. Heidinger, and T. Stefanvage. 2008. Gear-specific population demographics of channel catfish in a large Midwestern river. North American Journal of Fisheries Management 28:241-246.

Dahl, K. 1909. The assessment of age and growth in fish. Internationale Revue der gesamten Hydrobiologie und Hydrographie 2.

Davis, J. 1959. Management of channel catfish in Kansas. University of Kansas Museum of Natural History, Miscellaneous Publications 21:56.

Deacon, J. E. 1961. Fish population following a drought in the Noesha and Marais des Cygnes Rivers of Kansas. University of Kansas Museum of Natural History, Miscellaneous Publications 13:359-427.

Dudash, M., and R. C. Heidinger. 1996. Comparative survival and growth of various size channel catfish stocked into a lake containing largemouth bass. Transactions of the Illinois State Academy of Science 89:105-111.

Durham, B. W., K. L. Pope, and G. R. Wilde. 2005. Factors affecting regional variation in growth of channel catfish. North American Journal of Fisheries Management 25:93-97.

Edds, D. R., W. J. Matthews, and F. P. Gelwick. 2002. Resource use by large catfishes in a reservoir: Is there evidence for interactive segregation and innate differences. Journal of Fish Biology 60:1-12.

Evans, N. T., D. E. Shoup, and K. E. Kuklinski. 2011. Comparison of electrofishing and experimental gill nets for sampling size structure and relative abundance of Blue Catfish in reservoirs. Pages 599-606 *in* P. H. Michaletz and V. H. Travnichek, editors. Conservation, ecology, and management catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

FAO (Food and Agriculture Organization of the United Nations). 2003. Yearbook of fisheries statistics: capture and production, volume 9611. FAO, Rome.

Finnell, J. C., and R. M. Jenkins. 1954. Growth of channel catfish in Oklahoma waters. Oklahoma Fish Research Laboratory Report. 41:37.

Fischer, S. A., S. E. Stephen, and E. D. Aragon. 1999. Movements and habitat use of channel catfish and blue catfish in small impoundments in Missouri. American Fisheries Society Symposium 24:239-255.

Flammang, M. K., and R. D. Schultz. 2007. Evaluation of hoop- net size and bait selection for sampling channel catfish in Iowa impoundments. North American Journal of Fisheries Management 27:512-518.

Flammang, M. K., R. D. Schultz, and D. N. Cashatt. 2011. Utility of tandem hoop nets for indexing channel catfish structure and growth. American Fisheries Society Symposium 77:545-555.

Gabelhouse, D. W., Jr. 1984. A length-categorization system to assess fish stocks. North American Journal of Fisheries Management 4:273-285.

Geibel, G. E., and P. J. Murray. 1961. Channel catfish in California. Progressive Fish Culturist. 23(3):99-105.

Gerhardt, D. R., and W. A. Hubert. 1989. Effect of cheese bait on seasonal catches of channel catfish in hoop nets. North American Journal of Fisheries Management 9:377-379.

Guy, C. S., R. M. Neumann, D. W. Willis, and R. O. Anderson. 2007. Proportional size distribution (PSD): A further refinement of population size structure index terminology. Fisheries 32(7):348.

Hall, G. E., and R. M. Jenkins. 1952. The rate of growth of channel catfish, *Ictalurus punctatus*, in Oklahoma waters. Proceedings of the Oklahoma Academy of Science 33:121-129.

Hanson, W. D. 1986. An evaluation of catfish populations which are maintained by annual stocking. Missouri Department of Conservation, Federal Aid in Sport Fish Restoration, Project F-1-R-34, Study I-23, Job 2, Final Report, Jefferson City.

Harlan, J. R., and E. B. Speaker. 1956. Iowa fish and fishing. Iowa State Conservation Commission. Page 377.

Harrison, H. M. 1954. An estimation of the population of channel catfish in the Humbolt area with notes on the hoop net as a sampling instrument. Pages 21-25 *in* Iowa Conservation Commission quarterly biology report. Iowa Conservation Commission, Des Moines.

Hayes, D. B., W. W. Taylor, and P. A. Soranno. 1999. Natural lakes and large impoundments. Pages 589-622 *in* C.C. Kohler and W.A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland, USA.

Heidinger, R. C. 2000. Commercial harvest and history of major freshwater finfish species. Pages 209-252 *in* R. E. Martin, E. P. Carter, G. J. Fhik, and L. M. Davis, editors. Marine and freshwater products handbook. Technomic Publishing, Lancaster, Pennsylvania.

Heidinger, R. C., D. R. Helms, T. I. Heibert, and P. H. Howe. 1983. Operational comparison of three electrofishing systems. North American Journal of Fisheries Management 3:254-243.

Helms, D. R. 1973. Progress report from the first year study of sub legal sized channel catfish on the Mississippi River. Iowa Conservation Commission, Des Moines.

Helms, D. R. 1975. Variations in the abundance of channel catfish year classes in the Upper Mississippi River and causative factors. Iowa Conservation Commission, Technical Series 75(1):31

Hesse, L. W., C. R. Wallace, and L. Lehman. 1976. Fishes of the channelized Missouri: Age growth, length frequency, length-weight, coefficient of condition, catch curves and mortality of 25 species of channelized Missouri River fishes. Report to Nebraska Game and Park Commission, Project Number NEB F-004-R, Lincoln.

Hill, K. 1984. Classification of Iowa lakes and their fish standing stock. Iowa Conservation Commission, Federal Aid in Sport Fish Restoration, Completion Report F-90-R, Des Moines.

Holland, R. S., and E. J. Peters. 1992. Differential catch by hoop nets of three mesh sizes in the lower Platte River. North American Journal of Fisheries Management 12:237-243.

Holland-Bartels, L. E., and M. C. Duval. 1988. Variations in abundance of young-of-the year channel catfish in a navigation pool of the upper Mississippi River. Transactions of the American Fisheries Society 117(2):202-208.

Howell, M. H., and R. K. Betsill. 1999. Evaluation of different sizes of advanced channel catfish fingerlings stocked in small Texas impoundments. Pages 461-465 *in* Irwin et al. (1999).

Hubert, W. A. 1996. Passive capture techniques. Pages 157-192 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Hubert, W. A. 1999a. Standards for assessment of age and growth data for channel catfish. Journal of Freshwater Ecology 14:313-326.

Hubert, W. A. 1999b. Biology and management of channel catfish. Pages 3-22 *in* W.A. Hubert, C. F. Rabeni, H. L. Schram, and T. Coon, editors. Catfish 2000: Proceedings of the International Ictalurid Symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Hubert, W. A., and D. N. Schmitt. 1982. Factors influencing hoop net catches in channel habitats of Pool 9, Upper Mississippi River. Proceedings of the Iowa Academy of Science 89:84-88.

Jackson, D. C. 2004. Natural history and fisheries. Pages 15-35 *in* C. S. Tucker and J. A. Hargreaves, editors. Biology and Culture of Channel Catfish. Elsevier, Amsterdam.

Jackson, J. R., and D. C. Jackson. 1999. Macrohabitat use by catfishes in a Southern United States floodplain-river ecosystem. American Fisheries Society Symposium 24:215-222.

Jacobs, K. E., and W. D. Swink. 1982. Estimations of fish population size and sampling efficiency of electrofishing and rotenone in two Kentucky tailwaters. North American Journal of Fisheries Management 2:239-248.

Justus, B. 1994. Observations on electrofishing techniques for three catfish species in Mississippi. Proceedings of Annual Conference South-eastern Association of Fish and Wildlife Agencies 48:524-532.

Keith, W. E. 1971. Culture, stocking, and management of catfish in Arkansas. Proceedings of North Central Warm-water Fish Culture Management Workshop. Cooperative Fisheries Unit, Iowa State University. Page 5. (mimeograph).

Kilambi, R. V., J. Noble, and C. E. Hoffman. 1971. Influence of temperature and photoperiod on growth, food consumption and food conversion efficiency of channel efficiency of channel catfish. Proceedings of Annual Conference South eastern Association of Game and Fish Commissioners 24(1970):519-531.

Kitchell, J. F., D. J. Stewart, and D. Weininger. 1977. Applications of a bioenergetics model to yellow perch (*Perca flavescens*) and walleye (*Stizostedion vitreum*). Journal of the Fisheries Research Board of Canada 34:1922-1935.

Krummrich, J. T., and R. C. Heidinger. 1973. Vulnerability of channel catfish to largemouth bass predation. Progressive Fish-Culturist 35(3):173-175.

Kuklinski, K. E., and J. Boxrucker. 2008. Catfish angling and harvest statistics with an emphasis on trophy blue catfish management in Oklahoma. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 62:149-153.

Kwak, T. J., M. T. Porath, P.H. Michaletz, and V.H. Travnichek. 2010. Catfish science: Status and trends in the 21st century. Pages 755-780 *in* P. H. Michaletz and V. H. Travnichek. Conservation, Ecology, and Management of Catfish: The Second International Symposium. American Fisheries Society. Bethesda, Maryland.

Lawler, R. E. 1960. Observation of the life history of channel catfish, *Ictalurus puntctatus* (Rafinesque), in Utah Lake, Utah. Master's Thesis, Utah State University, Logan. Page 69.

Lea, E. 1910. On the methods used in the herring-investigations. Publications de Circon stance, Conseil Permanent International pour l'Exploration de la Mer. No. 53.

Marzolf, R. G. 1955. Use of pectoral spines and vertebrae for determining age and rate of growth of the channel catfish. Journal of Wildlife Management 19:243-249.

Marzolf, R. G. 1957. The reproduction of channel catfish in Missouri ponds. Journal of Wildlife Management 21(1):22-28.

Mayhew, J. K. 1969. Age and growth of flathead catfish in the Des Moines River, Iowa. Transactions of the American Fisheries Society 98:118-120.

Mayhew, J. K. 1972. Some biological characteristics of a channel catfish population in the lower Des Moines River with an evaluation of potential commercial harvest. Iowa Conservation Commission, Technical Series 72-2, Des Moines.

Mayhew, J. K. 1973. Variations in the catch of channel catfish and carp in baited hoop nets. Proceedings of Iowa Academy of Science 80:136-139.

Mayhew, J. K., and L. R. Mitzner. 1969. Commercial fisheries investigations: A report on the third-year of studies at the Des Moines River and Coralville Reservoir. Iowa Conservation Commission, Des Moines.

Michaels, R., and P. Williamson. 1982. An evaluation of techniques for capturing channel catfish from the Altamaha River. Georgia Department of Natural Resource, Game, and Fish Division, Federal Aid in Sport Fish Restoration, Project F-29-9, Final Report, Atlanta.

Michaletz, P. H. 1998. Population characteristics of gizzard shad in Missouri reservoirs and their relation to reservoir productivity, mean depth, and sport fish growth. North American Journal of Fisheries Management 18(1):114-123.

Michaletz, P. H. 2001. Evaluation of channel catfish sampling methods in small impoundments. Missouri Department of Conservation, Federal Aid in Sport Fish Restoration, Project F-1-50, Study I-36, Job 1, Final Report, Jefferson City.

Michaletz, P. H. 2005. Does pectoral spine extraction cause mortality to channel catfish? North American Journal of Fisheries Management 25:533-535.

Michaletz, P. H. 2009. Variable responses of channel catfish populations to stocking rate: Density-dependent and lake productivity effects. North American Journal of Fisheries Management 29(1):177-188.

Michaletz, P. H., and J. G. Dillard. 1999. A survey of catfish management in the United States and Canada. Fisheries 24(8):6-11.

Michaletz, P. H., and K. P. Sullivan. 2002. Sampling channel catfish with tandem hoop nets in small impoundments. North American Journal of Fisheries Management 22:870-878.

Michaletz, P. H., K. E. Doisy, and C. F. Rabeni. 2005. Influences of productivity, vegetation, and fish on macroinvertebrate abundance size in Midwestern USA impoundment. Hydrobiologia 543:147-157.

Miranda, L. E., and P. W. Bettoli. 2007. Mortality. Pages 229-277 *in* C. S. Guy and M. L. Brown, editors. Analysis and Interpretation of Freshwater Fisheries Data. American Fisheries Society, Bethesda, Maryland.

Mitzner, L. 1989. Assessment of maintenance stocked channel catfish in Iowa lakes. Iowa Department of Natural Resources, Federal Aid in Fish Restoration, Project F-94-R-8, Completion Report, Des Moines.

Mitzner, L. 1990. Assessment of maintenance-stocked channel catfish in Iowa lakes. Iowa Department of Natural Resources. Project F-94-R, Study 6, Job 1-4, Final Report. Des Moines, Iowa.

Mitzner, L. 1991. Effect of environmental variables upon crappie young, year-class strength, and the sport fishery. North American Journal of Fisheries Management 11:534-542.

Mitzner, L. 1999. Assessment of maintenance-stocked channel catfish populations in Iowa lakes. Pages 467-474 *in* Irwin et al. (1999).

Mosher, T. D. 1999. Characteristics of channel catfish in Kansas state fishing lakes: Effects of watershed on growth. Pages 353-360 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. S. Jr, and T. Coon. Catfish 2000: Proceedings of the International Ictalurid Symposium. American Fisheries Society, Bethesda, Maryland.

Muncy, R. J. 1959. Age and growth of channel catfish from the Des Moines River, Boone County, Iowa, 1955 and 1956. Iowa State Journal of Science 34:127-137.

Nash, M. K., and E. R. Irwin. 1999. Use of otoliths versus pectoral spines for aging adult flathead catfish. American Fisheries Society Symposium 24:309-316.

Neely, B. C., and S. C. Dumont. 2011. Effect of soak duration on precision of channel catfish catch with baited, tandem hoop nets. American Fisheries Society Symposium 77:557-561.

Nickum, J. G. 1976. Personal communication. Aquaculture Program, Cornell University.

Olive, J. A. 2004. Lower Ouachita River catfish study. Arkansas Game and Fish Commission, Project Completion Report, Federal Aid in Sportfish Restoration Grant F-68, Camden.

Olive, J., H. L. Schramm Jr., P. D. Gerard, and E. Irwin. 2011. An evaluation of agreement between pectoral spines and otoliths for estimating ages of catfishes. American Fisheries Society Symposium 77:679-688.

Olive, J., J. Barnett, J. Miller, B. Batten, and J. Quinn. 2015. Arkansas catfish management plan- 2^{nd} edition. Arkansas Catfish Plan.

Paukert, C. P., D. W. Willis, and J. A. Klammer. 2002. Effects of predation and environment and quality of yellow perch and bluegill populations in Nebraska sandhill lakes. North American Journal of Fisheries Management 22:86-95.

Pierce, R. B., D. W. Coble, and S. Corley. 1981. Fish catches in baited and unbaited hoop nets in the upper Mississippi River. North American Journal of Fisheries Management 1:204-206.

Porath, M. T., L. D. Pape, L. K. Richters, K. L. Pope, and M. A. Pegg. 2011. Influence of throat configuration and fish density on escapement of channel catfish from hoop nets. American Fisheries Society Symposium 77:563-571.

Pugibet, E. E., and D. C. Jackson. 1991. Sampling flathead catfish in small streams. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 43(1989):133-137.

Putman, J. H., C. L. Pierce, and D. M. Day. 1995. Relationship between environmental variables and size specific growth rates of Illinois stream fishes. Transactions of the American Fisheries Society 124:252-261.

Quist, M. C., C. S. Guy, and J. L. Stephen. 2003. Recruitment dynamics of walleyes (*Stizostedion vitreum*) in Kansas reservoirs: generalities with natural systems and effects of a centrarchid predator. Canadian Journal of Fisheries and Aquatic Sciences 60(7):830-839.

Rachels, R. T., and K. W. Ashley. 2002. Comparison of 3 electrofishing gear types used to capture catfish. Proceedings of the Southeastern Association of Fish and Wildlife Agencies 56:44-54.

Rasband, W. Image J. Version 1.48. Research Services Branch, National Institute of Mental Health, Bethesda, Maryland, USA.

Reitz, R. A., and V. H. Travnichek. 2006. Examining the relationship between species preference and catfish angler demographics, angling behavior, and management opinions. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 60:145-151.

Reynolds, J. B. 1996. Electrofishing. Pages 221-254 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society. Bethesda, Maryland.

Richters, L. K., and K. L. Pope. 2011. Catch of channel catfish with tandem-set hoop nets and gill nets in lentic systems of Nebraska. 77:573-580 *in* P.H. Michaletz and V.H. Travnichek, editors. Conservation, Ecology, and Management of Catfish: The Second International Symposium. American Fisheries Society Symposium 77, Bethesda, Maryland.

Robinson, J. W. 1994. Sampling procedures to capture flat head catfish and channel catfish in the Missouri and Mississippi Rivers. Missouri Department of Conservation, Sport Fish Restoration Project F-I-R-43, Study S-30, Job I, Final Report, Columbia.

Robinson, M. S. 1999. Evaluation of three gear types for sampling channel catfish in small impoundments. Pages 265-269 *in* E. R. Irwin, W. A. Hubert, C. F. Rabeni, H. L. Schramm, Jr., and T. Coon, editors. Catfish 2000: Proceedings of the International Ictalurid Symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Rutherford, D. A., W. E. Kelso, C. F. Bryan, and G. C. Constant. 1995. Influence of physicochemical characteristics on annual growth increments of four fishes from the lower Mississippi River. Transactions of the American Fisheries Society 124:687-697.

Santucci, V. J., D. H. Wahl, and T. W. Storck. 1994. Growth, mortality, harvest, and cost-effectiveness of stocked channel catfish in a small impoundment. North American Journal of Fisheries Management 14:781-789.

Santucci, V. J., Jr., D. H. Wahl, and D. F. Clapp. 1999. Efficiency and selectivity of sampling methods used to collect channel catfish in impoundments. Pages 317-328 *in* Irwin et al. (1999).

SAS Institute Inc. 2011. Base SAS® 9.3 Procedures Guide. Cary, NC: SAS Institute Inc.

Shipman, T. S. 1977. Spawning biology of channel catfish *Ictalurus puntatus* (Rafinesque) in Willard Bay Reservoir, Utah. All Graduate Thesis and Dissertation. Paper 3400. http;//digitalcommns.usu.edu/etd/3400

Shoup, D. E., S. P. Callahan, D. H. Wahl, and C. L. Pierce. 2007. Size-specific growth of bluegill, largemouth bass and channel catfish in relation to prey availability and limnological variables. Journal of Fish Biology 70(1):21-34.

Sigler, W. F., and R. B. Miller. 1963. Fishes of Utah. Utah State Department of Fish and Game. Salt Lake City. Page 203.

Slipke, J. W., and M. J. Maceina. 2014. Fishery analysis and modeling simulator (FAMS). Version 1.64. American Fisheries Society, Bethesda, Maryland.

Sneed, K. E. 1951. A method for calculating the growth of channel catfish, *Ictalurus lacustris punctatus*. Transactions of the American Fisheries Society 80:174-183.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry. Freeman, New York.

Stevens, T. M. 2013. Feeding ecology and factors influencing growth and recruitment of channel catfish in South Dakota reservoirs. Master's Thesis. South Dakota State University.

Stevenson, F., and R. E. Day. 1986. An evaluation of channel catfish populations in Ohio impoundments. Ohio Department of Natural Resources, Federal Aid in Sport Fish Restoration, Project F-29-R-20 to R-25, Study 14, Final Report, Columbus.

Stickney, R. R. 1971. Intensive catfish fingerling production. American Fish Farmer June, 1971. Pages 9-13.

Stopha, M. E. 1994. Hoop and mesh size influences on hoop net catches of buffalofishes (Catostomidae) and catfish (Ictaluridae) in the Upper Yazoo River basin of north central Mississippi. Master's Thesis. Mississippi State University, Mississippi State.

Sullivan, K. P., and C. M. Gale. 1999. A comparison of channel catfish catch rates, size distributions, and mortalities using three different gears in a Missouri impoundment. American Fisheries Society Symposium 24:293-300.

Tomcko, C. M., and Pierce, R. B. 2001. The relationship of bluegill growth, lake morphometry, and water quality in Minnesota. Transactions of the American Fisheries Society 130:317-321.

Turner, P. R. 1982. Procedures for age determination and growth rate calculations of flathead catfish. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 34:253-262.

U.S. Department of the Interior, U.S. Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau. 2011. National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

Van Eeckhout, G. 1974. Movement, reproduction, and ecological relationships of channel catfish, *Ictalurus punctatus* (Rafinesque), in the Little Missouri River, North Dakota, 1972-1973. Master's Thesis, No. Dakota University p.71

Vokoun, J. C., and C. F. Rabeni. 1999. Catfish sampling in rivers and streams: A review of strategies, gears and methods. Pages 271-286 *in* E.R. Irwin, W.A. Hubert, C. F. Rabeni, H.L. Schramm Jr., and T. Coon, editors. Catfish 2000: Proceedings of the International Ictalurid Symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Vokoun, J. C., and C. F. Rabeni. 2001. A standardized sampling protocol for channel catfish in prairie streams. North American Journal of Fisheries Management 21:188-197.

von Bertalanffy, L. 1951. Theoretische Biologie, Zweiter Band: Stowechsel, Wachstum. A Francke AG Verlag, Bern, Switzerland. Page 418.

Weeks, J. P. 1972. Producing catfish fingerlings. Cooperative Extension Service Auburn University. Page 18. (mimeograph).

Weithman, A. S. 1991. Recreational use and economic value of Missouri fisheries. Missouri Department of Conservation, Federal Aid in Sportfish Restoration, Project F-1 R-40, Study SI-1, Final Report, Jefferson City.

Wellborn Jr., T. L. 1984. Farm pond management. Managing Mississippi ponds and small lakes: A landowner's guide.

Wilde, G. R. 1995. Gill net sample size requirements for temperate basses, shads, and catfishes. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 47(1993):588-595.

Wildhaber, M. L., V. M. Tabor, J. E. Whitaker, A. L. Allert, D. W. Mulhern, P. J. Lamberson, and K. L. Powell. 2000. Ictalurid populations in relation to the presence of a main-stem reservoir in a Midwestern warmwater stream with emphasis on the threatened Neosho Madtom. Transactions of the American Fisheries Society 129:1264-1280.

Winemiller, K. O., S. Tarim, D. Shormann, and J. B. Cotner. 2000. Fish assemblage structure in relation to environmental variation among Brazos River oxbow lakes. Transactions of the American Fisheries Society 129:451-468.

Yeh, C. F. 1977. Relative selectivity of fishing gear used in a large reservoir in Texas. Transactions of the American Fisheries Society 106:309-313.

Table 2.1. - Characteristics of sampled reservoirs.

Reservoir Characteristics					
Reservoir	Reservoir Type	Size (ha)	Substrate	Major Fish Species	Daily Channel Catfish Bag Limit
Overcup	Shallow	415	Silt	Channel Catfish, Crappie, Largemouth Bass, Bluegill	10
Erling	Shallow	2,833	Sand, Silt, Clay	Channel Catfish, Crappie, Largemouth Bass, Bluegill, Redear Sunfish	10
Columbia	Shallow	1,214	Sand, Silt, Clay	Channel Catfish, Flathead Catfish, Crappie, Largemouth Bass, Bluegill, Pickerel, Gar, Bowfin	10
Nimrod	Deep	1,437	Sand, Silt, Gravel, Cobble, Boulder	Channel Catfish, Crappie, Largemouth Bass, Bluegill	10
Catherine	Deep	785	Sand, Silt, Gravel, Cobble, Boulder	Channel Catfish, Flathead Catfish, Crappie, Largemouth Bass, Walleye, Sauger, Saugeye, Bluegill	10
De Queen	Deep	680	Sand, Silt, Clay, Gravel, Cobble, Boulder	Channel Catfish, Crappie, Largemouth Bass, Bluegill, Walleye, Spotted Bass, Hybrid Striped Bass	10

Table 2.2a. – Relative abundance (number of fish) of individual species each month while sampling Channel Catfish in each reservoir during the month of April 2014.

	Catch Composition					
Species	Catherine	De Queen	Nimrod	Columbia	Erling	Overcup
Ictalurus punctatus	47	1	132	33	2070	75
Pylodictis olivaris	0	0	0	1	1	0
Ictalurus furcatus	0	0	0	0	0	0
Pomoxis annularis	9	0	390	0	-[a]	137
Pomoxis nigromaculatus	7	0	81	0	-[a]	29
Lepomis macrochirus	287	-[a]	763	-[a]	-[a]	352
Micropterus punctulatus	1	-[a]	0	-[a]	-[a]	0
Micropterus dolomieu	0	-[a]	0	-[a]	-[a]	0
Morone chrysops	1	-[a]	2	-[a]	-[a]	4
Lepisosteus oculatus	0	-[a]	0	-[a]	-[a]	1
Moxostoma carinatum	11	-[a]	0	-[a]	-[a]	0
Lepomis gulosus	0	-[a]	11	-[a]	-[a]	5
Ictiobus bubalus	0	-[a]	1	-[a]	-[a]	0
Sander vitreus	0	-[a]	0	-[a]	-[a]	0
Lepomis cyanellus	3	-[a]	7	-[a]	-[a]	1
Micropterus salmoides	0	-[a]	0	-[a]	-[a]	0
Lepomis microlophus	2	-[a]	7	-[a]	-[a]	7
Lepomis megalotis	53	-[a]	101	-[a]	-[a]	0
Morone mississippiensis	16	-[a]	0	-[a]	-[a]	0
Ameiurus natalis	0	-[a]	0	-[a]	-[a]	0

[a] Number of individuals were not obtained.

Table 2.2b. – Relative abundance (number of fish) of individual species each month while sampling Channel Catfish in each reservoir during the month of May 2014.

	Catch Composition					
Species	Catherine	De Queen	Nimrod	Columbia	Erling	Overcup
Ictalurus punctatus	26	144	165	380	5695	815
Pylodictis olivaris	2	1	0	1	0	2
Ictalurus furcatus	0	0	0	0	0	0
Pomoxis annularis	8	0	18	0	-[a]	2
Pomoxis nigromaculatus	0	59	27	0	-[a]	6
Lepomis macrochirus	252	-[a]	14	-[a]	-[a]	105
Micropterus punctulatus	0	-[a]	0	-[a]	-[a]	1
Micropterus dolomieu	1	-[a]	0	-[a]	-[a]	0
Morone chrysops	0	-[a]	0	-[a]	-[a]	0
Lepisosteus oculatus	0	-[a]	0	-[a]	-[a]	1
Moxostoma carinatum	7	-[a]	0	-[a]	-[a]	0
Lepomis gulosus	0	-[a]	2	-[a]	-[a]	0
Ictiobus bubalus	0	-[a]	0	-[a]	-[a]	0
Sander vitreus	3	-[a]	0	-[a]	-[a]	0
Lepomis cyanellus	5	-[a]	0	-[a]	-[a]	0
Micropterus salmoides	0	-[a]	0	-[a]	-[a]	0
Lepomis microlophus	13	-[a]	0	-[a]	-[a]	3
Lepomis megalotis	62	-[a]	6	-[a]	-[a]	0
Morone mississippiensis	1	-[a]	0	-[a]	-[a]	0
Ameiurus natalis	2	-[a]	0	-[a]	-[a]	0

[a] Number of individuals were not obtained.

Table 2.2c. – Relative abundance (number of fish) of individual species each month while sampling Channel Catfish in each reservoir during the month of June 2014.

Catch Composition						
Species	Catherine	De Queen	Nimrod	Columbia	Erling	Overcup
Ictalurus punctatus	106	112	822	140	3157	436
Pylodictis olivaris	1	1	0	2	0	1
Ictalurus furcatus	0	0	0	0	0	0
Pomoxis annularis	8	0	14	0	-[a]	4
Pomoxis nigromaculatus	3	0	4	0	-[a]	12
Lepomis macrochirus	85	-[a]	143	-[a]	-[a]	186
Micropterus punctulatus	0	-[a]	3	-[a]	-[a]	0
Micropterus dolomieu	0	-[a]	0	-[a]	-[a]	0
Morone chrysops	0	-[a]	0	-[a]	-[a]	0
Lepisosteus oculatus	0	-[a]	0	-[a]	-[a]	2
Moxostoma carinatum	24	-[a]	0	-[a]	-[a]	0
Lepomis gulosus	2	-[a]	2	-[a]	-[a]	1
Ictiobus bubalus	0	-[a]	0	-[a]	-[a]	0
Sander vitreus	2	-[a]	0	-[a]	-[a]	0
Lepomis cyanellus	3	-[a]	0	-[a]	-[a]	1
Micropterus salmoides	0	-[a]	0	-[a]	-[a]	0
Lepomis microlophus	8	-[a]	2	-[a]	-[a]	7
Lepomis megalotis	44	-[a]	30	-[a]	-[a]	0
Morone mississippiensis	0	-[a]	0	-[a]	-[a]	0
Ameiurus natalis	0	-[a]	0	-[a]	-[a]	0

[a] Number of individuals were not obtained.

Table 2.3a. – Percent composition of individual species each month while sampling Channel Catfish in each reservoir during the month of April 2014.

	Catch Composition					
Species	Catherine	De Queen	Nimrod	Columbia	Erling	Overcup
Ictalurus punctatus	10.8%	100.0%	8.8%	97.1%	100.0%	12.3%
Pylodictis olivaris	0.0%	0.0%	0.0%	2.9%	0.0%	0.0%
Ictalurus furcatus	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pomoxis annularis	2.1%	0.0%	26.1%	0.0%	-[a]	22.4%
Pomoxis nigromaculatus	1.6%	0.0%	5.4%	0.0%	-[a]	4.7%
Lepomis macrochirus	65.7%	-[a]	51.0%	-[a]	-[a]	57.6%
Micropterus punctulatus	0.2%	-[a]	0.0%	-[a]	-[a]	0.0%
Micropterus dolomieu	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%
Morone chrysops	0.2%	-[a]	0.1%	-[a]	-[a]	0.7%
Lepisosteus oculatus	0.0%	-[a]	0.0%	-[a]	-[a]	0.2%
Moxostoma carinatum	2.5%	-[a]	0.0%	-[a]	-[a]	0.0%
Lepomis gulosus	0.0%	-[a]	0.7%	-[a]	-[a]	0.8%
Ictiobus bubalus	0.0%	-[a]	0.1%	-[a]	-[a]	0.0%
Sander vitreus	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%
Lepomis cyanellus	0.7%	-[a]	0.5%	-[a]	-[a]	0.2%
Micropterus salmoides	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%
Lepomis microlophus	0.5%	-[a]	0.5%	-[a]	-[a]	1.1%
Lepomis megalotis	12.1%	-[a]	6.8%	-[a]	-[a]	0.0%
Morone mississippiensis	3.7%	-[a]	0.0%	-[a]	-[a]	0.0%
Ameiurus natalis	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%

[a] Number of individuals were not obtained.

Table 2.3b. – Percent composition of individual species each month while sampling Channel Catfish in each reservoir during the month of May 2014.

	Catch Composition					
Species	Catherine	De Queen	Nimrod	Columbia	Erling	Overcup
Ictalurus punctatus	6.8%	70.6%	71.1%	99.7%	100.0%	87.2%
Pylodictis olivaris	0.5%	0.5%	0.0%	0.3%	0.0%	0.2%
Ictalurus furcatus	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pomoxis annularis	2.1%	0.0%	7.8%	0.0%	-[a]	0.2%
Pomoxis nigromaculatus	0.0%	28.9%	11.6%	0.0%	-[a]	0.6%
Lepomis macrochirus	66.0%	-[a]	6.0%	-[a]	-[a]	11.2%
Micropterus punctulatus	0.0%	-[a]	0.0%	-[a]	-[a]	0.1%
Micropterus dolomieu	0.3%	-[a]	0.0%	-[a]	-[a]	0.0%
Morone chrysops	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%
Lepisosteus oculatus	0.0%	-[a]	0.0%	-[a]	-[a]	0.1%
Moxostoma carinatum	1.8%	-[a]	0.0%	-[a]	-[a]	0.0%
Lepomis gulosus	0.0%	-[a]	0.9%	-[a]	-[a]	0.0%
Ictiobus bubalus	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%
Sander vitreus	0.8%	-[a]	0.0%	-[a]	-[a]	0.0%
Lepomis cyanellus	1.3%	-[a]	0.0%	-[a]	-[a]	0.0%
Micropterus salmoides	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%
Lepomis microlophus	3.4%	-[a]	0.0%	-[a]	-[a]	0.3%
Lepomis megalotis	16.2%	-[a]	2.6%	-[a]	-[a]	0.0%
Morone mississippiensis	0.3%	-[a]	0.0%	-[a]	-[a]	0.0%
Ameiurus natalis	0.5%	-[a]	0.0%	-[a]	-[a]	0.0%

[a] Number of individuals were not obtained.

Table 2.3c. – Percent composition of individual species each month while sampling Channel Catfish in each reservoir during the month of June 2014.

	Catch Composition					
Species	Catherine	De Queen	Nimrod	Columbia	Erling	Overcup
Ictalurus punctatus	37.1%	99.1%	80.6%	98.6%	100.0%	67.1%
Pylodictis olivaris	0.3%	0.9%	0.0%	1.4%	0.0%	0.2%
Ictalurus furcatus	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Pomoxis annularis	2.8%	0.0%	1.4%	0.0%	-[a]	0.6%
Pomoxis nigromaculatus	1.0%	0.0%	0.4%	0.0%	-[a]	1.8%
Lepomis macrochirus	29.7%	-[a]	14.0%	-[a]	-[a]	28.6%
Micropterus punctulatus	0.0%	-[a]	0.3%	-[a]	-[a]	0.0%
Micropterus dolomieu	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%
Morone chrysops	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%
Lepisosteus oculatus	0.0%	-[a]	0.0%	-[a]	-[a]	0.3%
Moxostoma carinatum	8.4%	-[a]	0.0%	-[a]	-[a]	0.0%
Lepomis gulosus	0.7%	-[a]	0.2%	-[a]	-[a]	0.2%
Ictiobus bubalus	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%
Sander vitreus	0.7%	-[a]	0.0%	-[a]	-[a]	0.0%
Lepomis cyanellus	1.0%	-[a]	0.0%	-[a]	-[a]	0.2%
Micropterus salmoides	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%
Lepomis microlophus	2.8%	-[a]	0.2%	-[a]	-[a]	1.1%
Lepomis megalotis	15.4%	-[a]	2.9%	-[a]	-[a]	0.0%
Morone mississippiensis	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%
Ameiurus natalis	0.0%	-[a]	0.0%	-[a]	-[a]	0.0%

[a] Number of individuals were not obtained.

Table 2.4. – Average reservoir water conditions and Channel Catfish relative abundance.

	Depth (m)		Temperature (^{0}C)		Dissolved oxygen (mg/L)		Turbidty (m)		CPUE [c]	
Reservoir	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
April										
Catherine [b]	1.4-3.1	2.4	12.7-20.2	16.7	9.5-12.3	10.8	0.7-2.0	1.2	0.0-15.0	2.9
Columbia [a]	1.2-2.8	2.2	17.0-22.0	20.4	n/a	n/a	1.0-2.4	1.7	0.0-10.0	2.1
DeQueen [b]	1.0-4.3	2.2	14.1-17.9	16.3	0.9-6.9	3.4	0.3-1.9	1.1	0.0-1.0	0.1
Erling [a]	1.7-2.6	1.9	16.0-17.6	16.9	na	na	0.6-1.1	0.7	45.0-231.0	129.4
Nimrod [b]	2.0-4.2	2.8	15.2-17.4	16.3	7.0-9.9	8.6	0.7-1.0	0.9	0.0-38.0	8.3
Overcup [a]	1.0-2.5	1.6	15.2-17.1	16.0	8.2-9.6	9.0	0.4-0.7	0.6	0.0-27.0	4.7
May										
Catherine [b]	1.2-3.5	2.1	15.4-21.7	17.5	8.0-11.9	10.8	0.6-2.8	1.3	0.0-7.0	1.9
Columbia [a]	1.2-2.4	1.9	22.0-25.0	23.8	n/a	n/a	1.2-1.9	1.6	1.0-52.0	23.8
DeQueen [b]	0.9-2.9	2.0	22.1-27.0	23.9	2.8-6.7	4.3	0.9-1.9	1.3	1.0-44.0	9.0
Erling [a]	1.3-2.5	1.8	19.4-24.8	23.1	2.3-6.9	4.6	0.6-0.8	0.6	122.0-580.0	355.9
Nimrod [b]	4.0-6.3	5.0	18.0-22.3	20.3	6.3-8.4	7.5	0.3-0.6	0.4	0.0-51.0	11.8
Overcup [a]	1.0-3.1	1.8	22.4-25.4	23.8	5.5-9.7	8.2	0.5-0.7	0.6	4.0-144.0	58.2
June										
Catherine [b]	1.4-2.9	2.3	16.8-27.1	21.8	8.8-12.8	10.4	0.4-1.5	1.0	0.0-24.0	6.6
Columbia [a]	1.6-3.0	2.3	29.0-30.0	29.3	n/a	n/a	1.2-1.7	1.5	0.0-41.0	8.8
DeQueen [b]	1.4-3.2	1.9	28.7-30.4	29.7	1.5-3.1	2.3	0.4-1.6	1.3	0.0-27.0	7.0
Erling [a]	0.9-2.5	1.7	26.7-28.7	27.6	1.1-3.4	2.5	0.4-0.8	0.6	47.0-380.0	197.3
Nimrod [b]	2.3-4.3	3.2	23.8-28.6	26.4	6.4-10.0	8.6	0.7-1.0	0.9	9.0-121.0	51.4
Overcup [a]	1.1-2.9	1.8	22.8-27.9	25.8	5.8-10.3	7.5	0.5-0.9	0.6	1.0-55.0	27.3

[a] Shallow reservoirs.

[b] Deep reservoirs

[c] Number of fish per tandem set.

Table 2.5. - Percent substrate composition of reservoirs sampled.

	Percent Composition				
Lake	Sand	Silt	Clay	Gravel	Other
Overcup[a]	0.0%	100.0%	0.0%	0.0%	0.0%
Nimrod	2.2%	44.6%	0.0%	3.3%	50.0%
Catherine	18.4%	27.2%	0.0%	27.2%	27.2%
Columbia[a]	8.3%	87.5%	4.4%	0.0%	0.0%
DeQueen	7.4%	41.9%	7.1%	21.4%	20.5%
Erling[a]	2.2%	56.5%	41.3%	0.0%	0.0%

[a] Shallow reservoirs.

Table 2.6. – Mean relative abundance (fish/net-set) for Channel Catfish sampled during May 2014.

		CPUE					
		Lower		Upper		Pooled	
Reservoir type	Reservoir	Mean	SD	Mean	SD	Mean	SD
Deep	Catherine	1.4	2.4	2.3	2.4	1.9	2.1
	De Queen	5.9	4.3	12.1	14.1	9.0	10.5
	Nimrod	6.4	8.5	17.1	17.4	11.8	14.3
	Pooled	4.6	10.4	10.5	11.6	7.5	10.9
Shallow	Columbia	22.1	17.9	25.4	17.9	23.8	17.8
	Erling	400.6	111.2	311.3	153.0	355.9	137.2
	Overcup	29.3	22.1	87.1	43.9	58.2	44.9
	Pooled	150.7	193.8	141.3	156.2	146.0	174.2
	Grand Mean	77.6	156.6	75.9	130.2	76.8	143.2

Table 2.7. – Comparison of Channel Catfish length frequency distributions among reservoirs by using Kolmogorov-Smirnov two-sample tests.

	Kolmogorov-smirnov two- sample test statistics											
	Nimrod		Columbia[a]		Catherine		DeQueen		Erling[a]		Overcup[a]	
Reservoir	Ksa	P<Ksa	Ksa	P<Ksa	Ksa	P<Ksa	Ksa	P<Ksa	Ksa	P<Ksa	Ksa	P<Ksa
Nimrod	-	-	8.95	<0.001	1.4	0.04	4.2	<0.001	11.11	<0.001	8.04	<0.001
Columbia[a]			-	-	6.34	<0.001	5.91	<0.001	17.14	<0.001	10.89	<0.001
Catherine					-	-	2.67	<0.001	4.24	<0.001	3.78	<0.001
DeQueen							-	-	8.75	<0.001	2.12	<0.001
Erling[a]									-	-	20.03	<0.001
Overcup[a]											-	-

[a] Shallow Reservoirs.

Table 2.8. - Channel Catfish proportional size distribution for each reservoir sampled during the year 2014.

	Proportional Size Distribution		
Reservoir	Standard	Preferred	Memorable
Overcup	48.0%	1.0%	0.0%
Erling	18.0%	0.0%	0.0%
Columbia	84.0%	20.0%	1.0%
Nimrod[a]	42.0%	4.0%	0.2%
Catherine[a]	38.0%	1.0%	0.0%
DeQueen[a]	58.0%	3.0%	0.0%

[a] Deep reservoirs.

Table 2.9. - Average length (mm) at age percentiles of Channel Catfish from sampled reservoirs (pooled; in **bold**) compared to Channel Catfish growth standards in reservoirs published by W. A. Hubert (1999a).

	Channel Catfish Growth Percentiles									
Age	Min		25th		50th		75th		Max	
2		**122**		**182**		**235**		**270**		**390**
3	172	**206**	211	**276**	238	**325**	282	**385**	331	**537**
4	217	**260**	268	**358**	291	**415**	332	**469**	396	**605**
5	240	**217**	307	**484**	341	**532**	386	**593**	476	**736**
6	291	**274**	353	**543**	386	**597**	429	**635**	537	**721**
7	303	**295**	388	**518**	434	**598**	479	**633**	596	**696**
8	331	**600**	417	**615**	469	**630**	513	**645**	620	**660**

Table 2.10. – Back-calculated lengths (mm) for Channel Catfish sampled from Lake Catherine during the spring of 2014.

			Back-calculated length at age						
Year class	Age	n	1	2	3	4	5	6	7
2013	1	5	116.43						
2012	2	33	117.87	237.54					
2011	3	35	88.06	197.63	309.66				
2010	4	22	110.64	201.18	326.88	422.67			
2009	5	10	84.18	164.05	261.27	385.75	469.61		
2008	6	3	139.13	241.64	304.22	403.25	455.81	508.37	
2007	7	1	107.24	191.76	271.55	365.75	486.22	544.87	619.92
		109 [a]	109.08 [b]	205.63 [b]	294.72 [b]	394.35 [b]	470.55 [b]	526.62 [b]	619.92 [b]

[a] Total number of individuals sampled.
[b] Mean back-calculated length.

Table 2.11. – Back-calculated lengths (mm) for Channel Catfish sampled from Lake Columbia during the spring of 2014.

			Back-calculated length at age						
Year class	Age	n	1	2	3	4	5	6	7
2012	2	31	130.52	249.74					
2011	3	61	117.85	222.61	309.75				
2010	4	37	144.92	246.67	371.21	485.76			
2009	5	35	145.68	244.55	365.14	488.99	570.64		
2008	6	3	100.20	168.11	241.41	348.24	462.45	554.50	
2007	7	2	122.72	318.57	368.71	408.80	483.95	541.72	581.03
		169 [a]	126.98 [b]	241.71 [b]	331.24 [b]	432.95 [b]	505.68 [b]	548.11 [b]	581.03 [b]

[a] Total number of individuals sampled.
[b] Mean back-calculated length.

Table 2.12. – Back-calculated lengths (mm) for Channel Catfish sampled from De Queen Lake during the spring of 2014.

			Back-calculated length at age						
Year class	Age	n	1	2	3	4	5	6	7
2013	1	5	150.93						
2012	2	21	92.42	180.17					
2011	3	42	119.61	228.88	339.29				
2010	4	33	119.57	241.93	350.10	443.26			
2009	5	8	111.04	182.68	328.72	439.45	508.49		
2008	6	5	101.34	199.70	305.11	414.77	479.92	540.66	
2007	7	1	111.09	132.46	290.19	382.98	449.21	508.31	603.85
		115 [a]	115.14 [b]	194.30 [b]	322.68 [b]	420.11 [b]	479.21 [b]	524.49 [b]	603.85 [b]

[a] Total number of individuals sampled.
[b] Mean back-calculated length.

Table 2.13. – Back-calculated lengths (mm) for Channel Catfish sampled from Lake Erling during the spring of 2014.

			Back-calculated length at age					
Year class	Age	n	1	2	3	4	5	6
2013	1	29	125.38					
2012	2	34	114.08	219.15				
2011	3	19	119.62	213.15	296.08			
2010	4	25	121.87	209.99	288.64	363.47		
2009	5	16	117.58	169.56	249.97	327.48	410.08	
2008	6	8	109.66	153.30	218.79	289.52	368.53	434.02
		131 [a]	118.03 [b]	193.03 [b]	263.37 [b]	326.82 [b]	389.30 [b]	434.02 [b]

[a] Total number of individuals sampled.
[b] Mean back-calculated length.

Table 2.14. – Back-calculated lengths (mm) for Channel Catfish sampled from Lake Nimrod during the spring of 2014.

			Back-calculated length at age							
Year class	Age	n	1	2	3	4	5	6	7	8
2013	1	13	141.69							
2012	2	31	131.46	257.55						
2011	3	42	123.42	244.79	352.23					
2010	4	23	130.83	265.08	383.24	454.69				
2009	5	19	193.91	300.05	389.53	466.54	516.63			
2008	6	17	191.63	316.69	406.10	476.05	541.52	595.39		
2007	7	11	195.98	294.41	374.14	448.24	518.04	574.94	638.17	
2006	8	1	104.90	221.46	321.99	407.04	469.14	506.47	590.07	653.99
		157 [a]	151.73 [b]	271.43 [b]	371.20 [b]	450.51 [b]	511.33 [b]	558.93 [b]	614.12 [b]	653.99 [b]

[a] Total number of individuals sampled.
[b] Mean back-calculated length.

Table 2.15. – Back-calculated lengths (mm) for Channel Catfish sampled from Lake Overcup during the spring of 2014.

			Back-calculated length at age							
Year class	Age	n	1	2	3	4	5	6	7	8
2013	1	23	138.32							
2012	2	44	122.90	227.18						
2011	3	38	105.53	241.15	392.68					
2010	4	29	101.08	183.48	365.75	476.71				
2009	5	12	113.06	204.64	330.16	458.80	545.33			
2008	6	7	106.43	196.51	346.47	456.05	538.03	590.84		
2006	8	1	105.69	159.34	236.20	342.70	403.11	464.50	494.63	561.17
		154 [a]	113.29 [b]	202.05 [b]	334.25 [b]	433.56 [b]	495.49 [b]	527.67 [b]	494.63 [b]	561.17 [b]

[a] Total number of individuals sampled.
[b] Mean back-calculated length.

Table 2.16. – Channel Catfish mean back-calculated (historic) and length at capture (current) growth coefficient (*k*), asymptotic length ($L\infty$), and time at 0 (t_0) for each reservoir sampled during the year 2014.

	Growth coefficient		Asymptotic length (mm)		Time at 0	
Reservoir	Historic	Current	Historic	Current	Historic	Current
Catherine	0.066	0.114	1658.1	1084.6	0.031	0.058
Columbia [a]	0.209	0.397	776.6	655.2	-0.181	-0.917
DeQueen	0.142	0.145	963.9	959.6	-0.189	-0.05
Erling [a]	0.101	0.262	924.7	556.4	0.343	-0.045
Nimrod	0.191	0.188	827.1	863.6	0.075	-0.09
Overcup [a]	0.329	0.378	607.1	637.2	-0.485	-0.48

[a] Shallow reservoirs.

Table 2.17. – Channel Catfish annual mortality for each reservoir sampled during the year 2014.

	Annual mortality	
Reservoir	Weighted [b]	Unweighted
Catherine	50%	57%
Columbia [a]	41%	48%
DeQueen	39%	45%
Erling [a]	56%	58%
Nimrod	52%	59%
Overcup [a]	70%	73%

[a] Shallow reservoirs.

[b] Percent annual mortality calculated with a correction for gear selectivity.

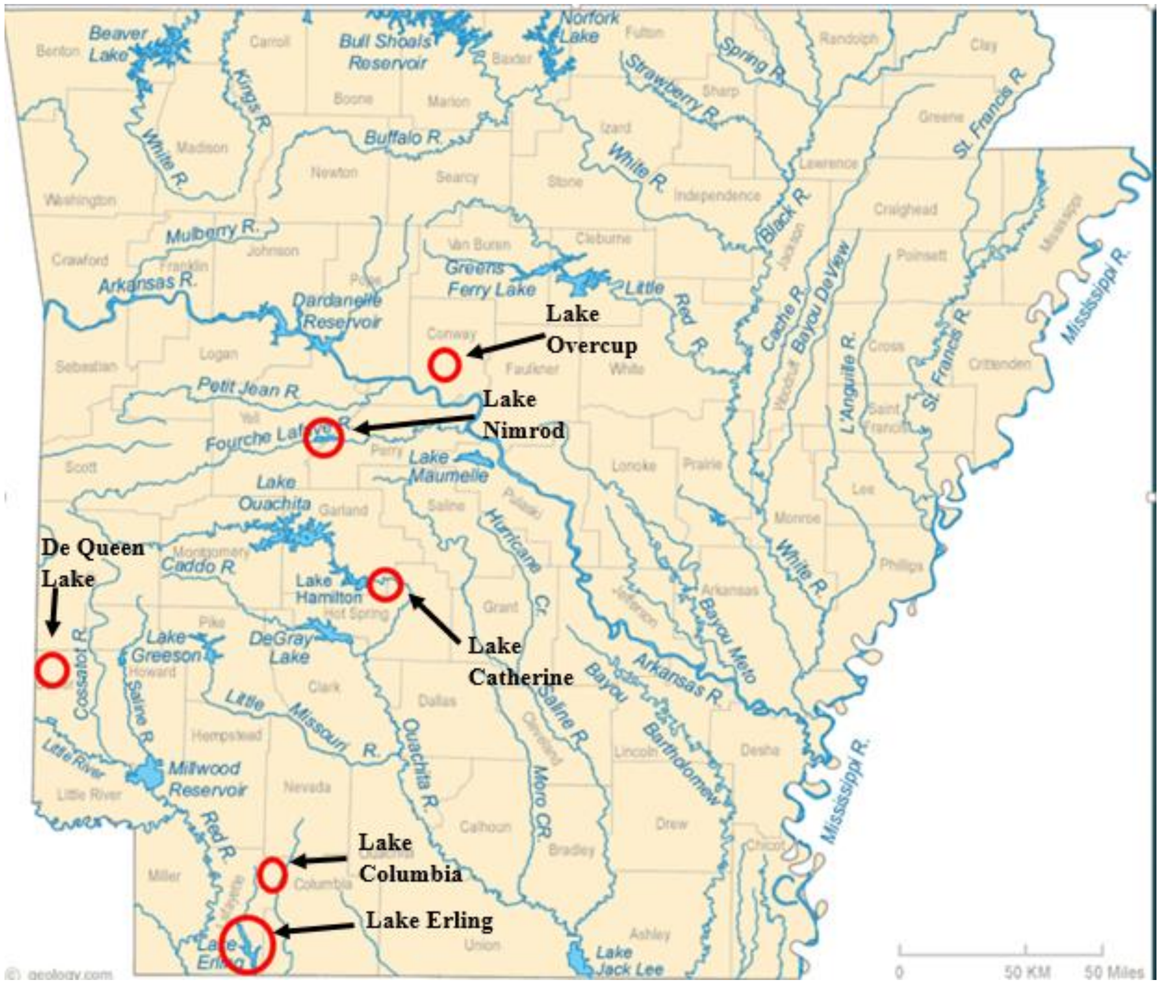

Figure 2.1. - Reservoirs sampled in the study to assess effective tandem hoop net sample size.

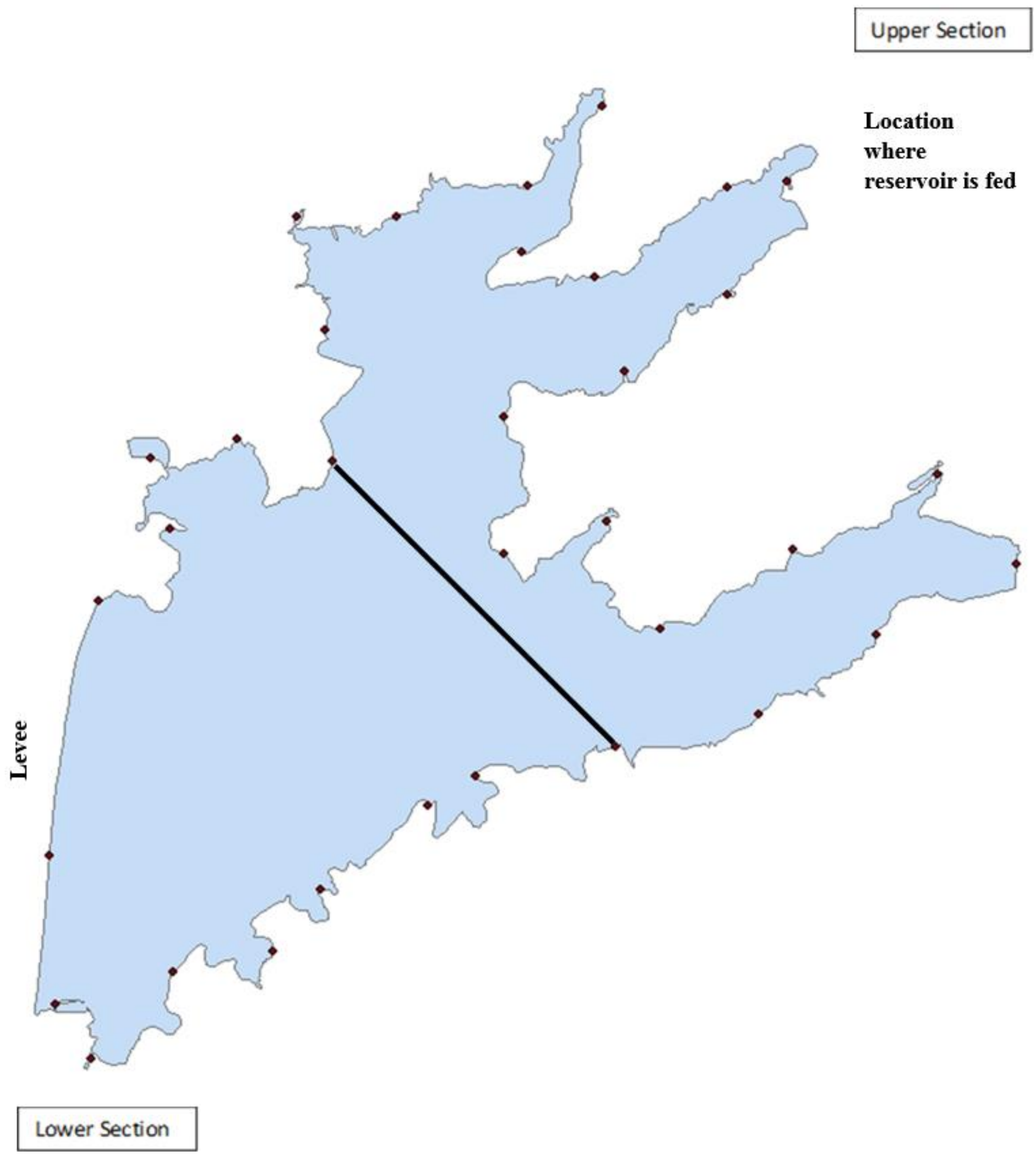

Figure 2.2. - A map of Lake Overcup demonstrating how the reservoirs in the study were divided to create a lower and upper section for sampling and analyses. The points labeled represent AGFC electrofishing markers that were used to randomly select tandem hoop net set locations.

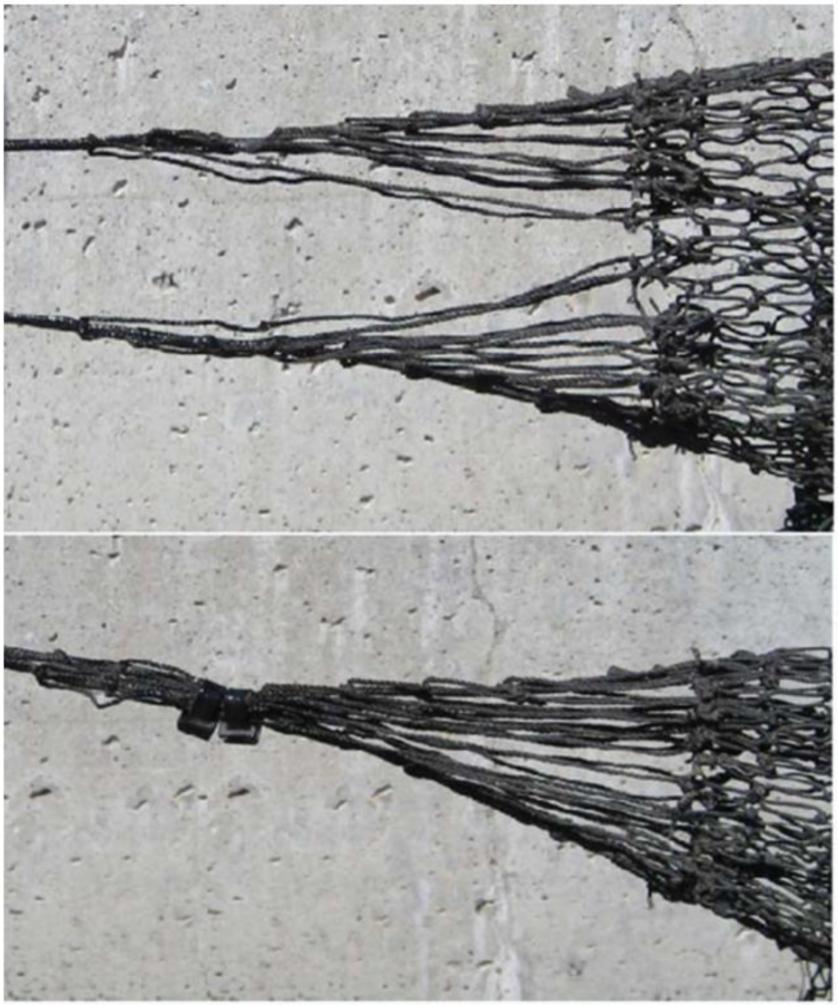

Figure 2.3. - Image from study performed by Flammang et al. (2011) showing where second cod end was restricted to reduce escapement of Channel Catfish.

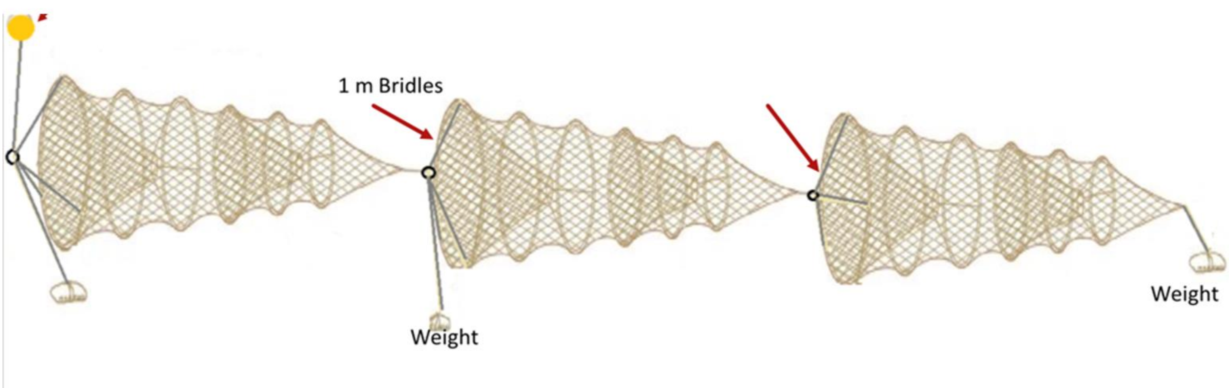

Figure 2.4. - A diagram demonstrating tandem hoop net configuration as described by Sullivan and Gale (1999).

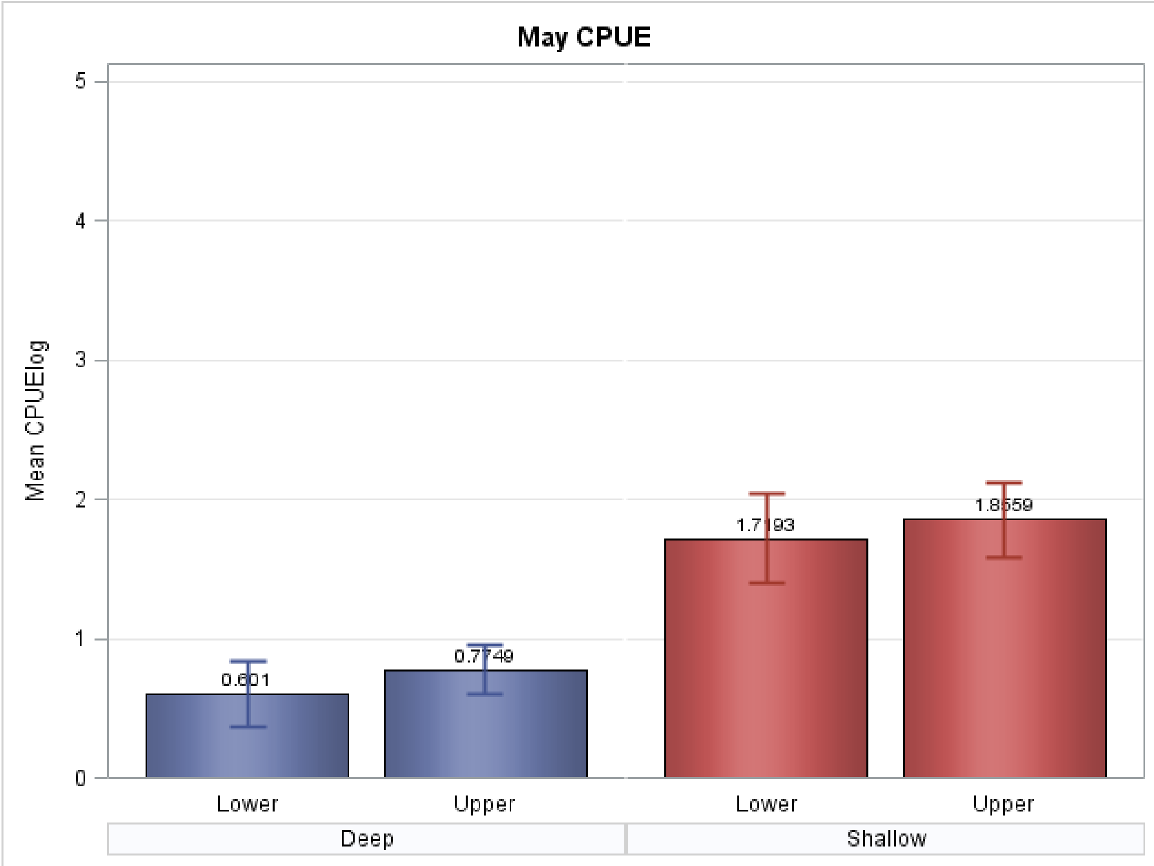

Figure 2.5. - Comparison of Channel Catfish CPUE for the month of May 2014 between deep and shallow reservoirs and their upper and lower sections.

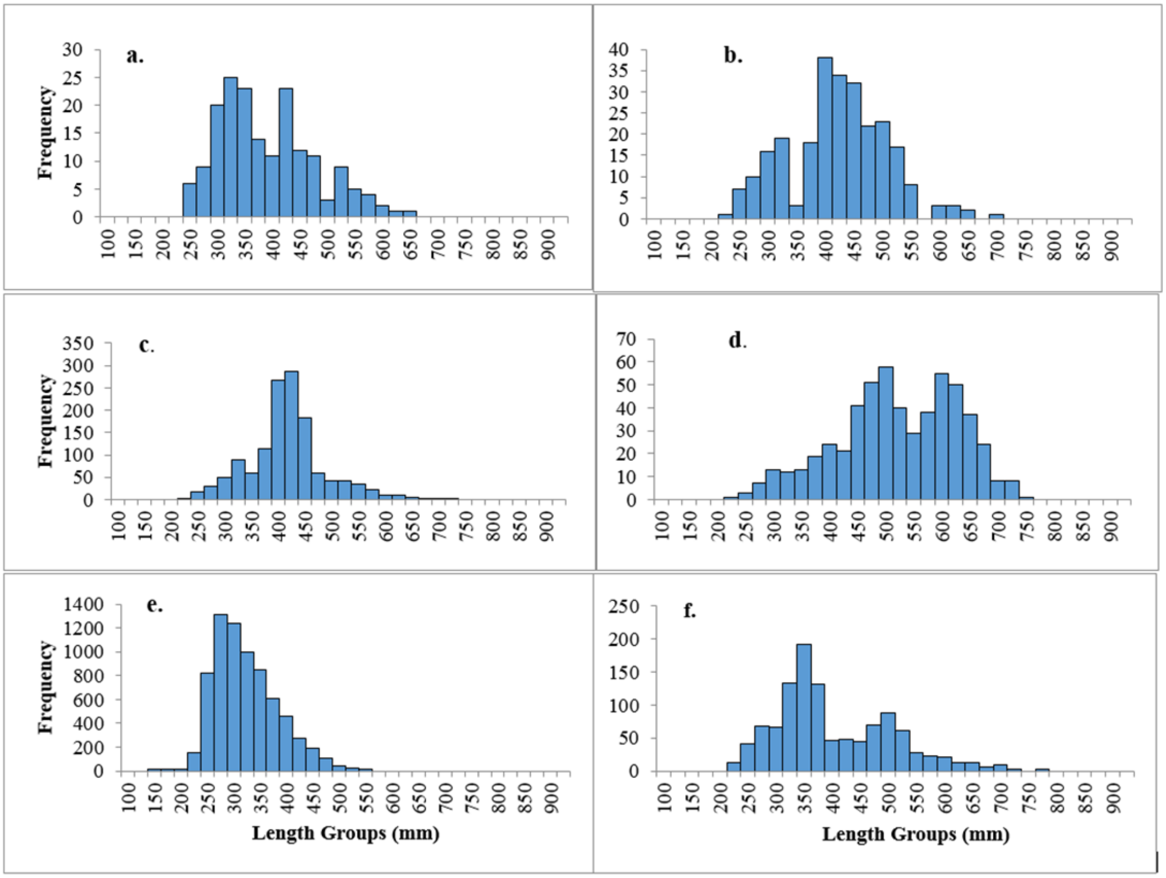

Figure 2.6. – Channel Catfish length frequency distributions (months pooled) for **(a)** Lake Catherine (n = 179), **(b)** De Queen Lake (n = 257), **(c)** Lake Overcup (n = 1,326), **(d)** Lake Columbia (n = 553), **(e)** Lake Erling (n = 7,100), and **(f)** Lake Nimrod (n = 1,119) during the spring of 2014.

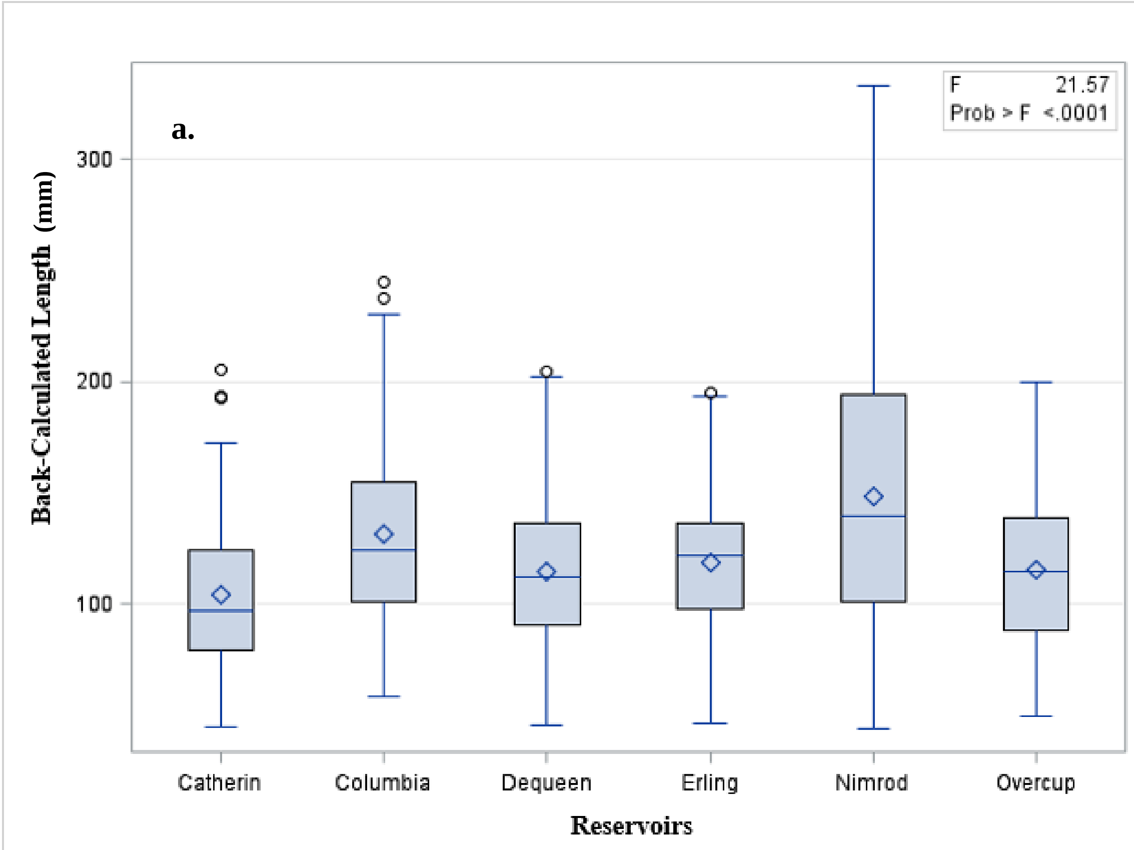

Figure 2.7a. - Comparison of mean back-calculated lengths for age 1 Channel Catfish among reservoirs sampled during the spring of 2014 by using box and whisker plots.

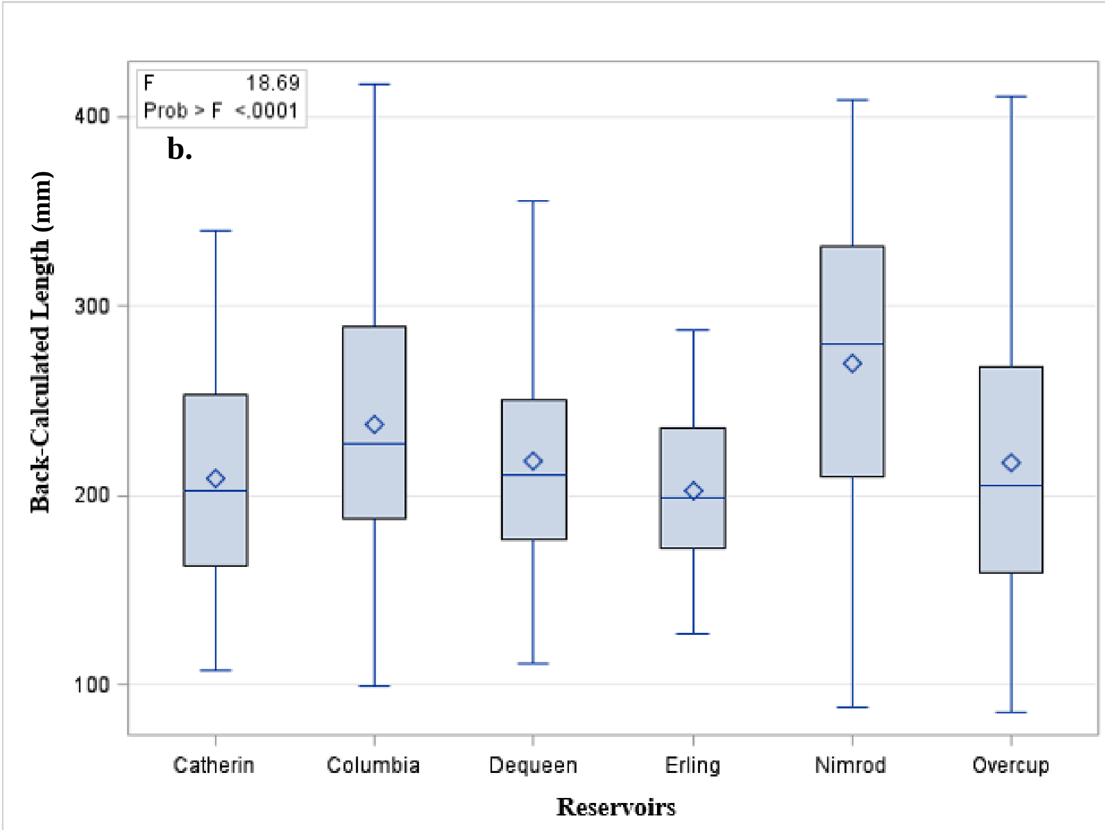

Figure 2.7b. - Comparison of mean back-calculated lengths for age 2 Channel Catfish among reservoirs sampled during the spring of 2014 by using box and whisker plots.

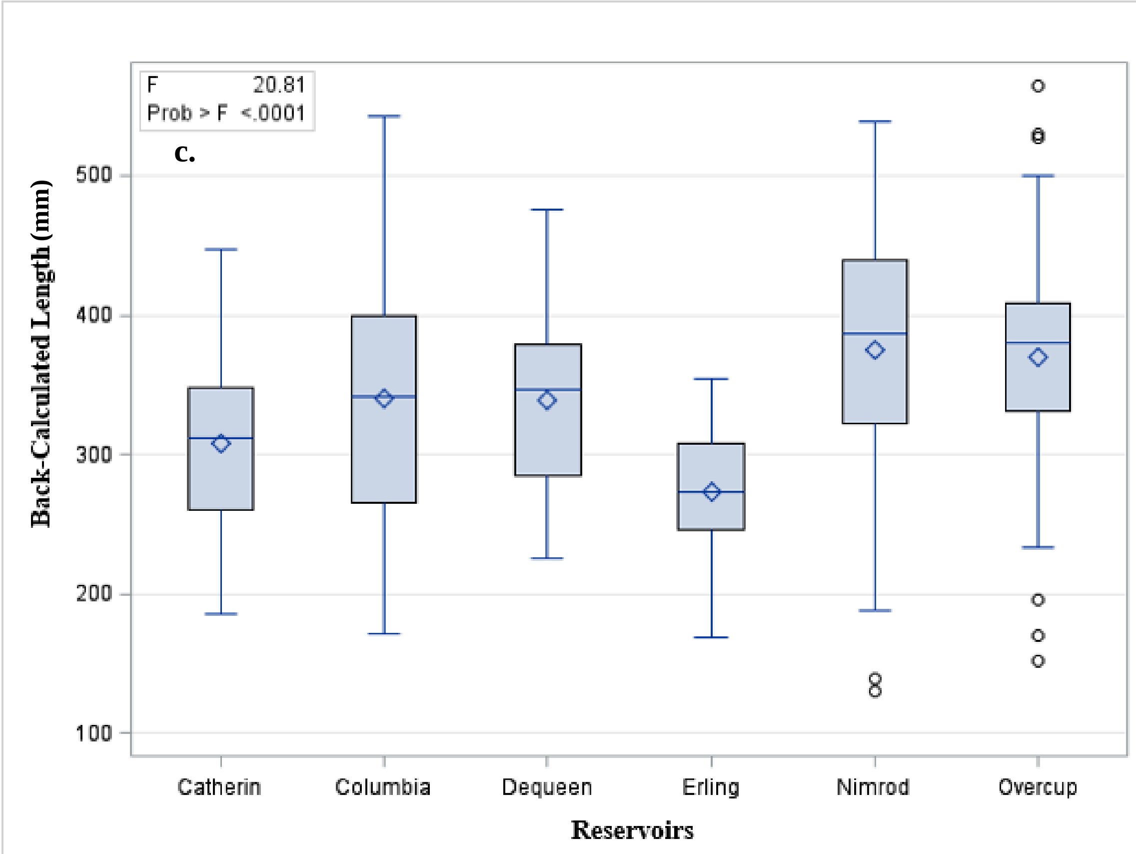

Figure 2.7c. - Comparison of mean back-calculated lengths for age 3 Channel Catfish among reservoirs sampled during the spring of 2014 by using box and whisker plots.

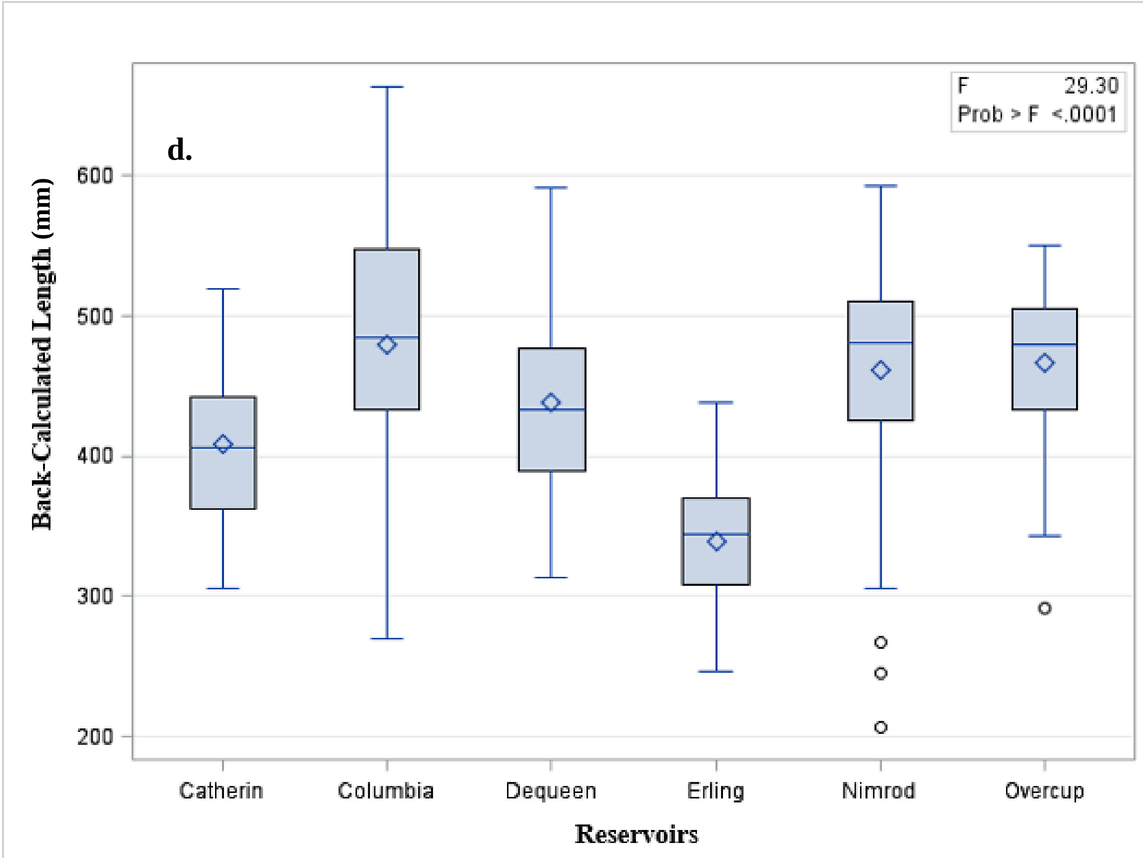

Figure 2.7d. - Comparison of mean back-calculated lengths for age 4 Channel Catfish among reservoirs sampled during the spring of 2014 by using box and whisker plots.

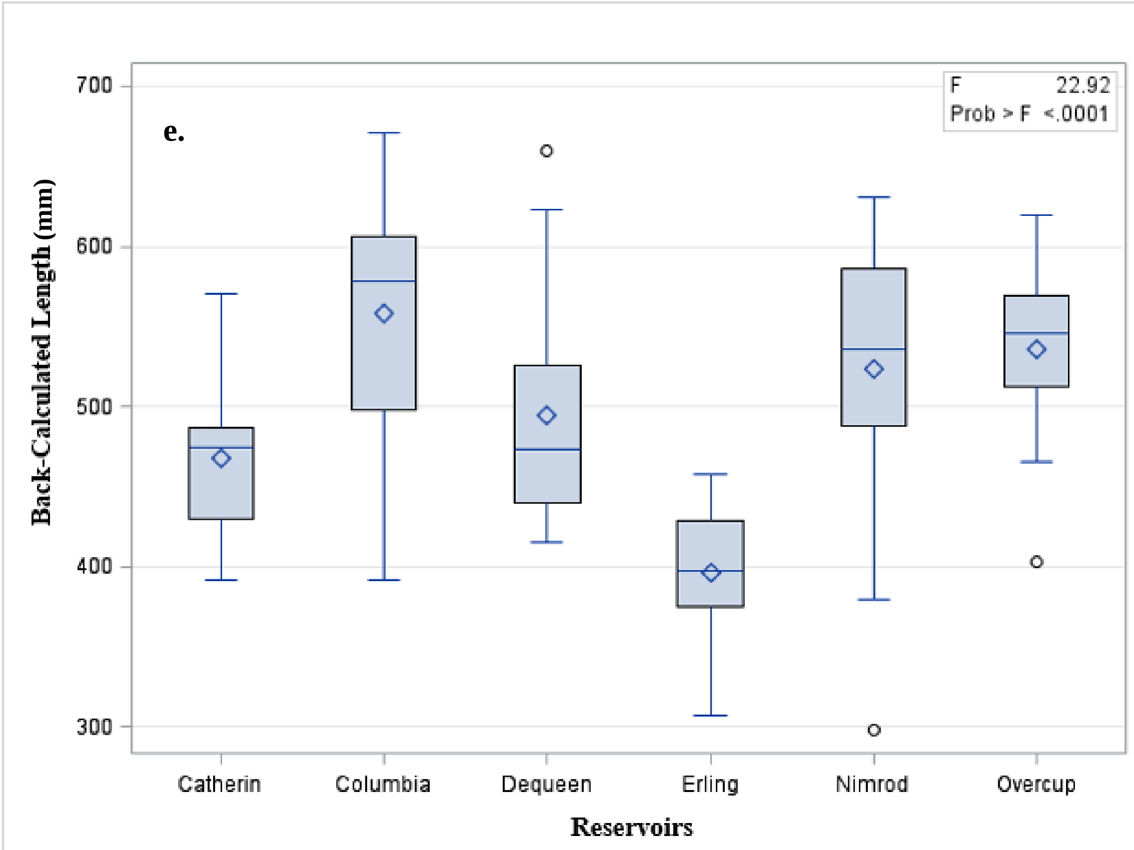

Figure 2.7e. - Comparison of mean back-calculated lengths for age 5 Channel Catfish among reservoirs sampled during the spring of 2014 by using box and whisker plots.

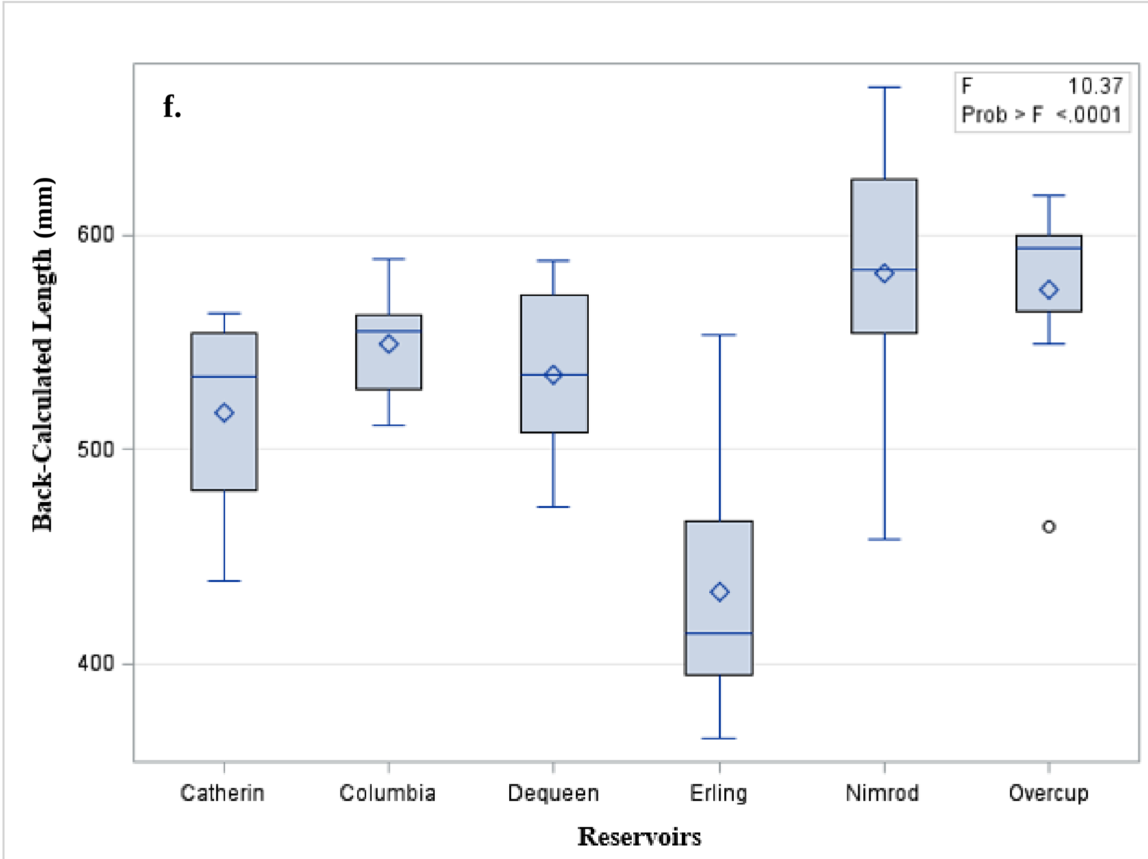

Figure 2.7f. - Comparison of mean back-calculated lengths for age 6 Channel Catfish among reservoirs sampled during the spring of 2014 by using box and whisker plots.

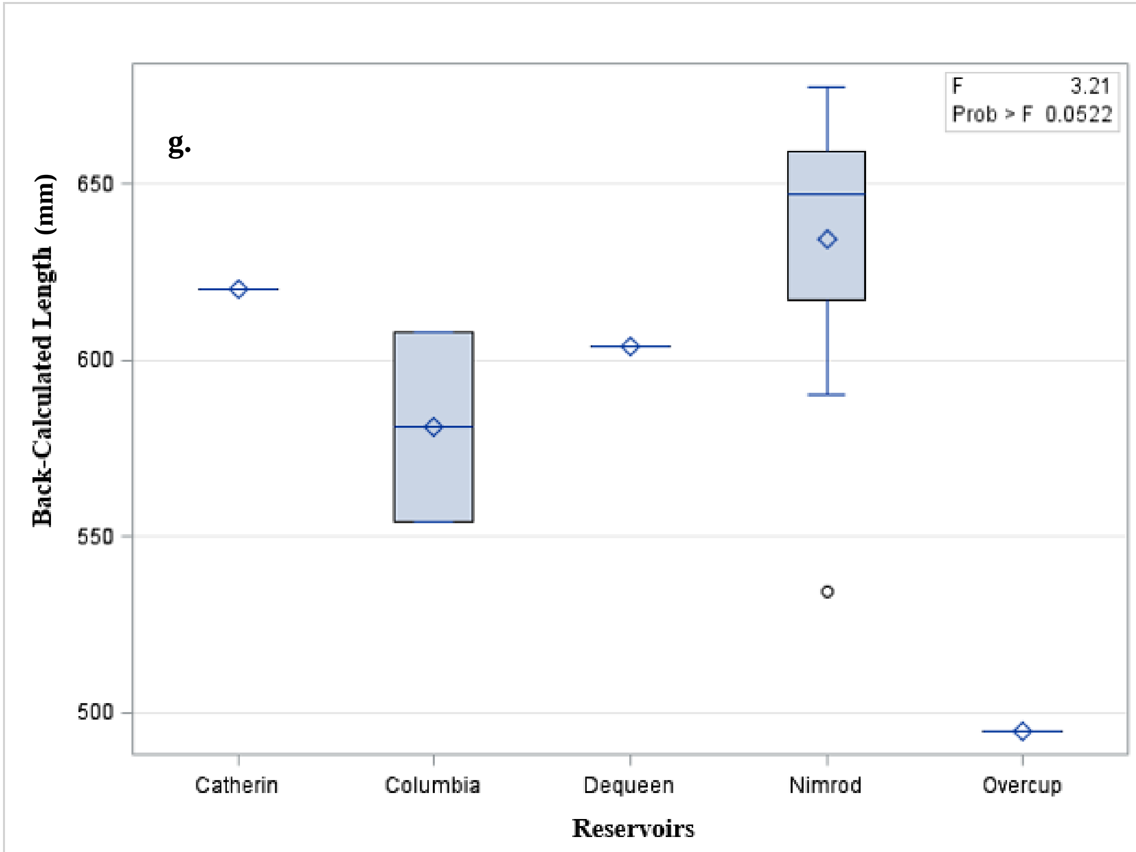

Figure 2.7g. - Comparison of mean back-calculated lengths for age 7 Channel Catfish among reservoirs sampled during the spring of 2014 by using box and whisker plots.

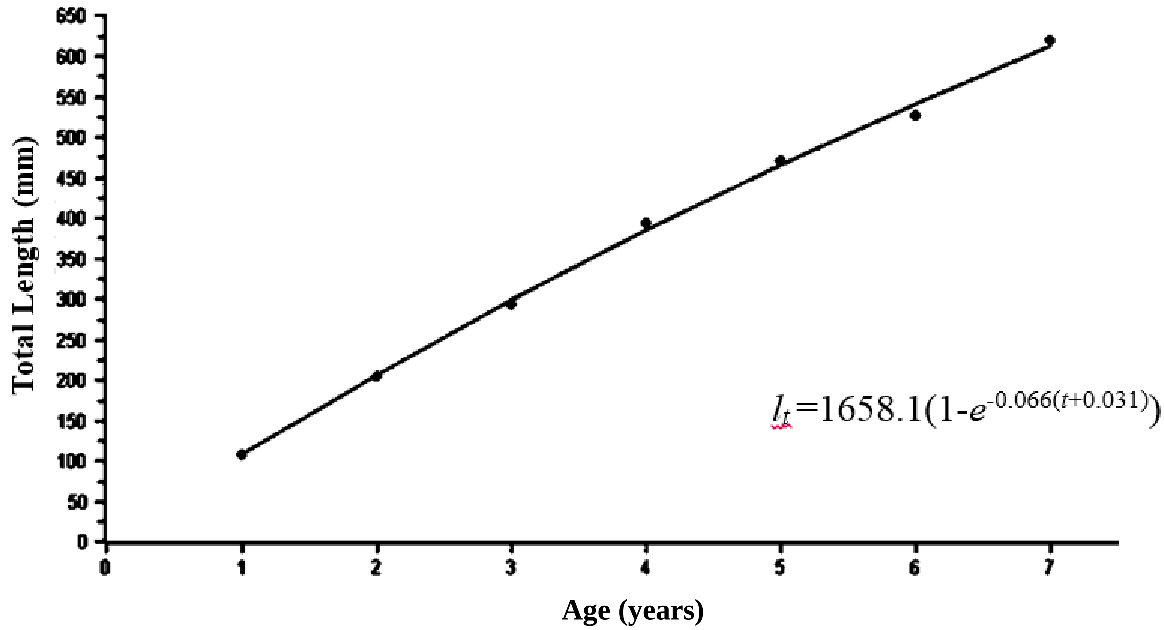

Figure 2.8. – Von Bertalanffy growth curve, calculated by using mean back-calculated length data, for Channel Catfish sampled in Lake Catherine, Arkansas, spring 2014.

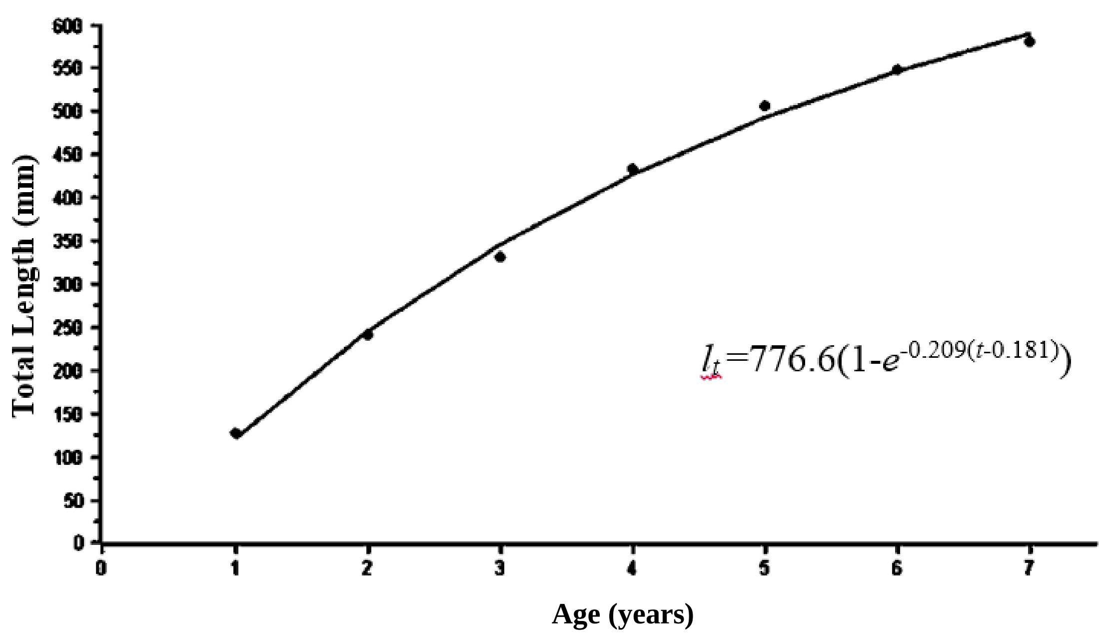

Figure 2.9. – Von Bertalanffy growth curve, calculated by using mean back-calculated length data, for Channel Catfish sampled in Lake Columbia, Arkansas, spring 2014.

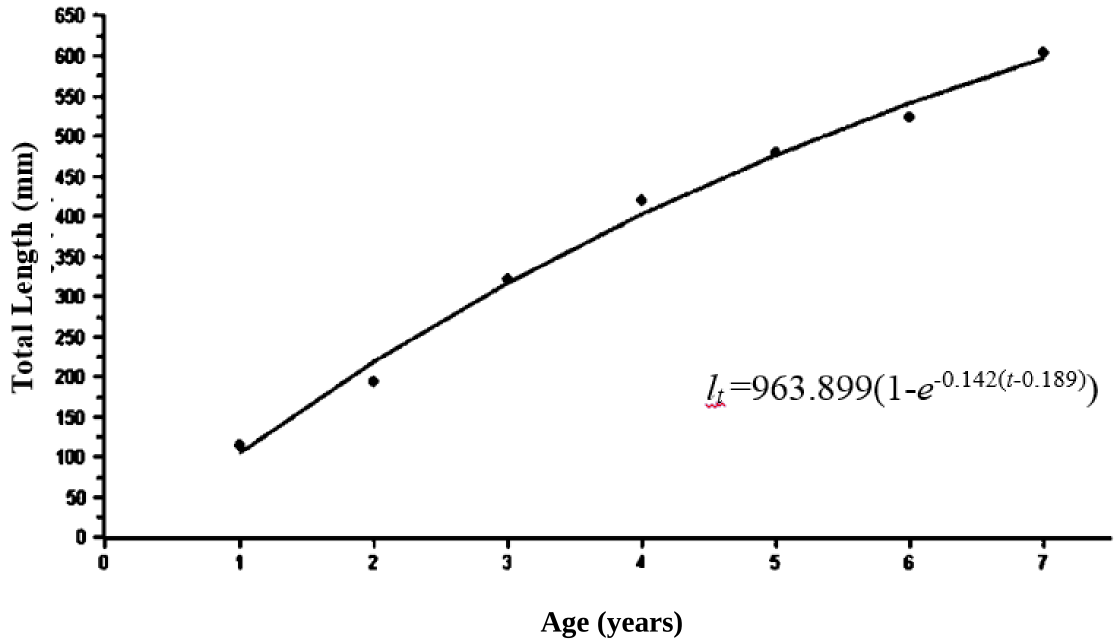

Figure 2.10. – Von Bertalanffy growth curve, calculated by using mean back-calculated length data, for Channel Catfish sampled in De Queen Lake, Arkansas, spring 2014.

Figure 2.11. – Von Bertalanffy growth curve, calculated by using mean back-calculated length data, for Channel Catfish sampled in Lake Erling, Arkansas, spring 2014.

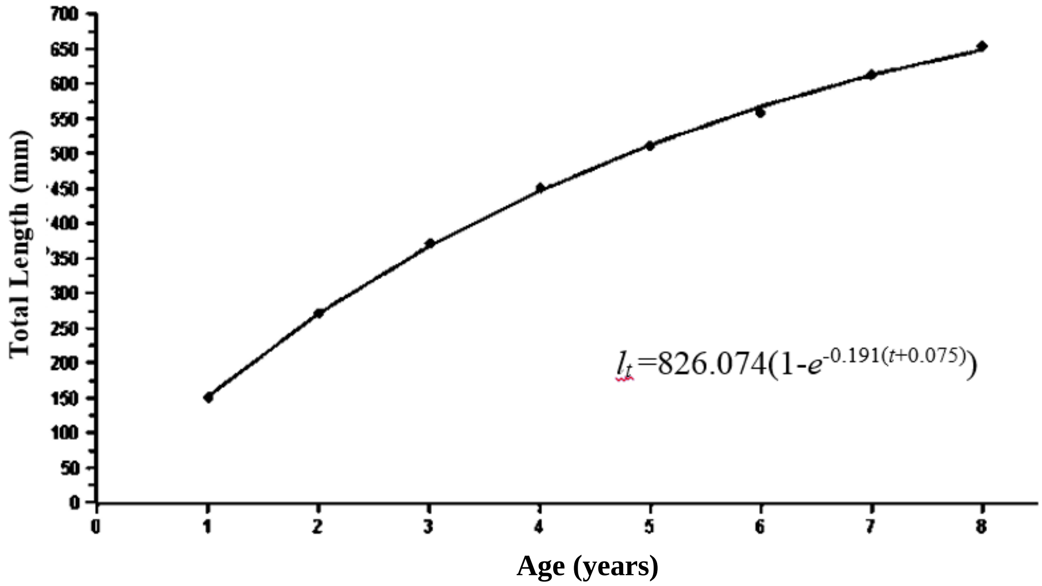

Figure 2.12. – Von Bertalanffy growth curve, calculated by using mean back-calculated length data, for Channel Catfish sampled in Lake Nimrod, Arkansas, spring 2014.

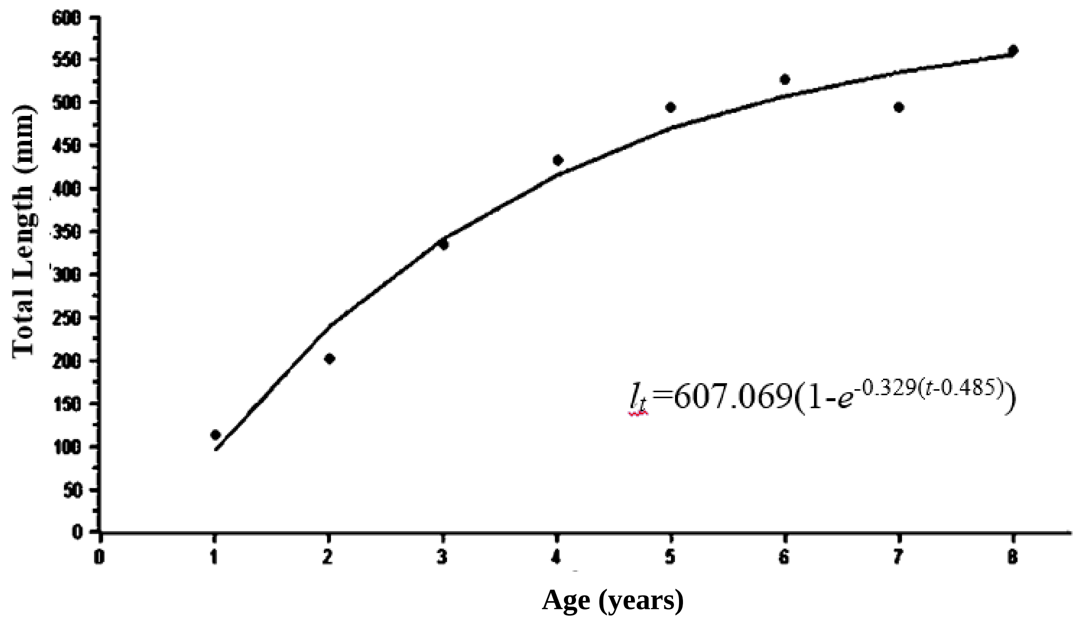

Figure 2.13. – Von Bertalanffy growth curve, calculated by using mean back-calculated length data, for Channel Catfish sampled in Lake Overcup, Arkansas, spring 2014.

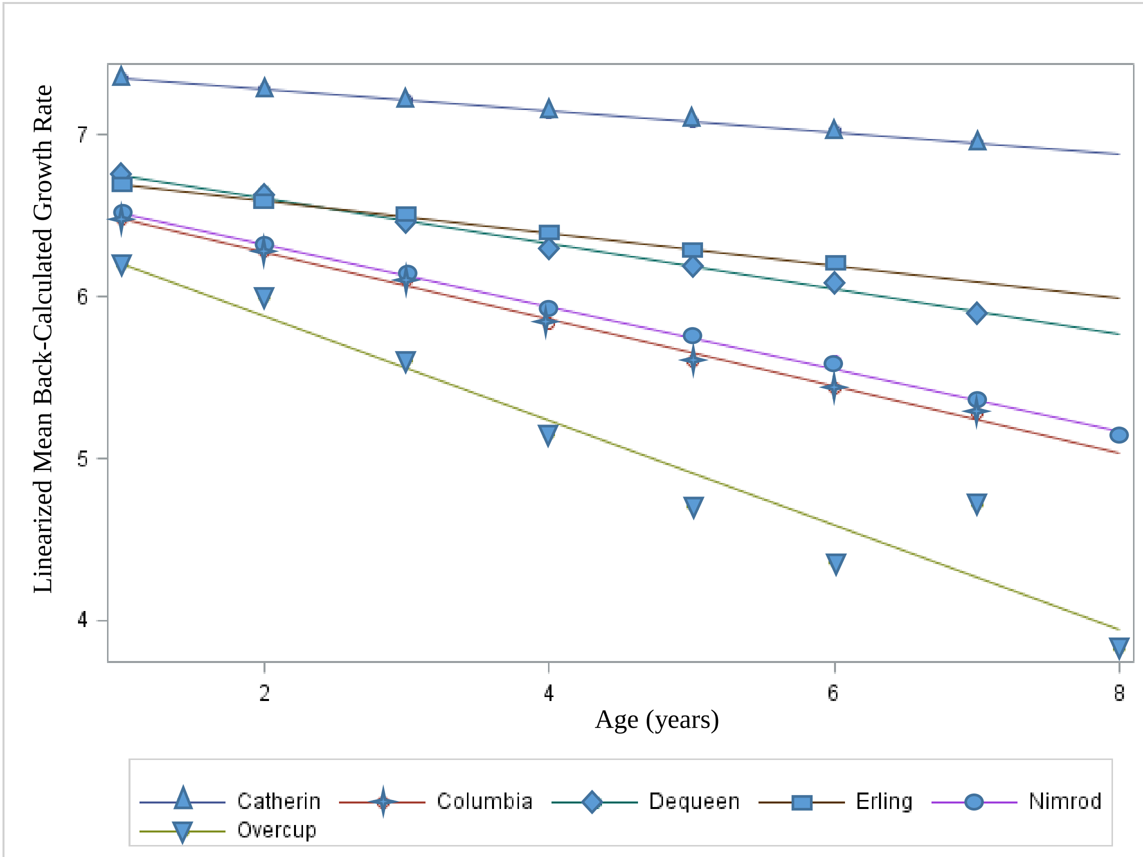

Figure 2.14. – Comparison of linearized mean back-calculated Channel Catfish growth rates (slope of the growth coefficient) derived from each reservoir.