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Sampling Efficiency, Population Characteristics, and Potential Impacts of Harvest Regulations on Three Riverine Species of Catfish

Zachary Adam Mitchell
Eastern Illinois University

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Sampling efficiency, population characteristics, and potential impacts of harvest regulations on three riverine species of Catfish

(TITLE)

BY

Zachary Adam Mitchell

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SAMPLING EFFICIENCY, POPULATION CHARACTERISTICS, AND POTENTIAL IMPACTS OF HARVEST REGULATIONS ON THREE RIVERINE SPECIES OF CATFISH

By

Zachary Adam Mitchell

B.S. Wildlife, Fisheries, and Aquaculture Science

Mississippi State University

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ABSTRACT

Catfish (family: Ictaluridae) are both commercially and recreationally important in North America. Catfish account for the majority of harvest by weight within many Midwestern states including Illinois. The Wabash River supports a substantial commercial and recreational fishery for three species of Catfish: Channel Catfish (*Ictalurus punctatus*), Flathead Catfish (*Pylodictis olivaris*), and Blue Catfish (*Ictalurus furcatus*). Knowledge of sampling efficiency and selectivity for gear types used for the collection of Catfish are needed to accurately describe population dynamics. Furthermore, the potential impacts of fishing regulations and exploitation on Catfish populations must be monitored to ensure sustainability of the fishery. This study characterizes the sampling efficiency, population characteristics, and potential impacts of minimum length limits on three riverine species of Catfish in the Wabash River. Catfish were collected throughout the lower 322-km of the Wabash River from 2014-2016. A multiple-gear approach was used to sample for catfish in order to accurately describe the populations. A total of 882 Catfish was collected comprising of 361 Channel Catfish, 427 Flathead Catfish, and 94 Blue Catfish. Low-frequency electrofishing, bank poles, and hoop nets sampled more Catfish compared to high-frequency electrofishing, trot lines, and gill nets ($P < 0.001$). Catfish were sampled in higher numbers during the spring and summer for all gears ($P < 0.05$), except high-frequency electrofishing ($P > 0.05$). All three species were in relatively good condition (Wr: 93-98). Mean annual mortality estimates for Channel (43%), Flathead (38%), and Blue Catfish (18%) were comparable to other populations. Yield-per-recruit models estimated that a 330-mm minimum length limit for Channel Catfish would produce a higher yield and number of fish harvested compared to the 381-mm minimum length limit. Conversely, Flathead Catfish are experiencing growth overfishing in the estimated ranges of exploitation. Blue Catfish may experience slight growth overfishing with a minimal increase in exploitation. Overall, low-frequency electrofishing, bank poles, and hoop nets were the most efficient gear at capturing Catfish. The most efficient sampling gears for Channel Catfish were hoop nets and bank poles fished in the spring, summer, or fall. Low-frequency electrofishing was the most efficient gear for Flathead Catfish, in the summer and fall, and for Blue Catfish in the spring. Channel and Blue Catfish populations are currently not exhibiting growth overfishing. A 525-mm MLL would prevent growth overfishing and increase growth and abundance of Flathead Catfish. Due to varying responses to the current minimum length limits between species, varying optimal sampling strategies, and differing life histories, we recommend that these catfish species be regulated on an individual basis instead of a single entity. This study will provide updated base-line Catfish population information and provide insight for future regulation implementation for the Wabash River.

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INTRODUCTION

Inland water systems provide several uses to people throughout the world. Fish are one of the most important resources from inland water systems, providing extensive recreational and commercial fisheries. The FAO reported that inland fisheries harvest continue to increase; with 11.6 million tons of fish harvested in 2012 (FAO 2014). Increased pressure on fisheries has many unknown effects in inland systems because they are complex and poorly studied in some instances, which has led to the collapse of some fisheries (Post et al. 2002).

Most freshwater fish stocks are exploited recreationally or commercially. Exploitation of freshwater fish stocks can lead to a change in size structure, mortality, growth, and recruitment (Hubert et al. 2010). If exploitation rates are high a fishery can experience declining yield and a shift towards smaller, younger fish (Pitlo 1997; Hubert et al. 2010). If mortality rates increase at a rapid rate, exploitation can cause a fisheries collapse (Liermann et al. 1997; Walters et al. 2001; Hubert et al. 2010).

Catfish (Ictaluridae) are both recreationally and commercially important throughout North America (Kwak et al. 2011). Catfish angling was conducted by 26% of anglers and composed 22% of the total freshwater fishing effort (excluding the Great lakes) expended by anglers in 2011 (USFWS 2011). Channel Catfish (*Ictalurus punctatus*), Flathead Catfish (*Pylodictis olivaris*), and Blue Catfish (*I. furcatus*) are the most desirable Catfish species to anglers. These species are especially desired throughout impoundments and rivers in the Midwest (Michaletz and Travnichek 2011). The Wabash River in Illinois has historically supported a substantial recreational and commercial Catfish fishery (Maher 2015; personal communication). Commercial catch in the Wabash

River from 2003-2012 had a yearly average of 7,482 kg for Channel Catfish, 6,048 kg for Flathead Catfish, and 3,301 kg for Blue Catfish (Maher 2015; unpublished data).

Although catfish are extremely popular with anglers, these species are often difficult to manage. These difficulties are a result of low management priority, habitat degradation, and inadequate or biased sampling, which has resulted in a lack of understanding of Catfish populations throughout North America (Michaletz and Dillard 1999; Vokoun and Rabeni 1999). Without accurate information on catfish population demographics, fisheries managers are unable to implement regulations encouraging sustainable harvest (Vokoun and Rabeni 1999). Information on population dynamics are derived from data collected using different sampling gears. A variety of sampling techniques are used for Catfish, because to accurately describe a catfish population, current thinking suggest that multiple gear types must be used (Vokoun and Rabeni 1999; Bodine et al. 2013). Some of these sampling gears include hoop nets, gillnets, electrofishing, trotlines, trap nets, slat traps, and hook-and-line methods (Bodine et al. 2013). Some of these gears are used more commonly than others, but little is known about their personnel-hour efficiency (Bodine et al. 2013). Further knowledge of efficiency, accuracy, and precision are needed for different sampling gears used for the collection of Catfish in lotic systems.

Information collected by various gears allow managers to estimate density, size structure, condition, age structure, mortality, and growth. Age estimations inform growth and mortality estimates (Buckmeier et al. 2002; Maceina et al. 2007; Marshall et al. 2009; Colombo et al. 2010; Olive et al. 2011; Barada et al. 2012) and are conducted using hard structures of catfish (e.g. scales, spines, fin rays, otoliths); (Quist et al. 2012). These population characteristics can be used to predict the potential impacts of different harvest regulations.

My objective was to develop a labor and cost effective sampling protocol to monitor Channel, Flathead, and Blue Catfish in the Wabash River, IL. Additionally, I wanted to describe the population attributes (condition, growth, and mortality) of these populations. Furthermore, I wanted to provide estimates of exploitation of all three species of Catfish. Finally, simulation modeling was used to evaluate the new MLL's for all three species of Catfish to estimate the impacts on total yield, number of fish harvested, mean length at harvest, and the proportion of Channel, Flathead and Blue Catfish reaching 711 mm and 889 mm, respectively.

LITERATURE CITED

Barada, T.J., Blank, A.J., and M.A. Pegg. 2011. Bias, precision, and processing time of otoliths and pectoral spines used for age estimation of channel catfish. Pages 723-731 *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.

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

Buckmeier, D.L., Irwin, E.R., Betsill, R. K., and J. A. Prentice. 2002. Validity of Otoliths and Pectoral Spines for Estimating Ages of Channel Catfish. North American Journal of Fisheries Management 22(3): 934-942.

Colombo, R.E., Phelps, Q.E., Miller, C.M., Garvey, J.E., Heidinger, R.C., and N. S. Richards. 2010. Comparison of Channel Catfish Age Estimates and Resulting Population Demographics Using Two Common Structures. North American Journal of Fisheries Management 30(1): 305-308.

FAO (Food and Agriculture Organization of the United Nations). 2014. The State of World Fisheries and Aquaculture 2014. Rome, FAO.

Hubert, W.A. and M.C. Quist, editors. 2010. Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Kwak, T.J., Porath, M.T., Michaletz, P.H., and V.H. Travnichek. 2011. Catfish Science: Status and Trends in the 21st Century. Pages 755- 780 *in* P.H. Michaletz and V.H. Travnichek, editors. Cnservation, ecology, and management of catfish: the second international symposium. American Fisherie Society, Symposium 77, Bethesda, Maryland.

Liermann, M. and R. Hilborn. 1997. Depensation in fish stocks: a hierarchic Bayesian meta- analysis. Canadian Journal of Fisheries and Aquatic Sciences. 54: 1976-1984.

Maceina , M.J., Boxrucker, J., Buckmeier, D.L., Gangl , R.S., Lucchesi, D.O., Isermann, D.A., Jackson, J.R., and P. J. Martinez. 2007. Current Status and Review of Freshwater Fish Aging Procedures Used by State and Provincial Fisheries Agencies with Recommendations for Future Directions. Fisheries 32(7):329-340.

Marshall, M.D., Maceina, M.J., and M.P. Holley. 2009. Age and growth variability between sexes of 3 catfish species in Lake Wilson, AL. North American Journal of Fisheries Management 29(5):1283-1286.

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 V.H. Travnichek, editors. 2011. Conservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Olive, J., Schramm, H.L. Jr., Gerard, P.D. and E. Irwin. 2011. An evaluation of agreement between pectoral spines and otoliths for estimating ages of catfishes. Pages 679-688 *in* P.H. Michaletz and V.H. Travinchek, editors. Conservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Pitlo, J., Jr. 1997. Response of upper Mississippi River channel catfish populations to changes in commercial harvest regulations. North American Journal of Fisheries Management 17(4): 848-859.

Post, J.R., M. Sullivan, S. Cox, N.P. Lester, C.J. Walters, E.A. Parkinson, A.J. Paul, L. Jackson and B.J. Shuter. 2002. Canada's Recreational Fisheries: The Invisible Collapse? Fisheries 27(1): 6-17.

Quist, M.C., M.A. Pegg, and D.R. DeVries. 2012. Age and Growth. Pages 677-721 *in* A.V. Zale, D.L. Parrish, and T.M. Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

USFWS (U.S. Fish and Wildlife service) and the Bureau of the Census. 2014. 2011 national survey of fishing, hunting, and wildlife-associated recreation. USFWS and Bureau of the Census, Washington, D.C.

Vokoun, J.C., and C.F. Rabeni. 1999. Catfish sampling in rivers and streams: a review of strategies, gears, and methods. 1999. 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.

Walters, C. and J.F. Kitchell. 2001. Cultivation / depensation effects on juvenile survival and recruitment: implications for the theory of fishing. Canadian Journal of fisheries and Aquatic Sciences 58: 39-50.

CAPTURE EFFICIENCY AND SIZE SELECTIVITY OF CATFISH SAMPLING GEAR IN A LARGE MIDWESTERN RIVER

ABSTRACT

Catfish (family: Ictaluridae) are both commercially and recreationally important in North America. It is imperative to understand the dynamics of these fish populations to ensure long-term population viability. Knowledge of efficiency, selectivity, and labor requirements for sampling gears used for the collection of Catfish are needed to accurately describe population demographics. This study characterizes the capture efficiency (fish/person-hour) and size selectivity of six Catfish sampling gears in the Wabash River. Catfish were collected throughout the lower 322-km of the Wabash River from 2014–2016 using a multiple-gear approach. A total of 882 Catfish were sampled; 361 Channel Catfish, 427 Flathead Catfish, and 94 Blue Catfish. Low-frequency electrofishing was more efficient at sampling Flathead and Blue Catfish; whereas, bank poles and hoop nets sampled more Channel Catfish ($P < 0.001$). Except high-frequency electrofishing ($P > 0.05$), Catfish were sampled in higher numbers during the spring and summer for all gears ($P < 0.05$). Size structure differed among gear types for each species ($P < 0.001$); with low-frequency electrofishing selecting for smaller individuals and hook-and-line methods selecting larger size classes.

INTRODUCTION

North American Catfish (family Ictaluridae) are popular sport fishes and are both recreationally and commercially exploited throughout North America (Kwak et al. 2011). Although catfish are extremely popular with anglers, these species are often difficult to manage. These difficulties are a result of low management priority, habitat degradation, and inadequate or biased sampling, which has resulted in a lack of understanding of catfish populations throughout North America (Michaletz and Dillard 1999; Vokoun and Rabeni 1999). Without accurate information on catfish population demographics, fisheries managers are unable to implement regulations encouraging sustainable harvest (Vokoun and Rabeni 1999). Historically, Catfish sampling inefficiencies and biases have caused a lack of accurate information of Catfish abundance, size structure, growth, and mortality (Michaletz and Dillard 1999).

Knowledge of efficiency, accuracy, and precision are needed for different sampling gears used for the collection of Catfish. A variety of sampling gears are used to sample Catfish, because to accurately describe a catfish population, current thinking suggests that multiple gear types must be used (Vokoun and Rabeni 1999; Bodine et al. 2013). Recently, Bodine et al. (2013) provided an extensive review of current Catfish sampling knowledge. This article summarized gear performance characteristics (i.e. accuracy and precision) and sampling efficiencies (fish collected per unit of effort) for several popular Catfish sampling gears used throughout the country. The majority of these studies evaluated gear-specific (e.g. fish/net-night, fish/hook, fish/hr-electrofishing, etc.) performance and efficiency characteristics for Channel, Flathead, and Blue Catfish (Bodine et al. 2013). However, these gear-specific units of effort can only compare catch efficiencies within-gear types (e.g. hoop net mesh sizes, electrofishing surveys) and are incapable of comparing catch efficiencies among different gear types (e.g. hoop nets versus bank pole catch rates; Bodine et al. 2013). This issue can be problematic for managers trying to find the most efficient gears to sample Catfish. In order to properly compare different gear types the same units of effort (e.g. fish/hr or fish/person-hr) and sampling design (e.g. travel time included or not) must be used (Bodine et al. 2013).

A useful and comparable unit of effort is the number of fish captured per person-hour (Bodine et al. 2013). This unit of effort is important because time and manpower often limit the success and usefulness of gear types. This can allow managers to determine the minimum number of workers and equipment needed to increase catch rates and simultaneously decrease cost. Increased efficiency and decreased cost will allow for expanded sampling in additional areas that might not have been covered previously. Although using a comparable unit of effort (fish/person-h) seems to have many advantages for comparing sampling techniques, it has had little use in past studies (Bodine et al. 2013). There have only been a few studies that have directly compared capture efficiencies and size selectivity between gear types using fish per person-hour as their unit of effort (Jons 1997; Pugh and Schramm 1998; Robinson 1999; Santucci et al. 1999; Stauffer and Koenen 1999; Sullivan and Gale 1999; Michaletz 2001; Vokoun and Rabeni 2001). These studies compared several sampling gear efficiencies (fish/person-hr) from a variety of aquatic systems (i.e. small impoundments and rivers).

Channel Catfish have been the most heavily studied game species of Catfish and are one of the most popular and managed freshwater species in North America (Hubert 1999; Bodine et al. 2013). Six of the above studies included standardized sampling efficiencies (fish/person-hr) for Channel Catfish using a variety of gears with varying degrees of success. Pugh and Schramm (1999) found high-frequency (60 Hz) electrofishing provided a more efficient and inclusive length range of Channel Catfish, compared to low-frequency (15 Hz) electrofishing and baited hoop nets (61-cm and 122-cm bar mesh) in the lower Mississippi River. Santucci et al. (1999) found no differences in fish/person-hr between several gears in a small impoundment in Illinois, but did recommend experimental gill nets for collecting Channel Catfish because it sampled similar length frequencies to the actual population and reflected annual changes in relative abundances. Similarly, Robinson (1999) suggested experimental gill nets be used because they caught significantly more Channel Catfish/person-hr compared to slat traps and hoop nets in a small Texas impoundment. Baited hoop nets with different mesh sizes or 25.4-mm tandem nets set for 2-3 days captured significantly more Channel Catfish per person-hour than experimental gill nets in several impoundments in Missouri (Sullivan and Gale 1999; Michaletz 2001). Additionally, baited 25.4-mm and 13-mm bar mesh nets set over night in three prairie streams in South Dakota caught significantly more Channel Catfish/person-hr compared to an AC electrofishing raft and bank poles (Vokoun and Rabeni 2001).

Blue Catfish are the second most-studied game species of Catfish in North America (Bodine et al. 2013). Despite this species' popularity with anglers, there is still a relatively small amount of information known about this species (Graham 1999). Only two studies have compared sampling efficiencies of Blue Catfish between gears using a standardized (fish/person-hr) unit of effort (Jons 1997; Pugh and Schramm 1999). Jons (1997) sampled more Blue Catfish with low-frequency (15 Hz) electrofishing (11.4

fish/p-h) compared to baited 25.4-mm bar mesh hoop nets in two Texas rivers; however these results were not statistically different due to high variation between sites. Additionally, low-frequency (15 Hz) electrofishing sampled significantly more Blue Catfish compared to high-frequency (60 Hz) electrofishing and baited hoop nets in the Lower Mississippi River (Pugh and Schramm 1999).

Similarly to the Blue Catfish only two studies have evaluated standardized sampling efficiencies between gear types for Flathead Catfish. Stauffer and Koenen (1999) evaluated the effectiveness of two hook and line methods (trot lines and limblines), baited hoop nets, high-frequency (80 -100 Hz) electrofishing, low-frequency (7.5 Hz) electrofishing, AC-chase boat electrofishing, and creel surveys for Flathead Catfish in the Minnesota River. Low-frequency (7.5 Hz) electrofishing was the most efficient gear followed by trot lines and limb lines set in the summer (Stauffer and Koenen 1999). Low-frequency (7.5 Hz) electrofishing and trot lines were recommended for sampling Flathead Catfish because they were the most cost effective and produced accurate estimates of mean length and age (Stauffer and Koenen 1999). Low-frequency (15 Hz) was also recommended for sampling Flathead Catfish over high-frequency (60 Hz) electrofishing and baited hoop nets (Pugh and Schramm 1999).

Although these studies have recommended particular gears used to sample a variety of Catfish in the most labor and cost efficient way, these recommendations may not be suitable for all types of aquatic systems or when sampling multiple species of Catfish. Of these studies, four were conducted in small impoundments and the others were conducted in varying sizes of rivers across a broad geographic scale from Minnesota to Texas. Catfish sampling in large midwestern rivers such as the Wabash

River, IL may require a different approach then those recommended by past studies. A different approach may be necessary due to differences in environmental parameters, exploitation rates, and the number of anglers utilizing the Wabash River compared to other studied systems. Although there have been studies focusing on within-gear capture efficiency there is a lack of standardized efficiency (fish/person-hr) and between gear studies on these larger midwestern rivers.

Our objective was to develop a labor and cost effective sampling protocol to monitor Channel, Flathead, and Blue Catfish in the Wabash River, IL. Catfish were sampled during 2014-2016 using various sampling gears that have been previously recommended by others. We evaluated these gears on four categories: (1) how many Catfish are captured per person-hour for each gear? (2) are there any seasonal differences of catch rates between gears? (3) are there any differences in the capture efficiency of gears based on species? and (4) are the size structures for individual species different between gear types?

METHODS

Sampling Site.— Channel, Flathead, and Blue Catfish were sampled in the lower 322-km of the Wabash River, IL. Ten 1.6-km sites were sampled using a multiple gear approach in order to accurately describe the relative densities and size structure of the populations (Vokoun and Rabeni 1999). Gear types evaluated were low and high-frequency pulsed-DC electrofishing, hoop nets, bank poles, trot lines, and experimental gill nets. Sites were sampled seasonally during the winter (December-February), spring (March-May), fall

(September-November), and summer (June-August) during 2014-2016. The most northern site was located at Darwin, IL and the most southern site was New Haven, IL.

Pulsed-DC Electrofishing.— Catfish were collected seasonally at all ten sites using both low (15 Hz) and high frequency (60 Hz) electrofishing. The unit consisted of a generator powered pulsator electrofisher (ETS; MBS-1D). The 6.81-m boat was configured with two booms, each containing one Wisconsin ring that acted as the anodes whereas the boat hull acted as the cathode. Each Wisconsin ring contained four droppers made of stainless steel pipe and cable. All ten sites were sampled during the fall 2014, whereas only 9 sites were sampled during the winter 2014 due to limitations of site access. In 2015 all ten sites were sampled during the spring, summer, and winter. Only nine sites were sampled during the fall 2015 due to site access issues. All ten sites were sampled during the spring of 2016.

At each site, a bank and pulse frequency (15 or 60 Hz) were randomly selected to initiate sampling. Sampling started at the upstream extent of the site, using the randomly selected pulse frequency (15 Hz or 60 Hz; 25% duty cycle) and bank, and continued downstream for a period of fifteen minutes. After fifteen minutes of sampling the pulse frequency was switched to the alternate frequency and continued downstream for another fifteen minutes. Sampling on the opposite bank was conducted in a similar manner. Power goals were determined by temperature and conductivity levels of the water following the Illinois DNR Long Term Electrofishing Monitoring Program (LTEF) protocols. Each bank was sampled for thirty minutes (15 min/frequency) adding to total of one hour of electrofishing effort per site.

Hoop nets.— Hoop nets were deployed at six of the ten sampling sites during the spring, summer, and fall of 2014 - 2015. The hoop net sampling design was similar to the design used by Sullivan and Gale (1999). Baited and unbaited hoop nets contained varying mesh sizes (25.4, 38.1, and 50.8 mm bar mesh), seven 0.91-m diameter hoops, two throats, and were 4.27-m in length. Baited hoop nets were either baited with 2-kg of cut silver carp (*Hypophthalmichthys molitrix*) or four (7.05 oz) Zote™ soap bars. Silver carp are in high abundance in the Wabash River and are a cost effective bait alternative for hoop nets. Zote™ soap has been shown to efficiently sample Channel Catfish and reduce turtle bycatch in hoop nets (Cartabiano et al. 2015). Nets were positioned in the river parallel to the flow with the mouth of the nets facing downstream. Nets with varying mesh size and bait combinations were set randomly for each site so that equal proportions of mesh size to bait type (cut bait or Zote) were set over the sampling sites during each season. Hoop nets were set approximately every 100-m along both banks at each site. Nets were left overnight at each site before being pulled the following day.

Hook and Line.— Hook and line gears included trot lines and bank poles. Trot lines were constructed with 52-m long main lines from 107-kg test nylon twine. Each trot line contained fifty droppers that were 40-cm long and made of 51-kg test nylon twine, and spaced 91-cm apart from one another. Droppers were attached to the main line using stainless steel trotline clips. Trotlines contained 7/0 Gamakatsu™ circle hooks on each dropper connected by a 3/0 barrel swivel. Hooks were baited with cut silver carp. Cut bait has been shown to be an efficient bait for Catfish, with the exception of Flathead Catfish

(Arterburn and Berry 2002; Barabe and Jackson 2011). Two trot lines were set at six sites during the summer of 2014 and 2015. Trotlines were set parallel to the flow of water at randomly selected locations within each site. Trotlines were allowed to soak overnight before being pulled.

Bank poles were constructed out of 2.5-m long sections of 19-mm diameter polyvinyl chloride (PVC) piping. Droppers made of 51-kg test nylon were tied to the upper end of the bank pole. Bank poles were equipped with 7/0 Gamakatsu™ circle hooks and baited with cut silver carp. Bank poles were exclusively used in the spring, summer, and fall of 2015. Bank poles were set at six sites during the spring, fall, and summer. Due to gear tampering only five sites of summer bank pole data were used in analyses. Twenty bank poles were set at each site, including ten pairs of bank poles on each bank separated by at least 91-m. Bank poles were set overnight before being pulled.

Gill nets.— Gill nets were 49-m long and 2.4-m high and constructed out of monofilament webbing. Each net contained eight 6.1-m long panels of the following mesh sizes in a quasi-random order: 25.4, 88.9, 76.2, 114.3, 50.8, 63.5, 38.1, and 101.6 mm bar mesh. Gill nets were only fished during the fall of 2015 at six sites. Four nets were set at each site perpendicular to the channel, fished at night, and retrieved after three hours.

Data Analysis.— Effort was recorded as the total person-hours needed to complete of unit of sampling at each site, including the time to deploy and retrieve gear. Effort calculations did not include soak time for hoop nets, gill nets, and hook and line methods.

Additionally, travel time to and from sample sites was not included in efficiency analyses, though it is an important component of determining which sites to sample.

As an estimate of relative density, fish per person-hour (fish/p-h) was used to compare densities of Catfish among species, season, and gear. Statistical analyses were performed in R version 3.2.1 (R Core team 2015). All effort data were tested for normality and homogeneity of variance using the Shapiro-Wilk and Levene's test. Effort data were $\log_{10}(x+1)$ transformed in order to meet the assumptions of normality. Sampling replicates were considered to be independent of one another because catfish have been shown to be very mobile in rivers, traveling maximum linear ranges up to 44.5-km in Channel Catfish, 751.0-km in Flathead Catfish, and 689-km for Blue Catfish (Wendel and Kelsch 1999, Garret and Rabeni 2011, Tripp et al. 2011). Since sampling periods were spaced over long periods of time and the Wabash River is un-impounded, we assumed that sampling periods were independent of one another and that each site would experience substantial movement (i.e. immigration and emigration) of Catfish. This would argue against the use of a repeated-measures design as implemented by another study in Missouri streams (Vokoun and Rabeni 2001). Influence of gear and season on catch rates (fish/p-h) for all Catfish were tested using a two-way analysis of variance (ANOVA). Gear (low-frequency electrofishing, high-frequency electrofishing, variable-mesh hoop nets, bank poles, trot lines, and gill nets), season (winter, spring, summer, and fall), and their interaction were included in this model. Influence of species and season on catch rates (fish/p-h) for each individual gear were evaluated using a two-way ANOVA. Species (Channel, Flathead, and Blue Catfish), season (winter, spring, summer, and fall), and their interaction were included in the model. Individual differences for all ANOVA models were identified using the Tukey HSD multiple comparison test.

Size selectivity of species among gear types were examined by comparing length frequency histograms using Kolmogorov-Smirnoff nonparametric tests with adjusted p-values for multiple comparisons (Sekhon 2011). Proportional size distribution (PSD, Guy et al. 2007) were calculated for all species of Catfish using the length classes defined in Anderson and Neumann (1996). A chi-square test was used to determine if PSD indices differed among gears for each species (Neumann and Allen 2007). Size structure analyses were not performed when the sample size was less than 20 individuals (Santucci et al. 1999).

RESULTS

Catfish gear performance

A total of 882 Catfish was sampled during 2014-2016, including 361 Channel Catfish, 427 Flathead Catfish, and 94 Blue Catfish (Figure 1.1). Low and high frequency electrofishing sampled a total of 519 and 129 individuals, respectively. Hoop nets sampled a total of 174 Catfishes. Bank poles, trot lines, and gill nets captured the lowest number of Catfish with individual catch rates of 55, 5, and 1. Catch rates (mean ± SE [standard error]) for total Catfish sampled from 2014 -2016 were 3.79 ± 0.52 fish/p-h for low-frequency electrofishing, 0.94 ± 0.16 fish/p-h for high-frequency electrofishing, 0.94 ± 0.54 fish/p-h for hoop nets, 2.95 ± 0.47 fish/p-h for bank poles, 0.34 ± 0.15 fish/p-h for trot lines, and 0.04 ± 0.04 fish/p-h for gill nets (Table 1.1). Mean catch rates for all Catfish were significantly different among gears ($F = 11.11$; $df = 5, 184$; $P < 0.001$).

Additionally, mean catch rates were significantly different among individual species and gear types ($F = 14.68$; $df = 17, 546$; $P < 0.001$). Low-frequency electrofishing, hoop nets, and bank poles all had significantly higher mean catch rates for total Catfish compared to high-frequency electrofishing, trot lines, and gill nets (Table 1.1; Tukey HSD; $P < 0.05$). Season had a significant effect on mean catch rates for various gears ($F = 17.63$; $df = 15, 174$; $P < 0.001$). I found seasonal differences in total catfish catch rates for low-frequency electrofishing, hoop nets, and high frequency electrofishing. Mean catch rates among seasons for low-frequency electrofishing was 0.18-7.25 fish/p-h with significantly more Catfish being sampled in the spring and summer seasons (Table 1.1; Tukey HSD; $P < 0.05$). Seasonal mean hoop net catch rates ranged from 0.9-3.07 fish/p-h and sampled significantly more Catfish in the summer and spring (Table 1.1; Tukey HSD; $P < 0.05$). Mean catch rates among seasons for high-frequency electrofishing ranged from 0.2-1.88 fish/p-h and sampled significantly more Catfish in the fall (Table 1.1; Tukey HSD; $P < 0.05$). Bank poles, trot lines, and gill nets did not show any seasonal variation due to lack of seasonal sampling (e.g. trot lines and gill nets) or insignificant differences in mean catch rates (e.g. bank poles; Table 1.1; Tukey HSD; $P > 0.05$).

Channel Catfish: gear performance and size structure

A total of 361 Channel Catfish was collected in 2014-2016, 116 with low-frequency electrofishing, 80 with high-frequency electrofishing, 119 with hoop nets, 46 with bank poles, 1 with trot lines, and 1 with gill nets. Total catch rates (mean ± SE) for Channel Catfish sampled were 0.85 ± 0.16 fish/p-h for low-frequency electrofishing, 0.59 ± 0.13 fish/p-h for high-frequency electrofishing, 1.76 ± 0.45 fish/p-h for hoop nets, 2.46 ± 0.45 fish/p-h for bank poles, 0.07 ± 0.07 fish/p-h for trot lines, and 0.04 ± 0.04 fish/p-h for gill nets (Table 1.2). Mean catch rates were significantly different between gears (Tukey's HSD; $P < 0.001$). Bank poles and hoop nets had significantly higher catch rates compared to the other gear (Table 1.2; Tukey's HSD; $P < 0.05$). Seasonal differences between mean catch rates of gears was only observed in low and high-frequency electrofishing. Low-frequency electrofishing sampled more fish/p-h in the spring, summer, and fall; whereas, high-frequency electrofishing sampled more fish/p-h in the fall compared to all other seasons (Table 1.2; Tukey's HSD; $P < 0.05$).

The lengths of Channel Catfish sampled ranged from 37-675 mm. Length (mean ± SE mm) of Channel Catfish sampled was 190.1 ± 13.1 mm in low-frequency electrofishing, 422.8 ± 12.6 mm in high-frequency electrofishing, 431.3 ± 11 mm in hoop nets, and 520.7 ± 9 mm in bank poles (Figure 1.2). Due to low sample size trot line and gill net samples were not included in Channel Catfish size structure analysis. Length frequencies were significantly different between all gears (K-S Test; adjusted $P < 0.001$). Channel Catfish PSD was 71 in low-frequency electrofishing, 71 in high-frequency electrofishing, 78 in hoop nets, and 96 in bank poles (Figure 1.2). Channel Catfish PSD values differed significantly between all gears ($X^2 = 11.16$; df = 3; $P < 0.05$).

Flathead Catfish: gear performance and size structure

A total of 427 Flathead Catfish was collected in 2014-2016, 333 with low-frequency electrofishing, 42 with high-frequency electrofishing, 51 with hoop nets, and 1 with bank poles. Total catch rates (mean ± SE) for Flathead Catfish sampled were 2.44 ± 0.37 fish/p-h for low-frequency electrofishing, 0.32 ± 0.07 fish/p-h for high-frequency electrofishing, 0.75 ± 0.13 fish/p-h for hoop nets, and 0.05 ± 0.05 fish/p-h for bank poles (Table 1.3). Total mean catch rates were significantly different between gears (Tukey's

HSD; $P < 0.001$). Low-frequency electrofishing had significantly higher catch rates compared to all other gears (Table 1.3; Tukey's HSD; $P < 0.05$). Seasonal differences between mean CPUE of gears were only observed in low and high-frequency electrofishing. Low and high-frequency electrofishing sampled more fish/p-h in the spring, summer, and fall (Table 1.3; Tukey's HSD; $P < 0.05$).

The lengths of Flathead Catfish sampled ranged from 55-1114 mm. Length (mean ± SE mm) of Flathead Catfish sampled was 283.3 ± 9.2 mm in low-frequency electrofishing, 367.1 ± 23.9 mm in high-frequency electrofishing, and 521.3 ± 21.2 mm in hoop nets (Figure 1.3). Bank pole, trot line, and gill net samples were not included in Flathead Catfish size structure analysis. Length frequencies were significantly different between all gears (K-S Test; adjusted $P < 0.001$). Flathead Catfish PSD was 47 in low-frequency electrofishing, 28 in high-frequency electrofishing, and 53 in hoop nets (Figure 1.3). Flathead Catfish PSD values were similar between all gears ($X^2 = 3.39$; df = 2; $P = 0.18$).

Blue Catfish: gear performance and size structure

A total of 94 Blue Catfish were collected in 2014-2016, 71 with low-frequency electrofishing, 7 with high-frequency electrofishing, 4 with hoop nets, 8 with bank poles, and 4 with trot lines. Total catch rates (mean ± SE) for Blue Catfish sampled were 0.52 ± 0.2 fish/p-h for low-frequency electrofishing, 0.05 ± 0.03 fish/p-h for high-frequency electrofishing, 0.06 ± 0.05 fish/p-h for hoop nets, and 0.43 ± 0.23 fish/p-h for bank poles (Table 1.4). Although low-frequency electrofishing had substantially higher individuals sampled, there was no significant differences in mean CPUE between gears (Table 1.4; Tukey's HSD; $P > 0.05$). Seasonal differences in mean CPUE of gears was only observed in low-frequency electrofishing. Low-frequency electrofishing sampled more fish/p-h in the spring compared to fall and winter, and summer showed no difference between all other seasons (Table 1.4; Tukey's HSD; $P < 0.05$).

The lengths of Blue Catfish sampled ranged from 39-1300 mm. Length (mean ± SE) of Blue Catfish sampled was 464.8 ± 30.2 mm in low-frequency electrofishing, 412.4 ± 108 mm in high-frequency electrofishing, 341.5 ± 76.1 mm in hoop nets, 762 ± 57.8 mm in bank poles, and 792 ± 177 mm in trot lines. Due to low catch rates of Blue Catfish the size structure was only analyzed for low-frequency electrofishing (Figure 1.4). Blue Catfish PSD was 67 in low-frequency electrofishing.

DISCUSSION

Overall, low-frequency electrofishing, bank poles, and hoop nets were the most efficient gear at capturing Catfish. Too few catfish were sampled with trot lines and gill nets to be used as a primary sampling gear. However, like bank poles, trot lines could be used to contribute larger fish in smaller quantities to sampling data (Vokoun and Rabeni 1999; Gale et al. 1999; Arterburn and Berry 2002; Steffensen et al. 2011). Additionally, trot lines and bank poles are methods used by anglers and could give managers an expected creel size structure (Vokoun and Rabeni 2001). Bank poles were the most efficient gear (fish/p-h) for Channel Catfish. Bank poles were ineffective for Flathead Catfish but did show some success sampling larger Blue Catfish. There were no seasonal differences observed in bank pole catches for total Catfish or between species.

Boat electrofishing captured the highest number of Catfish compared to other gears. Low-frequency electrofishing captured substantially higher number of Catfish; however, when catch rates are compared with person-hours expended, low-frequency, bank poles, and hoop net catch rates were similar. Overall, low-frequency electrofishing caught more Catfish of all three species in the fall season. Blue Catfish seemed to be sampled in higher amounts in the spring; whereas, Channel and Flathead Catfish were sampled in similar proportions in the spring, summer, and fall with low-frequency electrofishing. There were species specific differences in low-frequency catch rates between species. Flathead Catfish were overwhelmingly sampled in higher abundance and wider size ranges with low-frequency electrofishing. Low-frequency electrofishing caught significantly higher amounts of Flathead Catfish compared to all other gears, but this was not observed for Channel and Blue Catfish. The high catch rates of Flathead Catfish and moderate catch rates of Channel Catfish were similar to other studies sampling Catfish in riverine habitats with low-frequency electrofishing (Pugh and Schramm 1999; Satuffer and Koenen 1999). Low-frequency electrofishing has been shown to be an efficient (fish/p-h) gear for sampling Flathead Catfish and to also provide representative length and age data (Stauffer and Koenen 1999; Pugh and Schramm 1999). Our sampling suggest similar patterns for Blue Catfish to that of Flathead Catfish. Although, low-frequency electrofishing sampled higher numbers of Blue Catfish compared to all other gears, this difference was not statistically different. This is most likely due to the small sample sizes and high variation within the data. Jons (1997) experienced higher individual catches of Blue Catfish (11.4 fish/person-h) but these differences were also found to not be statistically different due to the large variation between sampling sites. This issue seems to be prominent in several studies focused on Blue Catfish due to difficulties obtaining adequate samples in riverine ecosystems (Graham et al. 1999). Although low-frequency electrofishing catch rates were not statistically higher for Blue Catfish, I think it is likely that this gear is substantially better for sampling Blue Catfish.

High-frequency electrofishing captured the third highest amount of Catfish in this study. Despite high individual catch rates high-frequency electrofishing was significantly lower compared to low-frequency electrofishing, bank poles, and hoop nets when analyzing fish per person-hour. High-frequency electrofishing did not seem to be an efficient gear for Blue or Flathead Catfish during any season; however, high-frequency electrofishing seems to perform best during the summer and fall season for Channel Catfish. High-frequency electrofishing is the third most popular Channel Catfish sampling gear (Brown 2009). The usefulness and efficiency of high-frequency electrofishing for Channel Catfish has been supported by past studies (Pugh and Schramm 1999; Bodine et al. 2013). Additionally, high-frequency electrofishing could be a useful sampling gear when it is already being used to sample other species of fish (Bodine et al. 2013).

Hoop nets seemed to be a successful sampling gear for Catfish relative to the others. Hoop nets sampled the second highest number of Catfish with 68% being Channel Catfish and 29% being Flathead Catfish. Blue Catfish only constituted a little over two percent of the hoop net catch. The hoop net sets only captured significantly more Channel Catfish compared to the other gears. Mean catch rates (fish/p-h) of Channel Catfish were substantially lower in the Wabash River compared to studies conducted in three prairie streams in South Dakota (23.9- 107.3 CCF/p-h) and impoundments in Missouri (14.8 CCF/p-h; Sullivan and Gale 1999; Vokoun and Rabeni 2001). The differences in Channel Catfish catch rate are likely due to the fact that the previous studies used tandem and multiple day net sets, whereas we used single overnight variable-mesh net sets. The hoop nets had similar catch rates to a study that also used single baited hoop nets fished overnight in an impoundment in Texas (Robinson 1999). Hoop nets had similar low catch rates (fish/p-h) for Flathead and Blue Catfish compared to studies in rivers located in Minnesota and Texas (Stauffer and Koenen 1999; Jons 1997).

Size structure is an extremely vital piece of information that fisheries managers need. A wider size range of Blue Catfish were sampled followed by Flathead Catfish. Channel Catfish had the narrowest length range. Length frequencies for Channel and Flathead Catfish analyses were significantly different between all gears tested. Bank poles and trot lines captured larger size Channel Catfish. However, bank poles and trot lines failed to sample sufficient numbers of Flathead and Blue Catfish. These results were similar to past studies (Santucci et al. 1999; Vokoun and Rabeni 2001). High-frequency electrofishing, hoop nets, and bank poles sampled larger Channel Catfish than low-frequency electrofishing. Flathead Catfish samples for low-frequency electrofishing were also composed of smaller individuals compared to other gears. Channel Catfish and Flathead Catfish had similar size ranges sampled with hoop nets and electrofishing methods compared to other studies (Stauffer and Koenen 1999; Vokoun and Rabeni 2001). The Channel Catfish population is largely made up of quality and preferred size individuals (PSD: 71-96 depending on gear type). There were no memorable or trophy size Channel Catfish sampled. Flathead Catfish seem to be comprised of smaller individuals (PSD: 28-53), but there were a few individuals of memorable and trophy size (4-6% of sample depending on gear). Due to high catches with low-frequency electrofishing and low sample sizes with other gears, Blue Catfish size structure was not compared among gears. Blue Catfish had a PSD value of 67 for low-frequency electrofishing. Caution should be used when interpreting the size structure and PSD results for Blue Catfish because the sample is lower than recommended levels for an accurate description of population length distributions (Vokoun et al. 2001; Miranda 2007).

Based on my results, I suggest that Channel Catfish should be sampled seasonally (spring, summer, and fall) with baited hoop nets and bank poles. However, managers should not dismiss the advantages of boat electrofishing, especially since many biologists use boat electrofishing for annual surveys. Boat electrofishing could provide additional data needed for a better determination of Channel Catfish population dynamics. Additionally, high-frequency electrofishing may sample Catfish species in proportion to their actual abundances. Flathead Catfish should be sampled with low-frequency electrofishing from spring through fall. Guy et al. (2009) also recommended low-frequency electrofishing during the summer season. Blue catfish should also be sampled using low-frequency electrofishing during the spring season. It may be advantageous to supplement Flathead and Blue Catfish sampling with hook and line methods (Bodine et al. 2013). Catfish sampling should be avoided during the winter season as these species do not seem to be vulnerable to these sampling gears during this time. These sampling techniques are what we recommend for the Wabash River, IL in order to produce sufficient sample sizes of Catfish that encompass a wide range of lengths using the least amount of personnel time. This will provide the most time efficient sampling methods that will allow for a more efficient use of work hours for biologists.

These sampling gears could show similar results in other large midwestern rivers. Bodine et al. (2013) stated that "there is no one-size-fits-all gear that will always meet this goal for ictalurids." Our results support his statement for Catfish sampling in the Wabash River. Sampling recommendations stated here are similar to the ones that were recently made with a few exceptions (Bodine et al. 2013). First, gill nets were not successful and should not be used for Catfish sampling in large riverine systems like the Wabash River. Secondly, hoop nets did not seem to be very efficient at sampling Flathead Catfish.

The choice of sampling gear depends on the species, location, and season at which they are being collected. Sampling for a specific species of Catfish may require a different gear than a multi-species sampling approach. Managers must use discretion when implementing their own Catfish sampling protocols. This standardized unit of effort (fish/p-h) is more directly linked with decision making by managers and will allow for more efficient allocation of resources under personnel and fiscal restraints. Additionally, managers must consider the financial cost associated with each gear. Time and money are probably the two most important factors to consider when developing a sampling protocol. The initial cost for electrofishing equipment was about $12,000 (excluding boat), $8,000 for 35 hoop nets, $1,700 for eight experimental gill nets, $300 for five trot lines, and about $200 for fifty bank poles. The initial cost for electrofishing and hoop nets are substantially higher compared to other gears, but higher catch rates with these gears results in a lower cost per fish compared to the other gears with the exception of bank poles. Finally, we think that it is important to continue to research more time efficient methods for sampling Catfish in large river systems.

LITERATURE CITED

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

Barabe, R.M., and D.C. Jackson. 2011. Using soap bait to prevent turtle bycatch on trotlines. Pages 637 – 644 *in* P.H. Michaletz and V.H. Travnichek, editors. Conservation, ecology, and management of catfish: the second internationals symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Bodine, K.A., Shoup, D.E., Olive, J., Ford, Z.L., Krogman, R., and T.J. 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 south-eastern association of fish and wildlife agencies 61(2007):6-9.

Cartabiano, E.C., Stewart, D.R., Long, J.M. 2015. Effect of bait and gear type on channel catfish and turtle bycatch in a reservoir. Journal of Freshwater Ecology 30(3): 407 – 415.

Gale, C.M., Graham, K., Deisanti, K., and J.S. Stanovick. 1999. Sampling strategies for Blue Catfish and Channel Catfish in the Harry S Truman Dam Tailwater, Missouri. Pages 301-307 *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.

Garret, D.L. and C.F. Rabeni. 2011. Intra-Annual movement and migration of Flathead Catfish and Blue Catfish in the lower Missouri River and tributaries. Pages 495 – 510 *in* P.H. Michaletz and V.H. Travnichek, editors. Conservation, ecology, and management of catfish: the second internationals symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Graham, K. 1999. A review of the biology and management of Blue Catfish. Pages 37–49 *in* E. R. Irwin, W. A. Huber, 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.

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

Guy, C.S., Braaten, P.J., Herzog, D.P., and J. Pitlo. 2009. Warmwater fish in rivers. Pages 59-82 *in* S.A. Bonar, W.A. Hubert, and D.W. Willis, editors. Standard methods for sampling North American freshwater fishes. American Fisheries Society, Bethesda, Maryland.

Jons, G. D. 1997. Comparison of low frequency electrofishing with hoop nets for assessing riverine Blue Catfish populations. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 51:72–78.

Kwak, T.J., Porath, M.T., Michaletz, P.H. and V.H. Travnichek. 2011. Catfish Science: Status and Trends in the 21st Century. Pages 755- 780 *in* P.H. Michaletz and V.H. Travnichek, editors. Cnservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

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. 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.

Miranda, L.E. 2007. Approximate sample sizes required to estimate length distributions. Transactions of the American Fisheries Society 136(2): 409 – 415.

Neumann, R.M., and Allen, M.S. 2007. Size Structure. Pages 375-421 *in* Guy, C.S. and Brown, M.L., editors, Analysis and Interpretation of Freshwater Fisheries Data. American Fisheries Society, Bethesda, Maryland.

Ogle, D.H. 2016. Introductory fisheries analyses with R. CRC Press, Florida.

Pugh, L.L. and H.L. Schramm Jr. 1998. Comparison of electrofishing and hoopnetting in lotic habitats of the lower Mississippi River. North American Journal of Fisheries Management 18(3): 649-656.

R Development Core Team (2008). R: A language and environment for statistical computing. Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Robinson, M.S. 1999. Evaluation of three gear types for sampling Channel Catfish in Small Impoundments. 1999. 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.

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

Sekhon, J.S. 2011. Multivariate and propensity score matching software with automated balance optimization: The Matching package for R. Journal of Statistical Software, 42(7):1-52.

Stauffer, K. W., and B. D. Koenen. 1999. Comparison of methods for sampling Flathead Catfish in the Minnesota River. Pages 329–333*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.

Steffensen, K.D., Eder, B.L., and M.A. Pegg. 2011. Using Lindgren-Pitman hook timers to understand the dynamics of trotline catches in a large river. North American Journal of Fisheries Management 31(5): 980-985.

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. Pages 293-300 *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.

Tripp, S.J., Hill, M.J., Calkins, H.A., Brooks, R.C., Herzog, D.P., Ostendorf, D.E., Hrabik, R.A., and J.E. garvey. 2011. Blue Catfish movement in the upper Mississippi River. Pages 511- 520 *in* P.H. Michaletz and V.H. Travnichek, editors. Conservation, ecology, and management of catfish: the second internationals symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Vokoun, J.C., and C.F. Rabeni. 1999. Catfish sampling in rivers and streams: a review of strategies, gears, and methods. 1999. 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.

Vokoun, J.C., Rabeni, C.F., and J.S. Stanovick. 2001. Sample-size requirements for evaluating population size structure. North American Journal of Fisheries Management 21(3): 660-665.

Wendel, J. L., and S. W. Kelsch. 1999. Summer range and movement of channel catfish in the Red River of the North. Pages 203–214 *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.

Table 1.1— Mean catch per unit of effort (CPUE) of all three species of Catfish for 2014 - 2016 combined. Mean CPUE (SE) is the mean number of Catfish sampled per person-hour for all six types of gear: low-frequency electrofishing (LF), high-frequency electrofishing (HF), variable-mesh hoop net (HP), bank poles (BP), trot lines (TL), and gill nets (GN). Different capital letters (A/B) indicate significant ($P < 0.05$) differences in mean CPUE among gears. Different small letters indicate significant ($P < 0.05$) differences among seasons within gears.

Gear	Season	Catch	Mean CPUE	SE	Tukey 's Test	
LF	**Total**	**523**	**3.79**	**0.52**		**A**
	Fall	138	3.45	0.58	**x**	
	Winter	7	0.18	0.08	**y**	
	Spring	233	6.13	0.97	**z**	
	Summer	145	7.25	1.97	**z**	
BP	**Total**	**55**	**2.95**	**0.47**		**A**
	Fall	13	1.95	0.77		
	Spring	27	4.05	0.56		
	Summer	15	2.81	0.94		
HP	**Total**	**174**	**2.58**	**0.54**		**A**
	Fall	14	0.9	0.59	**x**	
	Spring	57	3.06	1.46	**xy**	
	Summer	103	3.07	0.63	**y**	
HF	**Total**	**130**	**0.94**	**0.16**		**B**
	Fall	75	1.88	0.42	**x**	
	Winter	8	0.2	0.08	**z**	
	Spring	23	0.61	0.2	**yz**	
	Summer	24	1.2	0.33	**xy**	
TL	**Total**	**5**	**0.34**	**0.15**		**B**
GN	**Total**	**1**	**0.04**	**0.04**		**B**

Table 1.2— Mean catch per unit of effort (CPUE) of Channel Catfish for 2014 - 2016 combined. Mean CPUE (SE) is the mean number of Channel Catfish sampled per person-hour for all six types of gear: low-frequency electrofishing (LF), high-frequency electrofishing (HF), variable-mesh hoop net (HP), bank poles (BP), trot lines (TL), and gill nets (GN). Different capital letters (A/B) indicate significant ($P < 0.05$) differences in mean CPUE among gears. Different small letters indicate significant ($P < 0.05$) differences among seasons within gears.

Gear	Season	Catch	Mean CPUE	SE	Tukey's Test	
LF	**Total**	**116**	**0.85**	**0.16**		**AC**
	Fall	32	0.84	0.2	**xy**	
	Winter	6	0.15	0.08	**y**	
	Spring	54	1.42	0.49	**x**	
	Summer	24	1.2	0.19	**x**	
BP	**Total**	**46**	**2.46**	**0.45**		**B**
	Fall	12	1.8	0.77		
	Spring	24	3.6	0.76		
	Summer	10	1.88	0.48		
HP	**Total**	**119**	**1.76**	**0.45**		**BC**
	Fall	11	0.71	0.63		
	Spring	40	2.15	1.31		
	Summer	68	2.02	0.49		
HF	**Total**	**80**	**0.59**	**0.13**		**A**
	Fall	54	1.42	0.38	**x**	
	Winter	8	0.2	0.08	**y**	
	Spring	13	0.34	0.14	**y**	
	Summer	5	0.25	0.11	**y**	
TL	**Total**	**1**	**0.07**	**0.07**		**A**
GN	**Total**	**1**	**0.04**	**0.04**		**A**

Table 1.3— Mean catch per unit of effort (CPUE) of Flathead Catfish for 2014 - 2016 combined. Mean CPUE (SE) is the mean number of Flathead Catfish sampled per person-hour for all six types of gear: low-frequency electrofishing (LF), high-frequency electrofishing (HF), variable-mesh hoop net (HP), bank poles (BP), trot lines (TL), and gill nets (GN). Different capital letters (A/B) indicate significant (P < 0.05) differences in mean CPUE among gears. Different small letters indicate significant (P < 0.05) differences among seasons within gears.

Gear	Season	Catch	Mean CPUE	SE	Tukey's Test	
LF	**Total**	**332**	**2.44**	**0.37**		**A**
	Fall	102	2.69	0.49	**x**	
	Winter	0	--	--	**y**	
	Spring	115	3.03	0.34	**x**	
	Summer	115	5.75	1.73	**x**	
BP	**Total**	**1**	**0.05**	**0.05**		**B**
	Fall	0	--	--		
	Spring	0	--	--		
	Summer	1	0.19	0.19		
HP	**Total**	**51**	**0.75**	**0.13**		**B**
	Fall	3	0.19	0.13		
	Spring	17	0.91	0.26		
	Summer	31	0.93	0.17		
HF	**Total**	**43**	**0.32**	**0.07**		**B**
	Fall	20	0.53	0.15	**x**	
	Winter	0	--	--	**y**	
	Spring	7	0.18	0.07	**xy**	
	Summer	16	0.8	0.24	**x**	
TL	**Total**	**0**	**--**	**--**		**B**
GN	**Total**	**0**	**--**	**--**		**B**

Table 1.4— Mean catch per unit of effort (CPUE) of Blue Catfish for 2014 - 2016 combined. Mean CPUE (SE) is the mean number of Blue Catfish sampled per person-hour for all six types of gear: low-frequency electrofishing (LF), high-frequency electrofishing (HF), variable-mesh hoop net (HP), bank poles (BP), trot lines (TL), and gill nets (GN). Different capital letters (A/B) indicate significant ($P < 0.05$) differences in mean CPUE among gears. Different small letters indicate significant ($P < 0.05$) differences among seasons within gears.

Gear	Season	Catch	Mean CPUE	SE	Tukey's Test
LF	**Total**	**71**	**0.52**	**0.2**	
	Fall	0	--	--	**x**
	Winter	1	0.03	0.03	**x**
	Spring	64	1.68	0.63	**y**
	Summer	6	0.3	0.25	**xy**
BP	**Total**	**8**	**0.43**	**0.23**	
	Fall	1	0.15	0.15	
	Spring	3	0.45	0.3	
	Summer	4	0.75	0.75	
HP	**Total**	**4**	**0.06**	**0.05**	
	Fall	0	--	--	
	Spring	0	--	--	
	Summer	4	0.12	0.09	
HF	**Total**	**7**	**0.05**	**0.03**	
	Fall	1	0.03	0.03	
	Winter	0	--	--	
	Spring	3	0.08	0.04	
	Summer	3	0.15	0.15	
TL	**Total**	**4**	**0.27**	**0.15**	
GN	**Total**	**0**	**--**	**--**	

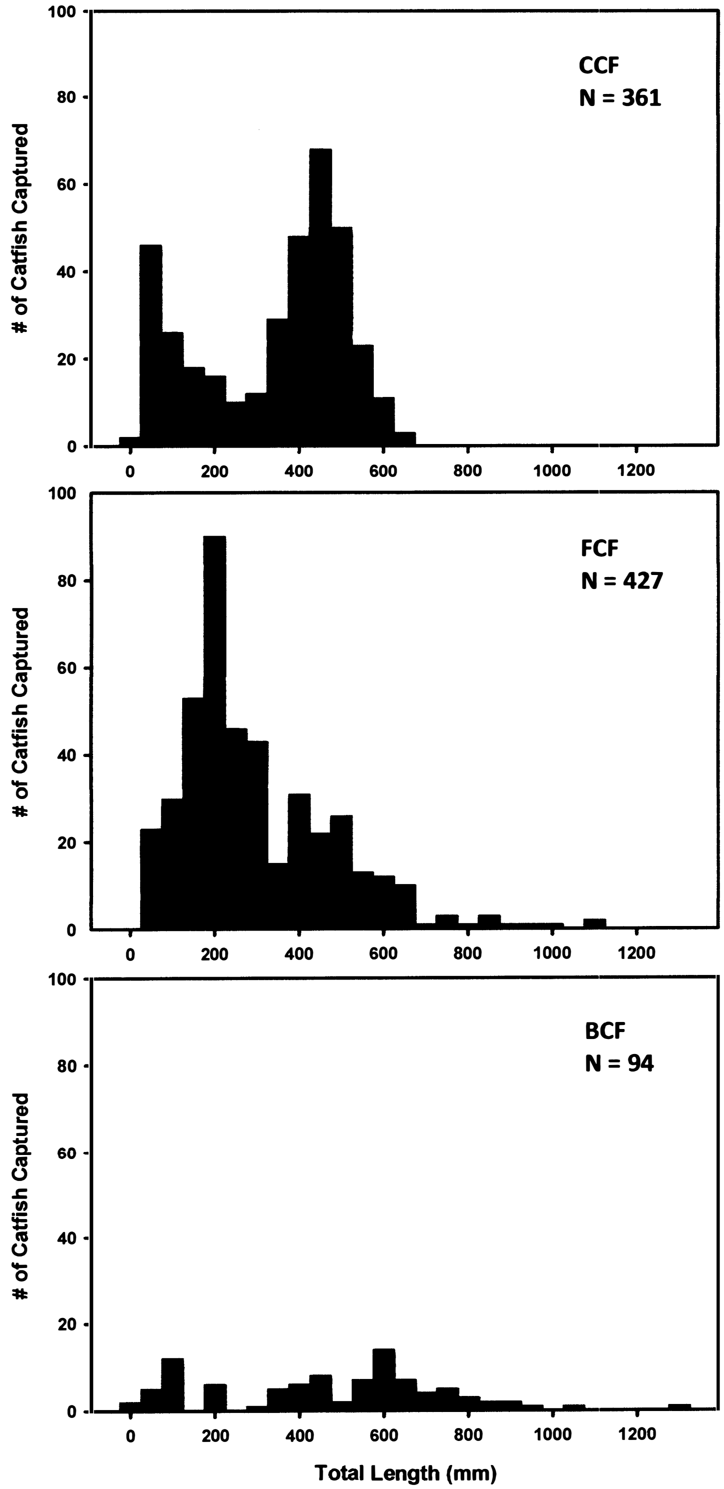

Figure 1.1— Length frequency histogram of all Channel (CCF), Flathead (FCF), and Blue Catfish (BCF) sampled with all gears in the Wabash River, 2014-2016.

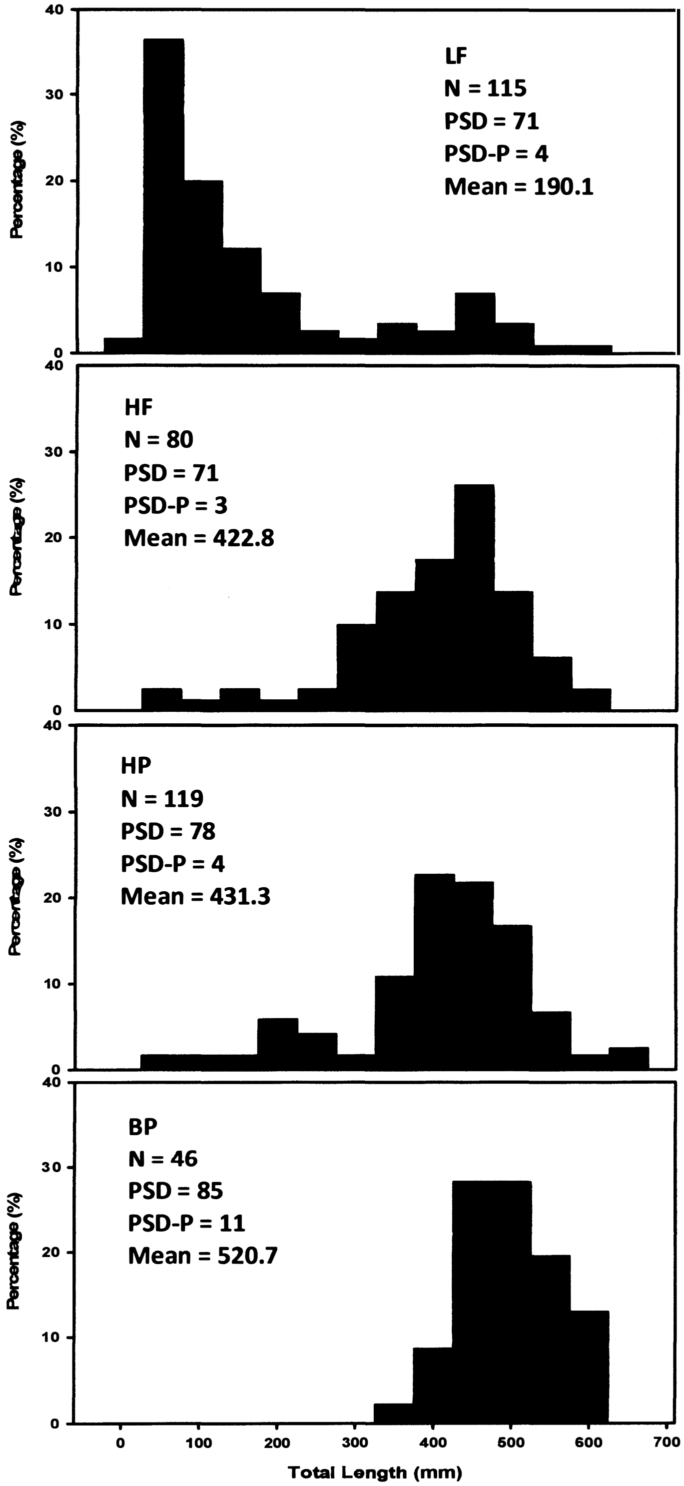

Figure 1.2— Length frequency histogram of Channel Catfish sampled with low-frequency electrofishing (LF), high-frequency electrofishing (HF), hoop nets (HP), and bank poles (BP) in the Wabash River, 2014-2016.

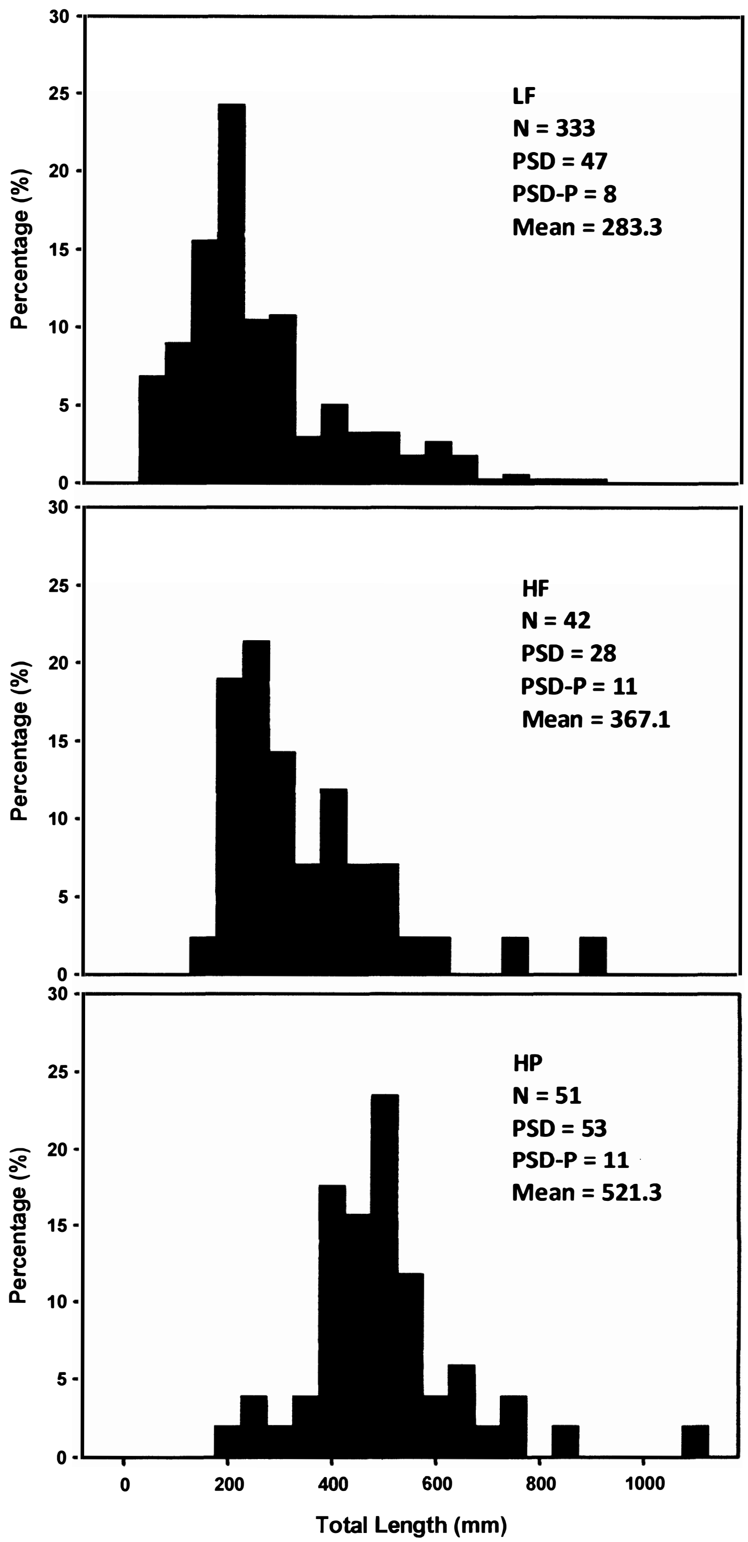

Figure 1.3— Length frequency histogram of Flathead Catfish sampled with low-frequency electrofishing (LF), high-frequency electrofishing (HF), and hoop nets (HP) in the Wabash River, 2014-2016.

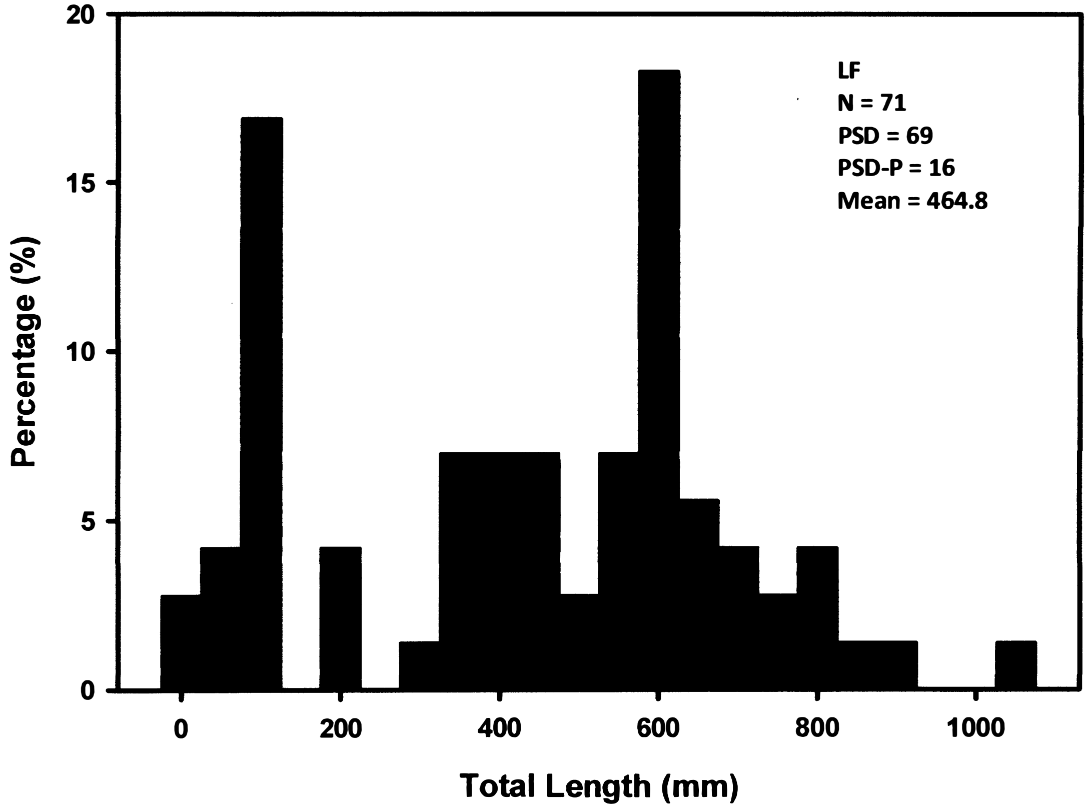

Figure 1.4— Length frequency histogram of Blue Catfish sampled with low-frequency electrofishing (LF) in the Wabash River, 2014-2016.

POPULATION CHARACTERISTICS AND POTENTIAL IMPACTS OF MINIMUM LENGTH LIMITS ON THREE SPECIES OF RIVERINE CATFISH

ABSTRACT

The Wabash River, Illinois, supports a substantial recreational and commercial fishery. Channel Catfish (*Ictalurus punctatus*), Flathead Catfish (*Pylodictis olivaris*), and Blue Catfish (*I. furcatus*) constitute the majority of harvest by weight. We described the condition, growth, mortality, and exploitation of these species. Population characteristics of these species were modeled to predict responses to two minimum length limits (MLL; 330 and 381-mm) under varying exploitation levels. All three species were in good condition (Wr: 93-98). Channel Catfish exhibited faster growth and shorter lifespans, compared to Blue and Flathead Catfish. Mean annual mortality estimates for Channel (43%), Flathead (38%), and Blue Catfish (18%) were comparable to other populations throughout North America. Yield-per-recruit models estimated that a 330-mm MLL for Channel Catfish would produce a higher yield and number of fish harvested compared to the 381-mm MLL. Conversely, Flathead Catfish are experiencing growth overfishing in the estimated ranges of exploitation. A 525-mm MLL would prevent growth overfishing and increase growth and abundance of Flathead Catfish. Additionally, Blue Catfish may experience slight growth overfishing with a minimal increase in exploitation. Due to varying responses to the current MLL's between species and differing life histories, we

recommend that these catfish species be regulated on an individual basis instead of as a single entity.

INTRODUCTION

Catfish (Ictaluridae) are both recreationally and commercially important throughout North America (Kwak et al. 2011). Catfish angling was conducted by 26% of anglers and composed 22% of the total freshwater fishing effort (excluding the Great Lakes) expended by anglers in 2011 (USFWS 2014). Channel Catfish (*Ictalurus punctatus*), Flathead Catfish (*Pylodictis olivaris*), and Blue Catfish (*I. furcatus*) are desirable species to anglers. These species are especially desired throughout impoundments and rivers in the Midwest (Michaletz and Travnichek 2011). The Wabash River in Illinois has historically supported a substantial recreational and commercial Catfish fishery (Maher 2015; personal communication). Commercial catch in the Wabash River from 2003-2012 had a yearly average of 7,482 kg for Channel Catfish, 6,048 kg for Flathead Catfish, and 3,301 kg for Blue Catfish (Maher 2015; unpublished data). Although Catfish are extremely popular with recreational and commercial anglers, these species are often difficult to manage. Historically, these difficulties have resulted in a lack of comprehensive knowledge of population dynamics and impacts of harvest (Irwin et al. 1999).

Recently, there have been a few studies providing a comprehensive amalgamation of Catfish population dynamics and the effects of harvest under varying fishing regulations (e.g. Sakaris et al. 2006; Marshall et al. 2009; Holley et al. 2009; Dorsey et al. 2011; Eder et al. 2016). These population assessments mainly focused on the age structure, growth, mortality, and the effects of exploitation. However, these assessments were predominantly based on southern populations which likely experience different environmental conditions and exploitation levels, that affect growth and mortality rates of those populations, compared to the Wabash River. Currently there are few comprehensive syntheses, such as the ones previously mentioned, of Catfish populations in large Midwestern rivers like the Wabash River.

Comprehensive assessments require accurate size and age data. Condition, as measured by relative weight, is a reliable and popular method used by fisheries biologists to assess the well-being of fish populations (Wege and Anderson 1978). Age estimations inform growth and mortality estimates and are conducted using hard structures of catfish (e.g. spines, fin rays, otoliths); (Quist et al. 2012). Pectoral spines have been used to age catfish because it is nonlethal and shows a relatively low age bias (Michaletz 2005; Colombo et al. 2010; Olive et al. 2011). Parameters that are produced from size and age data can be used to simulate the effects of varying exploitation rates on fish regulated under different length limits (Slipke and Maceina 2014).

Exploitation of these three species of Catfish vary widely throughout North America (Irwin et al. 1999). Estimates of exploitation for the Wabash River are currently lacking in the literature. Although many inland commercial fisheries are in decline or closed, the Wabash River still supports a rather substantial commercial fishery (Krogman et al. 2011; Kwak et al. 2011; Craig Jansen, personal communication). Additionally, the harvest rates of recreational fishermen are largely unknown but are assumed to be relatively high. Prior to 2016, Illinois did not regulate recreational fishing for any Catfish species in the Wabash River. A minimum length limit (MLL) of 381 mm and no bag limit was enforced for all three species for commercial fishermen. The state of Illinois recently modified its Catfish regulations for recreational fishermen. A MLL of 330 mm for all three species has been implemented. Additionally, only one Channel Catfish over

711 mm and one Flathead and Blue Catfish over 889 mm can be harvested each day. Regulations for commercial fishermen are identical for all three species of Catfish.

The goals of this project were to describe the population attributes (condition, growth, and mortality) of Channel, Flathead, and Blue Catfish in the Wabash River, IL. Furthermore, we wanted to provide estimates of exploitation of all three species of Catfish. Finally, simulation modeling was used to evaluate the new MLLs for all three species of Catfish to estimate the impacts on total yield, number of fish harvested, mean length at harvest, and the proportion of Channel, Flathead and Blue Catfish reaching the target size (711 and 889 mm) for larger individuals.

METHODS

Study site and field sampling.— Catfish were sampled in the lower 322-km of the Wabash River, IL. Ten 1.6-km sites were sampled using a multiple gear approach in order to accurately describe the size and age structure of the populations (Vokoun and Rabeni 1999). Gear types that were used were low (15 Hz) and high-frequency (60 Hz) pulsed-DC electrofishing, hoop nets (25.4, 38.1, and 50.8 mm bar mesh), bank poles, trot lines, and experimental gill nets. Sites were sampled seasonally during 2014-2016. The most northern site was located at Darwin, IL and the most southern site was New Haven, IL. Additional Catfish were collected from Illinois' long term electrofishing (LTEF) monitoring program conducted on the Wabash River every summer. All Catfish were measured (mm) and weighed (g). A sub-sample of pectoral spines were extracted for aging purposes.

Aging procedures.—Pectoral spines were sectioned at the articulating process with a Buehler low speed isomet saw. Spine sections were cut to a thickness of 700 μm. All sections were viewed with a stereo microscope and then photographed using a top mounted digital camera. Annuli were counted by two independent readers to determine age. If age estimates differed and the readers could not come to an agreement the fish was removed from further data analysis. Reader precision for age estimates ranged from 90% to 96% among species. An age-length key was created, using the FSA package in R, for fish not aged using pectoral spines (R core team 2015; Ogle 2016).

Data analysis.—All statistical analyses were conducted in FAMS 1.64 and R 3.2.1 (Slipke and Maceina 2014; R core team 2015). As an estimate of condition, relative weights (Wr) were calculated between all gear types for all species. The Wr of each fish is calculated by dividing the weight of an individual by the standard weight and then multiplying by one-hundred (Wege and Anderson 1978). Standard weight equations have been developed for Channel, Flathead, and Blue Catfish (Brown et al. 1995; Bister et al. 2000; Muoneke and Pope 1999). Mean relative weights were compared among gear types for each species using a one-way ANOVA. Individual differences for all ANOVA models were identified using the Tukey HSD multiple comparison test.

Age frequency histograms were created to observe the age distributional patterns of Catfish sampled. The mean age among gear types for each species were compared using a two-way ANOVA and Tukey HSD multiple comparison test. Growth was estimated for each species using the von Bertalanffy growth function in FAMS. Catfish from the different gears were combined to create a more accurate and precise growth estimate (Wilson et al. 2015). Annual mortality (A), instantaneous mortality (Z), and survival (S) estimates between gears for each species were created using the weighted-regression catch curve method (Maceina and Bettoli 1998). Instantaneous morality estimates were distinguished between instantaneous natural mortality (M) and instantaneous fishing mortality (F). Instantaneous natural mortality (M) rates for all three species were estimated from six recommended published equations and then averaged (Slipke and Maceina 2014). Instantaneous fishing mortality was computed as $F = Z\text{-}M$ (Slipke and Maceina 2014). Exploitation was estimated as $\mu=F*A/Z$ (Eder et al. 2016).

Population characteristics from all three species of Catfish were used to predict the effects of two MLLs (330 mm and 381 mm). Modeling was conducted using the yield-per-recruit (YPR) model in FAMS. The YPR model requires several parameters to evaluate the effects of MLLs. Parameters required for the YPR model include N_0 (the number of fish in the initial population), L_∞ (the theoretical maximum length), K (von Bertalanffy growth coefficient), t_0 (the theoretical age at which a fish's length would be zero), a (the intercept of the weight-length regression), b (the slope of the weight-length regression), W_∞ (the theoretical maximum weight), cm (the conditional natural mortality), and cf (the conditional fishing mortality). Growth parameters were used from the von Bertalanffy growth curves created for each species. A weight-length regression for each species were conducted in FAMS to obtain: a, b, and W_∞. Conditional natural mortality (cm) for each species was computed from the average M value as cm= $1 - e^{-M}$. Conditional fishing mortality (cf) was calculated as cf = $1 - e^{-F}$. Conditional fishing morality (cf) was modeled at levels ranging from 0% to 90%. All models used an initial population of 1,000 individuals.

I modeled MLL's using two minimum lengths: 330 and 381 mm. Several variables are reported in YPR model outputs in FAMS; however, this paper will focus on four. The results of yield (kg), number of fish harvested, mean total length of fish at harvest, and the proportion of Channel Catfish reaching 711 mm and Flathead and Blue Catfish reaching 889 mm were examined for each species under both minimum length limits. These three variables were used to determine the effects of both the recreational and commercial regulations and if these species are being harvested at sustainable levels (i.e. avoiding growth overfishing).

RESULTS

A total of 1,238 Catfish were collected during 2014 -2016, comprising of 512 Channel Catfish (TL range = 37-675 mm), 629 Flathead Catfish (TL range = 55-1,114 mm), and 97 Blue Catfish (TL range = 39-1,300 mm). Condition of Catfish varied among species and gear type (CCF: $F = 3.473$; df = 5,492; $P < 0.01$; FCF: $F = 4.95$; df = 3,569; $P < 0.01$; BCF: $F = 1.03$; df = 4,73; $P > 0.05$; Figure 2.1). Relative weight [mean (range)] for Channel Catfish [93 (71-109)] was higher in low-frequency electrofishing compared to all other gears except variable mesh hoop nets (Tukey HSD; $P < 0.05$). Relative weights for Flathead Catfish [98 (89-105)] were higher for low and high-frequency electrofishing samples compared to bank poles and variable mesh hoop nets (Tukey HSD; $P < 0.05$). Blue Catfish condition estimates [96 (87-108)] did not significantly vary among gear types.

Mean ages (range) for Catfish sampled were 3.2 (0-8) years for Channel Catfish, 2.0 (0 -14) years for Flathead Catfish, and 4.7 (0 -11) years for Blue Catfish (Figure 2.2).

Mean age of Catfish varied significantly among gear types (CCF: $F = 49.23$; df = 5,506; $P < 0.001$; FCF: $F = 24.2$; df = 3,625; $P < 0.001$; BCF: $F = 4.753$; df = 4,94; $P < 0.01$). Hook and line gear types had significantly higher mean ages for Channel Catfish (TL = 7; BP = 4.7 years), Flathead Catfish (BP = 6 years), and Blue Catfish (8.4 years; Tukey HSD; $P < 0.05$). Low and high-frequency electrofishing sampled on average the youngest age classes for all species of Catfish (Tukey HSD; $P < 0.05$).

Von Bertalanffy growth models generally fit well for all three species of Catfish (Figure 2.3). Flathead Catfish reached a higher theoretical maximum length (L_∞) followed by Blue Catfish and Channel Catfish (Figure 2.3). The predicted times for Catfish to obtain 330 and 381 mm were 2.1 and 2.7 years for Channel Catfish, 2.1 and 2.6 years for Flathead Catfish, and 2.1 and 2.6 years for Blue Catfish. Predicted times for Channel Catfish to reach 711 mm was 6.3 years, and 9.5 and 14.5 years for Flathead and Blue Catfish to reach 889 mm.

Catch curve regression for Channel, Flathead, and Blue Catfish resulted in a mean annual mortality of 43.1, 38.2, and 31.2%, respectively (Table 2.1). Instantaneous mortality rates ranged from 0.53-0.57 in Channel Catfish, 0.41-0.58 in Flathead Catfish, and 0.37 in Blue Catfish depending on gear type (Table 2.1). A significant difference was detected in mortality rates among gear types for Flathead Catfish ($F = 3.97$; df= 2,26; $P < 0.05$); whereas, no difference was observed for Channel Catfish ($F = 1.2$; df = 3,22; $P = 0.33$). Annual mortality for Blue Catfish were only estimated from one gear (low-frequency EF) due to low sample sizes of other gears. Estimates of *M* for Channel, Flathead, and Blue Catfish averaged 0.45, 0.201, and 0.266, respectively (Table 2.2).

Yield-per-recruit model parameters resulted in different reactions to the MLLs between all three species of Catfish (Table 2.3; Figure 2.4-2.6). Yield of Channel Catfish were higher under the 330 mm MLL compared to the 381 mm MLL until exploitation (*u*) rates passed 55%. The opposite prediction was made for Flathead and Blue Catfish: yields increased with the 381 mm MLL after the rate of exploitation passed 10%. Growth overfishing of Channel Catfish was not evident for either MLLs over all ranges of exploitation rates modeled. Growth overfishing was predicted to occur for Flathead Catfish at u = 16% under the 330 mm MLL and was delayed until u = 21% with a 381 mm MLL. Similarly, growth fishing was predicted for Blue Catfish at u = 29% under a 330 mm MLL and when u = 35% for a 381 mm MLL. The predicted number of fish harvested under the 330 mm MLL was higher compared to the 381 mm MLL for all three species; however, the predicted number of Channel Catfish harvested from the population is substantially lower compared to the Flathead and Blue Catfish. Additionally, the predicted mean total length of fish harvested is greater under the 381 mm MLL compared to a 330 mm MLL for all three species. Abundance of ≥ 889 mm sized Flathead and Blue Catfish are similar between both minimum length limits. A maximum of 15% (u = 0) of the Flathead population will reach at least 889 mm in length. The proportion decreases dramatically to less than 5% of the population reaching at least 889 mm under exploitation rates of 40%. Similarly, there is a low proportion (< 5%) of Blue Catfish reaching at least 889 mm under all modeled exploitation rates. The number of Flathead and Blue Catfish harvested decreases substantially after exploitation levels exceeded 10%. Predicting the abundance of Channel Catfish to reach 711 mm was not possible in the YPR models due to my samples containing individuals with only a maximum size of 675 mm.

DISCUSSION

This assessment of Channel, Flathead, and Blue Catfish population dynamics (growth and mortality) in the Wabash River highlighted differences among species and the effects harvest regulations. All three species within the Wabash River seem to be in relatively good condition with relative weights averaging from 93 in Channel Catfish to 96 and 98 in Blue and Flathead Catfish, respectively. Relative weight estimates for all three species were similar to other published studies (Doorenbos et al. 1999; Mosher 1999; Mackinster 2006; Barada and Pegg 2011). Growth analyses indicated that Channel Catfish were growing at a relatively fast rate, Blue Catfish at intermediate levels, and that Flathead Catfish are experiencing slower growth. The growth rate of Channel Catfish was higher in the Wabash River compared to several populations (e.g. Holley et al. 2009; Eder et al. 2016); although similar age structures and growth rates were observed in other studies (Crumpton 1999; Marshall et al. 2009; Jolley and Irwin 2011). Growth in Flathead and Blue Catfish populations have also been described as slow to intermediate by several researchers (Mauk and Boxrucker 2004; Sakaris et al. 2006; Holley et al. 2009; Marshall et al. 2009). However, relatively fast growth rates have been reported for Flathead and Blue Catfish in some riverine populations (Mayo and Schramm 1999; Sakaris et al. 2006; Kwak et al. 2006; Steuck and Schnitzler 2011). Faster growth rates estimated for Channel and Blue Catfish in the Wabash River are likely caused by the low sample size of older individuals. Pectoral spines were used for aging in this study so caution must be used in the interpretation of growth estimates due to evidence suggesting that otoliths provide more accurate age estimates (Buckmeier et al. 2002; Barada et al. 2011; Olive et al. 2011). Although it is largely assumed that otoliths are more accurate, a lack of age validation studies have made it impossible to validate this assumption (Kwak et al. 2011). The majority of Catfish aged were relatively young and pectoral spines have been shown to provide accurate age estimates for younger age classes of Catfish (Kwak et al. 2011).

Mean annual mortality estimates varied between all three species. Channel Catfish annual mortality estimates (41-46%) were comparable to other populations in the U.S. (Graham and Deisanti 1999; Holley et al. 2009; Eder et al. 2016). Flathead Catfish mortality estimates (34-44%) were higher than several populations of Flathead Catfish throughout the country, although most of these studies focused on introduced or lightly-exploited populations (Sakaris et al. 2006; Kwak et al. 2006; Marshall et al. 2009; Kaeser et al. 2011). The annual mortality estimate for Blue catfish (31%) was mostly higher compared to estimates in populations located in southern reservoirs and rivers (Graham and DeiSanti 1999; Mauck and Boxrucker 2004; Holley et al. 2009).

Exploitation rates for Catfish are highly variable throughout North America (Irwin et al. 1999), and varied between Catfish species in the Wabash River. Estimated exploitation rates for Channel Catfish ranged from (6 – 13%). These rates were similar to estimates reported in Lake Wilson (4-11%; Holley et al. 2009), Lake Kentucky (11%; Timmons 1999), and Truman tail water in Missouri (15%; Graham and Deisanti 1999). Estimated exploitation rates for Channel Catfish have been reported over a broad range of levels (1-50%; Hubert 1999; Kwak et al. 2011; Eder et al. 2016). Exploitation estimates

(17-29%) for Flathead Catfish in the Wabash River were similar to estimates reported in the Flint River, Georgia (14-25%; Quinn 1993). Estimates were higher than a lightly-exploited populations of Flathead catfish in Lake Wilson, Alabama and other southern populations (Makinster and Paukert 2008; Marshall et al. 2009; Travnichek 2011). Blue Catfish exploitation in the Wabash River (8%) were lower compared to reservoir populations (Timmons 1999; Holley et al. 2009) and a southern riverine population in Alabama (Graham and Desanti 1999).

Overall, Catfish estimates of growth, mortality, and exploitation in the Wabash River were comparable to other populations previously studied throughout the U.S. The potential effects of MLL regulations varied between individual species. Channel Catfish exhibited shorter life spans, faster growth, and higher mortality compared to the other species. Channel Catfish did not exhibit an increased yield with an increase from a 330 to 381 mm MLL until exploitation rates rose above 55%. Similar responses from Channel Catfish to increased MLLs were also identified in other populations (Holley et. al 2009; Eder et al. 2016). Under current estimated exploitation rates in the Wabash River, fishermen will have a higher yield and catch rate of Channel Catfish under the 330 mm MLL. Additionally, no growth overfishing was detected for all levels of exploitation modeled for both MLLs. The quality of fishing after implementing a 381 mm MLL for Channel Catfish has shown mixed results (Hesse 1994; Pitlo 1997). On the other hand, Flathead Catfish exhibited slower growth and higher exploitation in the Wabash River. Yield was increased under the 381 mm MLL after exploitation rates pass 10%; however, estimated exploitation in the Wabash River indicates that Flathead Catfish are currently experiencing growth overfishing. Additionally, there are very low numbers of Flathead

Catfish reaching the 889 mm size under both MLL's. Minimum length limits of 254 and 356 mm in Alabama and Georgia caused significant decreases in Fathead Catfish biomass (Sakaris et al. 2006). A 610 mm MLL was reported to maintain stock structure and preserve a quality fishery for Flathead Catfish in the Kansas River, Kansas (Makinster and Paukert 2008). Additionally, a 610 mm MLL was recommended to maintain a higher proportion of larger Flathead Catfish in Lake Wilson, Alabama (Marshall et al. 2009). Blue Catfish exhibited moderate growth and low exploitation in the Wabash River. A 381 mm MLL maximizes yield and average size of fish harvested in the Wabash River, but there are low numbers of fish reaching 889 mm in length. Growth overfishing does not seem to be a problem under estimated exploitation rates, but could become a problem with moderate increases in exploitation to 29% to 35%. Holley et al. (2009) recommended a 660 mm MLL to increase yields, prevent growth overfishing, and increase memorable-length (890 mm) Blue Catfish. Stricter harvest regulations were also suggested in Lake Texoma to preserve the "trophy" Blue Catfish fishery (Mauck and Boxrucker 2004). Dorsey et al. (2011) reported that a bag limit of one fish over 813 mm, under a 813 mm maximum size limit, would have limited or no impact on increasing numbers of large Blue Catfish, but it could allow for protection of older and rarer individuals.

Since these three Catfish species have considerably different life histories it is apparent that one single MLL is not practical or appropriate for the Wabash River fishery. A 330 mm MLL for Channel Catfish should increase yield and prevent growth overfishing, even under high levels of exploitation. Unlike Channel Catfish, the Flathead catfish population in the Wabash River seems to be in great stress. Growth overfishing seems to have limited the number of memorable and trophy-sized fish. The recreational and commercial MLLs are currently unsustainable. Additionally, Blue Catfish in the Wabash River are approaching growth over fishing. Minimal increases in exploitation could cause Blue Catfish to become overfished in the Wabash River. Similarly to Flathead Catfish, there is only a small fraction of individuals reaching larger sizes within the population. Limiting the harvest of these larger individuals could lead to an increased fecundity and recruitment into the populations.

Due to varying responses to the current MLL's between species, we recommend that these catfish species be regulated on an individual species basis, as opposed to one entity of "Catfish." Current recreational and commercial regulations seem to be sustainable for Channel Catfish. We recommend the MLL of Flathead Catfish be increased to 525 mm to limit growth overfishing and increase harvest yields. Implementing a bag limit for recreational anglers could also help improve the stock structure and abundance of Flathead Catfish in the Wabash River. Blue Catfish regulations should be monitored closely and adjusted if exploitation increases in the future in order to avoid growth overfishing. With increases in popularity of trophy fishing it may be prudent for managers to increase the MLL for Blue Catfish in order to preserve larger size individuals (Arterburn et al. 2002). Further increases in MLL regulations will most likely be opposed by commercial fishermen. In order to maintain the current commercial MLL of 381 mm for all Catfish species, bag limits for recreational fishermen should be considered in order to limit the amount of fish being harvested from the system. Further research is warranted to estimate the overall harvest, impacts, and human dimensions of recreational fishermen on the Wabash River. Commercial and recreational anglers often desire different fisheries, and it is the difficult task of fisheries managers to find a balance between stakeholders to implement regulations encouraging long-term sustainability.

LITERATURE CITED

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

Barada, T.J., Blank, A.J., and M.A. Pegg. 2011. Bias, precision, and processing time of otoliths and pectoral spines used for age estimation of channel catfish. Pages 723-731 *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.

Bister, T.J., Willis, D.W., Brown, M.I., Jordan, S.M., Neumann, R.M., Quist, M.C. and C.S. Guy. 2000. Proposed standard weight (Ws) equations and standard length categories for 18 warmwater nongame and riverine fish species. North American Journal of Fisheries Management 20:570-574.

Brown, M.L., Jaramillo, F. Jr., Gatlin, D.M. III, and B.R. Murphy. 1995. A revised standard weight (W_s) equation for channel catfish. Journal of Freshwater Ecology 10:295-302.

Buckmeier, D.L., Irwin, E.R., Betsill, R. K., and J. A. Prentice. 2002. Validity of Otoliths and Pectoral Spines for Estimating Ages of Channel Catfish. North American Journal of Fisheries Management 22(3): 934-942.

Colombo, R.E., Phelps, Q.E., Miller, C.M., Garvey, J.E., Heidinger, R.C., and N. S. Richards. 2010. Comparison of Channel Catfish Age Estimates and Resulting Population Demographics Using Two Common Structures. North American Journal of Fisheries Management 30(1): 305-308.

Crumpton, J.E. 1999. Relative abundance, age, growth, and food habits of Channel and White Catfish from the Clermont Chain of Lakes, Florida. Pages 115-120 *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.

Dorsey, L.G., McRae, B.J., and T.M. Thompson. 2011. Evaluation of an 813-mm maximum size limit for Blue Catfish in two North Carolina reservoirs. Pages 177-187 *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.

Doorenbos, R., Berry, C.R., and D.J. Wickstrom. 1999. Ictalurids in South Dakota. Pages 377-390 *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.

Eder, B.L., Pegg, M.A., and E.M. Gerald. 2016. Modeling effects of length limit regulations on riverine populations of channel catfish. North American Journal of Fisheries Management 36(1): 140-146.

Graham, K., and K. DeiSanti. 1999. The population and fishery of Blue Catfish and Channel Catfish in the Harry S Truman Dam tailwater, Missouri. Pages 361-376 *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.

Hesse, L. W. 1994. The status of Nebraska fishes in the Missouri River, 3.Channel Catfish (Ictaluridae: Ictalurus punctatus). Transactions of the Nebraska Academy of Sciences 21:73–87.

Holley, M.P., Marshall, M.D., and M.J. Maceina. 2009. Fishery and population characteristics of Blue Catfish and Channel Catfish and potential impacts of minimum length limits on the fishery in Lake Wilson, Alabama. North American Journal of Fisheries Management 29(4): 1183-1194.

Hubert, W.A. 1999. Biology and management of Channel Catfish. Pages 3-22 *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.

Irwin, E.R., Hubert, W.A., Rabeni, C.F., Schramm, H.L., Jr., and T. Coon, editors. 1999. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Jolley, J.C. and E.R. Irwin. 2011. Catfish population characteristics in tailwater and reservoir habitats of the Coosa River, Alabama. Pages 155- 166 *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.

Kaeser, A.J., Bonvechio, T.F., Harrison, D., and R.R. Weller. 2011. Population dynamics of introduced Flathead Catfish in rivers of southern Georgia. Pages 409-422 *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.

Krogman, R.M, Fischer, J.R., Quist, M.C., Steuck, M.J. and M.M. Marron. 2011. Historical trends in ictalurid catfish commercial harvest in the upper Mississippi River. Pages 127- 140 *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.

Kwak, T.J., Pine, W.E., III, and D.S. Waters. 2006. Age, growth, and mortality of introduced Flathead Catfish in Atlantic rivers and a review of other populations. North American Journal of Fisheries Management 26:73-87.

Kwak, T.J., Porath, M.T., Michaletz, P.H. and V.H. Travnichek. 2011. Catfish Science: Status and Trends in the 21st Century. Pages 755- 780 *in* P.H. Michaletz and V.H. Travnichek, editors. Cnservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Maceina, M.J., and P.W. Bettoli. 1998. Variation in Largemouth Bass recruitment in four mainstream impoundments on the Tennessee River. North American Journal of Fisheries Management 18:998-1003.

Makinster, A.S. 2006. Flathead Catfish population dynamics in the Kansas River. Master's thesis. Kansas State University, Manhattan.

Makinster, A.S., and C.P. Paukert. 2008. Effects and utility of minimum length limits and mortality caps for Flathead catfish in discrete reaches of a large prairie river. North American Journal of Fisheries Management 28: 97-108.

Marshall, M.D., Holley, M.P., and M.J. Maceina. 2009. Assessment of the Flathead Catfish population in a lightly exploited fishery in Lake Wilson, Alabama. North American Journal of Fisheries Management 29(4): 869-875.

Mauk, P., and J. Boxrucker. 2004. Abundance, growth, and mortality of the Lake Texoma Blue Catfish population: implications for management. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies.

Mayo, R.M., and H.L. Schramm, Jr. 1999. Growth of Flathead Catfish in the Lower Mississippi River. Pages 121-124 *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.

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., and V.H. Travnichek, editors. 2011. Conservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

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. Schramm, Jr, and T. Coon, editors. Catfish 2000: proceedings of the international ictalurid symposium. American Fisheries Society, Symposium 24, Bethesda, Maryland.

Muoneke, M.I., and K.L. Pope. 1999. Development and evaluation of a standard weight (W_S) equation for blue catfish. North American Journal of Fisheries Management. 19:878-879

Ogle, D.H. 2016. Introductory fisheries analyses with R. CRC Press, Florida.

Olive, J., Schramm, H.L. Jr., Gerard, P.D. and Irwin, E. 2011. An evaluation of agreement between pectoral spines and otoliths for estimating ages of catfishes. Pages 679-688 *in* P.H. Michaletz and V.H. Travinchek, editors. Conservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

Pitlo, J. Jr. 1997. Response of upper Mississippi River Channel Catfish populations to changes in commercial harvest regulations. North American Journal of Fisheries Management 17:848–859.

Quinn, S.P. 1993. Description of a multiuse fishery for Flathead Catfish. North American Journal of Fisheries Management 13:594-599.

Quist, M.C., M.A. Pegg, and D.R. DeVries. 2012. Age and Growth. Pages 677-721 *in* A.V. Zale, D.L. Parrish, and T.M. Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, Maryland.

R Development Core Team. 2015. R: A language and environment for statistical computing. Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Sakaris, P.C., Irwin, E.R., Jolley, J.C., and D. Harrison. 2006. Comparison of native and introduced Flathead Catfish populations in Alabama and Georgia: growth, mortality, and management. North American Journal of Fisheries Management 26(4): 867-874.

Slipke, J.W., and M. J. Maceina. 2014. Fishery Analysis and Modeling Simulator (FAMS). Version 1.64. American Fisheries Society, Bethesda, Maryland.

Steuck, M.J., and C.C. Schnitzler. 2011. Age and growth of Flathead Catfish from Pools 12 and 13 of the upper Mississippi River. Pages 699-712 *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.

Timmons, T.J. 1999. Movement and exploitation of Blue and Channel Catfish in Kentucky Lake. Pages 187-192 *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.

Travnichek, V.H. 2011. Angler size selectivity and exploitation of Flathead catfish from the Missouri River. Pages 119-126 *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.

USFWS (U.S. Fish and Wildlife service) and the Bureau of the Census. 2014. 2011 national survey of fishing, hunting, and wildlife-associated recreation. USFWS and Bureau of the Census, Washington, D.C.

Vokoun, J.C., and C.F. Rabeni. 1999. Catfish sampling in rivers and streams: a review of strategies, gears, and methods. 1999. 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.

Wege, G.W., and R.O. Anderson. 1978. Relative weight (Wr): A new index of condition for Largemouth Bass. Pages 79-91 *in* G.D. Novinger and J.G. Dillard, editors. New approaches to the management of small impoundments. American Fisheries Society, Special publication, volume 5.

Wilson, K.L., Matthias, B.G., Barbour, A.B., Ahrens, R.N.M., Tuten, T., and M.S. Allen. 2015. Combining samples from multiple gears helps to avoid fishy growth curves. North American Journal of fisheries Management 35(6): 1121-11

Table 2.1— Instantaneous rate of mortality (*Z*), percent annual mortality (*A*), and percent annual survival (*S*) of Channel (CCF), Flathead (FCF), and Blue Catfish (BCF) among gears in the Wabash River from 2014-2016.

Species	**Gear**[a]				
	LF	**HF**	**HP**	**BP**	**Mean**
CCF					
Z	0.55	0.57	0.53	0.62	**0.57**
A	42.00	43.40	40.90	45.90	**43.05**
S	58.00	56.60	59.10	54.10	**56.95**
FCF					
Z	0.47	0.58	0.41		**0.49**
A	37.20	43.80	33.50		**38.17**
S	62.80	56.20	66.50		**61.83**
BCF					
Z	0.37				
A	31.16				
S	68.84				

[a]LF is low-frequency electrofishing, HF is high-frequency electrofishing, HP are hoop nets, and BP are bank poles

Table 2.2— Sources, equations, and estimates of instantaneous natural mortality rates (*M*) for Channel (CCF), Flathead (FCF), and Blue Catfish (BCF) in the Wabash River.

Source	Equation	CCF	FCF	BCF
Quinn and Deriso (1999)	$-\ln(Ps)/t_{max}$	0.580	0.419	0.419
Hoenig (1983)	$1.46 - 1.01*\ln(t_{max})$	0.530	0.382	0.382
Jensen (1996)	$1.50*K$	0.450	0.069	0.210
Peterson and Wroblewski (1984)	$1.92*(WT^{-0.25})$	0.289	0.105	0.188
Pauly (1980)	$-0.0066 - 0.279*\log_{10}(L_{\infty}) + 0.643*\log_{10}(K) + 0.4634*\log_{10}(TEMP)$	0.455	0.049	0.127
Chen and Watanabe (1989)	$(1/t_f - t_i)*\ln(e^{K*tf} - e^{K*to})/e^{K*ti} - e^{K*to})$	0.396	0.184	0.270
Average *M* for all estimators		0.450	0.201	0.266

Table 2.3— Parameters used to model the effects of two minimum length limits for Channel (CCF), Flathead (FCF), and Blue (BCF) Catfish in the Wabash River with the yield-per-recruit model in FAMS.

Parameter	**CCF**	**FCF**	**BCF**
Von Bertalanffy growth coefficients			
L_{inf}	626.24	1,736.37	1007.7
K	0.3	0.068	0.14
t_0	-0.384	-1.013	-0.769
Maximum Age	8	14	11
Conditional natural mortality	0.36	0.18	0.23
Exploitation rate (%)	0-90	0-90	0-90
Log_{10} weight-length regression coefficients			
Intercept	-5.023	-4.805	-5.2306
Slope	2.982	2.935	3.0835
Minimum length limits (mm)	330 and 381	330 and 381	330 and 381
Initial population	1,000	1,000	1,000

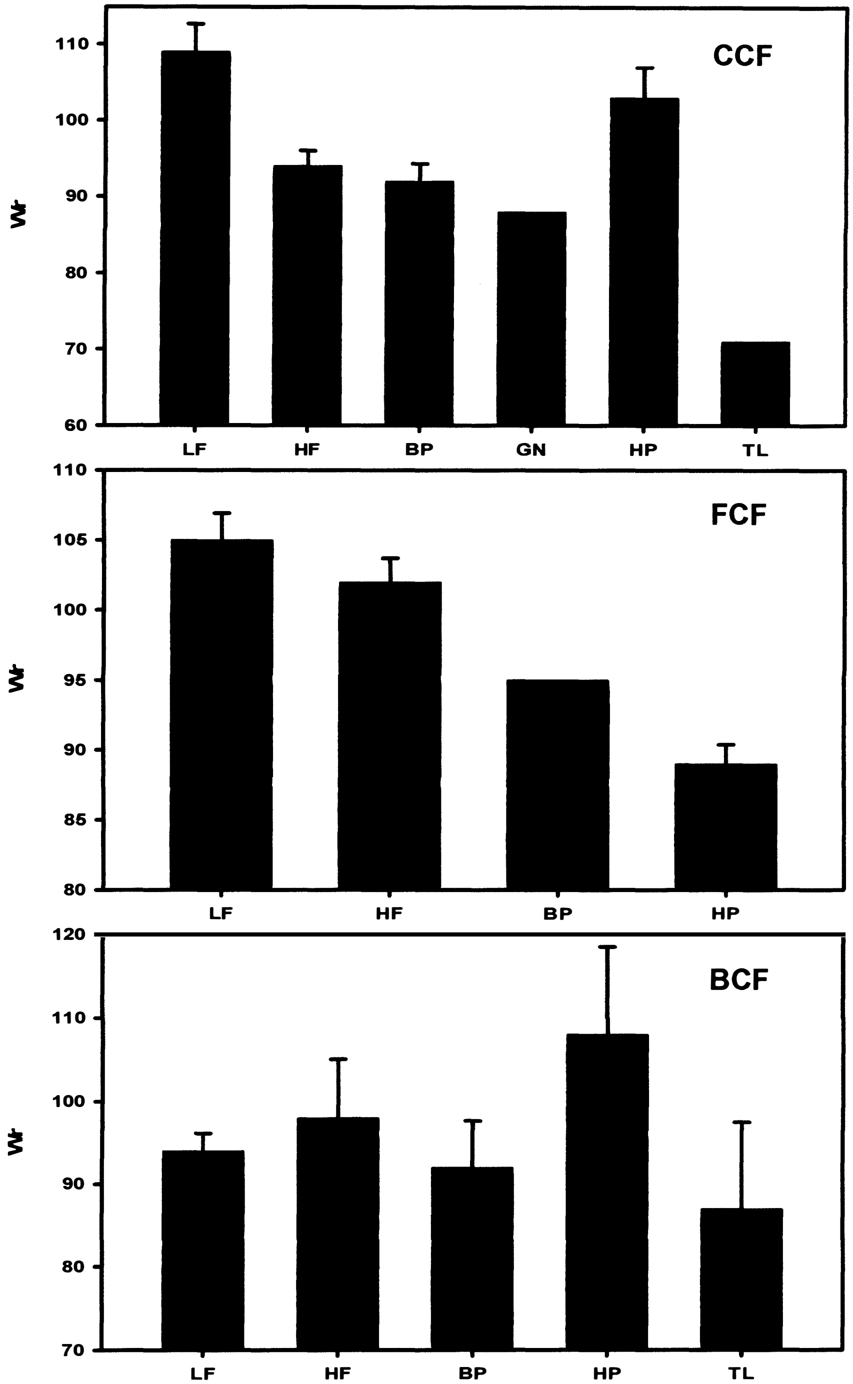

Figure 2.1— Relative weights (Wr) among gears (LF= low-frequency electrofishing, HF= high-frequency electrofishing, HP = hoop nets, BP = bank poles, TL = trot line, GN = gill net) for Channel (CCF), Flathead (FCF), and Blue Catfish (BCF) in the Wabash River. Error bars denote standard error.

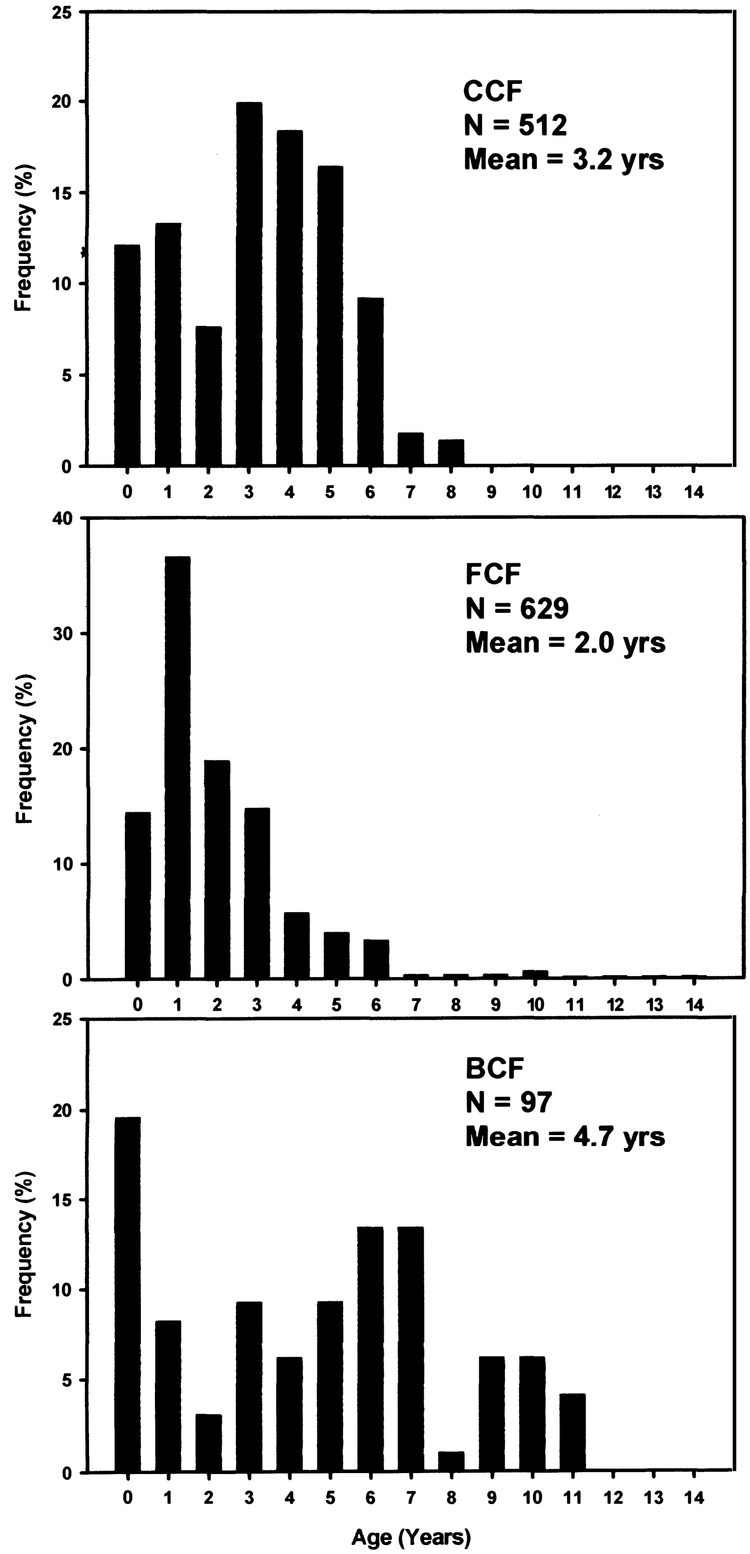

Figure 2.2— Age-frequencies of Channel (CCF), Flathead (FCF), and Blue Catfish (BCF) in the Wabash River.

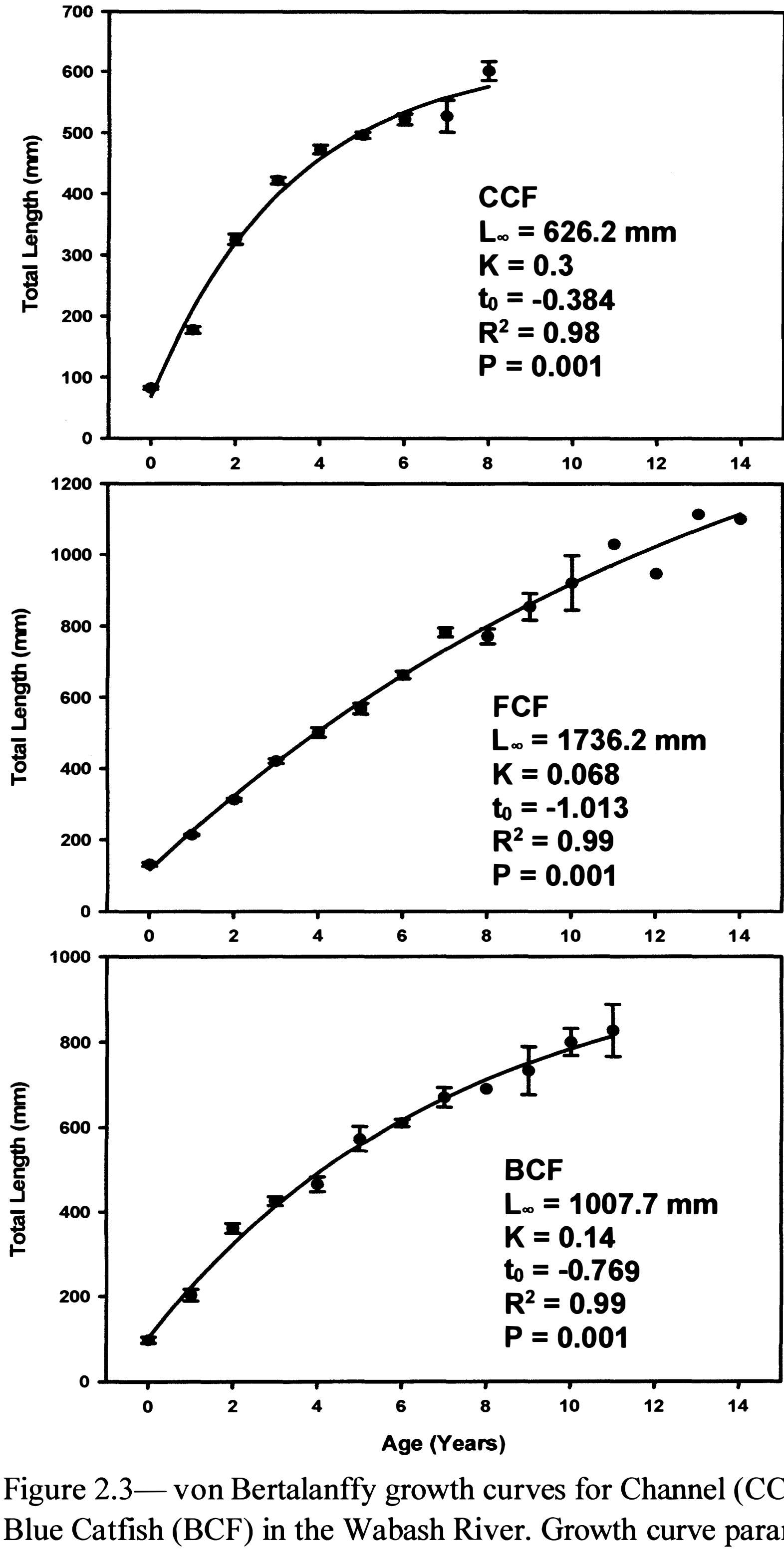

Figure 2.3— von Bertalanffy growth curves for Channel (CCF), Flathead (FCF), and Blue Catfish (BCF) in the Wabash River. Growth curve parameters include L_∞ (the theoretical maximum length), K (von Bertalanffy growth coefficient), and t_0 (the theoretical age at which a fish's length would be zero). Error bars denote standard error.

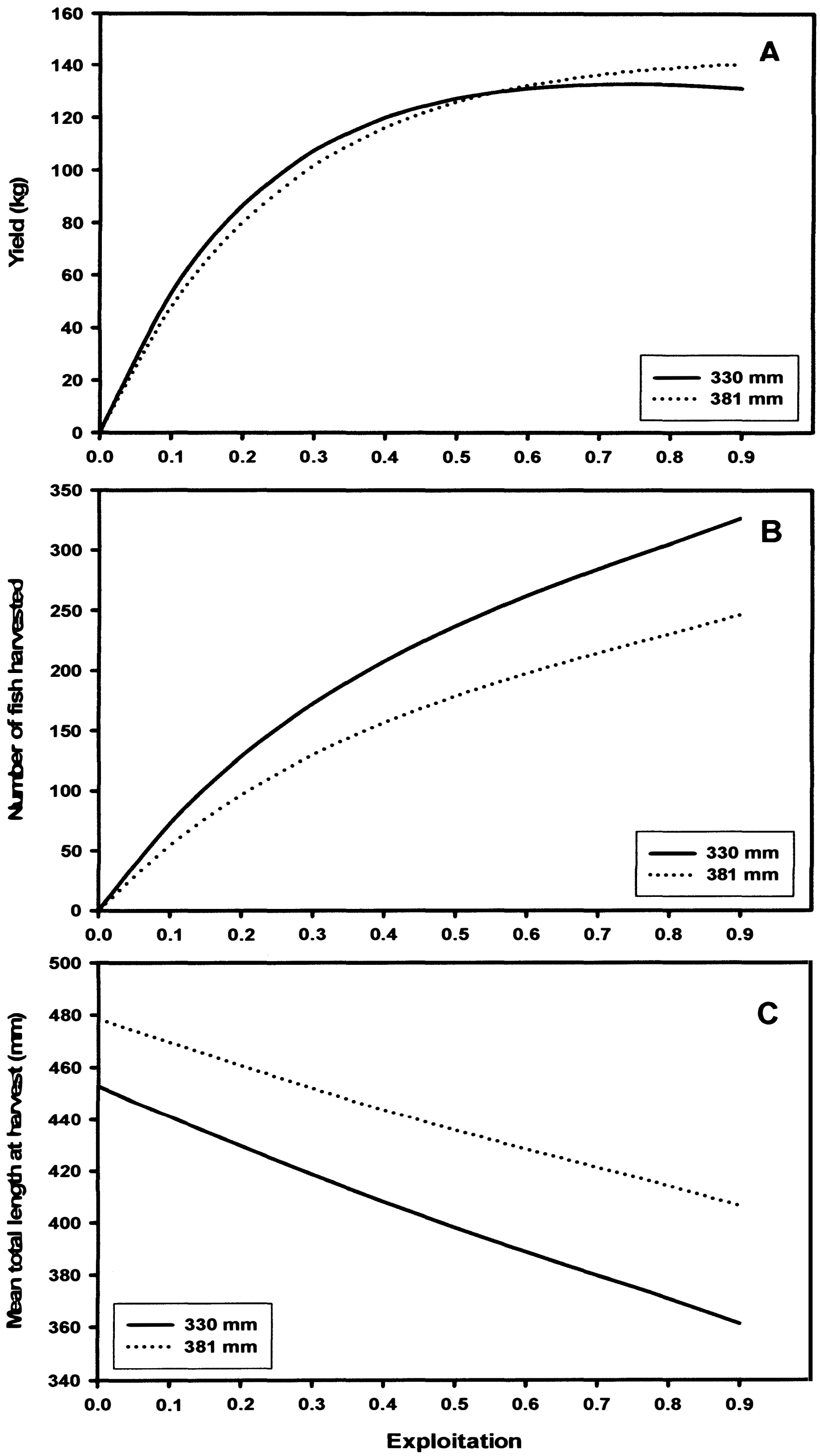

Figure 2.4— The predicted yield (kg) (A), the predicted number of fish harvested (B), and the predicted mean total length (C) of Channel Catfish harvested over a range of exploitation rates and minimum length limits of 330 and 381 mm in the Wabash River.

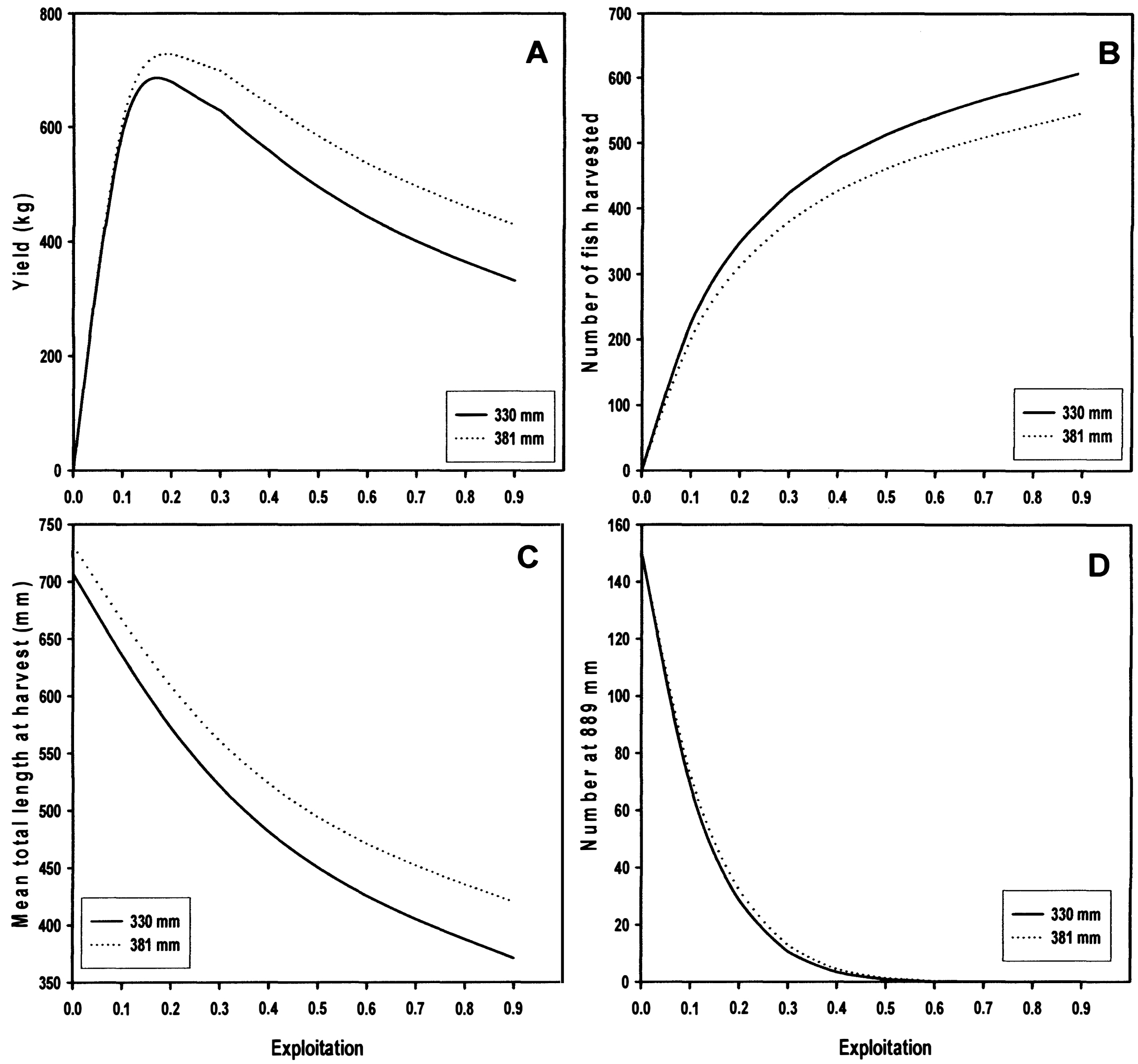

Figure 2.5— The predicted yield (kg) (A), the predicted number of fish harvested (B), the predicted mean total length (C), and the number of individuals at 889 mm (D) of Flathead Catfish harvested over a range of exploitation rates and minimum length limits of 330 and 381 mm in the Wabash River.

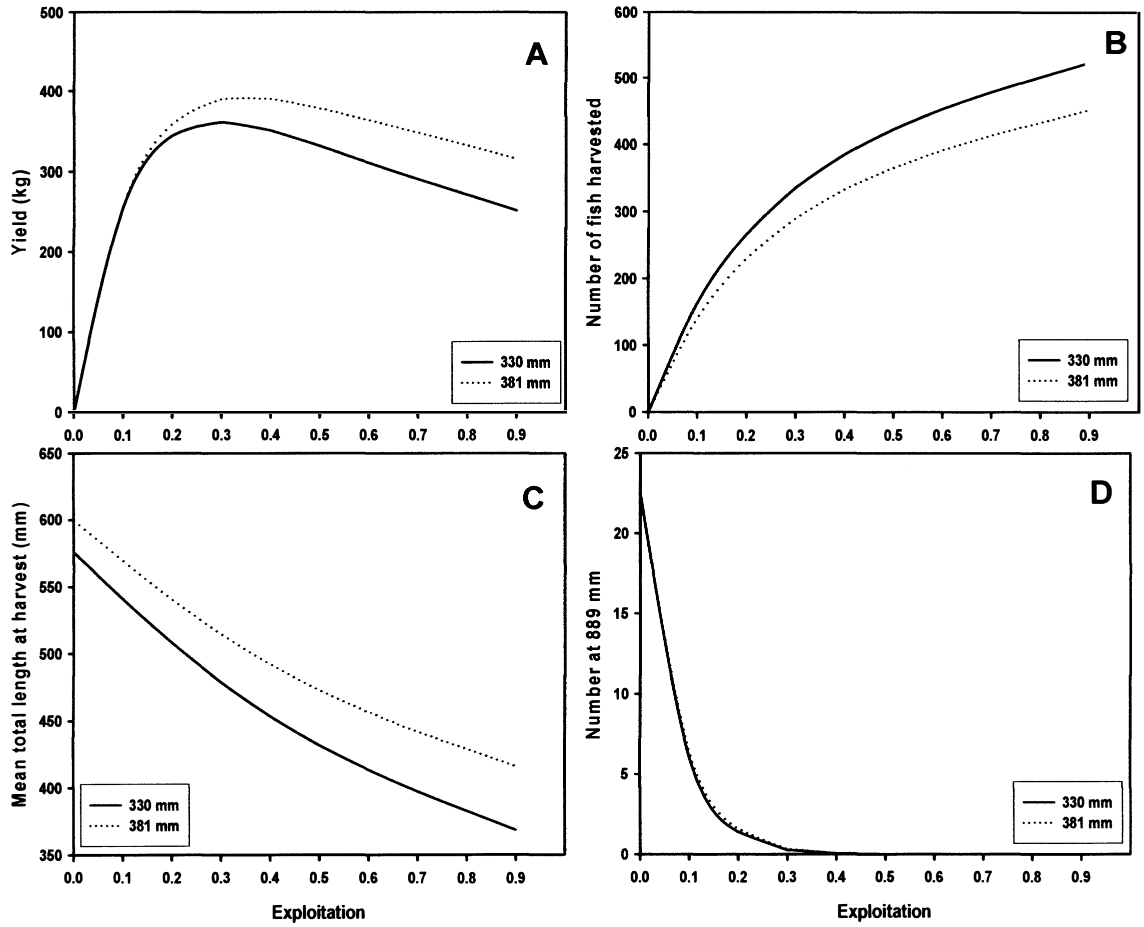

Figure 2.6— The predicted yield (kg) (A), the predicted number of fish harvested (B), the predicted mean total length (C), and the number of individuals at 889 mm (D) of Blue Catfish harvested over a range of exploitation rates and minimum length limits of 330 and 381 mm in the Wabash River.

CONCLUSION

The study of catfish is a diverse and expanding field that includes various topics of management, life history, and ecology (Kwak et al. 2011). Due to their popularity with anglers, Channel, Flathead, and Blue Catfish have become some of the most sought after freshwater game species (USFWS 2014). Although these species are increasingly becoming more popular with anglers, managers often struggle to manage these species (Michaletz and Dillard 1999; Vokoun and Rabeni 1999). Researchers must continue to expand on current knowledge to further the sustainable management of these three species. Accurate and precise population dynamic estimates are derived from data collected from sampling gears. There has been an immense amount of research comparing the efficiencies of gears (Bodine et al. 2013). However, researchers and managers need to start adopting a standardized unit of effort instead of gear-specific catch rates. The use of standardized catch rates will allow for a true comparison among gear types on the sampling efficiency of Catfish. Additionally, exploitation of these species needs to be monitored due to an increase in harvest throughout the country.

The Wabash River has supported a popular commercial fishery for several decades (Maher 2015; unpublished data). However, there has been a decline over the past couple of decades of commercial fishing licenses being sold. Although many inland commercial fisheries are in decline or closed, the Wabash still supports a rather substantial commercial fishery (Krogman et al. 2011; Kwak et al. 2011; Craig Jansen, personal communication). Additionally, harvest rates of recreational fishermen are largely unknown but are assumed to be relatively high. Catfish regulations in the Wabash River have recently been changed by the state of Illinois. A MLL of 330 mm for all three species has been implemented for recreational fishermen. Additionally, only one Channel Catfish over 711 mm and one Flathead and Blue Catfish over 889 mm can be harvested each day. Regulations for commercial fishermen remain unchanged for all three species of Catfish.

This project sought to develop a more efficient sampling protocol for the three Catfish species. I also wanted to assess the current status and predict the effects of the new fishing regulations on the Catfish populations in the Wabash River. Based on our results we suggest that Channel Catfish should be sampled seasonally (spring, summer, and fall) with baited variable-mesh hoop nets and bank poles. Flathead Catfish should be sampled with low-frequency electrofishing from spring through fall. Blue catfish should also be sampled using low-frequency electrofishing during the spring season. It may be advantageous to supplement Flathead and Blue Catfish sampling with hook and line methods (Bodine et al. 2013). These gears will provide the most efficient and cost effective sampling methods in the Wabash River for all three species of Catfish. Exploitation of these populations varied between species but were comparable to other populations throughout North America. Channel Catfish and Blue Catfish seemed to react favorably to the new regulations. In order for Flathead Catfish harvest to become sustainable, stricter fishing regulations need to be implemented. An increased minimum length limit or bag limit will help to prevent growth overfishing, increase yields, and improve stock structure of Flathead Catfish.

Monitoring fish populations is a continuous process for managers. Long term data will allow managers to see trends within the Wabash River Catfish populations. Recently, there has been an increase in the popularity of Catfish trophy fishing and recreational harvest (Arterburn et al. 2002; USFWS 2014). Further research is warranted to estimate the overall harvest, impacts, and human dimensions of recreational fishermen on the Wabash River. Continued monitoring and enforcement of new regulations will allow for managers to develop a more sustainable and productive fishery.

LITERATURE CITED

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

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

Krogman, R.M, Fischer, J.R., Quist, M.C., Steuck, M.J. and M.M. Marron. 2011. Historical trends in ictalurid catfish commercial harvest in the upper Mississippi River. Pages 127- 140 *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.

Kwak, T.J., Porath, M.T., Michaletz, P.H. and V.H. Travnichek. 2011. Catfish Science: Status and Trends in the 21st Century. Pages 755- 780 *in* P.H. Michaletz and V.H. Travnichek, editors. Cnservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.

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

USFWS (U.S. Fish and Wildlife service) and the Bureau of the Census. 2014. 2011 national survey of fishing, hunting, and wildlife-associated recreation. USFWS and Bureau of the Census, Washington, D.C.

Vokoun, J.C., and C.F. Rabeni. 1999. Catfish sampling in rivers and streams: a review of strategies, gears, and methods. 1999. 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.