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DEMOGRAPHICS AND THE ECOLOGICAL ROLE OF THE CHANNEL CATFISH (ICTALURUS PUNCTATUS) IN COMMERCIALLY EXPLOITED AND UNEXPLOITED REACHES OF THE WABASH RIVER WITH IMPLICATIONS FOR THE FLATHEAD CATFISH (PYLODICTIS OLIVARIS)

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by

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DISSERTATION APPROVAL

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Approved by:

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AN ABSTRACT OF THE DISSERTATION OF

ROBERT E. COLOMBO II, for the Doctor of Philosophy degree in ZOOLOGY, Presented on 17 September 2007, at Southern Illinois University Carbondale

TITLE: Demographics and the Ecological Role of the Channel Catfish (*Ictalurus punctatus*) in Commercially Exploited and Un-exploited Reaches of the Wabash River with Implications for the Flathead Catfish (*Pylodictis olivaris*)

MAJOR PROFESSORS: James E. Garvey and Roy Heidinger

Catfish are a major component of the Wabash River fish assemblage and are commercially fished below river kilometer (Rkm) 500. From Rkm 322 through 499 the commercial fishery is subjected only to Indiana fishing regulations. In this reach of river, there is a 254-mm minimum total length limit on both sport and commercially harvested catfish. Below RM 322, the Wabash River forms the state boundary of Indiana and Illinois. In this region of river there are two different length limits on commercially harvested catfish with Indiana having a 254-mm length limit and Illinois having a 381-mm length limit. There is no length limit on sport harvest of catfish by Illinois anglers; however, there is a 254-mm length limit on the Indiana sport fishers. The primary objective of this study was to assess the general population dynamics of the channel catfish (*Ictalurus punctatus*) under various sport and commercial fishing regulations and to determine the sources of energy for this species. To accomplish this, I sampled both fished (IN, IN & IL) and unfished (NON) treatment reaches of the Wabash River during fall 2001 through 2004 using three-phase alternating current (AC) electrofishing and cheese baited, 25-mm and 32-mm bar-mesh hoop nets. Of the 2,807 catfish collected,

91% were channel, 8% were flathead (*Pylodictis olivaris*) and 1% were blue catfish (*I. furcatus*). Length frequency distributions and mean age of fish differed across the three different gear types ($P < 0.02$), with electrofishing sampling larger, older channel catfish. Densities estimated from catch per unit effort (CPUE) did not differ among treatment reaches (NON, IN, IN & IL) using hoop nets (25-mm: $P < 0.1$, 32-mm: $P = 0.4$); however, electrofishing CPUE was greater in the unfished reach compared to the two commercially exploited reaches ($P < 0.001$). Additionally, length frequency distributions and stock indices differed among treatment reaches ($P = 0.017$). As suggested by the high relative stock density of preferred length fish (RSD-P) values, more large catfish resided in the unfished reach than the fished reaches. Age structure also varied among reaches. More old fish were in the commercially unexploited treatment reach, leading to greater mean age ($P < 0.005$). Ages derived from the articulating process of the pectoral spine agreed well with those determined from the sagittal otolith. Mortality estimated from the slope of the regression of age on Log_{10} frequency (catch curve) was greater for both gear types in the commercially exploited reaches than in the non exploited reach. Mean length at age 5 and condition of channel catfish was greater in the commercially exploited reaches than the unexploited reach. There was a positive relationship between channel catfish electrofishing CPUE and habitat quality as measured by the qualitative habitat assessment index (QHEI). Yield-per-recruit modeling of the commercially exploited river reaches predicted that at the current level of harvest the channel catfish fishery is sustainable; however, if both states adopted a 254-mm length limit and fishing mortality increased both growth and recruitment overfishing would likely occur even at fairly low levels of harvest (30% fishing mortality). Yield-per-recruit modeling of the

flathead catfish population suggested this population was not sustainable at any of the length limits modeled. Based on stable isotope analysis of $\delta^{13}C$ and $\delta^{15}N$, channel catfish did not differ in their trophic status among the treatment reaches, and the structures of the food webs among reaches were similar. These results provide additional support to the hypothesis that growth and condition are functions of density. The results of this study suggest that a harvest reserve in a large river acts similarly to marine reserves, in that density increases on the reserve lead to decreased growth and condition of individuals on the reserve.

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CHAPTER ONE

GENERAL INTRODUCTION

Fish provide one of the most important sources of animal protein for much of the world's human population, leading to a continual increase in production from capture fisheries and aquaculture worldwide (FAO 2002). Although fish production through aquaculture is increasing, capture fisheries provide the majority (71 %) of fish biomass consumed, with the overwhelming majority of marine origin. As many of the world's marine resources have become depleted both at the species level (Hutchings and Meyers 1994, Fogarty and Murwaski 1998) and at the ecosystem level (Pauly et al. 1998), more demand is being placed on inland fisheries sources (FAO 2002).

Over the past decade, commercial exploitation of inland fisheries has increased dramatically (FAO 2002). However, how commercial harvest affects these fisheries is poorly understood. Commercial exploitation affects the growth rate (Conover and Munch 2002, Walsh et al 2006), age at maturity (Olsen et al. 2004), density (Hutchings and Meyers 1994, Fogarty and Murwaski 1998), recruitment (Meyers 2001, Schnute and Krolund 2002), and mortality (Ricker 1975, Goodyear 1996) in anadromous and marine stocks, but researchers know little concerning the impacts of harvest on inland stocks (Post et al. 2002, Allan et al. 2005).

Exacerbating our lack of information is a lack of management tools or innovations. Reserves, quotas, and harvest restrictions that have been widely adopted in marine systems are rarely used in inland systems. Unlike contiguous marine systems, inland systems are often fragmented (e.g., lakes, ponds, reservoirs), leading to differential harvest in areas with high human density (Post et al. 2002) making statewide management a challenge. Many inland fisheries of the United States and Canada fall within the jurisdiction of two or more governing agencies, with differing strategies to manage the same resource. Further, the lack of fisheries observers, creel census data, and enforcement has led to gross underreporting by commercial fishers. Because of the lack of harvest data, managers must use surveys to determine the response of particular stocks to commercial harvest.

Catfish are the most consumed native freshwater fish in the US (NASS 2006). Although commercial aquaculture produces most catfish consumed (NASS 2006), free living populations of channel catfish (*Ictalurus punctatus*) still provide important sport and commercial fisheries throughout the US. Catfish are considered moderately or highly important to anglers in 32 states, are recreationally managed in 34 states and commercially fished in 28 states (Michaletz and Dillard 1999). Although harvest of catfish has declined in the US since 1988 (Heidinger 2000, FAO 2003), they remain recreationally and commercially important in the Midwest. In Illinois, for example, catfish account for 25% by weight of the fishes harvested annually from rivers by commercial fishers (Maher 2002).

Much of the inland yield of catfish is derived from rivers, which are spatially difficult to sample (Michaletz and Dillard 1999). Further, most large rivers have been impounded for human use, fragmenting the populations. Therefore, populations are difficult to define and assess. Understanding the dynamics of riverine fish species in a large unimpounded river requires baseline data. My research focuses on the Wabash River, one of the few remaining large unimpounded rivers still connected to its floodplain. The Wabash River currently sustains a large catfish commercial fishery, with catfish comprising approximately 50% (Maher 2002) and 80% (Stefanavage 1999) of the harvest by Illinois and Indiana commercial fishers, respectively. Most of this harvest consists of channel catfish (56% by weight), with a lesser capture of both blue (18%) (*I. furcatus*) and flathead (26%) catfish (*Pylodictis olivaris*). Channel catfish will be the focus of the body of this document with flathead and blue catfish examined in appendix B.

Illinois and Indiana share the fishery along the lower 322 km, where each state has its own minimum length limit. In Indiana, a "fiddler" fishery is maintained (254 mm minimum total length limit) allowing commercial fishers to harvest small immature catfish. In contrast, only fish greater than 381 mm total length can be harvested by Illinois fishers. The states recreational regulations also differ. In Indiana, there is a 254 mm minimum size limit on sport fish harvest, while Illinois has no minimum length limit. Recently, the annual commercial harvest of the catfish has been similar between the two states, with Indiana fishers and Illinois fishers harvesting approximately 20 tonnes (Stefanavage 1999) and 22 tonnes respectively (Maher 2002). In total, this equates to 84 kg of catfish harvested per river km (Rkm). Understanding how commercial exploitation affects this fishery can provide insight into the impact of harvest on large river species. Commercial fishing is prohibited in Indiana above Rkm 500, allowing comparisons to be made between fished and unfished stocks. Therefore, an assessment of the impacts of commercial fishing can be made on the catfish stocks.

Density and Size Structure

As with other fish species, commercial harvest can reduce the density of channel catfish populations. In some cases, such as the Missouri River, this reduction has led to recruitment overfishing (Pitlo 1997), which occurs when harvest rate is greater than reproduction and is often a precursor to fishery collapse (Gulland 1969, Allan et al. 2005). Therefore, commercially exploited populations need to be monitored intensively in order to develop and assess management strategies. Quantifying the sexual demographics (sex ratio, maturation schedule, size specific fecundity), density, and age-size structure of the population can help managers to determine how much loss of reproductive potential can be sustained (Goodyear 1993, Haddon 2001, King 2001, Quist et al. 2002, Slipke et al. 2002).

Commercial exploitation can alter the sexual demographics of fish populations, particularly when one sex is preferentially harvested (e.g, for caviar production; Fabrizio and Richards 1996). Sex ratios also can be skewed by sex-biased selection by a gear (Dew 1988). For example, one sex may be more susceptible to harvest due to unique behavior (e.g., congregation for spawning). Further, due to dimorphic growth, the faster-growing sex may recruit to the fishery more quickly, causing differential mortality. Detailed sex-specific demographics and size structure information allow managers to develop more accurate models for forecasting population growth and yield (Goodyear 1993, Slipke et al. 2002).

To accurately describe the size structure of catfish populations, multiple gear types must be used (Vokoun and Rabeni 1999). Hoop nets have been used extensively to sample catfish populations (Mayhew 1973, Gerhardt and Hubert 1989, Holland and Peters 1992, Michaletz and Sullivan 2002). This gear allows populations to be compared because of hoop nets are frequently used by both scientists and commercial fishers.

Hoop nets, as with any other gear, have inherent biases. Increasing mesh size increases the size of catfish sampled, so using multiple mesh sizes is necessary to quantify size structure (Holland and Peters 1992; Sullivan and Gale 1999; Santucci et al. 1999). In most cases, baiting hoop nets increases catch rates of catfish (Mayhew 1973), with the exception of spawning individuals (Gerhardt and Hubert 1989). Because of the size bias of hoop nets adequately describing the characteristics of a population using hoop nets requires using a large complement of mesh sizes, which is often impractical. Alternating current (AC) and direct current (DC) electrofishing also have been used to sample catfish (Jacobs and Swink 1982; Santucci et al. 1999; Vokoun and Rabeni 1999). These gears have produced conflicting measures of capture efficiency (Heidinger et al. 1983) and size selectivity (Reynolds 1996; Santucci et al. 1999). Therefore, care must be taken when determining size and age structure of the population. Because of the bias in any one particular gear type, a multi-gear approach for assessing populations may be beneficial.

It also is imperative to determine how density of population changes with commercial fishing. A minimum length regulation can cause size- and age-specific mortality (Goodyear 1996). If harvest is too high, compensatory mechanisms in natural mortality cannot counteract increases in fishing mortality (Ricker 1975). It is therefore essential to adequately determine the density of the differing age-size classes of fish to accurately determine population responses to various management protocols.

Age, Growth, and Mortality

Fishing can alter the growth rate, age structure, and mortality rate of fish populations. By reducing the density of a population, harvest can lessen intraspecific competition and potentially increase growth rate (Ricker 1975, Walters and Post 1993). Furthermore, harvest of a fish population above a specific minimum length can lead to age-specific mortality. As a fish population is exploited, the age frequency distribution shifts from one comprised of a large proportion of old, slow-growing individuals to one comprised mainly of small, young, fast-growing fish (Goodyear 1996). Populations dominated by small, young fish are more susceptible to population fluctuations caused by demographic (e.g., poor recruitment year) and environmental (e.g., dry year) stochasticity (Pitlo 1997). Total population mortality rate also may increase with harvest when not compensated for by a reduction in natural mortality.

Characterizing the age structure of a population requires an accurate means of estimating age. Catfish age can be estimated using several hard structures. Historically, the basal recess of the pectoral spine has been used (Sneed 1951), although estimates from this structure may under-represent the age of large, old fish in species such as flathead catfish (Nash and Irwin 1999). Recently, the sagittal otolith and the articulating process of the pectoral spine have been used to age catfish (Nash and Irwin 1999; Buckmeier et al. 2002). Both structures have been validated for pond-reared channel catfish ≤ age four (Buckmeier et al. 2002). Similarly, for flathead catfish, a section of the articulating process provided better agreement with the otolith than did the basal recess (Nash and Irwin 1999).

Several attributes of the catfish otolith make it less desirable for aging than the pectoral spines. The otolith requires sacrificing all fish for which age is to be estimated. Furthermore, the processing time is longer and it is difficult to determine back-calculated length at age for catfish from otolith mounts. The articulating process of catfish spines provide an alternative to otoliths. Sacrificing the fish is not necessary, and spines can be processed more quickly, providing good estimates of age. Length at age also can be determined easily except in very old fish (Nash and Irwin 1999; Buckmeier et al. 2002).

Once the age structure of a population is estimated, instantaneous mortality can be calculated from a catch curve. A catch curve is a simple regression of age against the log-transformed frequency. The descending slope of this plot estimates instantaneous mortality (Z) (Ricker 1975). To prevent bias, this technique requires that recruitment is constant (Van Den Avyle and Hayward 1999), which is generally untrue. If recruitment is not constant, mortality can be either overestimated or underestimated. One way to compensate for variable recruitment is to average the mortality rate over a number of years thereby dampening the impact of strong and weak age classes. A similar approach is to sum catch per age class across multiple years (Ricker 1975) and then generate a catch curve for the combined years to reduce the impact of recruitment variability.

Estimates of mortality are also biased by inherent selectivity of gears. Typically, most gears sample younger year classes accurately (Van Den Avyle and Hayward 1999). Therefore, mortality can only be estimated from year classes that are fully recruited to the sampling gear (Ricker 1975; Slipke and Maceina 2000). This bias also makes apparent the need to independently estimate mortality for differing gear types so that these biases are not compounded.

Along with mortality, estimating growth rate is essential to understanding how fish populations respond to harvest. Growth rates are used to estimate time to recruitment, time to maturity, and the yield of a fishery (Summerfelt and Hall 1987). Growth estimates require an accurate aging technique, which the articulating processes of spines provide. Taken together, mortality and somatic growth rate permit yield of the population to be estimated.

Several approaches are used to compare fish growth among populations. The simplest and most prevalent way is to compare mean length at age (Haddon 2001). Because fish somatic growth is non-linear, length at age does not allow for the estimates of the length of missing age classes, or other population parameters needed for between population comparisons (Beverton and Holt 1957, Ricker 1975). The von Bertalanffy model is commonly used to estimate growth parameters that can be compared among populations (Van Den Avyle and Hayward 1999, Haddon 2001) - the Brody growth constant (K) and the theoretical maximum length (L_∞) allows for the determination of theoretical maximum size. Due to its flexibility, simplicity, and similarity to the actual growth trajectory the von Bertalanffy approach is the preferred model of fisheries scientists (Haddon 2001).

Catfish growth appears to differ over the length of the Wabash River (Lauer 2000, Willenberg 2001). These growth differences have been attributed solely to latitude (Willenberg 2001) with no consideration of density differences along the river gradient. If channel catfish density differs among treatment reaches as a function of harvest intensity or size limits, growth rate may change independent of or converging with latitude. Habitat quality or water quality differences over the length of the Wabash River may also account for differences in catfish density.

Yield Modeling

If harvest is left unchecked, catfish populations can become overfished, leading to reduced in yield and recruitment (Pitlo 1997). Models such as the Beverton-Holt yield per recruit model have been effective in estimating the yield of populations under alternative management strategies (Maceina et al. 1998, Quist et al. 2002, Colombo et al. 2007) These models require information on the growth and mortality of the population.

Because the Wabash River has two minimum length limits (e.g. Indiana: 254 mm and Illinois: 381 mm) it is important to understand how these two length limits are affecting population yield. Characteristics of the Beverton-Holt yield per recruit model allow the estimation of which length limits allow the fishery to remain sustainable under various levels of harvest. The inflection point in the plot of yield per recruit model and fishing mortality is the maximum yield per recruit the associated level of fishing mortality (F_{max}) is the maximum that a population can withstand. Any harvest above this point is by definition growth overfishing (King 2001). To maintain a sustainable fishery harvest must take place at some level below F_{max} (King 2001). It has been assumed that a desirable sustainable fishery can be maintained if harvest is reduced to the $F_{0.1}$ level. The $F_{0.1}$ point is calculated by determining the level of mortality that results in a change in yield per recruit equal to 10% of the slope at very low levels of fishing mortality (King 2001).

The spawning potential ratio (SPR) has been used to assess how harvest impacts the reproductive potential of females in a population (Goodyear 1993, Slipke et al. 2002, Colombo et al. 2007). The SPR compares the potential proportion of eggs a recruit will produce in an exploited population with that of an unexploited one. In an unexploited population the proportion is equal to 1, and declines towards zero with increased fishing mortality due to removal of females before their total reproductive potential is met. For many marine fisheries, an SPR of 0.30 is considered the critical value below which the population reaches recruitment overfishing (Goodyear 1993). Recently, for the overfished population of channel catfish in the Upper Mississippi River, the critical SPR was between 0.10 and 0.20 (Slipke et al. 2002). Information regarding the sex ratio, maturation schedule, and fecundity are needed to determine the SPR for the Wabash River stocks. These data are currently lacking. However, suitable information is available for similar populations in large midwestern rivers. Although these data are less desirable than ones derived directly from the Wabash River population, they provide a good starting point.

Catfish in an ecological context

Much of the world's freshwater fauna is in strong need of conservation, with 35-37% of freshwater amphibians and fishes classified as vulnerable, imperiled, or extinct. This percentage is particularly alarming considering only 14-18% of terrestrial vertebrates maintain a similar status (Richter et al. 1997). The leading factor contributing to this problem is habitat degradation, which reduces biodiversity and thereby, alters food webs (Vaughn and Taylor, 1999). Habitat degradation is particularly problematic in most large rivers of North America where human expansion has necessitated impoundments and levees for flood control, hydropower, irrigation, and navigation. Without conservation efforts, we will see the demise of numerous large river freshwater species and ultimately an alteration of their food web interactions. Altered food webs and energy flow may feed back to further reduce the success of natives and may even enhance the establishment and growth of invasive species. Understanding river food webs will allow us to assess the underlying causes and consequences of loss of biodiversity.

The Wabash River provides an excellent baseline model for large river ecosystem studies. It is the 12th largest in the United States, and drains more than 60% of the land area of the state of Indiana (Gammon, 1998). The Wabash is unique in that it remains un-impounded and relatively un-leveed along its 764 km range, so it experiences predictable natural floods and remains in contact with its floodplain and tributary rivers. The structure and function of the Wabash River ecosystem and its food web remain relatively intact. The large spatial area involved and the un-channelized conditions allow a unique opportunity to address ecosystem level questions, and ultimately provide a reference for altered rivers allowing for better management of large rivers.

The Wabash River can be used as a model to investigate fundamental ecosystem questions. For example, how are natural food webs assembled and from where does the energy supporting native species come? Ecologists have attempted to investigate these questions using theoretical models. Over the past several decades, three models have emerged addressing energy origins in large rivers. Vannote et al. (1980) introduced the River Continuum Concept (RCC), which suggested that the majority of organic matter in a large river would be derived from inefficiencies upstream. Shortly thereafter, the Flood Pulse Concept (FPC) (Junk et al. 1989) emerged, which attributed the source of energy in a river to the floodplain with periodic and predictable periods of inundation. Most recently, the Riverine Productivity Model (RPM) (Thorp and Delong 1994) has addressed the issue of energy origin by suggesting the major source of organic matter in a river stems from local in-stream production.

All three theories have demonstrated validity in certain situations (Thorp et al. 1998), although none fully explains energy transport in large river systems such as those imperiled in the U.S. The RCC originated from the study of small, cold headwater streams and then was extrapolated to large river systems (Sedell et al. 1989). The FPC has relied heavily on animal migration as the source of energy transport from the flood plain to the main channel. The RPM dealt specifically with a constricted system that was both impounded and levied, neglecting the influence of the flood plain (Thorp and Delong 1994). Identifying the best model for various river systems will allow us to identify how river alteration affects energy flow, food webs, and the presence and persistence of resident species.

The most substantial problem common to all three of these models is their inability to quantify food web structure and energy flow between resident species. This can now be addressed with the application of stable isotopes that allow ecologists to study food webs in a quantitative manner (Kling et al. 1992, Cabana and Rasmussen 1994, Thorp et al. 1998, Vander Zanden and Rasmussen 1999). Stable isotopes are naturally occurring elemental isotopes that are heavier than the most common forms. The proportion of heavy isotopes of carbon provides insight into the sources of autotrophic production driving an ecosystem (France 1996, Vander Zanden and Rasmussen 1999). As a result, it can be determined whether an aquatic food web is supplied by terrestrial (allocthonous) inputs, production within the flood plain, by localized instream (autochthonous) production, or by production entering the system from upstream sources. Thus, this approach may allow me to determine how alteration of river ecosystems influences energy sources and flow. Isotopes of nitrogen change in a predictable manner as trophic status (e.g., herbivore, carnivore) in the food web changes (Vander Zanden et al. 1997, Cabana and Rasmussen 1999, Vander Zanden and Rasmussen 1999). These changes allow the assessment of how the trophic status species changes in response to differing food webs. This method will enable the determination of their status in an ecosystem context. In addition, I may be able to identify critical habitats along a river gradient that are important to maintaining ecosystem structure and function. These methods have been used extensively in both terrestrial (Cerling and Harris 1999, Hobson et al. 1999) and lacustrine (Gu et al. 1996, Johnson et al. 2002) ecosystems and large impounded rivers (Thorp et al. 1998); however, they have yet to be applied to large un-channelized midwestern river systems. In a conservation context, identifying the best river ecosystem model will provide insight into the effective approaches for rehabilitating and restoring altered rivers as well as improving conservation of resident species.

Because of its extensive range, wide range of foraging, and ability to use the floodplain, the channel catfish can be used as a model for other large riverine fish species. The channel catfish is an ecologically as well as economically important species. It is found in every continental state (Hubert 1999) and is a polytrophic feeder, feeding on fish, aquatic invertebrates and plant material (Hubert 1999), the diet of this species may change with life stage and river condition (Chick et al. 2003). Additionally, this species forages in floodplains during periods of floodplain inundation (Chick et al. 2003).

By determining where this species gets its energy and how it interacts with its environment, biologists would be better equipped to identify critical habitats essential to maintaining channel catfish populations. This is important for two reasons. First, the channel catfish is commercially harvested so enhancing its habitat will improve its conservation. Second, the channel catfish serves as a surrogate species for other riverine species such as the blue catfish which has been extirpated from the periphery of its historic range. Ultimately, this would allow for more focused attention to those habitats that are essential for population growth. Furthermore, we would be able to protect those habitats on the Wabash River that are vital to maintaining proper ecosystem function. Information derived from the Wabash River would allow for better conservation and management of other large river systems in the U.S. and the native fish species within them. For example, if it is determined that floodplain production is providing the energy needed to support large river food webs, conservationists could focus their efforts on protecting and restoring large river floodplains.

GOALS

A goal of this study is to determine how harvest affects the sexual demographics, size structure and density of catfish populations in the Wabash River by comparing populations in fished and unfished treatment reaches. Multiple gear types were used so that size structure and density could be more accurately quantified, allowing development of a standardized sampling protocol for future monitoring of catfish populations in the Wabash River. Further, I determined the age structure, mortality rate, and growth of catfish populations in the Wabash River. These parameters were used to model these populations, in order to estimate how different length regulations affect population yield. These data were used to predict at what level of fishing mortality the harvest of the channel catfish may reach critical levels. Finally, I used stable isotopes to assess whether the ecological role of catfish changes along the river continuum.

OBJECTIVES

- Determine the density, size structure, and condition of catfish populations in commercially fished and unfished regions of the Wabash River
- Determine the age structure, mortality, and growth of catfish populations in commercially fished and unfished regions of the Wabash River
- Assess the impact of commercial fisheries on the exploited treatment reaches of the Wabash River using simulation modeling
- Assess the theoretical impact of differing management strategies on the populations of catfish in the Wabash River using simulation modeling
- Assess the ecological role of the channel catfish along the length of a large un-impounded river.

CHAPTER TWO

IMPACT OF COMMERCIAL EXPLOITATION ON THE SIZE STRUCTURE, CONDITION AND DENSITY OF CHANNEL CATFISH

ABSTRACT

I estimated how harvest affects the size structure and density of channel catfish populations in the Wabash River. To accomplish this, I sampled both fished and unfished treatment reaches of the Wabash River using three-phase AC electrofishing and cheese baited, 25-mm and 32-mm bar-mesh hoop nets. Length frequency distributions differed across the three different gear types ($P < 0.02$). Overall, 25-mm hoop nets caught more small catfish (mean total length = 256 mm) and AC electrofishing caught more large catfish (mean total length = 417 mm). Densities based on catch per unit effort (CPUE) did not differ among treatment reaches using the two different mesh size hoop nets (25-mm: $P > 0.05$, 32-mm: $P = 0.4$). However, electrofishing CPUE was higher in the unfished reach compared to the two commercially exploited reaches ($P < 0.001$). Additionally, length frequency distributions and stock indices differed among treatment reaches ($P = 0.017$). As suggested by the high relative stock density of preferred length fish (RSD-P) values, more large catfish resided in the unfished treatment reach than the fished treatment reaches. Condition as measured by relative weight of channel catfish was higher ($P = 0.0009$), and the proportion of preferred length fish was lower in the commercially fished treatment reaches than the non-commercially fished treatment reach.

INTRODUCTION

A substantial catfish commercial fishery exists in the Wabash River with catfish comprising approximately 50% (Maher 2002) and 80% (Stefanavage 1999) of the commercial harvest by Illinois and Indiana fishers, respectively. Currently, the fishery has two differing length limits on commercial fishers. Illinois has a 381-mm minimum total length requirement on commercially harvested catfish, while Indiana employs a 254-mm minimum total length requirement. The states also differ in the length limits on the catfish sport fishery. In Indiana there is a 254-mm minimum size limit on sport fish harvest, while Illinois has no minimum length limit for sport fishers. Because of an agreement between Indiana and Illinois, fishers from both states can harvest the entire width of the river. Information is currently lacking about how these different regulations affect the catfish populations in Wabash River.

Commercial harvest can reduce the density of channel catfish populations. In some cases, this reduction has led to recruitment overfishing (Pitlo 1997), in which reproductive adults are sufficiently reduced to negatively affect production of offspring. Therefore, commercially exploited populations should be monitored intensively in order to develop and assess management strategies. Effective management of catfish populations requires quantification of the sexual demographics, density, and age-size structure of the population or subpopulations within the river.

Commercial exploitation has been shown to alter the sexual demographics of fish populations other than channel catfish. This is especially evident when one gender is preferentially harvested (e.g, for caviar production; Fabrizio and Richards 1996). Sex ratios can also be skewed by differential gear selection of a specific sex (Dew 1988). For example one sex may be more susceptible to sampling due to unique behavior (e.g., congregation for spawning) or large size. Further, due to dimorphic growth, the faster growing sex may recruit to the fishery more quickly, causing differential mortality. Detailed demographics and size structure information allows managers to develop more accurate models for forecasting population growth and yield (Slipke et al. 1998)

Multiple gear types must be used to accurately describe the size structure of catfish populations (Vokoun and Rabeni 1999). In terms of amount of human effort, hoop nets sample catfish populations easily and effectively (Mayhew 1973; Gerhardt and Hubert 1989; Holland and Peters 1992; Michaletz and Sullivan 2002). This gear allows populations to be compared because of their frequent use by both scientists and commercial fishers. Hoop nets, as with any other sampling gear, have inherent biases. Mesh size selects catfish size, making it necessary to use multiple mesh sizes to quantify size structure (Holland and Peters 1992; Sullivan and Gale 1999; Santucci et al. 1999). In most cases, baiting hoop nets increases catch rates of catfish (Mayhew 1973), except during the spawning season (Gerhardt and Hubert 1989). Because it is economically and physically difficult to sample with a large enough compliment of hoop nets to characterize the entire length frequency distribution of a catfish populaiton, electrofishing has been used to sample larger fish (Quinn 1986).

It also is desirable to determine how density changes with commercial fishing. A minimum length regulation causes size- and age-specific mortality (Goodyear 1996). If harvest is too high, compensatory mechanisms in natural mortality cannot counteract increases in fishing mortality (Ricker 1975). It is therefore essential to adequately determine the density of the differing age-size classes of fish in order to accurately determine population responses to various management protocols.

I sought to determine how harvest affected the sexual demographics, size structure and density of catfish populations in the Wabash River by comparing populations in fished and unfished treatment reaches. Multiple gear types were used so that the size structure and density could be more accurately quantified. To address these issues I tested the following null hypotheses: 1. there is no difference in the size structure sampled among gears, 2. there is no difference in the size structure among treatment reaches, and 3. there is no difference in density of channel catfish among treatment reaches.

METHODS

I sampled three treatment reaches and Wabash River (Figure 1, Appendix A) annually during fall 2001 through 2004 with three-phase alternating current electrofishing using a balanced six dropper electrode array and baited (rancid cheese) 25-mm and 32-mm hoop nets. Treatment reach IN & IL comprised the boundary fishery between Illinois and Indiana (322-km), with nine, 1.6-km sites (Table 1, Table 2, Appendix A). Treatment reach IN (108-km) was a commercially fished reach located entirely within the state of Indiana, with four, 1.6-km sampling sites (Table 1, Table 2, Appendix A). Treatment reach NON was the most upstream treatment reach and is currently not fished commercially (53-km). I sampled six, 1.6-km sites in this treatment reach (Table 1, Table 2, Appendix A).

Electrofishing

Sampling began in mid September in each of the four years with electrofishing at the most upstream site in the NON treatment reach and continued downstream until all possible designated sampling sites were sampled. At each site, catfish were sampled along each shoreline in a downstream manner until a 1.6-km of stream bank was sampled, leading to about 30 minutes of effort per shoreline. This entire sampling effort was repeated each year approximately one week subsequent to the first effort each year. Catch per unit effort (CPUE) is reported as number of fish captured per electrofishing hour (pedal time).

Hoop nets

After two full courses of electrofishing were completed across all treatment reaches, I started hoop netting at the most upstream site of the NON treatment reach, typically the first week in October of each year. Sampling with hoop nets continued downstream until all possible designated sampling sites were sampled. This equated to a minimum of 12 sites (240 net nights). Double-throated hoop nets were 0.91 m in diameter and 3.7 m long, containing seven fiberglass hoops. At each site, five 25-mm and five 32-mm bar mesh baited hoop nets were distributed evenly throughout the mile site. All hoop nets were baited with approximately 1.8 kg of rancid cheese trimmings enclosed in a perforated PVC container. Hoop nets were set in the afternoon and retrieved the morning of the next day; therefore, catch per unit effort was fish per net night. Upon completion of the most downstream site after about 1 week, I returned to the upstream site and repeated the hoop-netting sampling process.

Biologic Data

All three catfish species captured were weighed to the nearest g and measured to the nearest mm total length (TL). As an index of condition, relative weight (W_r) was calculated for each catfish using the equation given in Anderson and Neumann (1996). For channel catfish, I used a standard weight equation (W_s) of Log_{10} Ws = -5.800 + 3.294 Log_{10} TL (Mosher 1999). Both proportional stock density (PSD, Gabelhouse 1984) and relative stock density of preferred size fish (RSD-P, Gabelhouse 1984) stock indices were calculated for channel catfish (stock = 279 mm, quality = 406 mm, and preferred = 610 mm) using the length classes defined in Anderson and Neumann (1996). Additionally, during fall 2001 and fall 2002, a subsample of channel catfish was brought to the SIUC Fisheries and Illinois Aquaculture laboratory to estimate the sex ratio.

Aging

The left pectoral spine was removed from most channel catfish and used to determine age (see Chapter 3).

Discharge

To determine the effect of discharge on the capture of catfish the in the three different treatment reaches fall daily discharge data was obtained from the United States Geologic Survey for three different gauges. The three different gauges were Lafayette, IN (USGS station number: 03335500, Rkm 501) for the NON treatment reach, Montezuma, IN (USGS station number: 03340500, Rkm 390), for the IN treatment reach, and Mt. Carmel, IL (USGS station number: 03377500, Rkm 216), to represent the IN & IL treatment reach.

Statistics

As a surrogate for actual density, CPUE was used to compare density among the fishing treatments (IN & IL, IN, NON) and sampling years. CPUE data were $\log_{10}(X + 1)$ transformed to compensate for heteroscedascity. Because I returned to the same sampling sites within treatment reaches each year, I used repeated measures ANOVA to test for differences in density among treatment reaches. A least square difference analysis was used to compared means across treatment group. Densities were compared across years using ANOVA with a Tukey-Kramer multiple comparison test. Length frequency distributions were analyzed using Kolomogorov-Smirnov nonparametric tests to determine if distribution were different between sexes, among gears, and among treatment reaches. For multiple comparisons among length frequency distributions, I used Bonfferoni-corrected p-values to account for experiment-wise error rate (Sokal and Rohlf 1995). Analysis of proportions was used to determine if the sex ratio of the catfish population in the Wabash River differed from 1:1. A chi-square test was used to determine whether stock density indices differed between gears (Conover 1980). To determine whether body condition differed among treatment reaches, mean relative weights were compared using a Kruskal-Wallis nonparametric test. Unless otherwise stated (i.e. Bonfferoni correction) an $\alpha = 0.05$ was used to determine statistical differences.

RESULTS

Catfish Collected

Channel catfish were collected more frequently than both flathead and blue catfish during the course of this study. From 2001 through 2004, 2,556 channel (91 %), 218 flathead (8 %), and 33 blue (1 %) catfish were captured using both electrofishing and hoop nets. Information regarding the flathead and blue catfish is presented in Appendix B.

Discharge

The fall water discharge of the Wabash River varied among years and within each individual year. At the most upstream (NON), treatment reach the discharge varied widely (Figure 2). Notably, at low discharge, this river treatment reach was nearly impossible to sample due to shallow water levels. Downstream, the base flow increased and sampling could be conducted with ease, regardless of discharge (Figure 3). At the most downstream gauge, a larger drainage area assured ample water levels even at the lowest discharge (Figure 4). However, positive pairwise correlations among the river gauges ($P < 0.025$) suggest that the flow patterns in the Wabash were similar among treatment reaches (Figure 5). Overall, discharge was highest in 2003 with the exception of a flood during fall 2001 (Figures 2 - 5). In 2002 and 2004 the discharge of the Wabash River was relatively low during the entire field season (Figures 2 – 5).

Sexual Demographics

In 2001 and 2002, I determined sex in 827 channel catfish from the three treatment reaches of the Wabash River. Of these, 434 were males and 393 females, not differing from a 1:1 ratio ($\chi^2 = 2.0$, $P > 0.05$). These channel catfish ranged in length from 140 to 737 mm. From the two commercially fished treatment reaches, 535 channel catfish were sexed. Of these, 277 were males and 258 were females, again not differing from a 1:1 ratio ($\chi^2 = 0.68$, $P > 0.05$). From the NON treatment reach, 292 channel catfish were sexed. Of these, 157 were male and the remaining 135 female, not differing from a 1:1 ratio ($\chi^2 = 1.7$, $P > 0.05$). Furthermore, the results of the Kolomogorov-Smirnoff (*KS*) test suggests length frequency distributions did not differ between the sexes ($KS = 0.64$, $P > 0.05$, Figure 6).

Length Frequency among Gear Types

Length-frequency distributions of channel catfish sampled with electrofishing differed from the 25-mm ($KS = 17.42$, $P < 0.001$) and the 32-mm hoop nets ($KS = 5.64$, $P < 0.001$), with electrofishing sampling larger fish than either of the hoop net types (Figure 7). The 25-mm hoop nets sampled more small channel catfish and fewer catfish > 350 mm than the 32-mm hoop nets ($KS = 7.63$, $P < 0.001$) (Figure 7).

Corresponding to the differing length-frequency distributions, stock density indices differed among gear types. The PSD and the RSD-P values for electrofishing (PSD: 68 ± 3, RSD-P: 5) exceeded those for 25-mm hoop nets (PSD: 14 ± 4, RSD-P: 1) (PSD: $\chi^2 = 316$, $P < 0.001$; RSD-P: $\chi^2 = 9.4$, $P < 0.01$) (Figure 7). Similarly, the PSD value for electrofishing (68 ± 3) was greater than that of 32-mm hoop net (25 ± 7) ($\chi^2 = 124$, $P < 0.01$, Figure 7). There was, however, no difference in RSD-P between electrofishing (RSD-P = 5) and 32-mm hoop nets (RSD-P = 4) ($\chi^2 = 0.19$, $P > 0.017$). In addition, the PSD value for the 32-mm-mesh (25 ± 7) hoop net was greater than that of the 25-mm hoop net (14 ± 4) ($\chi^2 = 9.3$, $P < 0.01$, Figure 7), with no difference in RSD-P (25-mm: RSD-P = 1, 32-mm: RSD-P = 4) between these gears ($\chi^2 = 9.3$, $P > 0.017$, Figure 7). Sub-stock length fish comprised 64.6% of the channel catfish sampled using the 25-mm hoop nets but only accounted for 17.9% with 32-mm hoop nets and 12.6% with AC electrofishing. Length frequency distributions differed among all years ($P > 0.013$) (Figure 8) with the exception of those between 2002 and 2004 ($P = 0.12$) (Figure 8).

Density based on Electrofishing CPUE

A total of 143.8 hours of electrofishing was conducted during this study (Table 3). Mean CPUE of electrofishing for all three species combined was highest in NON treatment reach during all years except 2002 (Table 4). During fall 2002, low water (Figure 2) precluded me from effectively sampling the most upstream sites in the NON treatment reach. Similar trends in CPUE occurred when I excluded both blue and flathead catfish from the results (Table 5). Electrofishing CPUE differed among years ($F_{3, 141} = 3.5$, $P = 0.017$), being highest in 2003 and lowest in 2001 (Figure 9). Although there was a significant treatment by time interaction ($F_{14, 16} = 5.75$, $P < 0.007$), due to low water in 2002 precluding me from effectively sampling the NON treatment reach, electrofishing CPUE differed among the three treatment reaches ($F_{2, 16} = 17.19$, $P < 0.0001$) (Figure 10). Overall, CPUE of channel catfish was significantly greater in the NON treatment reach when compared with either the IN & IL ($t_{16} = 4.0$, $P < 0.0011$) or the IN treatment reaches ($t_{16} = 5.7$, $P < 0.0001$) (Figure 10). Furthermore, the IN treatment had lower channel catfish CPUE than did the IN & IL treatment (t_{16} = 2.68, P < 0.016) (Figure 10).

Density based on Hoop Net CPUE

A total of 1,253 net nights was fished during this study (Table 6). Mean CPUE for 25-mm hoop nets was highest in 2003 and lowest in 2002 and 2004 (Table 7). A similar trend occurred when blue and flathead catfish were excluded (Table 8). For channel catfish, CPUE with 25-mm mesh hoop net differed among years ($F_{3, 120}$ = 7.7, P < 0.001) (Figure 11). In contrast with the electrofishing data, there was no effect of treatment reach on 25-mm hoop net CPUE ($F_{2, 16}$ = 1.42, P > 0.05) (Figure 12).

Similar to the 25-mm hoop nets, CPUEs generated by 32-mm mesh hoop nets for all three species of catfish combined varied both among years and among treatment reaches (Table 9), with the highest CPUE occurring in 2003 and the lowest during 2002 and 2004. Again, excluding blue and flathead catfish from the analysis did not alter results (Table 10). CPUE 32-mm mesh hoop nets differed among years CPUE ($F_{3, 120}$ =3.0, P = 0.03), although all pairwise comparisons were non significant (Figure 13). Similar to the 25-mm mesh hoop nets, there was no apparent effect of treatment reach on 32-mm mesh hoop net CPUE ($F_{2, 16}$ = 0.95, P = 0.41) (Figure 14).

Discharge and Catch

Although no tests of significance were done, the Wabash River discharge did seem to affect the catchability of channel catfish. In the NON treatment reach only, catch seemed to increase with increasing discharge for both electrofishing (Figure 15) and hoop netting (Figure 16). In the IN and the IN & IL treatments, electrofishing CPUE appeared to decline with increased discharge (Figure 15). Conversely, no obvious relationship occurred between hoop netting and water discharge in the IN and IN & IL treatment reaches (Figure 16).

Length Frequency among Treatment Reaches

Length frequency distributions of channel catfish differed among treatment reaches ($P < 0.017$), with fish sampled in the NON (mean: 371, median: 363) treatment reach having greater mean and median lengths than in either the IN (mean: 348, median: 320) and IN & IL (mean: 312, median: 284) treatment reaches (Figure 17).

Stock Indices

Except in 2004, the proportional stock density (PSD) of channel catfish in the NON treatment reach was higher than in the other treatment reaches (Table 11). The PSDs in the IN treatment reach were greater than those in the IN & IL treatment reach in all years except 2001 (Table 11). Similarly, except for 2004, the relative stock density (RSD-P) values were highest in the NON treatment reach when compared with the IN and IN & IL treatment reaches (Table 11).

Relative Weight

Mean relative weight of channel catfish ranged from 86 to 98 (Table 12). Channel catish in the IN and IN & IL treatment reaches were in slightly better condition than those in the NON treatment reach ($P < 0.017$; Figure 18). Condition of channel catfish did not appear to differ between the IN & IL and IN treatment reaches ($\chi^2 = 2.26$, $P > 0.017$; Figure 18).

DISCUSSION

I conclude that commercial fishing has not affected the sexual demographics of the channel catfish populations in the Wabash River, because the sex ratio was not different from 1:1, and the length frequency distributions did not differ between males and females. Estimates of spawning potential and recruitment success are required to provide a more thorough understanding of catfish sexual demographics in the Wabash River. An understanding of the sexual demographics would allow managers to assess the impact of harvest on the spawners and the population yield (e.g., recruitment overfishing; Pitlo 1997). Recruitment overfishing caused by overharvest of spawning adults may occur suddenly and greatly reduce population reproductive potential (Allen et al. 2005). The effect of harvest on recruitment potential in the Wabash River can be gauged by determining the fecundity and length at maturity for the catfish at large as well as determining how production and survival of offspring varies among years.

As shown in other studies, I found that hoop net mesh size affected length frequency distribution of channel catfish sampled, with larger mesh selecting larger catfish (Holland and Peters 1992). Electrofishing was necessary to sample the largest catfishes. Clearly, any standardized monitoring program for catfish in this system will require a combination of gear types to effectively sample all sizes and year classes in the assemblage.

Density as estimated by CPUE varied highly among years, likely due to the effect of discharge on gear efficiency. This relationship was apparent in the most upstream treatment reach due to low base flow and resulting water levels causing sampling inefficiencies with both electrofishing and hoop nets. In the most upstream treatment reach, CPUE increased with increased discharge for both gear types. This effect was most apparent with hoop nets as low water may have led to a reduction in the movement of catfish. In the lower treatment reaches, the hydrograph is buffered by the expanding size of the river, leading to less dramatic effects of discharge on catch.

Densities of large channel catfish sampled with electrofishing were higher during most years in the non-commercially fished treatment reach. Thus, stock indices were higher in the unfished treatment reach relative to the commercially exploited ones. No apparent differences in density among treatment reaches emerged using hoop nets because these gears sampled small and intermediate size catfish, which were likely similar in abundance among all treatment reaches.

Density of the largest channel catfish was lower in the commercially fished treatment reaches than in the non-commercially fished treatment reach. This led to reduced PSD values and skewed length frequency distributions toward smaller individuals. Differing length regulations between commercially exploited treatment reaches also have appeared to shape size structure of fishes with the IN treatment reach having a larger proportion of larger channel catfish in the sample. Lower density of intermediate and large size channel catfish in the commercially fished treatment reaches may have led to decreased intraspecific competition. This competitive release caused by reduced density could explain the better condition of individuals in these treatment reaches. However, differences in habitat (Chapter 5) or differences in the food web structure (Chapter 7) may also contribute to these condition differences.

Table 1. Areas of the Wabash River sampled with electrofishing and hoop nets during fall 2001 through 2004.

Treatment Reach	River Kilometer	Commercial Exploitation	Number of Sites	Length limit (mm)	
				Illinois	Indiana
IN & IL	0-322	Yes	9	381	254
IN	394-500	Yes	4	n/a	254
NON	500-552	No	6	n/a	254

Table 2. Sites with their river kilometers and associated treatment designation sampled on the Wabash River during fall 2001 through 2004.

Site	River Kilometer	Treatment Reach
S1-1	19	IN & IL
S1-2	42	IN & IL
S1-3	80	IN & IL
S2-1	116	IN & IL
S2-2	154	IN & IL
S2-3	190	IN & IL
S3-1	230	IN & IL
S3-2	270	IN & IL
S3-3	309	IN & IL
S4-1	393	IN
S4-2	425	IN
S4-3	454	IN
S4-4	475	IN
S5-1	502	NON
S5-2	512	NON
S5-3	521	NON
S5-4	531	NON
S5-5	539	NON
S5-6	549	NON

Table 3. Electrofishing effort (hours) for treatment reaches of the Wabash River sampled during fall 2001 through 2004. N = number of sample sites. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

		Year			
Treatment Reach	N	2001	2002	2003	2004
IN & IL	9	17.7	16.8	17.1	17.9
IN	4	8.0	7.2	7.8	7.8
NON	6	12.3	9.2	12.1	9.9

Table 4. Mean electrofishing CPUE (fish/hour) for channel, flathead and blue catfishes combined from the Wabash River during fall 2001 through 2004. N = number of sample sites, SE = Standard error of the mean. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

		Year									
		2001		2002		2003		2004		*Combined*	
Treatment Reach	N	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*Mean*	*SE*
IN & IL	9	8.03	0.98	12.66	2.01	7.96	1.05	9.56	2.04	*9.51*	*0.81*
IN	4	6.10	1.24	5.97	1.11	5.49	1.30	4.06	1.17	*5.39*	*0.59*
NON	6	10.29	1.46	8.12	1.02	27.62	3.47	17.12	3.16	*16.26*	*1.70*
Mean		*8.34*	*0.73*	*10.00*	*1.18*	*13.64*	*1.97*	*10.25*	*1.55*	*10.63*	*0.73*

Table 5. Mean electrofishing CPUE (fish/hour) for channel catfish sampled from the Wabash River during fall 2001 through 2004. N = number of sample sites, SE = standard error of the mean. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

		Year									
		2001		2002		2003		2004		*Combined*	
Treatment Reach	N	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*Mean*	*SE*
IN & IL	9	5.58	0.74	9.78	1.90	6.48	1.03	8.35	2.45	*7.59*	*0.74*
IN	4	3.36	0.13	4.73	1.36	4.95	1.07	3.93	0.68	*4.26*	*0.50*
NON	6	9.73	1.29	6.76	1.22	26.55	2.81	16.53	3.15	*15.46*	*1.70*
Mean		*6.42*	*0.73*	*8.18*	*1.00*	*12.49*	*1.96*	*9.64*	*1.49*	*9.21*	*0.72*

Table 6. Hoop net effort (net night) for treatment reaches of the Wabash River sampled during fall 2001 through 2004. N = number of sample sites. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

		Year			
Treatment Reach	N	2001	2002	2003	2004
IN & IL	9	120	120	178	180
IN	4	60	40	80	79
NON	6	100	80	136	80

Table 7. Mean 25-mm mesh hoop net CPUE (fish/net night) for channel, flathead and blue catfishes combined from the Wabash River during fall 2001 through 2004. N = number of sample sites, SE = Standard error of the mean. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552). Italicized numerals represent column and row means.

		Year									
		2001		2002		2003		2004		*Combined*	
Treatment Reach	N	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*Mean*	*SE*
IN & IL	9	0.90	0.22	1.08	0.28	4.94	1.28	0.93	0.42	*2.16*	*0.42*
IN	4	3.25	0.83	0.30	0.10	1.55	0.52	0.50	0.13	*1.35*	*0.34*
NON	6	2.80	1.46	0.13	0.08	2.57	0.97	0.09	0.03	*1.58*	*0.53*
Mean		*2.00*	*0.64*	*0.63*	*0.15*	*3.48*	*0.62*	*0.63*	*0.22*	*1.81*	*0.27*

Table 8. Mean 25-mm mesh hoop net CPUE (fish/net night) for channel catfish sampled from the Wabash River during fall 2001 through 2004. N = number of sample sites SE = standard error of the mean. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552). Italicized numerals represent column and row means.

		Year									
		2001		2002		2003		2004		*Combined*	
Treatment Reach	N	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*Mean*	*SE*
IN & IL	9	0.78	0.21	1.07	0.29	4.72	1.23	0.92	0.42	*2.06*	*0.41*
IN	4	3.08	0.85	0.30	0.10	1.55	0.52	0.50	0.13	*1.30*	*0.32*
NON	6	2.77	1.43	0.13	0.08	2.51	0.94	0.09	0.03	*1.55*	*0.53*
Mean		*1.89*	*0.64*	*0.63*	*0.15*	*3.36*	*0.60*	*0.63*	*0.22*	*1.75*	*0.26*

Table 9. Mean 32-mm mesh hoop net CPUE (fish/net night) for channel, flathead and blue catfishes combined from the Wabash River during fall 2001 through 2004. N = number of sample sites, SE = Standard error of the mean. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552). Italicized numerals represent column and row means.

		Year									
		2001		2002		2003		2004		*Combined*	
Treatment Reach	N	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*Mean*	*SE*
IN & IL	9	0.08	0.05	0.27	0.21	0.57	0.15	0.17	0.04	*0.29*	*0.06*
IN	4	0.70	0.29	0.10	0.00	0.30	0.07	0.28	0.24	*0.33*	*0.11*
NON	6	0.87	0.22	0.15	0.06	0.63	0.21	0.11	0.05	*0.55*	*0.13*
Mean		*0.51*	*0.15*	*0.20*	*0.09*	*0.53*	*0.11*	*0.18*	*0.06*	*0.37*	*0.05*

Table 10. Mean 32-mm mesh hoop net CPUE (fish/net night) for channel catfish sampled from the Wabash River during fall 2001 through 2004. N = number of sample sites, SE = standard error of the mean. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552). Italicized numerals represent column and row means.

		Year									
		2001		2002		2003		2004		*Combined*	
Treatment Reach	N	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*Mean*	*SE*
IN & IL	9	0.08	0.05	0.27	0.21	0.54	0.15	0.14	0.03	*0.28*	*0.06*
IN	4	0.63	0.30	0.10	0.00	0.20	0.00	0.25	0.22	*0.28*	*0.09*
NON	6	0.83	0.21	0.10	0.06	0.60	0.22	0.08	0.03	*0.46*	*0.13*
Mean		*0.47*	*0.15*	*0.18*	*0.09*	*0.49*	*0.11*	*0.15*	*0.06*	*0.33*	*0.05*

Table 11. Values for stock indices of all channel catfish sampled from the three treatment reaches of the Wabash River. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552). (Stock = 279 mm. Quality = 409 mm, and Preferred = 610 mm). Italicized numerals represent column and row means.

	2001		2002		2003		2004		*Mean*	
Treatment Reach	PSD	RSD-P	PSD	RSD-P	PSD	RSD-P	PSD	RSD-P	*PSD*	*RSD-P*
IN & IL	50	1	57	2	21	1	56	1	*46*	*1*
IN	45	3	63	3	46	6	63	6	*54*	*4*
NON	57	5	75	15	54	7	56	5	*60*	*8*
Mean	*50*	*3*	*65*	*7*	*40*	*5*	*58*	*4*	*54*	*5*

Table 12. Mean relative weight (*Wr*) for channel catfish sampled from the three treatment reaches of the Wabash River. SE = Standard error of the mean. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552). Italicized numerals represent column and row means.

		Year									
		2001		2002		2003		2004		*Combined*	
Treatment Reach	N	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*Mean*	*SE*
IN & IL	9	92	1.0	90	0.7	89	0.7	91	1.6	*90*	*0.5*
IN	4	86	1.6	92	1.7	98	2.2	89	2.4	*91*	*1.0*
NON	6	86	1.1	92	1.2	89	0.7	87	1.0	*89*	*0.5*
Mean		*88*	*0.7*	*90*	*0.6*	*90*	*0.5*	*90*	*0.9*	*90*	*0.3*

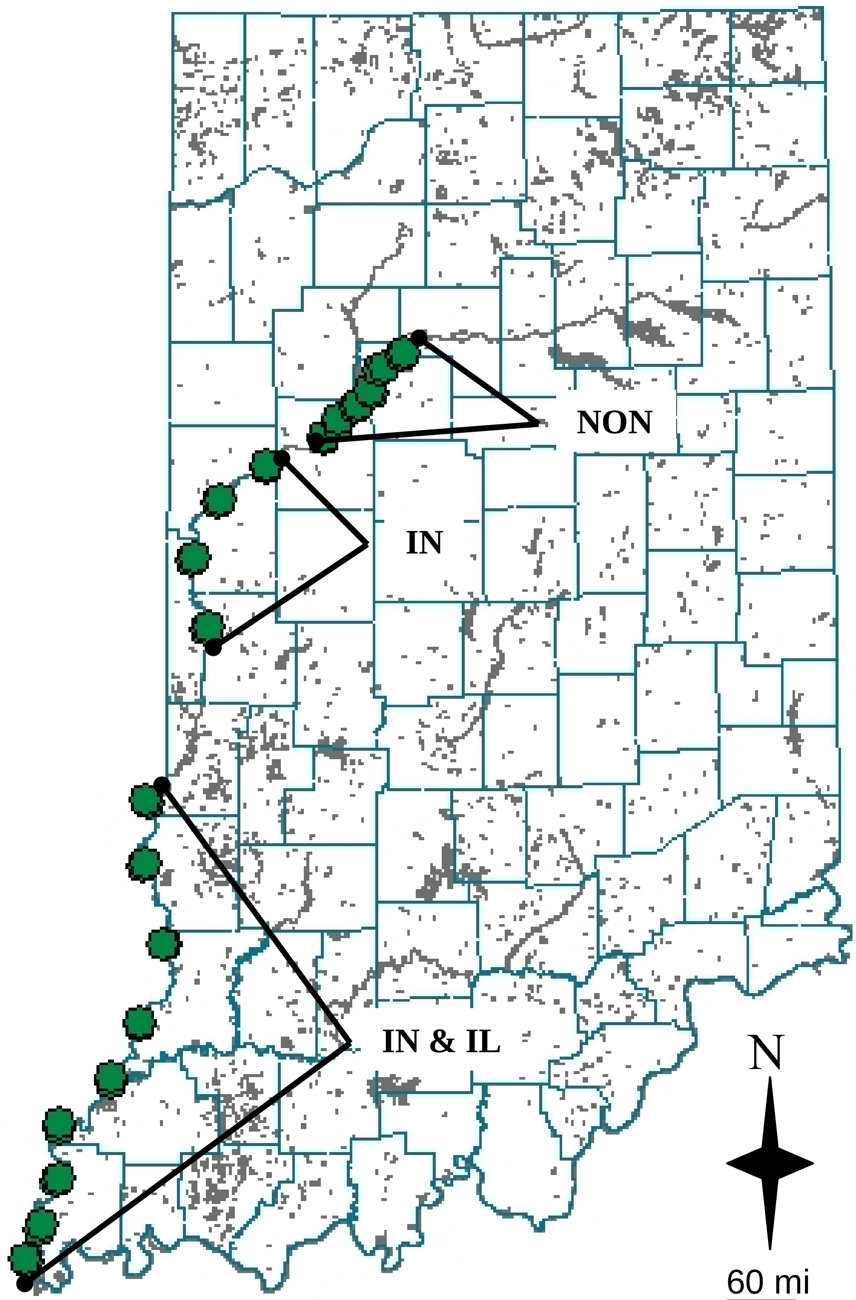

Figure 1. Map of the entire study reach of the Wabash River with treatment reaches outlined and sites indicated.

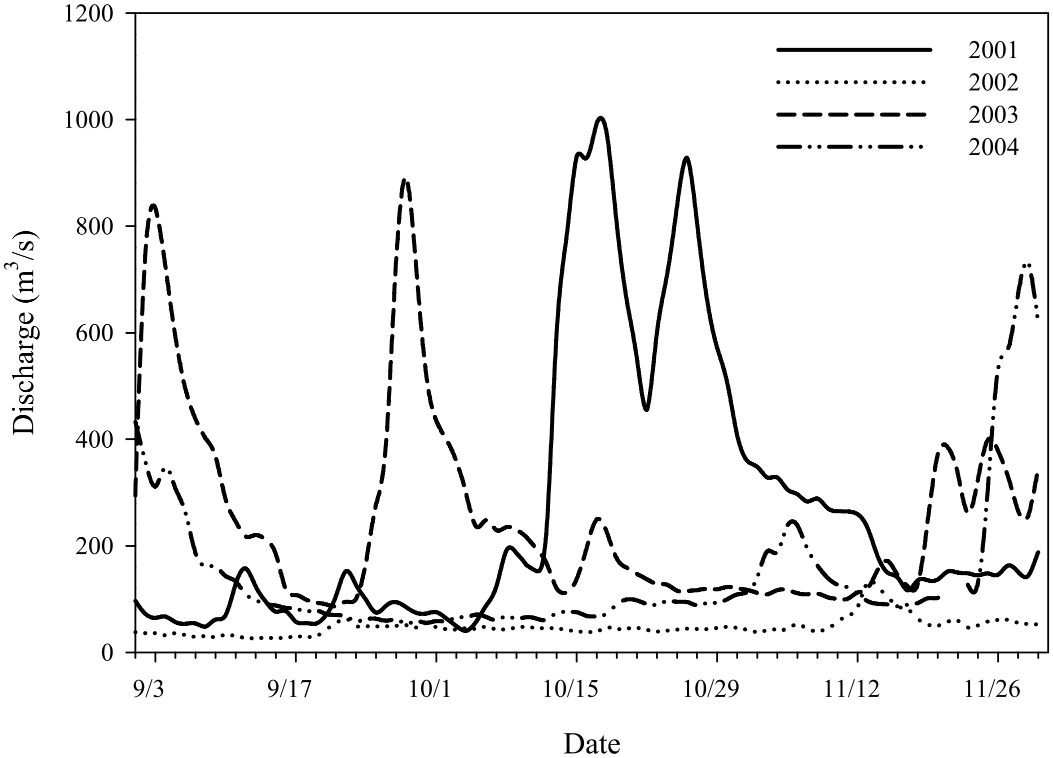

Figure 2. Fall mean daily discharge from the NON (Rkm 500-552) treatment reach of the Wabash River (USGS station number: 03335500, Rkm 501).

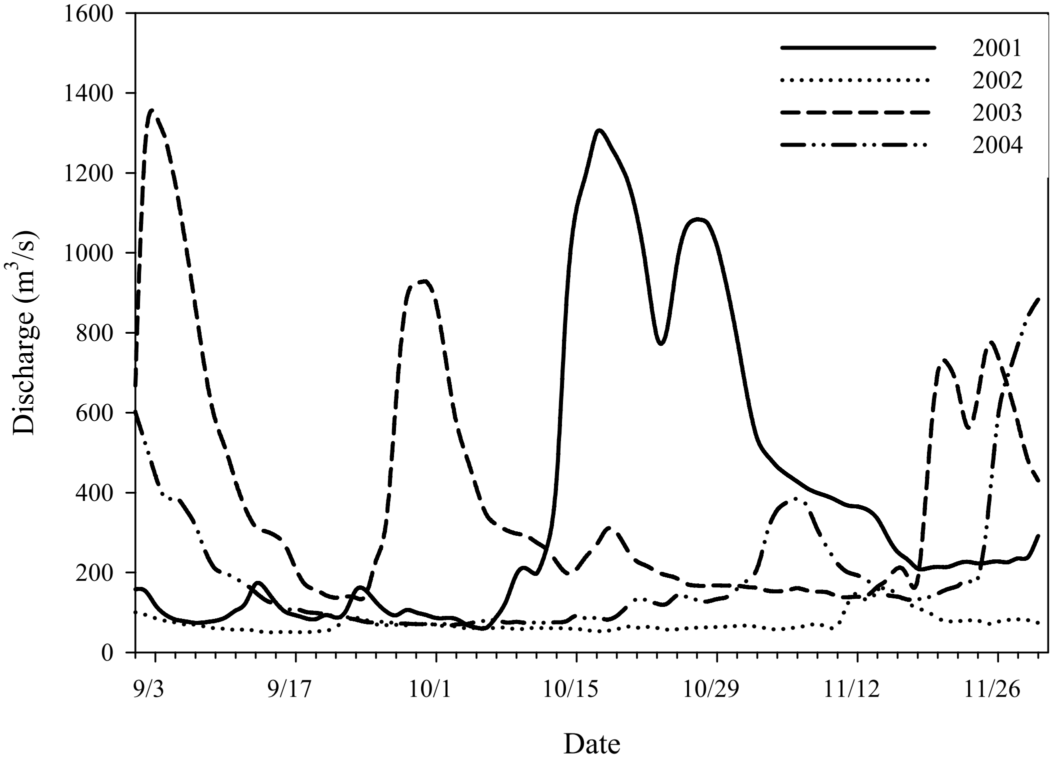

Figure 3. Fall mean daily discharge from the IN (Rkm 394-500) treatment reach of the Wabash River (USGS station number: 03340500, Rkm 390).

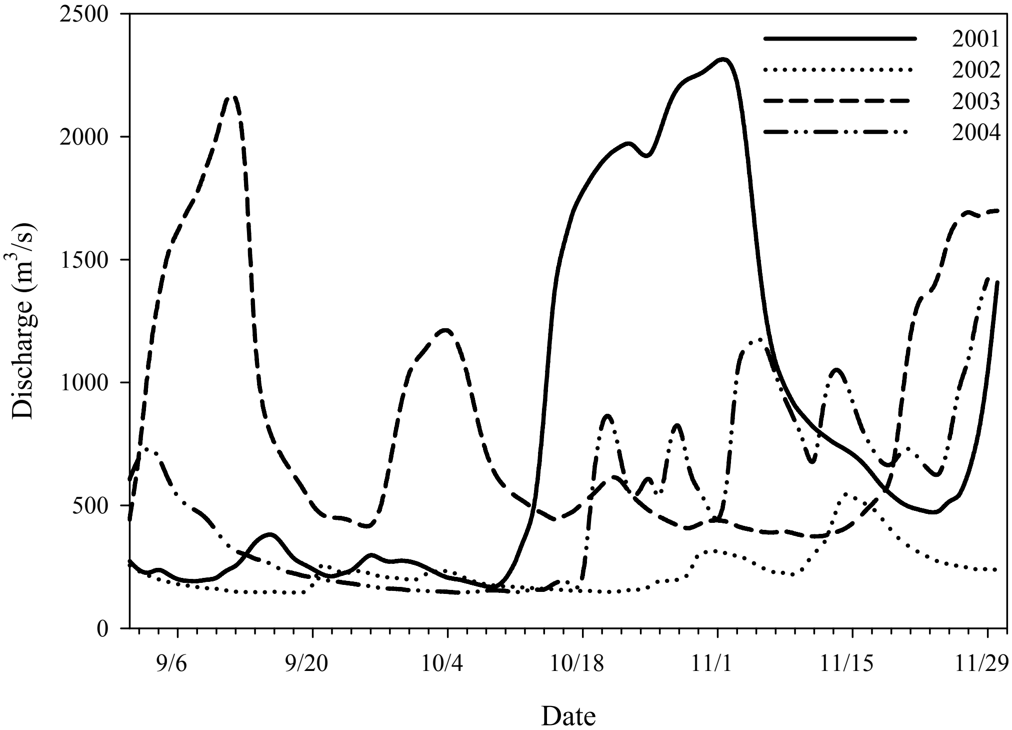

Figure 4. Fall mean daily discharge from the IN & IL (Rkm 0-322) treatment reach of the Wabash River (USGS station number: 03377500, Rkm 216).

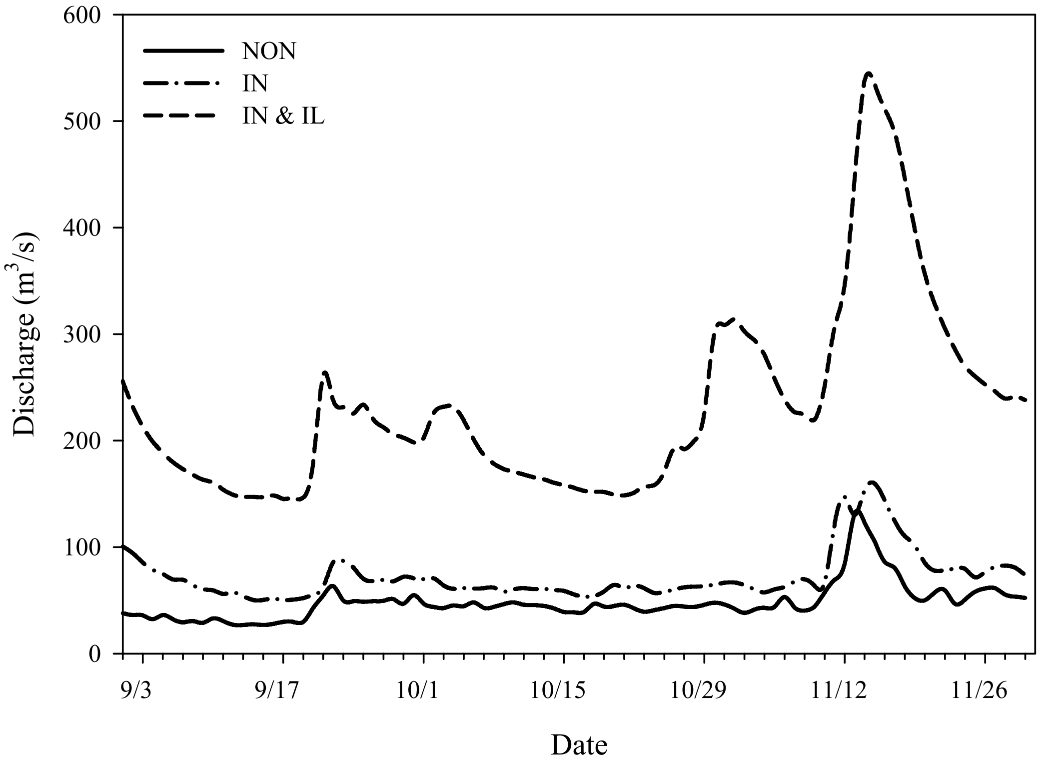

Figure 5. Fall mean daily discharge for fall 2002 for all treatment reaches of the Wabash River. Discharge among all treatment reaches was positively correlated ($P < 0.025$, NON – IN: $r = 0.83$, NON-IN & IL: $r = 0.81$, IN –IN&IL: $r = 0.85$).

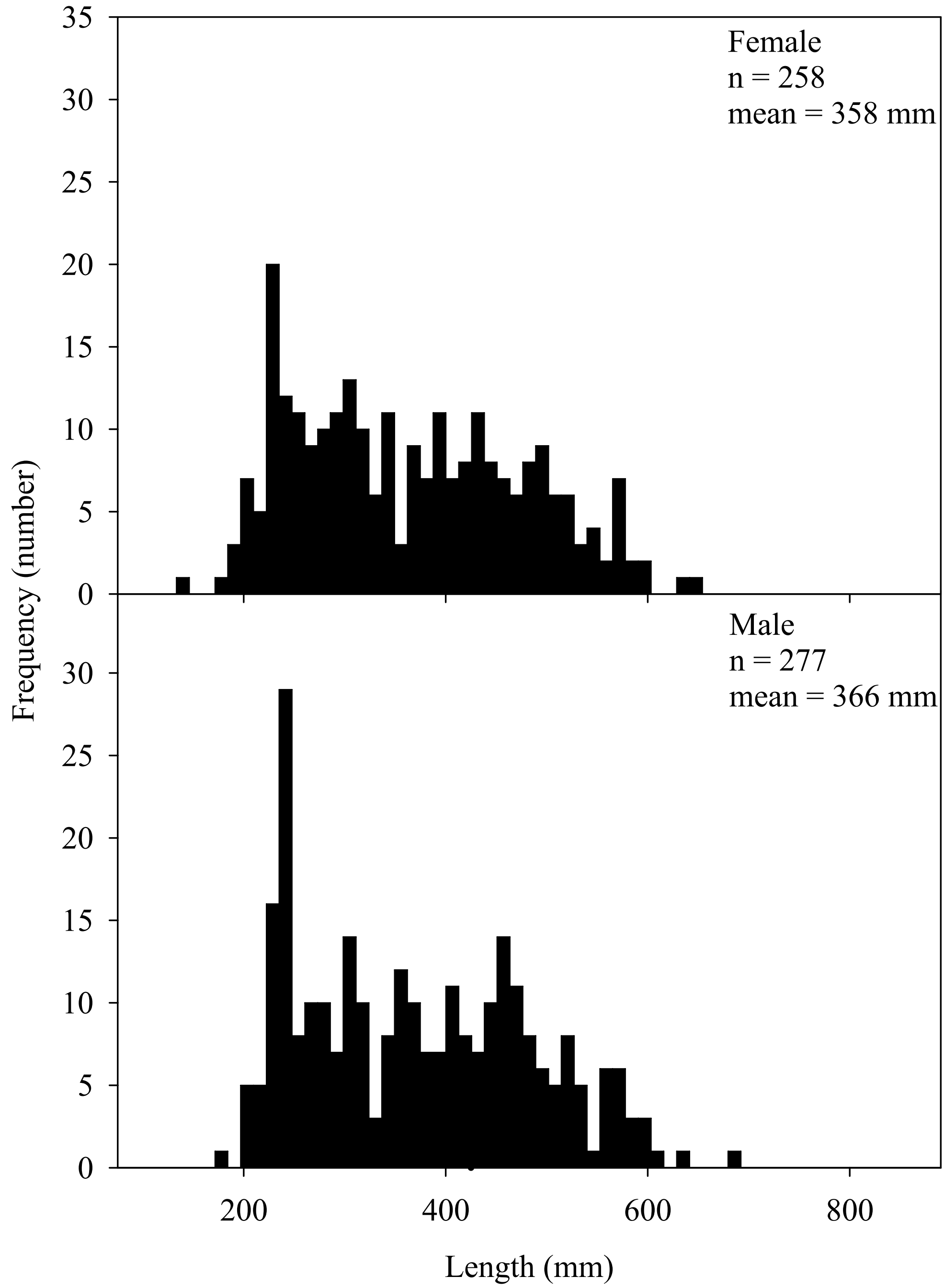

Figure 6. Length frequency distributions for female and male channel catfish sampled from the commercially exploited treatment reaches of the Wabash River during fall 2001 and 2002.

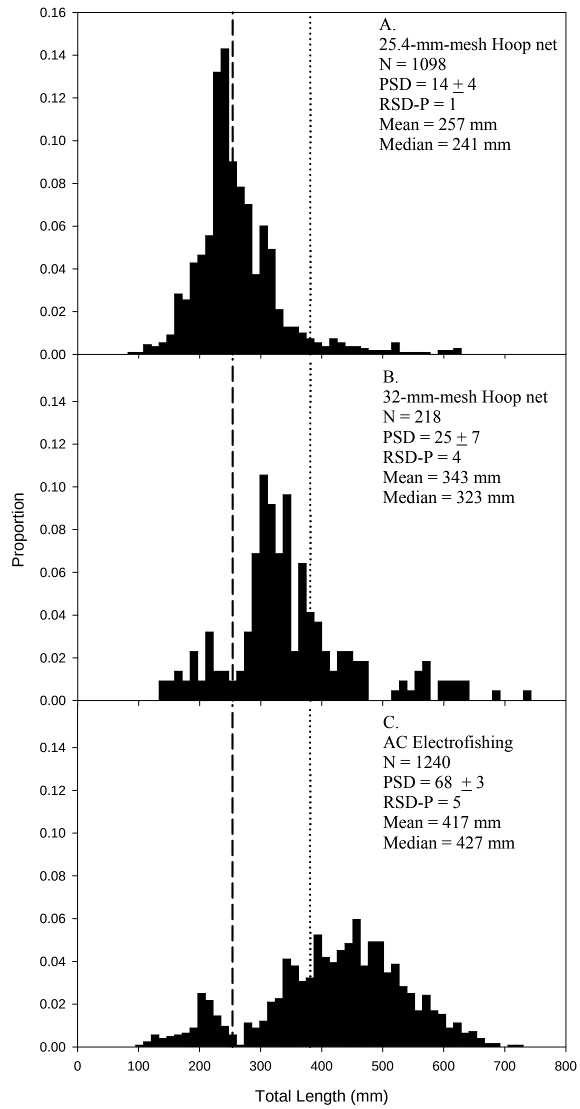

Figure 7. Length frequency distributions of channel catfish collected with 25.4-mm mesh hoop nets, 32-mm mesh hoop nets, and electrofishing from all treatment reaches of the Wabash River during fall 2001 through 2004. Dashed vertical line = 254 mm (Indiana length limit), dotted vertical line = 381 mm (Illinois length limit).

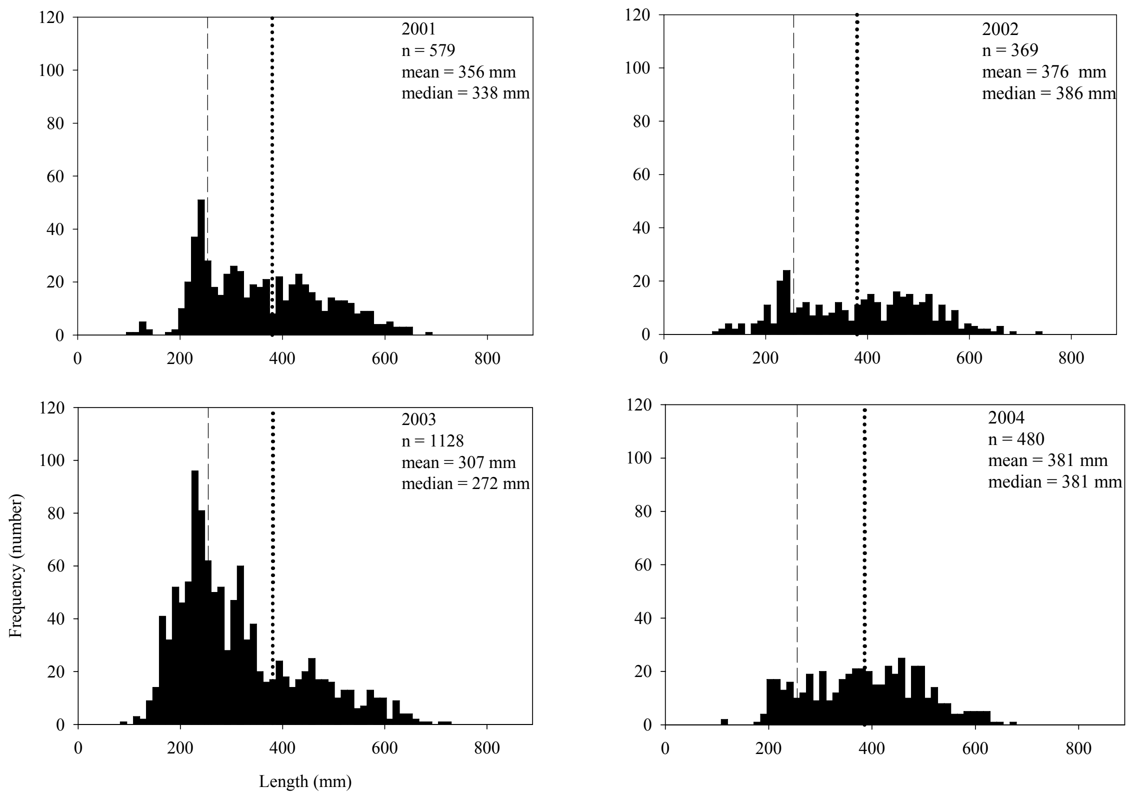

Figure 8. Length frequency distributions by sample year of channel catfish collected from all treatment reaches of the Wabash River during fall 2001 through 2004. Dashed vertical line = 254 mm (Indiana length limit), dotted vertical line = 381 mm (Illinois length limit).

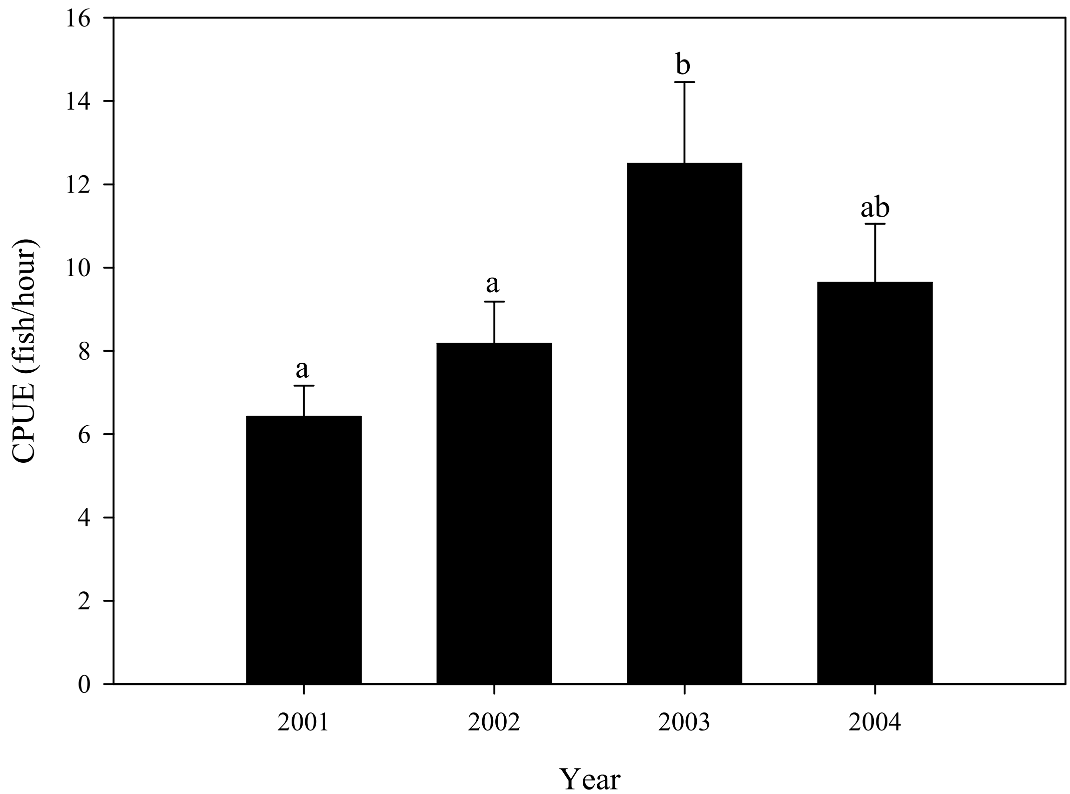

Figure 9. Mean electrofishing CPUE ± S.E. (fish/hour) by sampling year for channel catfish collected from all treatment reaches of the Wabash River (2001, n = 19; 2002, n = 17; 2003, n = 19; 2004, n = 19). Different letters denote significantly different means.

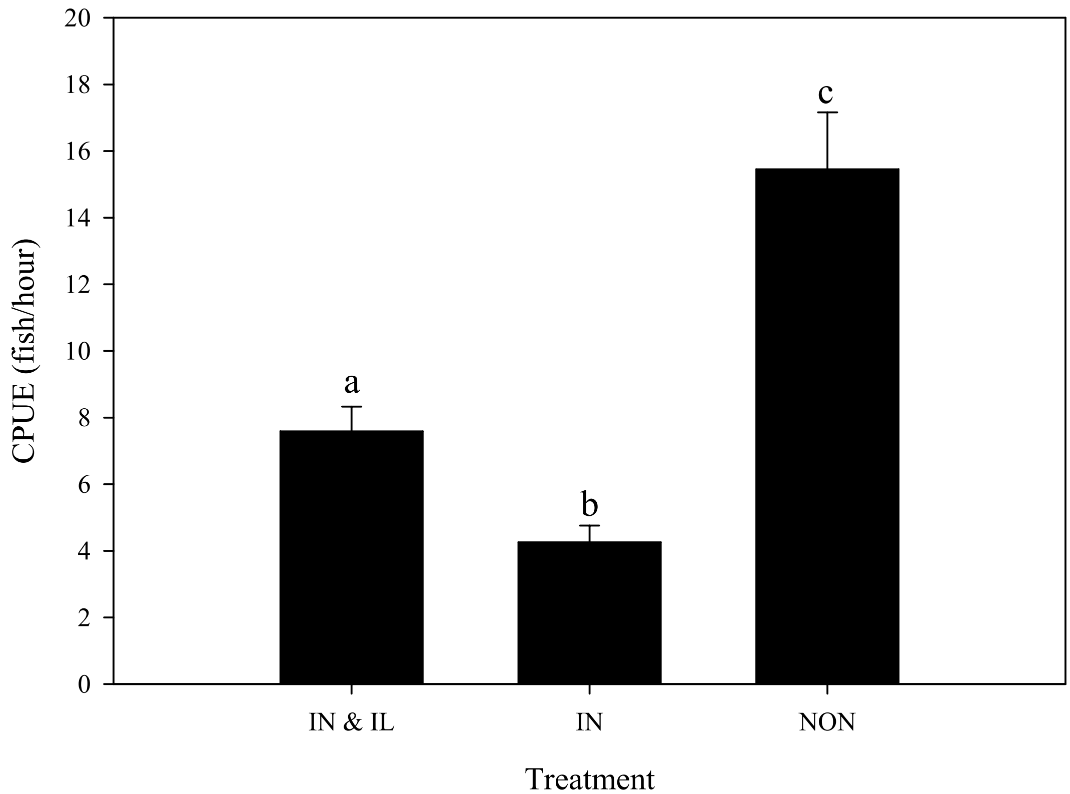

Figure 10. Mean electrofishing CPUE ± S.E. (fish/hour) by treatment reach for channel catfish sampled from the Wabash River during fall 2001 through 2004 (IN & IL; n = 71; IN, n = 31; NON, n = 43). Different letters denote significantly different means.

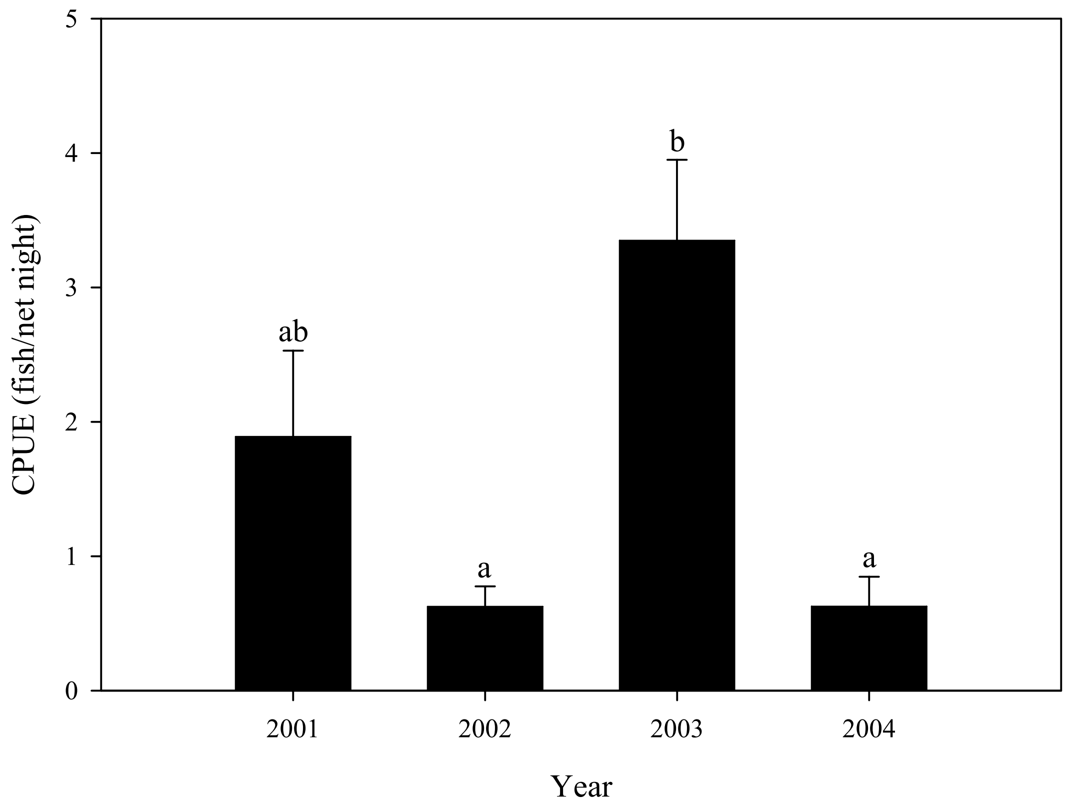

Figure 11. Mean 25-mm mesh hoop net CPUE ± S.E. (fish/net night) by year for channel catfish sampled from all treatment reaches of the Wabash River (2001, n = 14; 2002, n = 12; 2003, n = 19; 2004, n = 18). Different letters denote significantly different means.

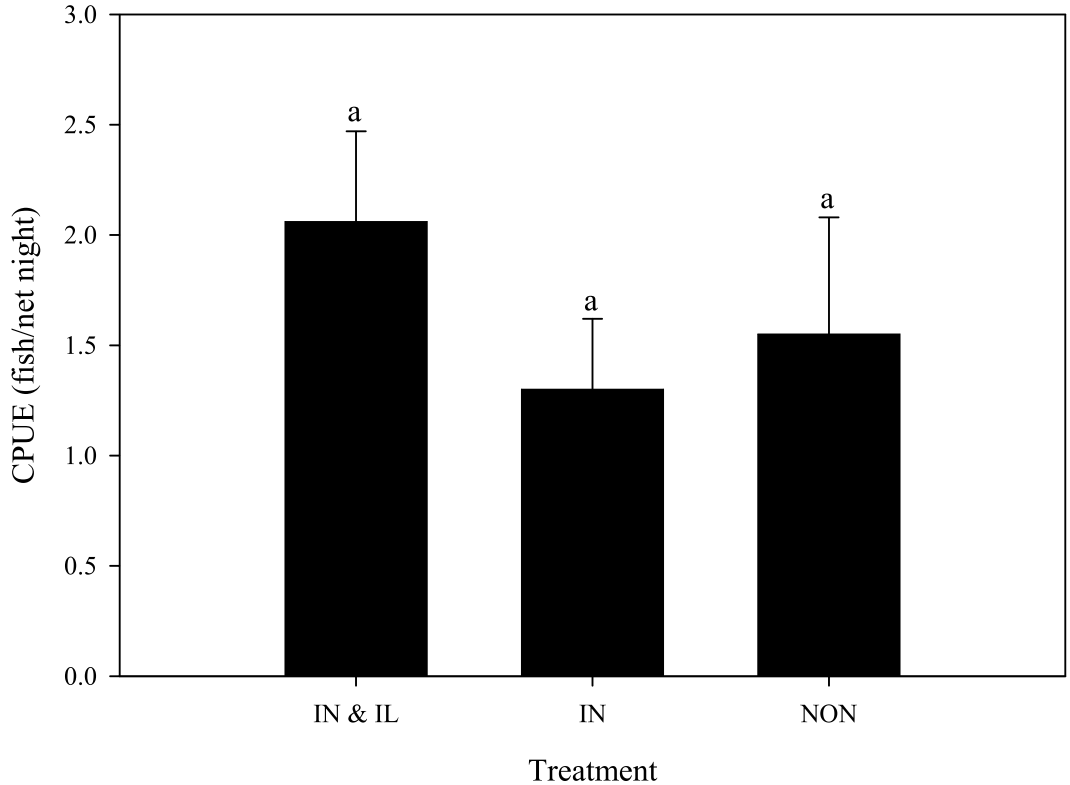

Figure 12. Mean 25-mm mesh hoop net CPUE ± S.E. (fish/net night) by treatment reach for channel catfish sampled from the Wabash River during fall 2001 through 2004 (IN & IL, n = 60; IN, n = 26; NON, n = 38). Different letters denote significantly different means.

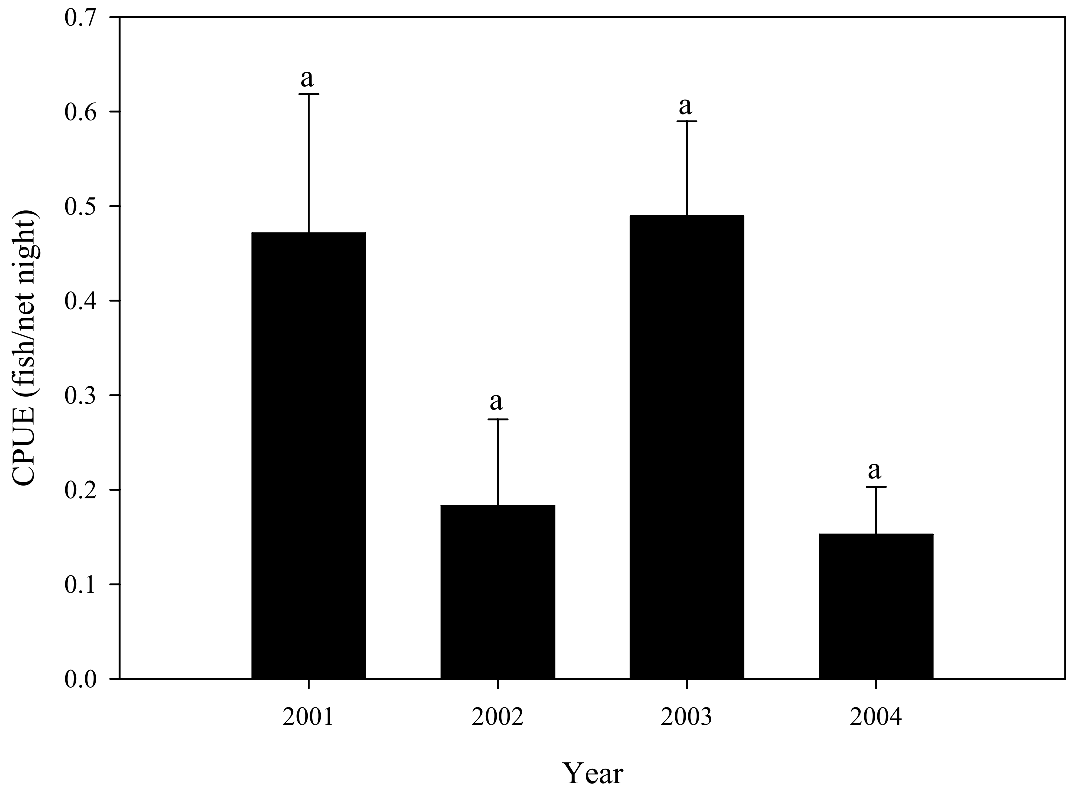

Figure 13. Mean 32-mm mesh hoop net CPUE ± S.E. (fish/net night) by year for channel catfish sampled from all treatment reaches of the Wabash River (2001, n = 14; 2002, n = 12; 2003, n = 19; 2004, n = 18). Different letters denote significantly different means.

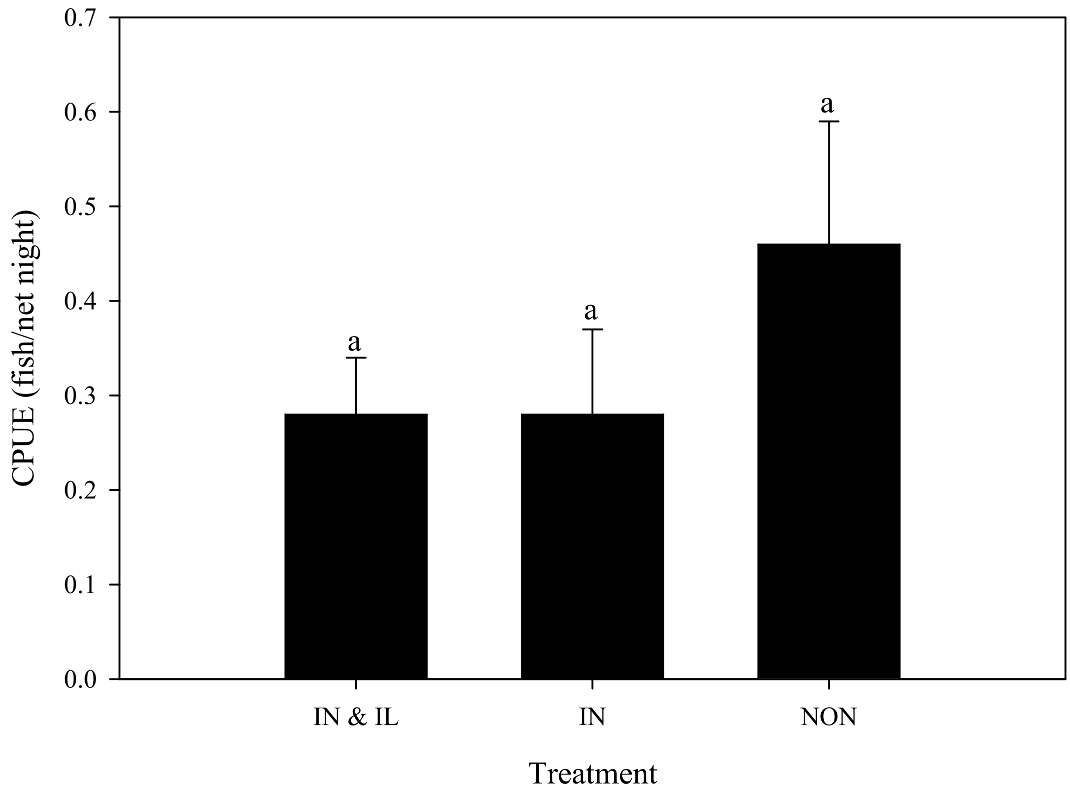

Figure 14. Mean 32-mm mesh hoop net CPUE ± S.E. (fish/net night) by treatment reach for channel catfish sampled from the Wabash River during fall 2001 through 2004 (IN & IL, n = 60; IN, n = 26; NON, n = 38). Different letters denote significantly different means.

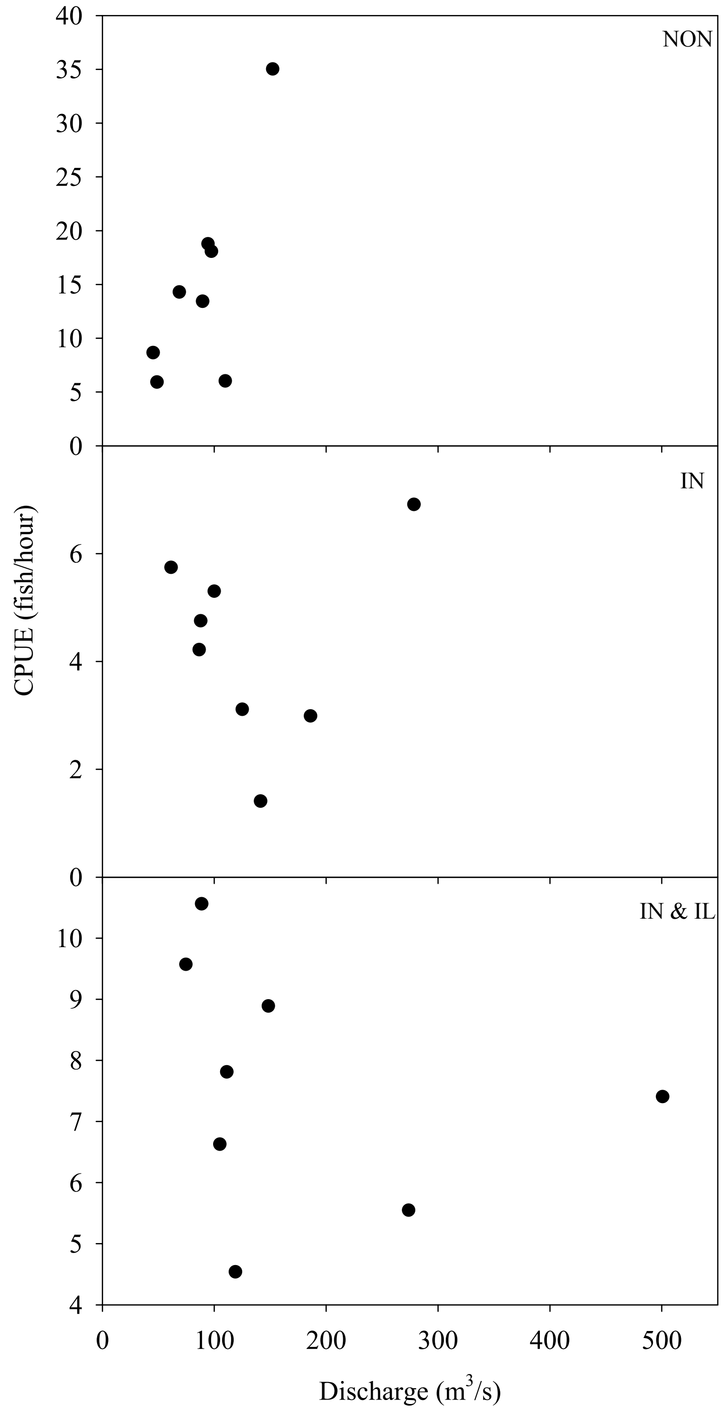

Figure 15. Relationships between discharge and channel catfish electrofishing CPUE for the three treatment reaches of the Wabash River sampled during 2001 through 2004.

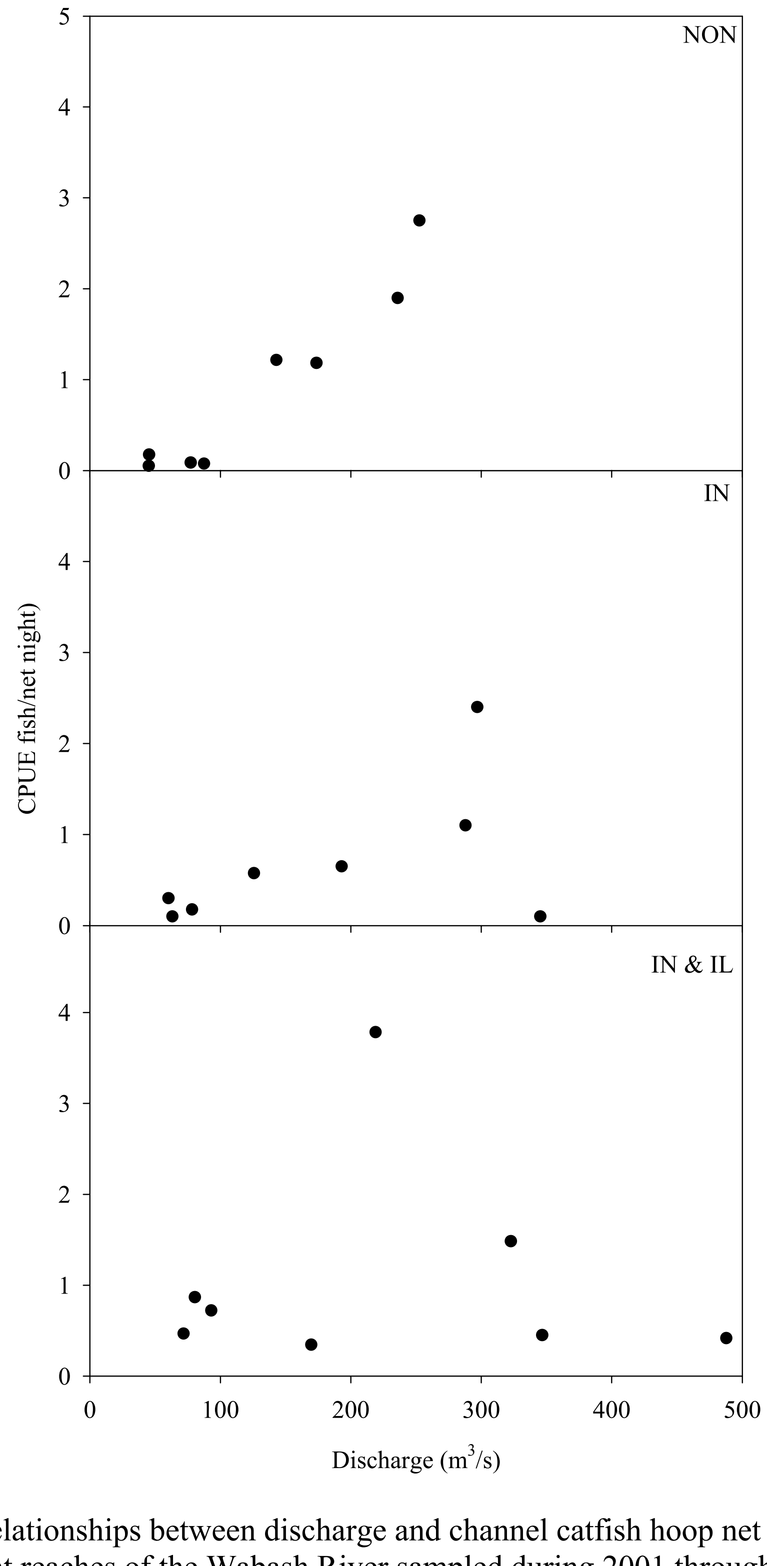

Figure 16. Relationships between discharge and channel catfish hoop net CPUE for the three treatment reaches of the Wabash River sampled during 2001 through 2004.

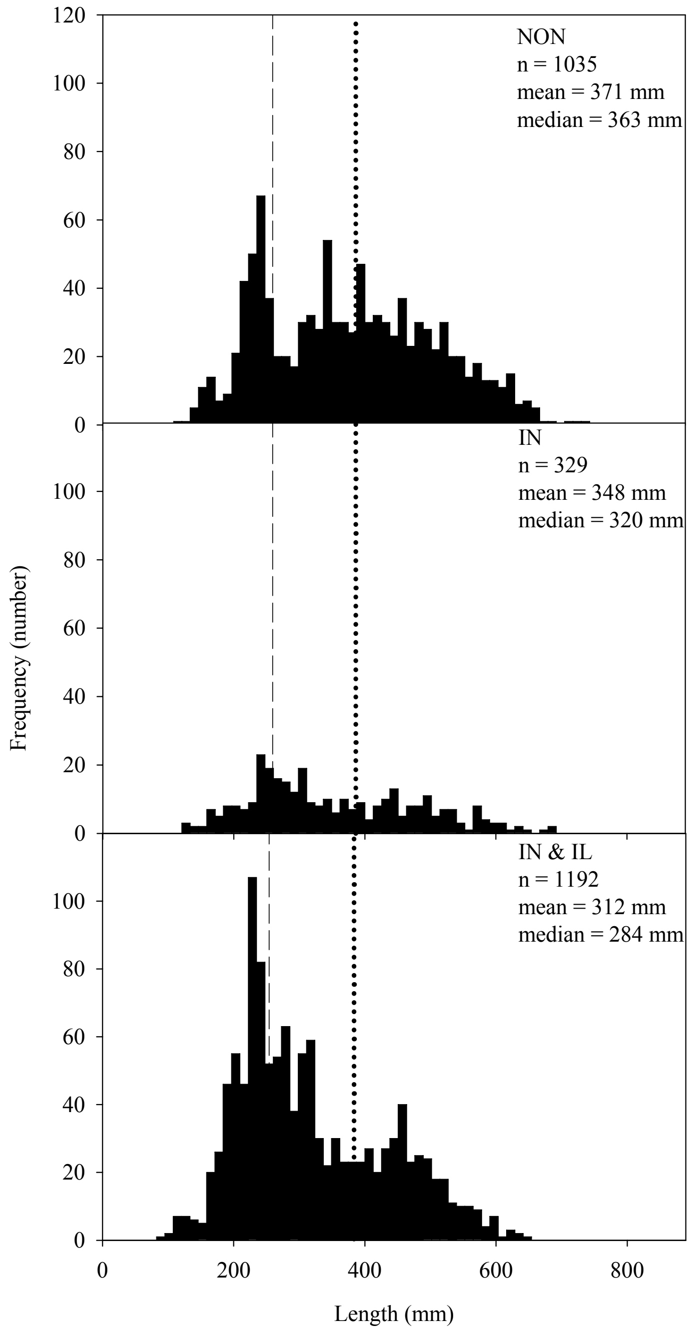

Figure 17. Length frequency distributions of channel catfish sampled from the NON, IN, and IN & IL treatment reaches of the Wabash River sampled during fall 2001 through 2004 Dashed vertical line = 254 mm (Indiana length limit), dotted vertical line = 381 mm (Illinois length limit).

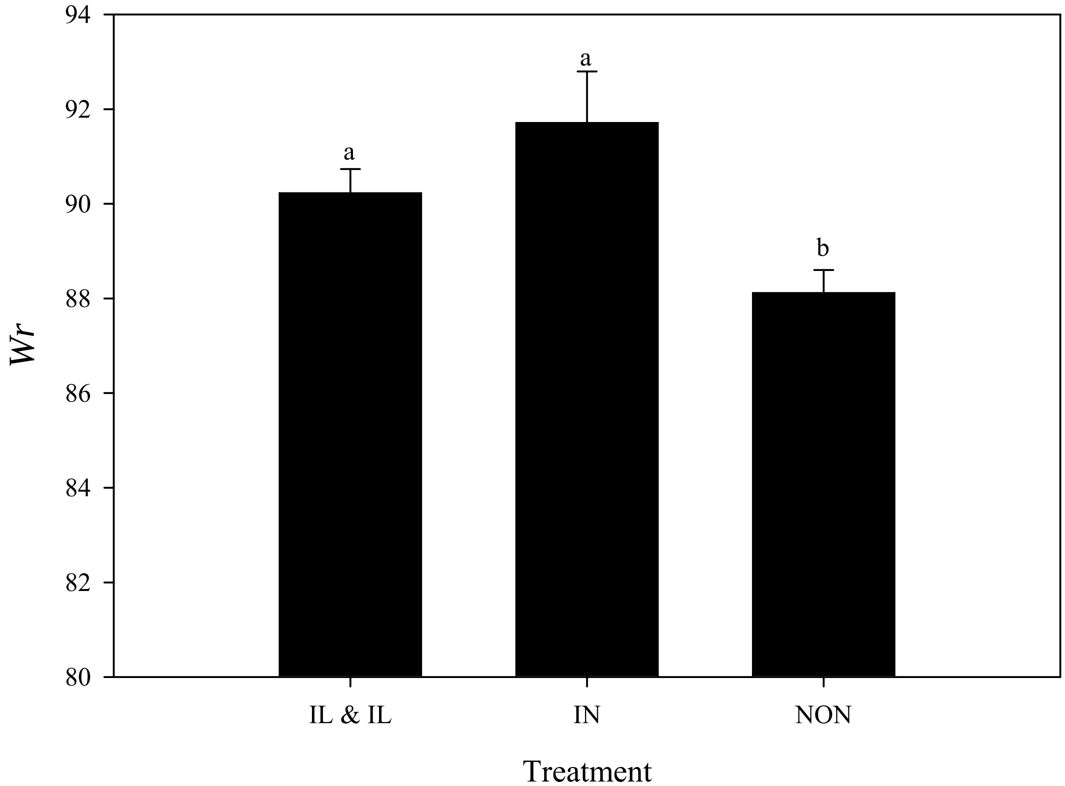

Figure 18. Mean relative weight (Wr) by treatment reach for channel catfish sampled from the Wabash River during fall 2001 through 2004. Different letters denote significantly different means.

CHAPTER THREE

IMPACT OF COMMERCIAL EXPLOITATION ON THE AGE, GROWTH AND MORTALITY OF THE CHANNEL CATFISH IN THE WABASH RIVER

ABSTRACT

I sought to determine how harvest affects the age structure, mortality and growth of catfish in commercially exploited and unexploited reaches of the Wabash River. This requires an accurate aging technique. For 110 channel catfish (2 – 16 years old), ages from a cross section of the articulating process agreed well with those from otoliths and I found no inherent bias between. Therefore, I chose the articulating process for ageing catfish. Mean age of fish captured varied among gear types, with electrofishing sampling older fish than to hoop nets did ($P < 0.001$). More old fish were present in the unexploited (NON) treatment reach than in the commercially exploited reaches leading to a greater mean age (NON = 5.3, IN = 3.8, IN & IL = 3.1 years; $P < 0.005$) in the NON reach. Mortality as estimated by catch curves was greater for both gear types in the commercially exploited treatment reaches (IN and IN & IL) than in the NON treatment reach. In the fishery shared by Illinois and Indiana (IN & IL), annual mortality was 15 to 20% greater than that in the unexploited treatment reach. In the Indiana-only fishery (IN), mortality was 5 to 7% percent higher than that of the unexploited treatment reach. In all years, growth as estimated using a von Bertalanffy model was slower in the NON treatment reach compared to the IN & IL treatment reaches ($P < 0.02$). There were no other significant differences in somatic growth between reaches.

INTRODUCTION

Fishing can alter the growth rate, age structure, and mortality rate of fish populations. Harvest can reduce the density, thereby of a population reducing intraspecific competition and potentially increasing somatic growth rate (Ricker 1975, Walters and Post 1993). Furthermore, harvest of fish above a specific minimum length can lead to size-specific mortality. As a fish population is exploited, the age-frequency distribution typically shifts a population from one comprised of a large proportion of old, slow-growing individuals to one comprised of small, young, fast-growing fish (Goodyear 1996). These populations dominated by small young fish are more susceptible to population fluctuations caused by harvest (e.g., recruitment overfishing) or environmental (e.g., dry year) stochasticity (Pitlo 1997). Mortality rate also may increase with harvest when not compensated for by a reduction in the natural mortality.

Characterizing the age structure of a population requires an accurate estimation of age. Catfish can be aged using several hard structures. Historically, the basal recess of the pectoral spine has been used (Sneed 1951), although derived estimates from this structure may under-represent the age of large old flathead catfish (Nash and Irwin 1999). Recently, the sagittal otolith and the articulating process of the pectoral spine have been used to age catfish (Nash and Irwin 1999; Buckmeier et al. 2002). Both structures have been validated for pond-reared channel catfish age ≤ four (Buckmeier et al. 2002). Similarly, for flathead catfish, a section of the articulating process provided better agreement with the otolith than did the basal recess (Nash and Irwin 1999).

Several attributes of the catfish otolith make it less desirable for aging than the pectoral spines. Extracting the otolith requires sacrificing the fish. Furthermore, since the otoliths must be mounted to a slide and ground, the processing time is longer, and because imaging the otolith is problematic, it is difficult to determine back-calculated length at age. The articulating process of catfish spines provides an alternative to otoliths. Sacrificing the fish is not necessary, and spines can be processed efficiently, providing fairly accurate and precise estimates of age. Length at age can also be determined more easily (Nash and Irwin 1999; Buckmeier et al. 2002).

Once the age structure of a population is determined, mortality can be assessed by a catch curve. The simple regression of age against log-transformed frequency provides an estimate of instantaneous mortality (Z; Ricker 1975), although this technique has several drawbacks. The catch curve method assumes that recruitment is constant (Van Den Avyle and Hayward 1999), which is generally untrue. If recruitment is not constant, mortality can be either overestimated or underestimated; therefore, it is not a conservative technique. These biases can be combated by averaging the mortality rate over a number of years, or by summing catch per age class across multiple years (Ricker 1975), and then generating a catch curve for the combined years. Both techniques reduce the impact of recruitment variability on mortality estimation, providing the best estimate of mortality aside from true cohort analysis.

Estimates of mortality are also biased due to inherent biases in gear types. Common gears generally under-represent the younger age classes that have not fully recruited to the gear (Van Den Avyle and Hayward 1999). Therefore, mortality can only be estimated from those age classes that are fully recruited to the sampling gear (Ricker 1975; Slipke and Maceina 2000). So that the biases are not compounded, it is important to estimate mortality for different gear types independently.

Along with mortality, estimating somatic growth is essential to understanding how fish populations respond to harvest. Time to recruitment, time to maturity, and the yield of a fishery to be estimated from the growth rate (Summerfelt and Hall 1987). Growth estimates require an accurate aging technique, which the articulating processes of spines provide. The von Bertalanffy model can be used to compare fish growth among populations (Van Den Avyle and Hayward 1999). The Brody growth constant (K) in this model allows for the comparison of growth, while the theoretic maximum length (L_{∞}) allows for the comparison of maximum size.

Currently, the Wabash River supports a substantial catfish commercial fishery, yielding 22 and 20 tons harvested per year by Illinois and Indiana commercial fishers respectively. Channel catfish growth differs over the length of the Wabash River (Lauer 2000, Willenberg 2001). These researchers attributed these differences solely to latitude (Willenberg 2001) with no mention of differences in population density along the river gradient. Because density of the channel catfish differs among reaches of the Wabash River, likely as a function of harvest (Chapter 2), growth may respond in predictable ways.

This chapter summarizes the age structure, mortality rate, and somatic growth of channel catfish in the Wabash River. To determine if there are differences in these parameters among treatment reaches I tested the null hypotheses: 1. mortality does not differ among treatment reaches, 2. Growth does not differ among treatment reaches. I also used these data to model these populations, and estimate the impact of harvest on channel catfish in response to three different length regulations (chapter 6).

METHODS

Aging

The left pectoral spine was removed from all catfish sampled for age determination and dried for 24 hours at 60°C. Three, 700-µm sections of the articulating process of each spine were made using a Beuhler low speed Isomet® saw. Spines were placed in immersion oil and viewed with a stereo microscope under low magnification (7 – 40x) and illuminated with reflected light. Age of each fish was estimated by counting the number of annuli (dark bands) on the articulating process cross section. In 2001 and 2002 ages were estimated by two independent readers. Disagreements were reconciled by consensus between the two readers. Consensus could not be reached on 51 out 2295 of the fish and these were excluded from the analysis. In 2003 and 2004, only one reader was used to estimate ages of catfish. Images of each readable section were captured with a top-mounted digital camera to back-calculate length at age.

For a subsample of 110 channel catfish from 2001, otoliths were removed and examined to determine whether the articulating process provided accurate age estimates. Otoliths were assumed to provide the actual age, as this structure has been validated for pond-raised channel catfish (Buckmeier et al. 2002). The sagittal otolith was removed by sectioning the cranium at the most rostral extent of the pectoral spine (Buckmeier et al. 2002). Otoliths were then dried and heated to 75°C on a hotplate. Once dried and heated, the otoliths were mounted on their posterior edge to glass microscope slides using thermoplastic cement. To provide a flat surface for aging, the otoliths were ground to their midpoint using a Dremel® high speed rotary tool with a medium grit sand attachment mounted to a drill press. Otoliths were aged with a stereo microscope under low magnification (7 – 40x), with side illumination from a fiber optic light source.

Mortality

I used catch-curve analysis to determine the mortality rate of the channel catfish populations in the Wabash River. Catch curves were generated both annually and by summing the number of fish caught per age class across years (Ricker 1975). Because the gears that were used during this study sampled different length frequency distributions (Chapter 2), mortality was estimated for hoop nets and electrofishing separately. Also, to reduce the amount of statistical leverage of a single point in the catch curve, I used weighted regression which reduces the importance of rare old fish (Slipke and Maceina 2000). The slope of the catch curve estimates the instantaneous mortality of the population (Z), and I used this estimate of Z was used to determine the total annual mortality (A) from the equation $A = 1 - e^{-Z}$.

Growth

Digitized images from the articulating process cross section were used to back calculate length at age. I used Scion® Image to measure the radius length of the cross section and length from the center to each annulus. Back-calculated length at age was estimated from these data using the equation (Le Cren 1947):

$$L_i = \frac{S_i}{S_c} L_c$$

L_i = back-calculated length at age i,
L_c = length at capture,
S_c = radius of the hard part at capture,

S_i = radius of hard part at annulus i.

These data were then used to estimate growth using a von Bertalanffy model with the Fisheries Analysis and Simulation Tool (FAST; Slipke and Maceina 2000). The von Bertalanffy model assumes that growth is asymptotic, reaching a theoretical maximum value (L_∞) at a constant growth trajectory (K). These parameters can be used to compare growth among populations.

Statistical Analysis

Both the average percent error (APE) and the coefficient of variation (CV) were calculated to estimate precision in age among readers (Beamish and Fournier 1981; Chang 1982). The slope of the age bias plot was compared to a slope of one to determine if there was an age bias either between readers or between structures (Campana et al. 1995). A Kruskal-Wallis non-parametric test was used to determine if mean age differed among gear types or treatment reaches. To determine whether mortality differed among treatment reaches, I used tested the slopes of the catch curves for homogeneity (analogous to the test for the assumption in ANCOVA) based on pooled age frequency distributions for each treatment reach. Differences in growth among treatment reaches were assessed using the method described in Gallucci and Quinn (1979). This approach develops a new parameter (w) based on the parameters of the von Bertalanffy model. Because of its desirable characteristics (i.e., corresponds to growth rate, statistically robust), this parameter allows for the testing of the null hypotheses that the growth parameters and the maximum length are the same between two populations. I used a one-way ANOVA to determine if the length of age 5 channel catfish differed among reaches.

In this case, age 5 catfish were used because they represent the first age class fully recruited to the electrofishing gear.

RESULTS

Structure Comparison

Suggested by the low values for both APE (8.4) and CV (11.4), high precision occurred between the two structures used to estimate age in the channel catfish. Furthermore, the slope of the age bias plot did not differ from one ($P < 0.05$) (Figure 19). Growth as estimated by the two structures was not different ($P < 0.05$) (Figure 20).

Aging Precision

For both 2001 and 2002, there was high precision between readers for age estimated using the articulating process. In 2001, the between-reader APE was 7.8 and the CV was 11.1. The result of the age bias plot for 2001 indicates an aging bias in one of the readers (slope $\neq 1$; $P < 0.05$) (Figure 21). Precision in 2002 was lower but still acceptable (APE = 10.1, CV =14.4, with no bias ($P > 0.05$) (Figure 22).

Age Selectivity

Differences in the size selectivity of the gears (Chapter 2) led to differences in age distributions of captured catfish. Catfish fully recruited at age 2 to the 25-mm hoop nets, at age 3 in the 32-mm hoop nets, and at age 5 using AC electrofishing (Figure 23). Channel catfish ages 1 through 4 dominated the 25-mm hoop net age-frequency distribution leading to a strongly positively skewed, leptokurtic distribution (*skewness* = 2.8 ± 0.09, *kurtosis* = 11.1 ± 0.19) (Figure 23). Catfish sampled with the 32-mm hoop nets displayed a slight positively skewed, platykurtic distribution (*skewness* = 1.2 ± 0.19, *kurtosis* = 1.5 ± 0.37) (Figure 23). The age-frequency distribution of catfish sampled with electrofishing showed a weak positively skewed platykurtic distribution (*skewness* = 0.5 ± 0.1, *kurtosis* = - 0.02 ± 0.15). Age-frequency distributions differed among gears (all comparisons, $KS = 3.44 – 12.90$, $P < 0.001$).

Different age distributions caused mortality rate estimates to differ among gear types (all comparisons, homogeneity of slopes, $P < 0.001$). Annual percent mortality (APM) was lowest for the 32-mm hoop net ($r^2 = 0.97$, $P < 0.01$, APM = 28 %), highest for the 25-mm hoop nets ($r^2 = 0.93$, $P < 0.01$, APM = 50 %), and intermediate for the electrofishing sample ($r^2 = 0.96$, $P < 0.01$, APM = 31 %).

Age Frequency

Mean age sampled using electrofishing ranged from 5.6 to 6.0 years and did not appear to differ among sampling years (Kruskal Wallis: P = 0.25; Figure 24). With hoop nets, mean ages ranged from 2.0 to 3.6 year which led to differences among sampling years (P < 0.001; Figure 25). In 2001 (3.6), the mean age of fish sampled with hoop nets was higher than any of the other three years. In contrast, the mean age of channel catfish sampled with hoop nets was lowest in 2003 (2.0), attributable to the high proportion of age one and two catfish sampled during that year.

Mean age sampled differed substantially among treatment reaches for both gear types (electrofishing P < 0.0001; hoop nets P < 0.0001) (Figure 26 and 27). For both electrofishing and hoop nets, the oldest mean age was in the NON (electrofishing: 5.3, hoop nets: 3.5) treatment reach compared to both the IN (electrofishing: 3.8, hoop nets:

2.9) and IN & IL (electrofishing: 3.1. hoop nets: 1.8) treatment reaches. Additionally, for hoop nets and electrofishing, the mean age sampled in the IN treatment reach was older than that of the IN & IL treatment reach (Figure 26 and 27). The combined gear age frequency for the IN & IL treatment reach showed a rapid decline of older age classes in the compared to the other two treatment reaches (Figure 28).

Mortality

Because the gear types generated different length frequency (Chapter 2) and age frequency distributions (Figure 23), I estimated mortality for each gear independently. The estimated annual mortality of the channel catfish in the Wabash River ranged from 25 to 40% for electrofishing and 36 to 67% for hoopnetting (Table 13). All mortality estimates from electrofishing were lower than those from hoop nets. For both gear types, mortality was lowest in the NON treatment reach and highest in the IN & IL treatment reach (electrofishing $P < 0.001$; hoop nets $P = 0.005$). Mortality in the IN & IL treatment reach exceeded that in the NON treatment reach by between 15 and 24 percent (Table 13). Mortality in the IN treatment reach was between 5 and 7 percent greater than the NON treatment reach (Table 13).

Growth

Channel catfish collected by both electrofishing and hoop netting were combined for analysis of growth. Overall, channel catfish were smaller at a given age in the NON treatment reach compared to the IN and the IN & IL treatment reaches (Table 14). The results of the von Bertalanffy growth model suggested that growth differed between the

NON and IN & IL treatment reaches in all years ($P < 0.02$). All other comparisons among treatment reaches were not significantly different ($P > 0.05$). However, there were some trends to the data.

The channel catfish in the NON treatment reach generally grew slower and to a larger body size than those IN & IL treatment reach. In 2001, the mean length at age of channel catfish in the NON treatment reach was smaller than in both the IN and IN & IL treatment reaches for all ages up to age eight (Figure 29). These differences led to differences in the fitted growth model among the treatment reaches (Figure 30). Channel catfish in the IN treatment reach grew the slowest (Table 15); however, the model suggested these catfish attained the largest body size. The catfish in the IN & IL treatment reach grew faster than those in either of the other two treatment reaches (Table 15; Figure 30).

In 2002, there was no apparent pattern in mean length at age related to reach (Figure 31). This may be attributed to low sample sizes during this sampling year. However, the results of the von Bertalanffy model showed similar trends to that of 2001 (Table 15; Figure 32). In 2003, the trends in mean length at age were similar to that of 2001 (Figure 33). Once again, the mean lengths at age of fish sampled in the NON treatment reach were smaller than the other two reaches (Figure 33). The von Bertalanffy models showed similar trends. Catfish in the NON treatment reach grew slower and to a larger maximum size than those in the IN & IL treatment reach (Figure 34). In the IN treatment reach, growth was intermediate; however, the maximum length was higher than either of the other treatment reaches (Table 15; Figure 34). The model for the IN treatment reach was influenced substantially by one point leading to an inflated maximum length (Figure 34).

Channel catfish growth in 2004 paralleled that of 2003. Mean lengths at age were lowest for those fish sampled in the NON treatment reach (Figure 35). Furthermore, the model suggested the slowest growth and largest maximum length for these fish (Figure 36). The IN treatment reach showed intermediate growth and maximum length (Figure 36). The mean growth constant was greatest for the IN & IL treatment reach and lowest for the NON treatment reach (Table 15). In addition, the maximum length was greatest for the NON treatment reach when compared to the other two treatment reaches (Table 15). Mean length of channel catfish age 5 was different among treatment reaches ($F2,9$ = 19.21, $P < 0.05$) with age 5 channel catfish in the NON treatment reach smaller that those in either the IN or the IN & IL treatment reaches ($P < 0.05$; Figure 37). Furthermore, the mean length of channel catfish seems to be related to density of channel catfish (Figure 37). These results suggest that those fish sampled in the unfished treatment reach grew slower.

DISCUSSION

No bias was associated with aging catfish using the articulating process compared to otoliths. Thus spines provide an accurate non-lethal method for aging of channel catfish providing an alternative to the otoliths. High between-reader precision demonstrates that the aging of channel catfish using spines is also repeatable among readers.

Age-frequency distributions differed between two different gear types, due to sampling biases associated with the different gears (Chapter 2). Electrofishing collected more individuals in older age classes compared to hoop nets. Additionally, electrofishing sampled a larger number of adult age classes when compared to the hoop nets. As such, electrofishing produced more accurate estimates of adult mortality. Although year class strength varied there were no missing year classes apparent with either gear type. My results indicate that multiple gear types are necessary to effectively sample lotic channel catfish populations (Chapter 2).

Differential mortality among treatment reaches led to changes in the age frequency distributions. Mortality was highest in the IN & IL treatment reach, likely due to the combined harvest by Illinois and Indiana fishermen. The increased mortality due to harvest in this treatment reach has also led to a strongly positively skewed length frequency distribution (Chapter 2). In this boundary fishery, two different length limits are imposed on the population; however, the largest, oldest fish seem to be most reduced by harvest. This may be attributable to the gear selectivity of the fishers. Illinois commercial fishers on the Wabash River seem to target fish larger than the minimum length limit of 381 mm which may be a function of the gears that they are using (Chapter 5).

Mortality of channel catfish in the IN treatment reach was intermediate, which may signify a lesser impact of commercial harvest. However, harvest still appeared to truncate the age structure and length frequency distribution towards young and small in this treatment reach. High PSD values in this treatment reach suggest that reductions in the abundance of intermediate-sized individuals led to increases in the proportion of large catfish remaining in the treatment reach (Chapter 2). This high PSD value may be a function of the 254-mm minimum size requirement in Indiana. Based on the harvest data

(Chapter 5), Indiana fishermen use smaller mesh hoop nets, selecting for small “fiddler-size” catfish for which there is an excellent market. High harvest of these “fiddler-size” fish may in reality operate as an inverted slot limit, where fish from 250 – 325 mm are more susceptible to harvest due to gear selectivity. This selection allows the rapid-growing survivors to achieve large maximum size.

Growth differed among the catfish subpopulations of the Wabash River, likely as a function of a variety of factors including latitude, treatment reach-specific food webs, fish density and habitat. The mean length at age was similar between the IN and IN & IL treatment reaches in all years except for 2002, suggesting that at higher density growth decreases. Catfish were larger at each age in areas where commercial fishing occurred suggesting a negative relationship between density and somatic growth.

Classical compensatory population regulation mechanisms appear to be at work in the Wabash River. With increased harvest and reduced densities, subpopulations appear to be responding with increased growth rates. However, in the treatment reach with shared harvest between the states, harvest of larger fish appears to be sufficiently high to reduce the maximum age and length of catfish. Therefore, if large size rather than total yield is desirable, this treatment reach is not producing at its maximum. Conversely, in both the IN harvested treatment reach and the non-commercially harvested treatment reach, both potential yield (as estimated by catch per unit effort) and maximum size and age appear to be high. Hence, the Wabash River has a variety of fishery scenarios that appear to be quite responsive to patterns of harvest intensity and size limits.

Table 13. Channel catfish annual percent mortality (A) for all three treatment reaches of the Wabash River sampled during 2001 through 2004 and the Mississippi River. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

	2001	2002	2003	2004	Cumulative
Electrofishing					
IN & IL	43	31	36	50	40
IN	n/a	n/a	n/a	n/a	32
NON	27	n/a	20	26	25
Hoop netting					
IN & IL	55	58	76	55	67
IN	n/a	n/a	n/a	n/a	38
NON	31	n/a	28	n/a	33
Mississippi River[a]					61

n/a – not available due to small sample sizes.
[a] – from Pitlo (1997)

Table 14. Back-calculated mean length (TL) at age and associated weight (Wt) for channel catfish from the three treatment reaches of the Wabash River sampled during 2001 through 2004. Italicized numerals represent calculated weight.

		Age in Years									
Treatment Reach		1	2	3	4	5	6	7	8	9	10
IN & IL	TL (mm)	116	212	280	333	396	421	450	474	506	536
	Wt (g)	*10*	*67*	*163*	*284*	*495*	*601*	*744*	*879*	*1083*	*1301*
IN	TL (mm)	124	210	275	336	399	419	447	457	451	502
	Wt (g)	*12*	*65*	*154*	*293*	*507*	*592*	*728*	*782*	*749*	*1055*
NON	TL (mm)	113	185	243	295	339	378	410	440	468	500
	Wt (g)	*9*	*43*	*104*	*193*	*301*	*426*	*553*	*693*	*844*	*1042*

Log (Wt) = 3.196 * Log(TL) - 5.06

Table 15. The von Bertalanffy parameters for channel catfish collected from all three treatment reaches of the Wabash River sampled during 2001 through 2004. L_{∞} (mm). IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

	Year									
	2001		2002		2003		2004		Mean	
Treatment Reach	L_{∞}	K	L_{∞}	K	L_{∞}	K	L_{∞}	K	L_{∞}	K
IN & IL	536	0.251	572	0.235	503	0.295	665	0.182	569	0.241
IN	572	0.184	620	0.193	757	0.134	709	0.164	665	0.172
NON	538	0.211	582	0.212	711	0.113	777	0.098	653	0.167

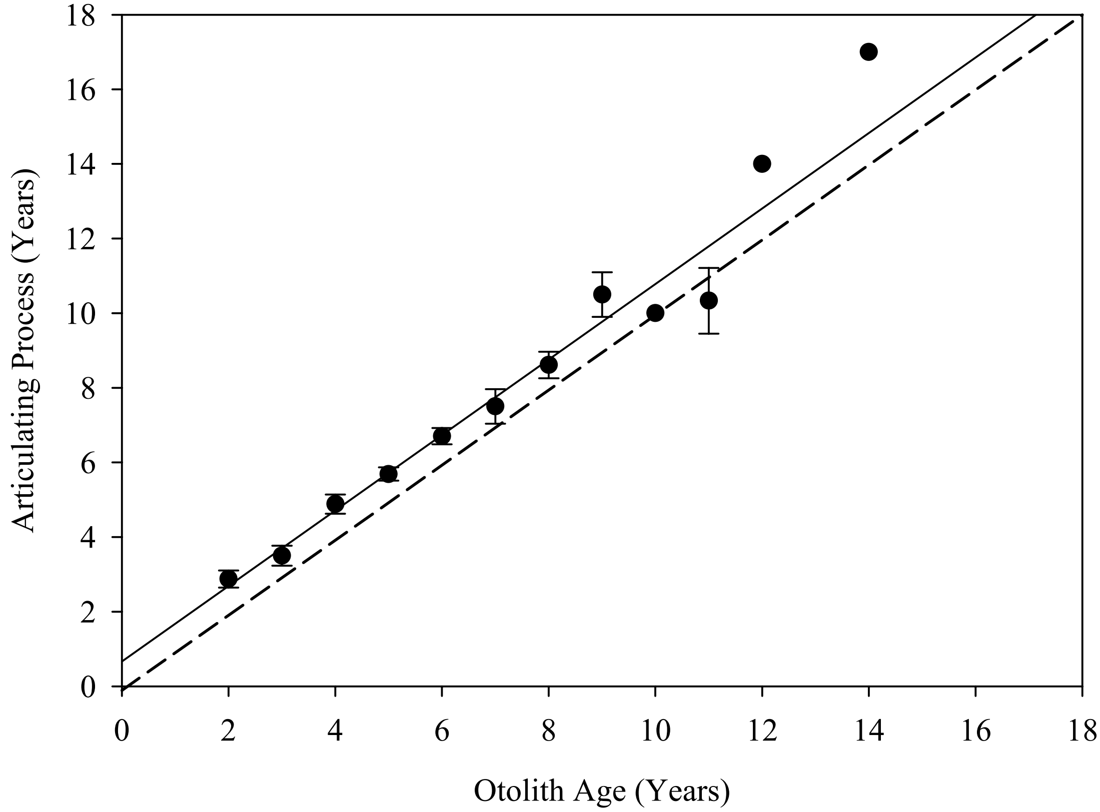

Figure 19. Age bias plot for otoliths compared to articulating process in channel catfish from the Wabash River (P >0.05). Solid line represents regression between otolith age and articulating process age, dashed line represents a slope of one, and error bars represent ± 1 S.E.

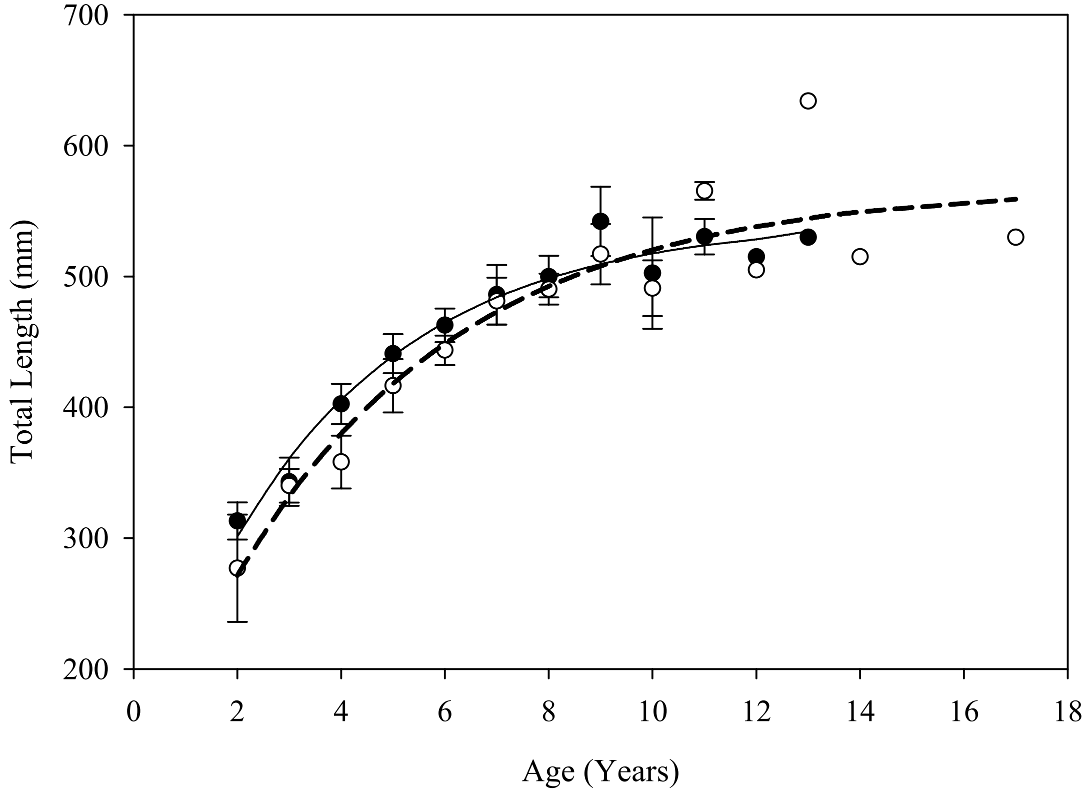

Figure 20. Mean length at age (circles) and von Bertalanffy models (lines) for channel catfish aged with otoliths (filled circles and solid line) and articulating process (open circles and dashed line). Error bars represent standard error of the mean ($P > 0.05$).

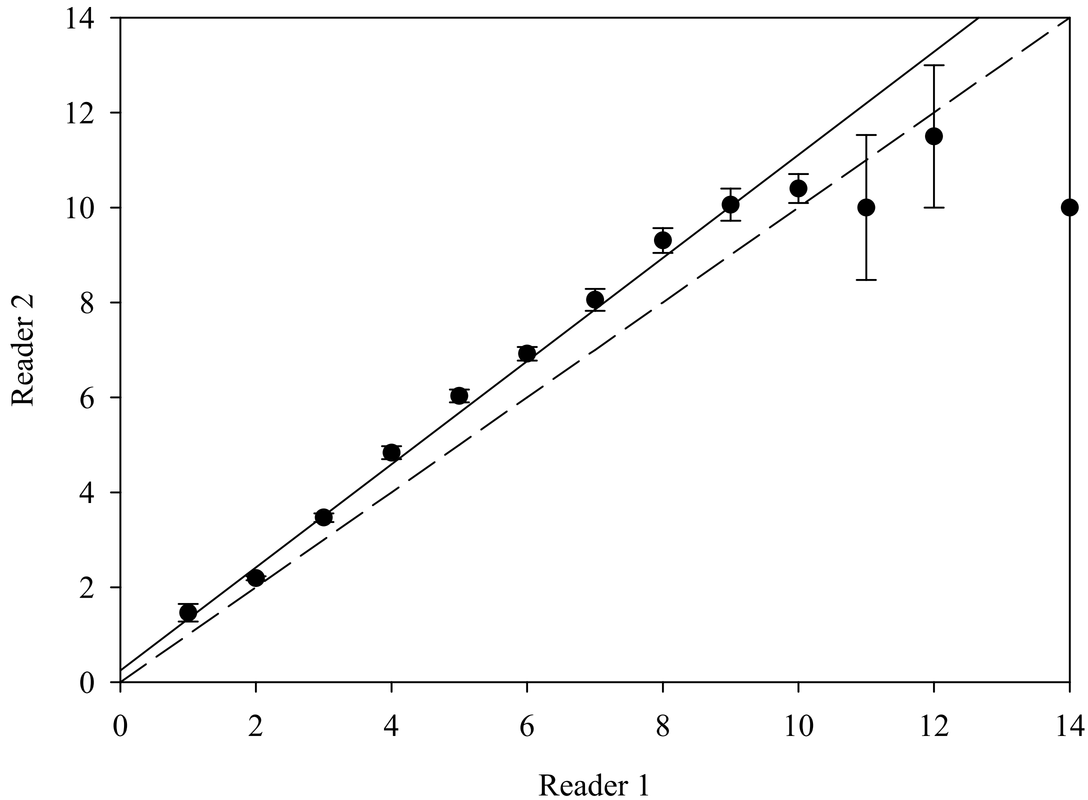

Figure 21. Age bias plot for reader one compared to reader two for channel catfish aged using the articulating process during 2001 points represent the mean age of reader 2 as compared to reader 1 ages ($P < 0.05$). Solid line represents regression between reader 1 and reader 2 age, dashed line represents a slope of one, and error bars represent ± 1 S.E.

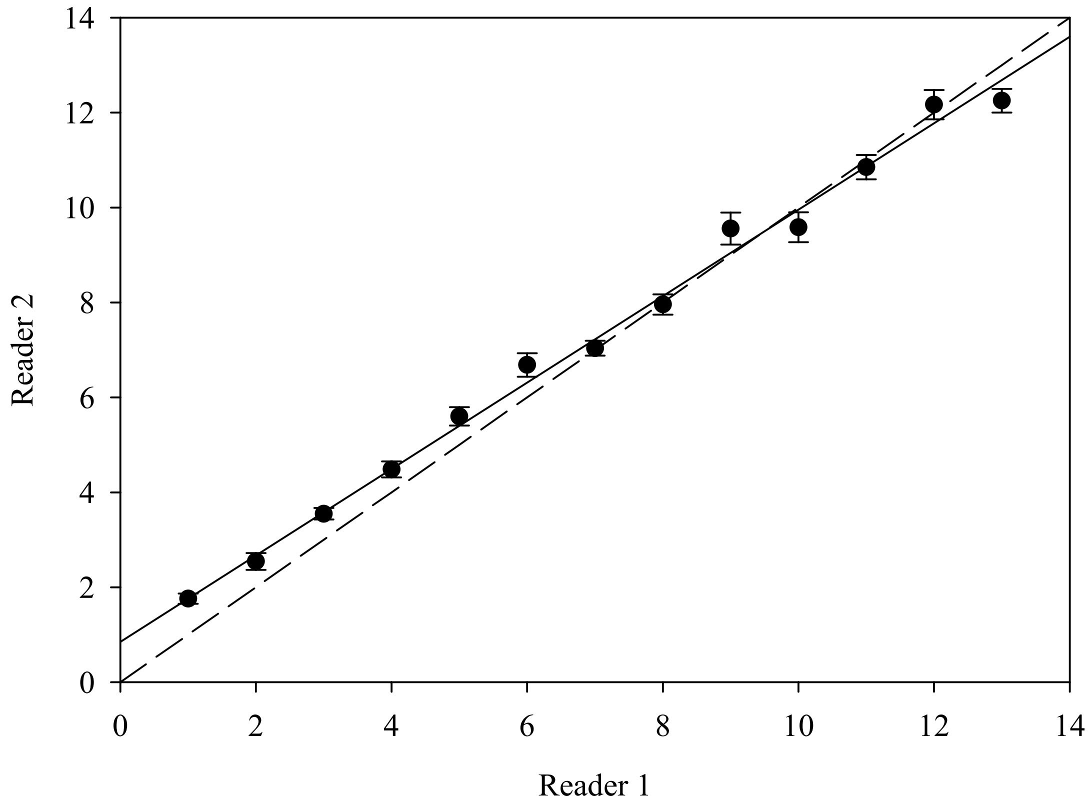

Figure 22. Age bias plot for reader one compared to reader two for channel catfish aged using the articulating process during 2002 points represent the mean age of reader 2 as compared to reader 1 ages ($P < 0.05$). Solid line represents regression between reader 1 and reader 2 age, dashed line represents a slope of one, and error bars represent ± 1 S.E.

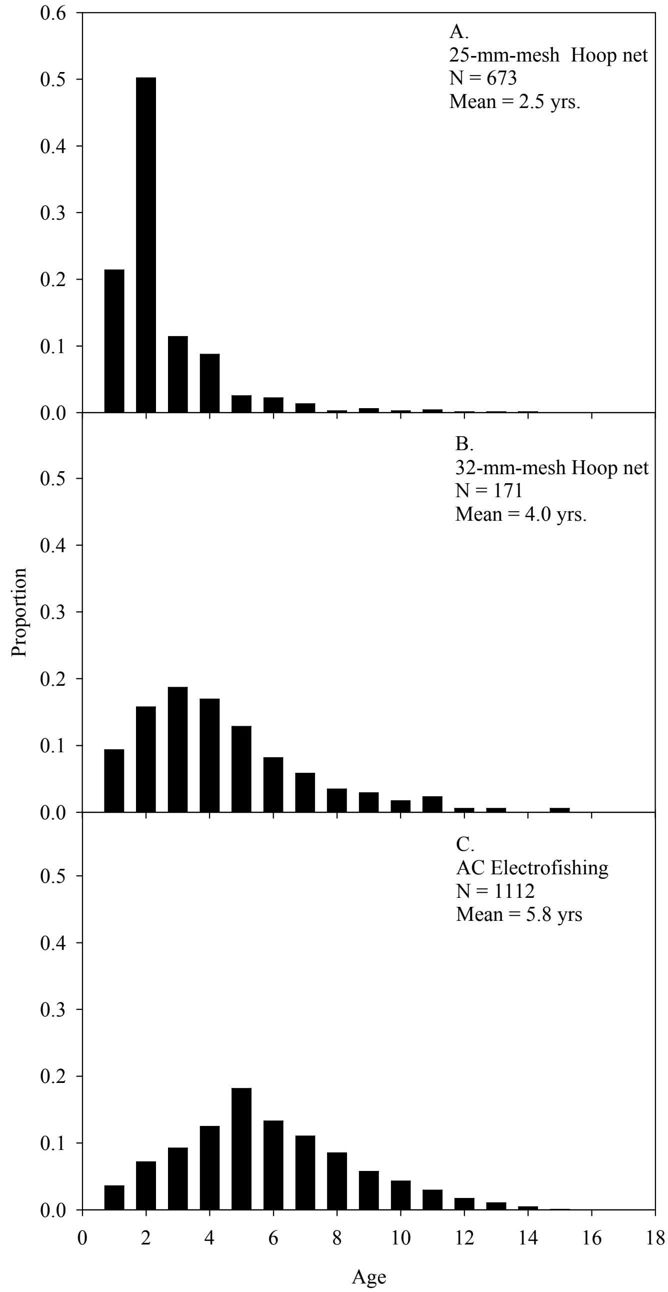

Figure 23. Pooled age frequency histograms for channel catfish sampled using 25-mm (A.) and 32-mm (B) hoop nets and electrofishing (C) from all treatment reaches of the Wabash River during 2001 through 2004.

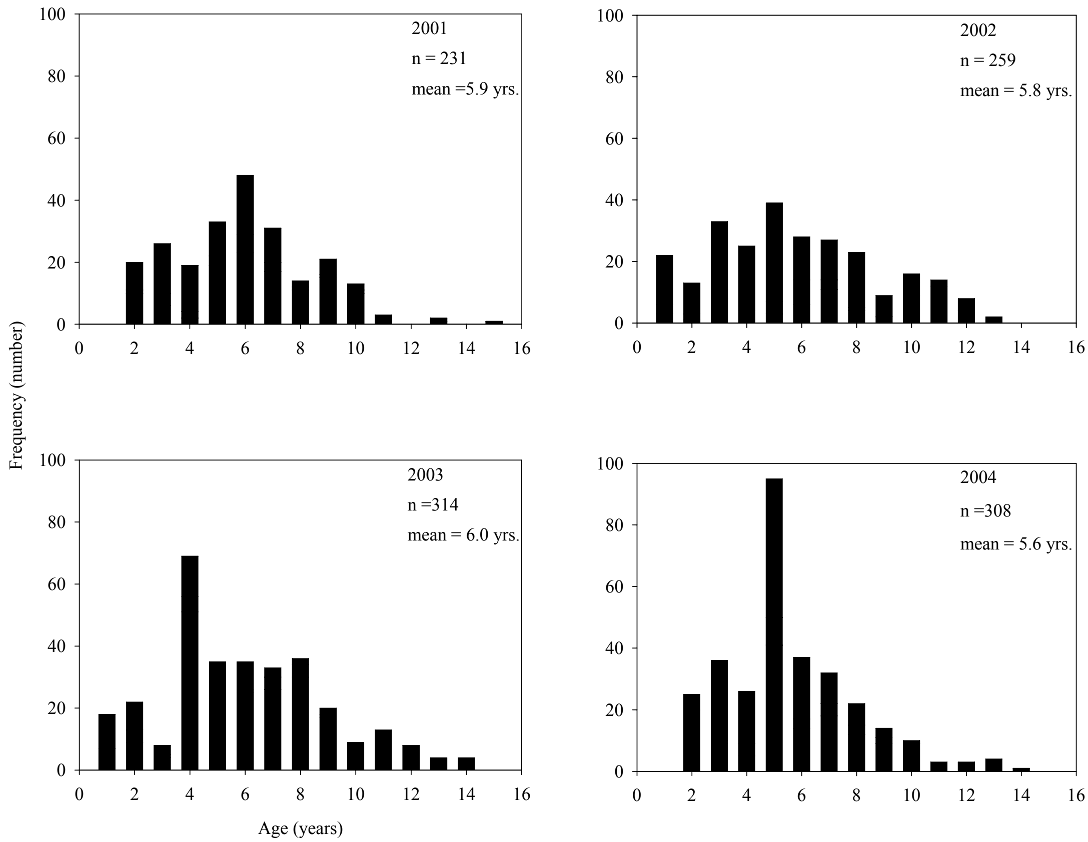

Figure 24. Age frequency distributions by sampling year for channel catfish sampled with electrofishing from all three treatment reaches of the Wabash River.

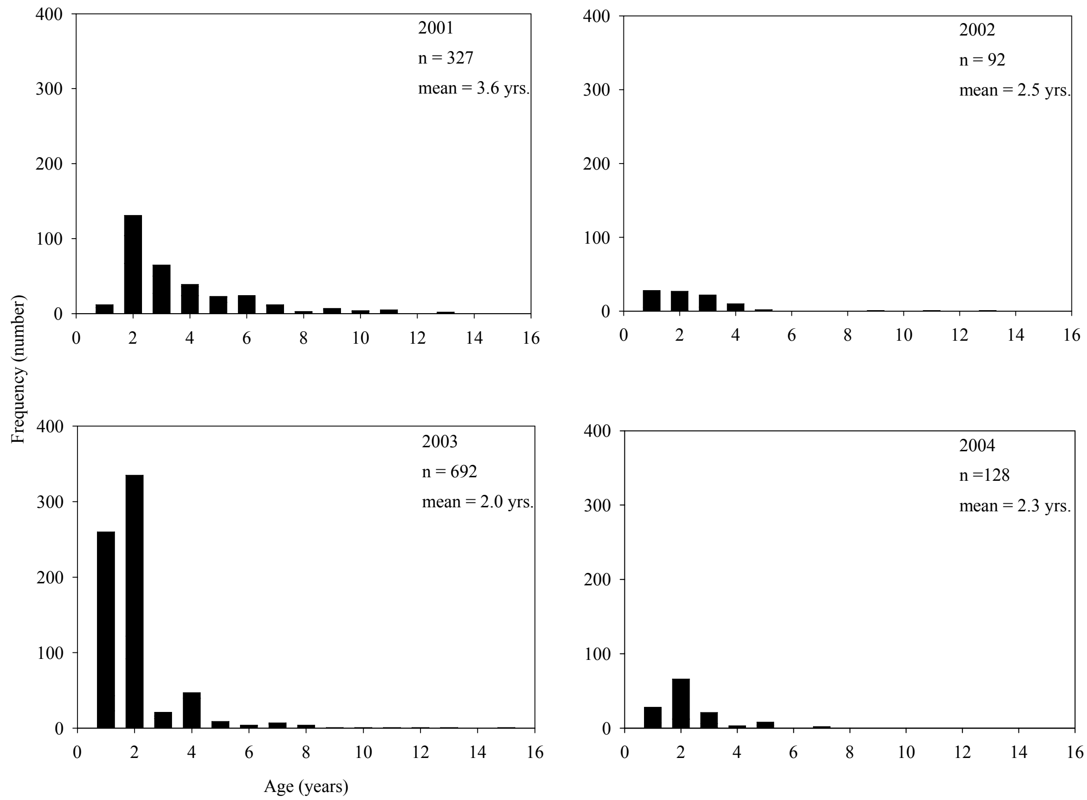

Figure 25. Age frequency distributions by sampling year for channel catfish sampled using hoop nets from all three treatment reaches of the Wabash River.

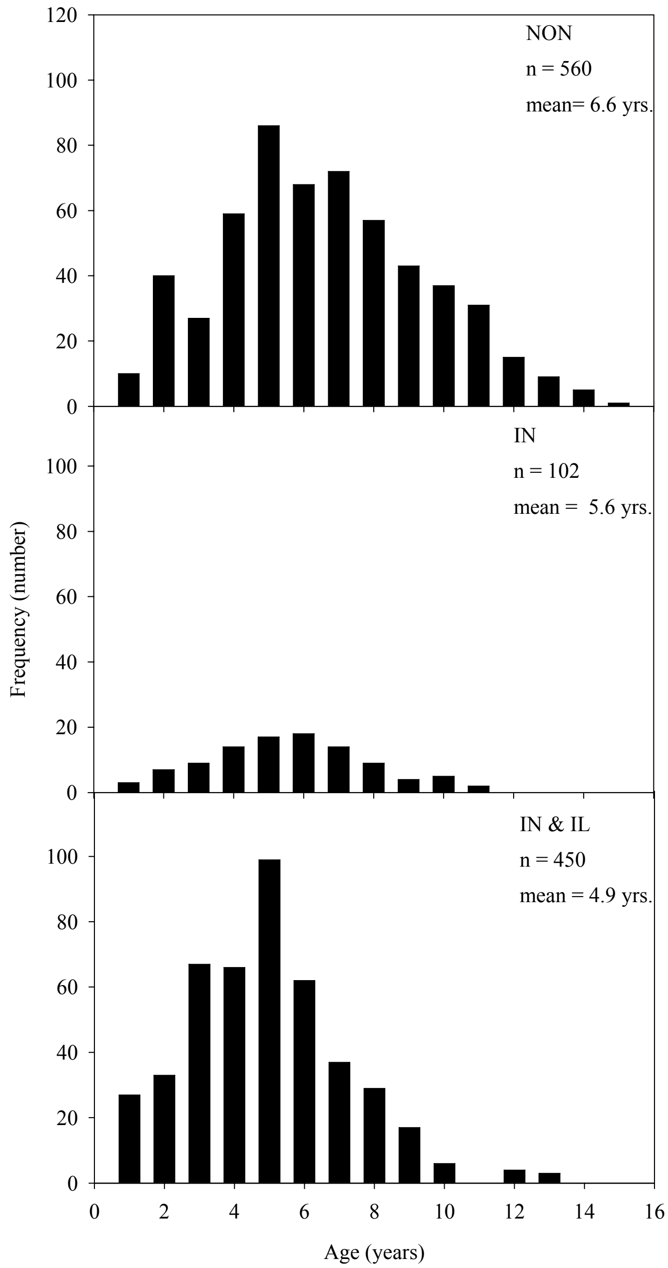

Figure 26. Age frequency histograms for channel catfish sampled using electrofishing from all three treatment reaches of the Wabash River during 2001 through 2004. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

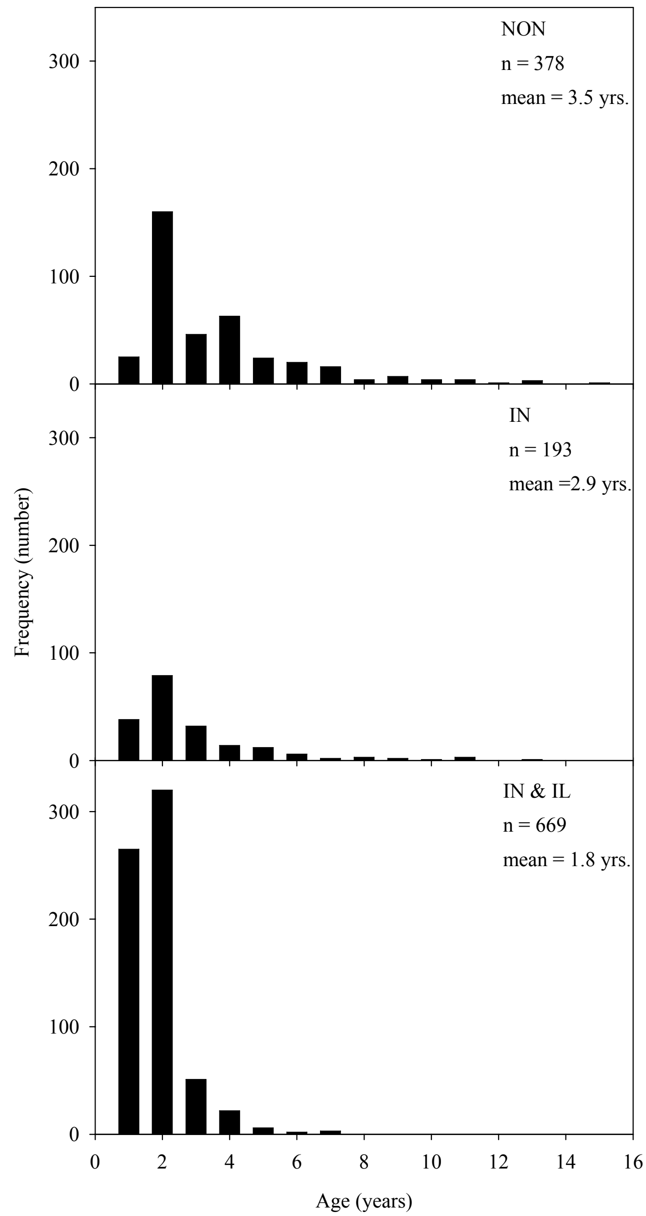

Figure 27. Age frequency histograms for channel catfish sampled using hoop nets from all three treatment reaches of the Wabash River during 2001 through 2004. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

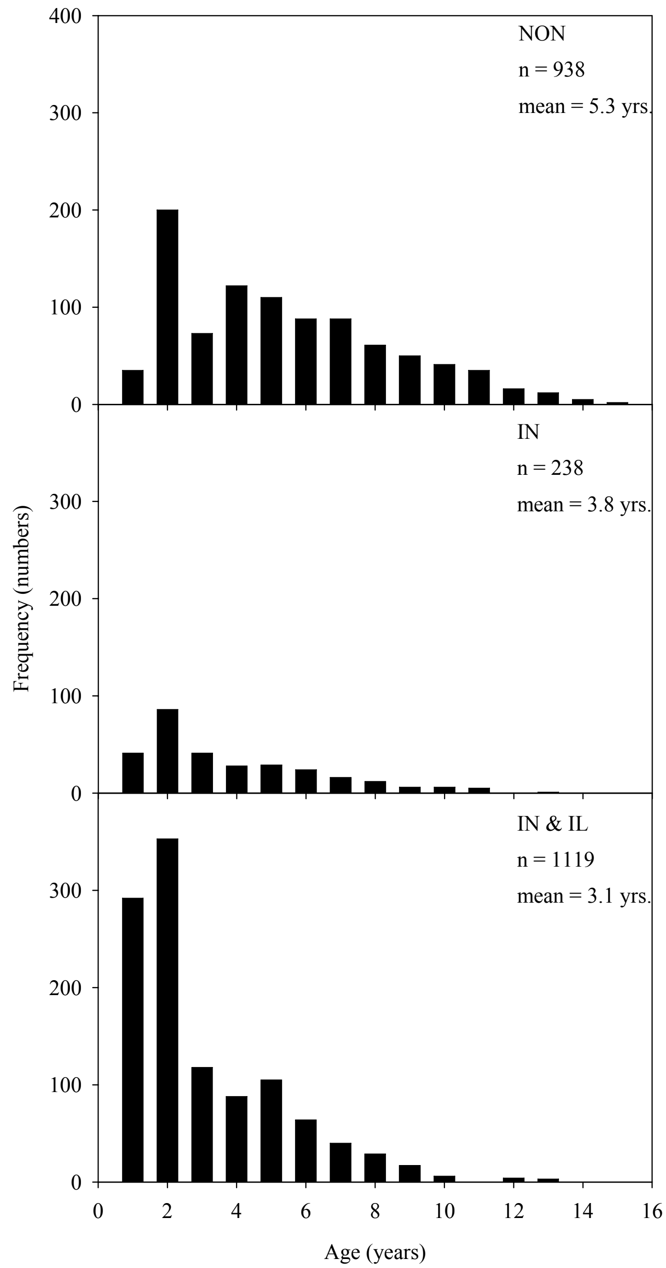

Figure 28. Age frequency histograms for channel catfish sampled using both gear types from all three treatment reaches of the Wabash River during 2001 through 2004. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

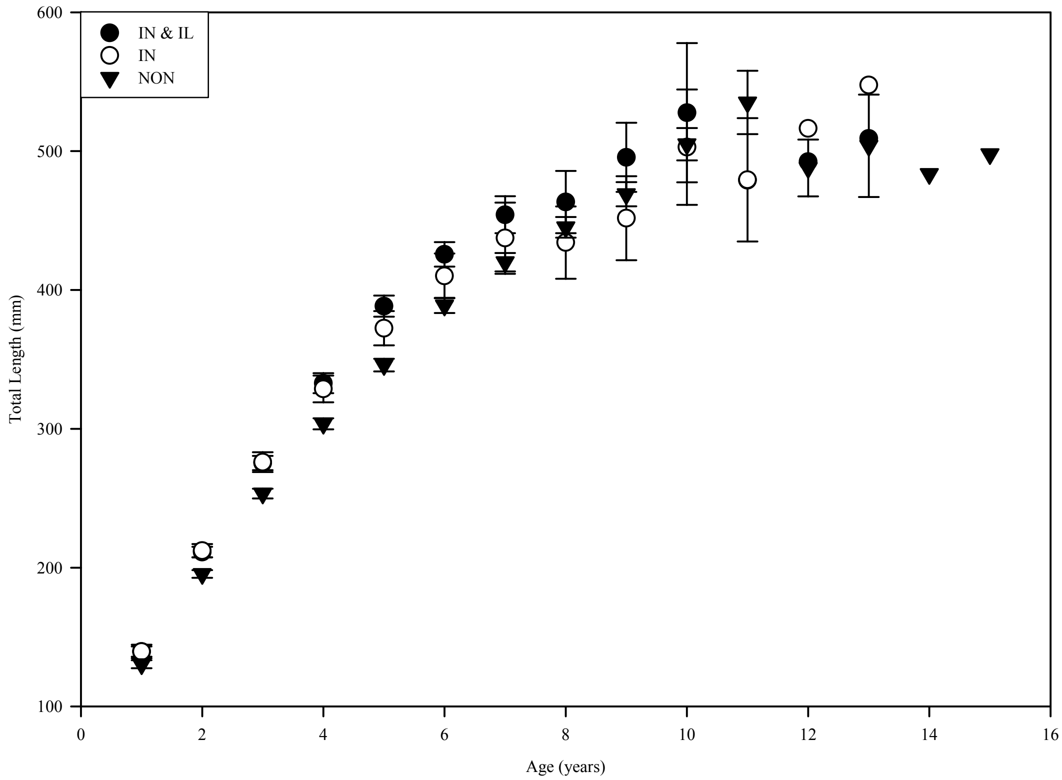

Figure 29. Mean length at age ±1 S.E. for channel catfish sampled using both gear types from the three different treatment reaches of the Wabash River during fall 2001 (IN & IL, n = 144; IN, n = 120; NON, n = 294). IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

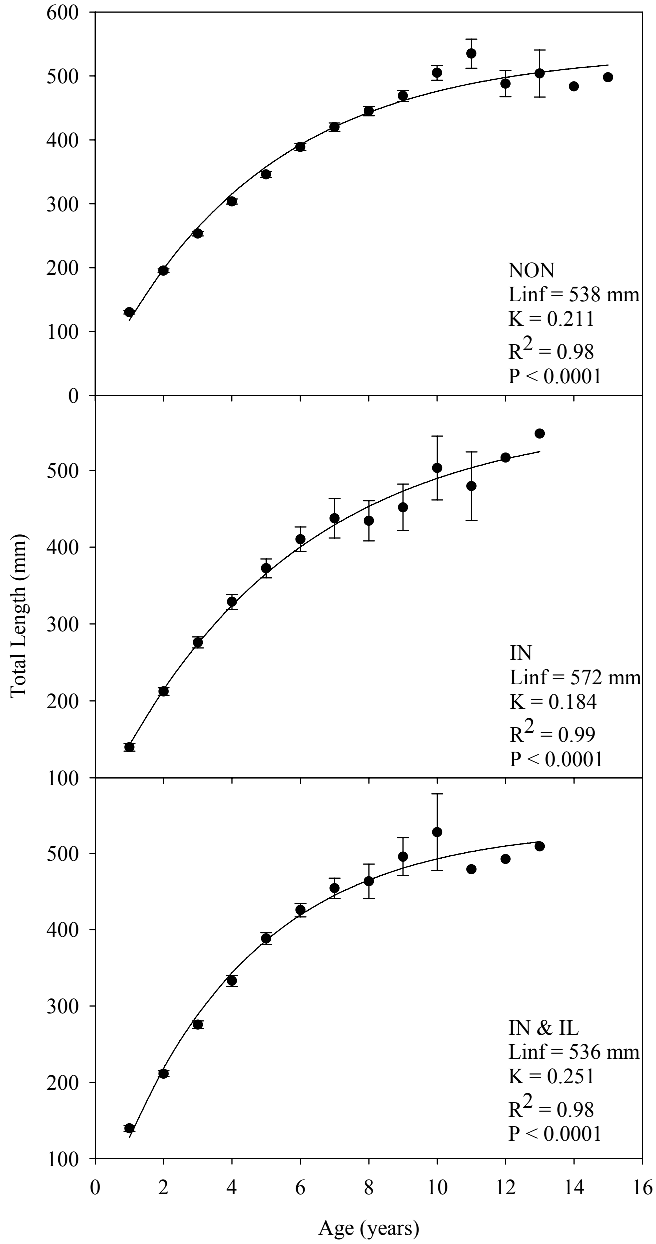

Figure 30. Channel catfish mean length at age and von Bertalanffy models for fish sampled using both gear types from the three different treatment reaches during 2001. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552). .

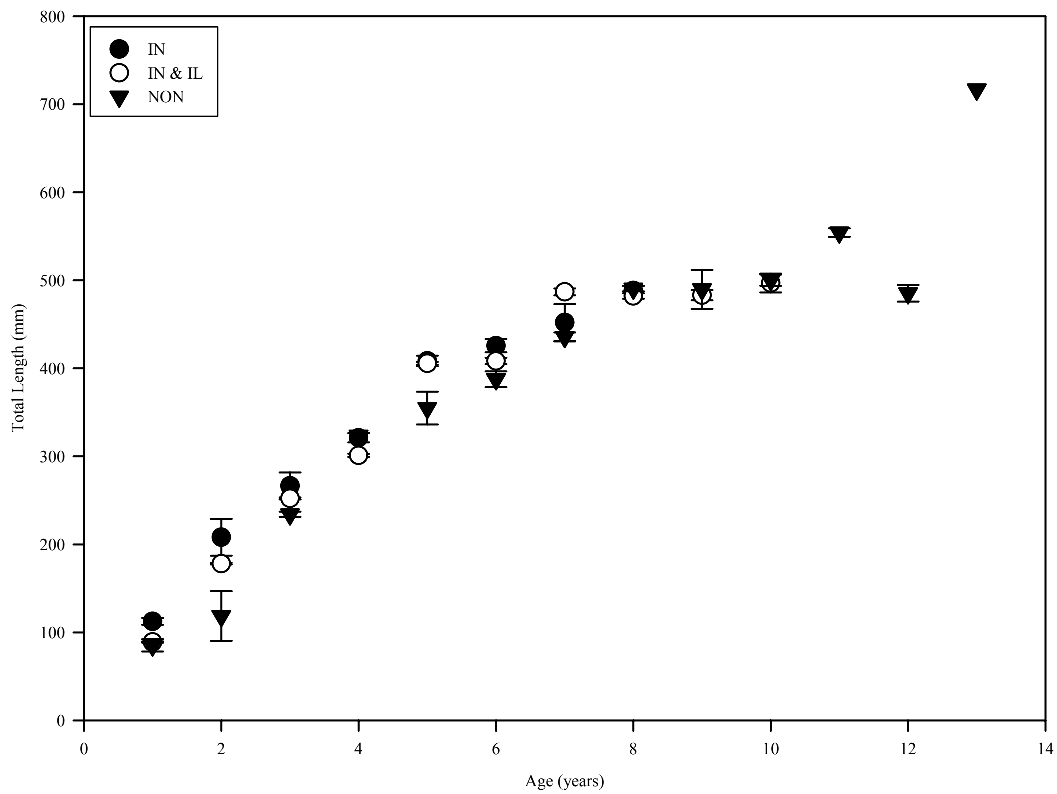

Figure 31. Mean length at age ±1 S.E. for channel catfish sampled using both gear types from the three different treatment reaches of the Wabash River during fall 2002 (IN & IL, n = 237; IN, n = 40; NON, n = 74). IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

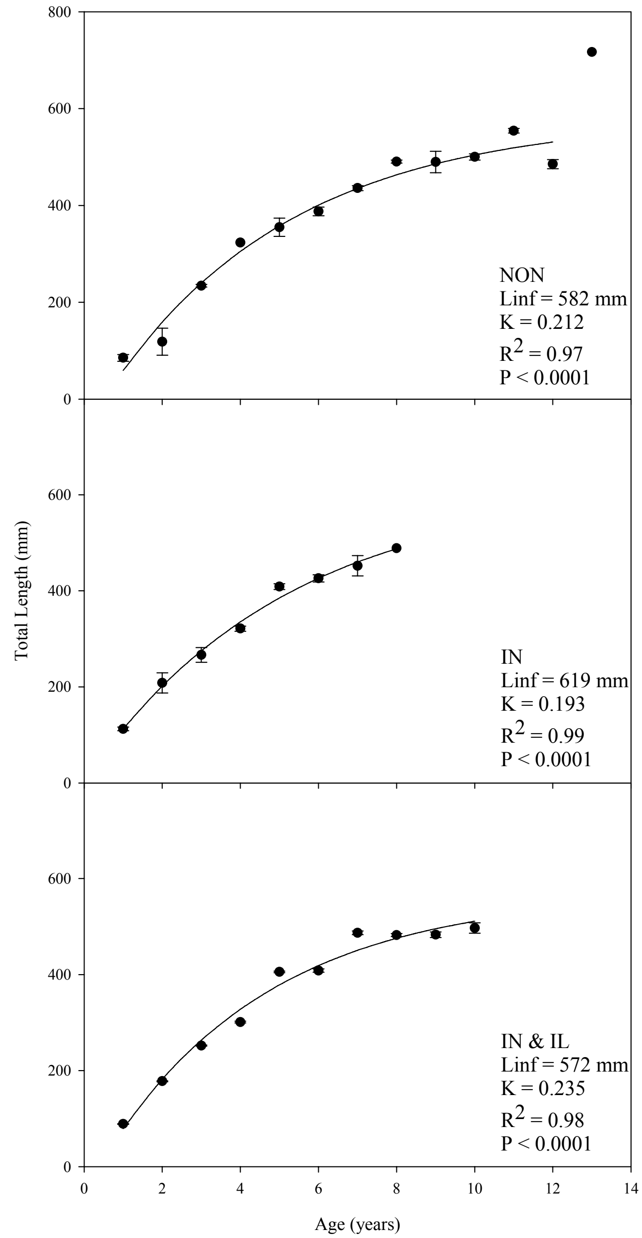

Figure 32. Channel catfish mean length at age and von Bertalanffy models for fish sampled using both gear types from the three different treatment reaches during 2002. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

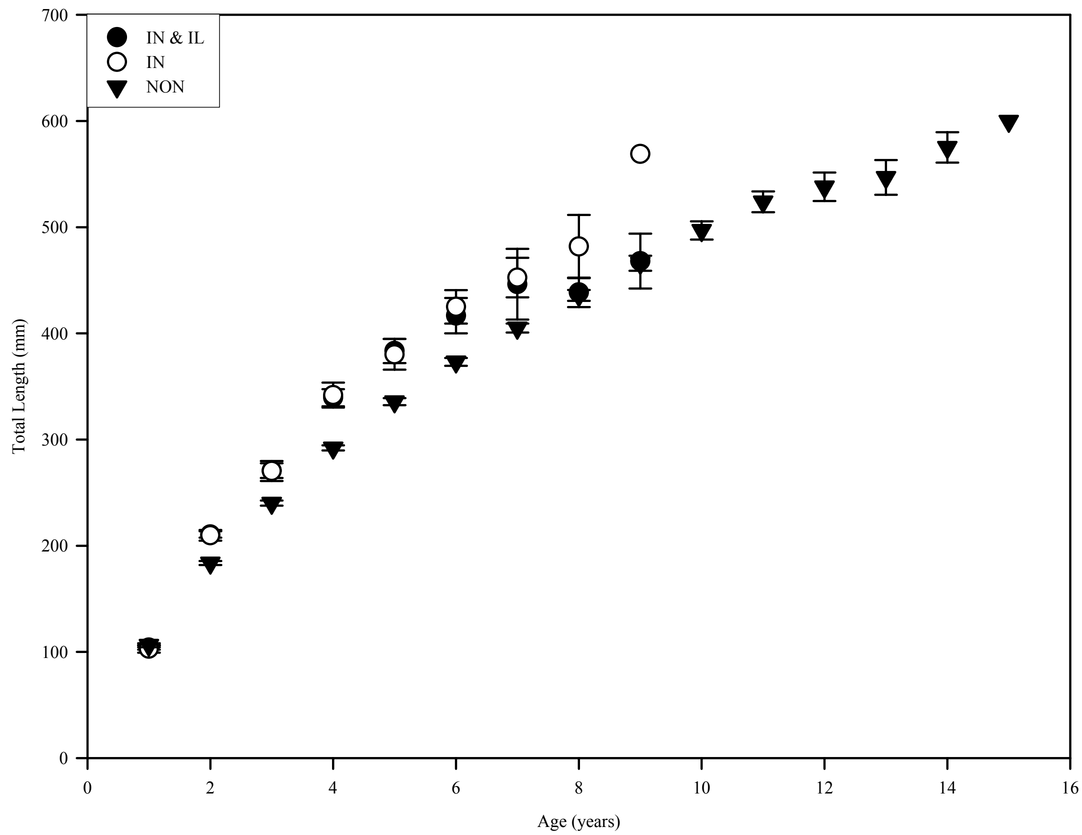

Figure 33. Mean length at age ±1 S.E. for channel catfish sampled using both gear types from the three different treatment reaches of the Wabash River during fall 2003 (IN & IL, n = 505; IN, n = 80; NON, n = 421). IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

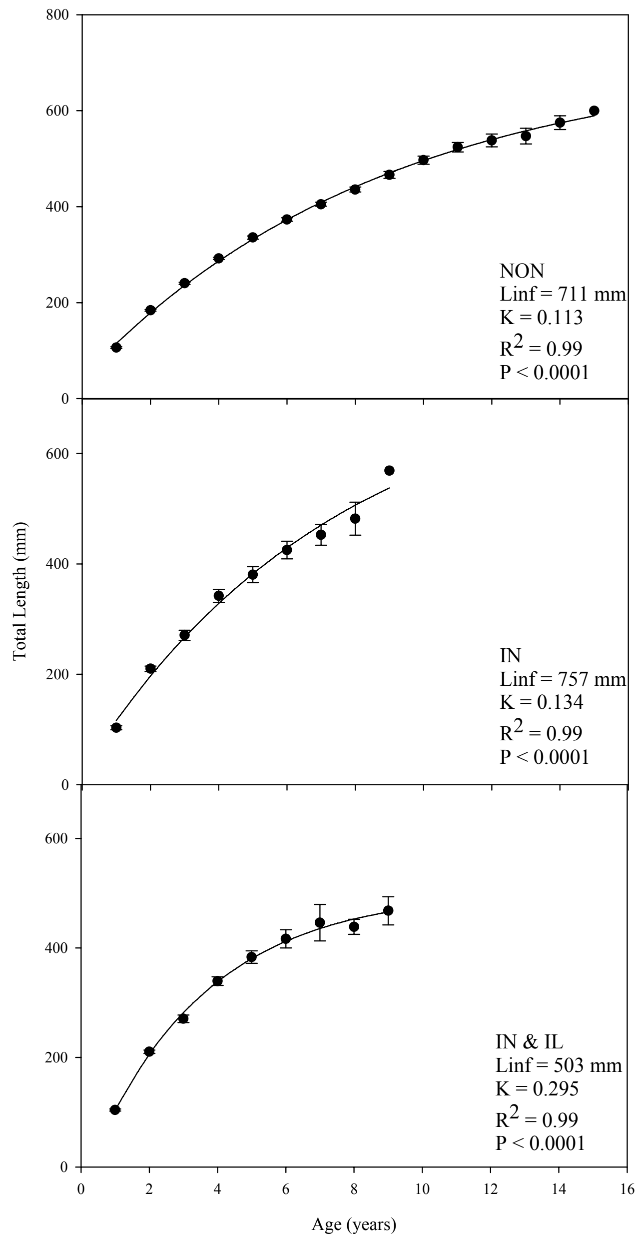

Figure 34. Channel catfish mean length at age and von Bertalanffy models for fish sampled using both gear types from the three different treatment reaches during 2003. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

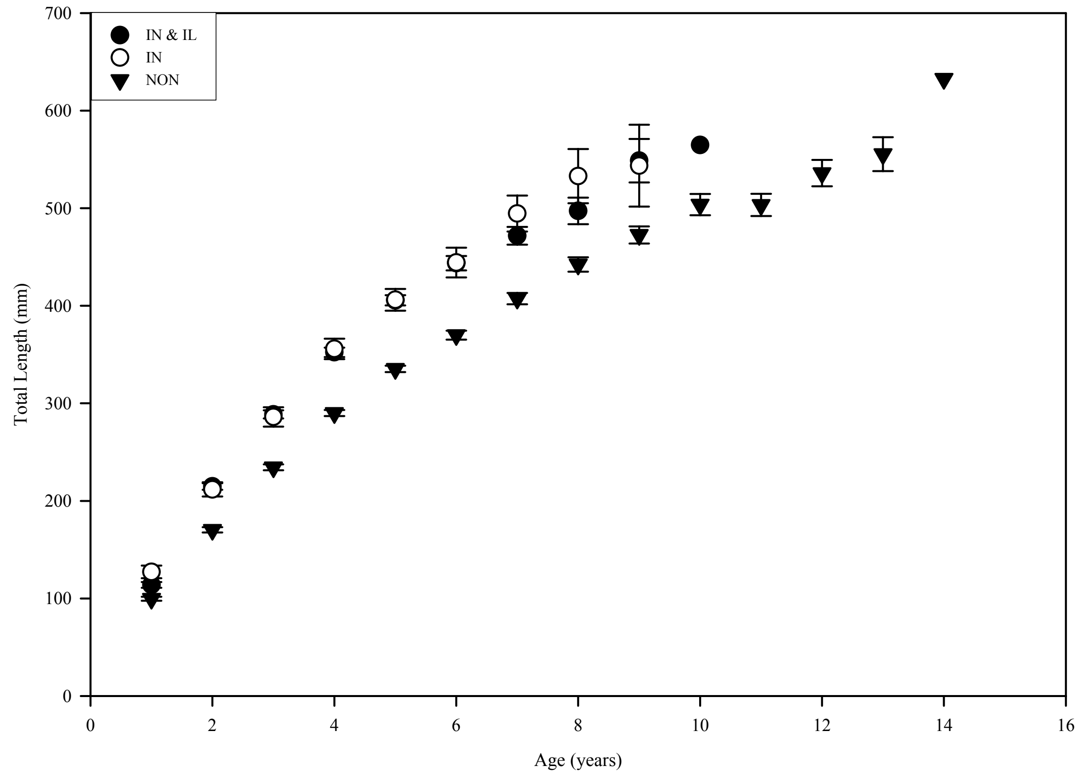

Figure 35. Mean length at age ±1 S.E. for channel catfish sampled using both gear types from the three different treatment reaches of the Wabash River during fall 2004 (IN & IL, n = 230; IN, n = 56; NON, n = 150). IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

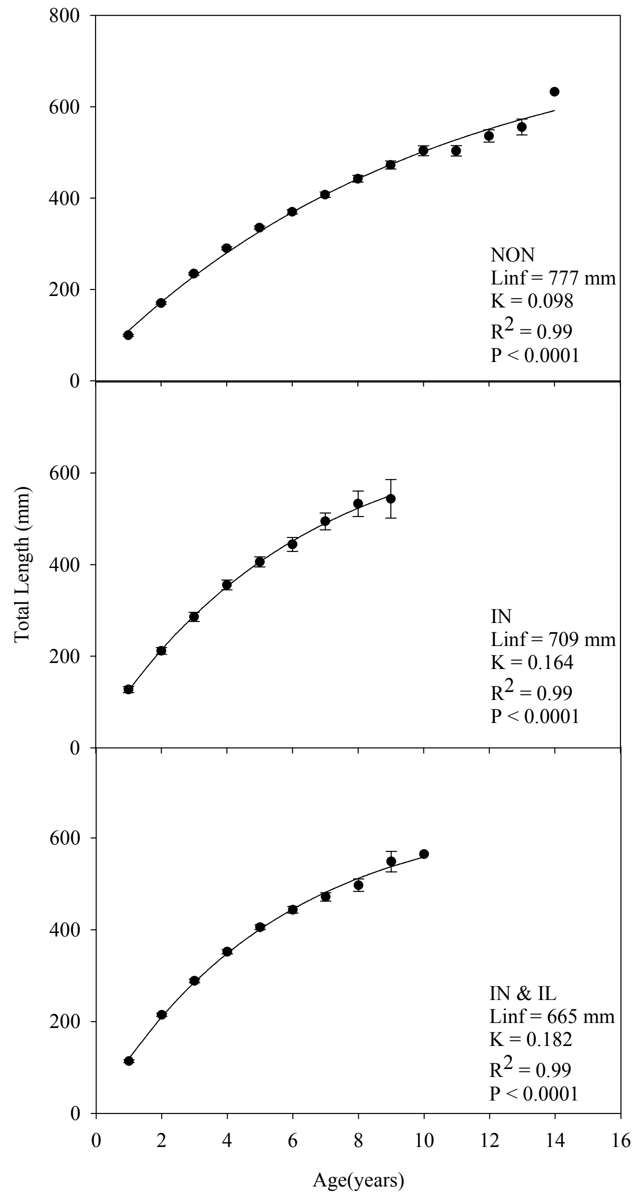

Figure 36. Channel catfish mean length at age and von Bertalanffy models for fish sampled from the three different treatment reaches during 2004. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552).

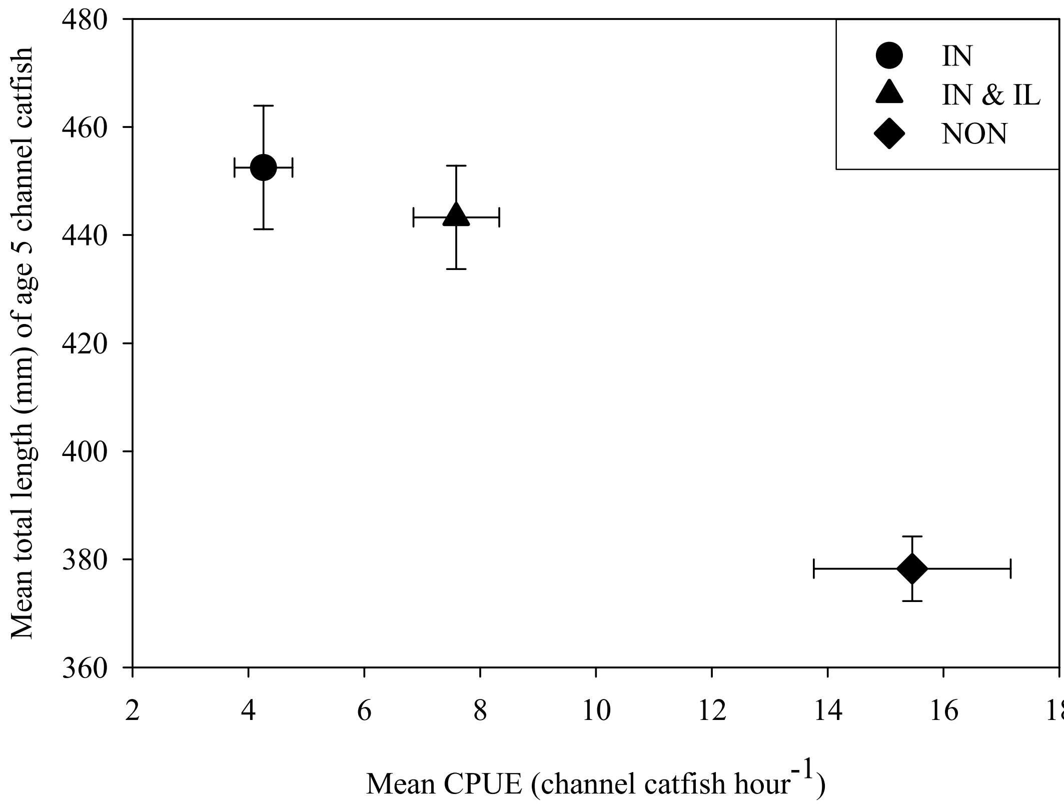

Figure 37. Mean length of age 5 channel catfish as a function of mean electrofishing CPUE for the three treatment reaches of the Wabash River Sampled during fall 2001 through 2004.

CHAPTER FOUR

ASSESSMENT OF WATER AND HABITAT QUALITY

INTRODUCTION

Some differential growth of channel catfish has occurred over the length of the Wabash River (Lauer 2000, Willenberg 2001). These authors found faster growth of channel catfish in downstream reaches compared to upstream reaches. These differences were attributed solely to latitude (Willenberg 2001) with no consideration of catfish density differences along the river gradient. To determine whether abiotic factors affected the density and growth rate of catfish, I assessed the water and habitat quality of the treatment reaches of the Wabash River.

METHODS

Water Quality

At each site, water quality was assessed using a Hydrolab® Quanta. The following parameters were measured at each site during each sampling trip: temperature, dissolved oxygen concentration, conductivity, and pH. Furthermore, water clarity was measured at each site using a secchi disk.

Habitat Quality

I assessed the habitat quality at each site using the Ohio EPA Qualitative Habitat Assessment Index (QHEI) (Rankin 1989). The QHEI ranks habitat on a scale from 0 to 100 with higher scores signifying better habitat quality. The ranking is based on six metrics: substrate type, instream cover, channel morphology, riparian zone, pool/riffle quality, and gradient. A QHEI was generated at each sampling site during all years of the study. A mean for each site was calculated from the four annual QHEI scores for that site. I used a one-way ANOVA with a Tukey-Kramer multiple comparisons test to determine if QHEI differed among treatment reaches. Regression was used to determine whether density of channel catfish was related to QHEI.

RESULTS

All water quality parameters were within the zone of tolerance for all three species of catfish inhabiting the Wabash River (Table 16). Habitat quality as measured by the QHEI differed among the three treatment reaches (($F_{2,16} = 5.4$, $P < 0.02$; Figure 38), with habitat quality being higher in the NON ($P < 0.05$) treatment reach compared to both the IN & IL and IN treatment reaches (Figure 38). Habitat quality did not differ between the IN & IL and the IN treatment reaches ($P > 0.05$) (Figure 38). Electrofishing CPUE of catfish increased with increasing QHEI scores ($Log(CPUE + 1) = 0.019 * QHEI - 0.45$; $r^2 = 0.54$;$P < 0.001$) (Figure 39). The was no apparent relationship between QHEI scores and hoop netting CPUE ($P > 0.05$, Figure 40).

DISCUSSION

The water quality of the treatment reaches of the Wabash River fell within expectation for a midwestern river. All values quantified were well within the zone of tolerance for catfish species endemic to the United States. The upper NON treatment reach had better habitat quality than either of the other two treatment reaches, primarily due to the small amount of bank erosion in the most upstream sites. Additionally, a large riparian zone and abundant riffle habitats were present in this treatment reach.

Based on the relationship between QHEI scores and electrofishing CPUE the density of channel catfish was correlated with habitat quality. Although this result makes some intuitive sense, it is confounded by the fact that no commercially fished treatment reach with high QHEI scores was surveyed. Furthermore, the QHEI index was not specifically developed to correlate with high quality channel catfish habitat. Thus, it is impossible to fully separate the impact of latitude, habitat quality and commercial fishing on the density of catfish. For example, we might expect high habitat quality to translate especially to the abundance of young, small catfish, which should be more sensitive to the availability of foraging areas and refuge. This was not the case as QHEI scores were not to hoop net CPUE, which was an index of the density small, young catfish.

Table 16. Summary of water quality for the all three treatment reaches of the Wabash River.

Parameter	Year 2001	2002	2003	2004
IN&IL (Rkm 0-322)				
Temperature (C)	11.7	18.8	18.5	24.5
Conductivity (mS/ml)	0.62	0.67	0.52	0.59
Dissolved Oxygen (mg/L)	6.33	9.90	8.76	13.84
pH	9.55	8.40	8.26	8.40
Secchi (cm)	N/A	36.0	34.6	32.1
IN (Rkm 394-500)				
Temperature (C)	12.2	18.4	16.9	23.0
Conductivity (mS/ml)	0.62	0.67	0.54	0.60
Dissolved Oxygen (mg/L)	6.93	8.89	9.14	11.83
pH	9.63	8.25	8.26	8.56
Secchi (cm)	N/A	44.5	38.1	39.5
NON (Rkm 500-552)				
Temperature (C)	12.4	18.5	17.3	21.6
Conductivity (mS/ml)	0.58	0.58	0.48	0.55
Dissolved Oxygen (mg/L)	6.97	8.26	9.23	10.81
pH	9.54	8.24	8.50	8.38
Secchi (cm)	N/A	53.2	48.4	52.2

n/a – not available.

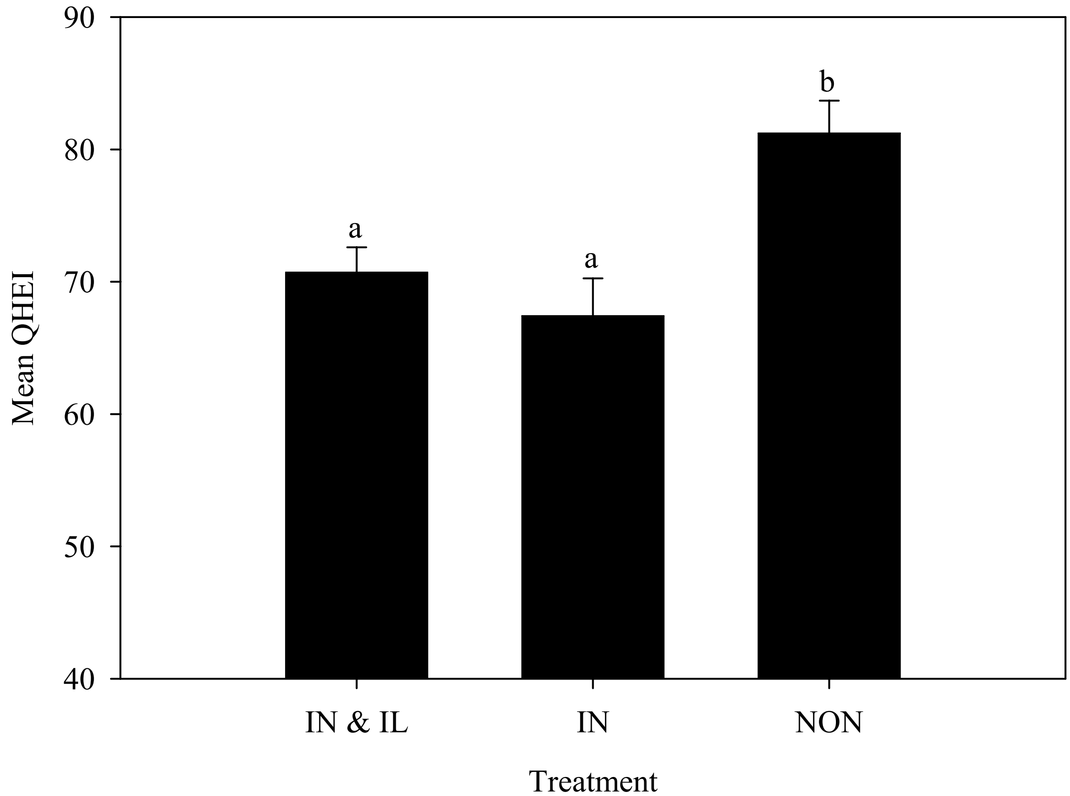

Figure 38. Mean QHEI for the three treatment reaches of the Wabash River during fall 2001 through 2004. Different letters denote significantly different means (ANOVA, Tukeys $P < 0.05$).

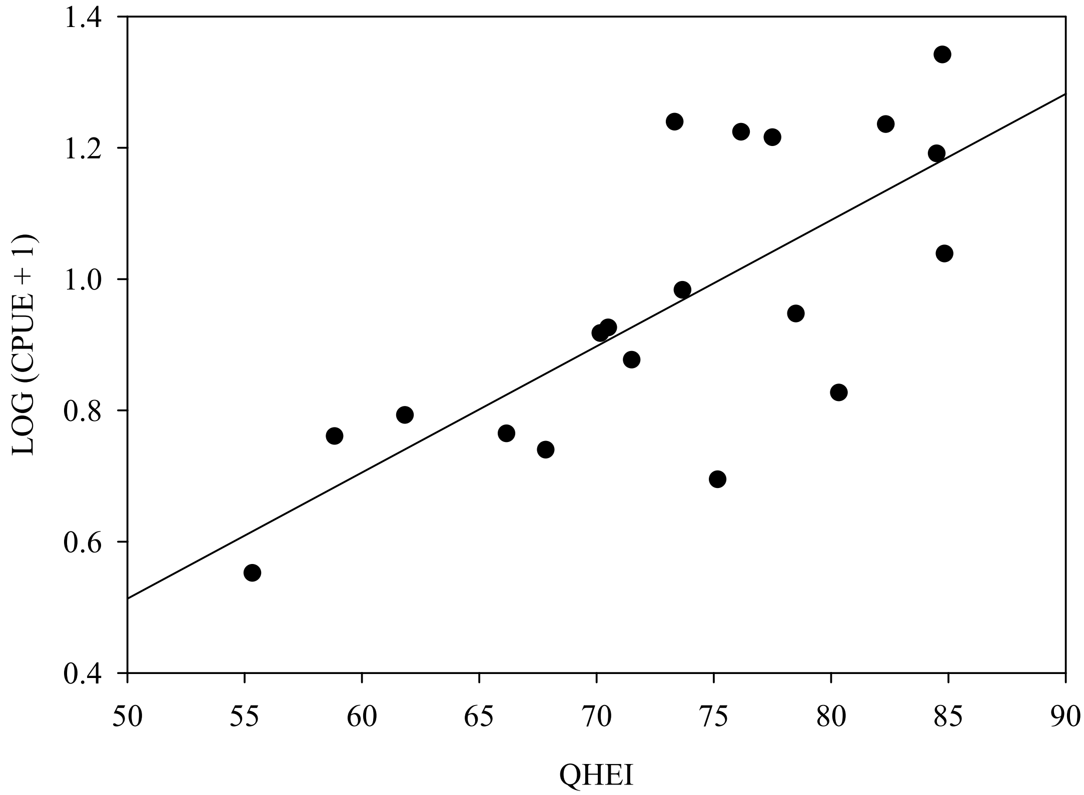

Figure 39. Relationship between QHEI and mean electrofishing CPUE of channel catfish (Log (CPUE + 1) = 0.019 * QHEI – 0.45; $r^2 = 0.54$; $P < 0.001$) sampled during fall 2001 through 2004 in the Wabash River.

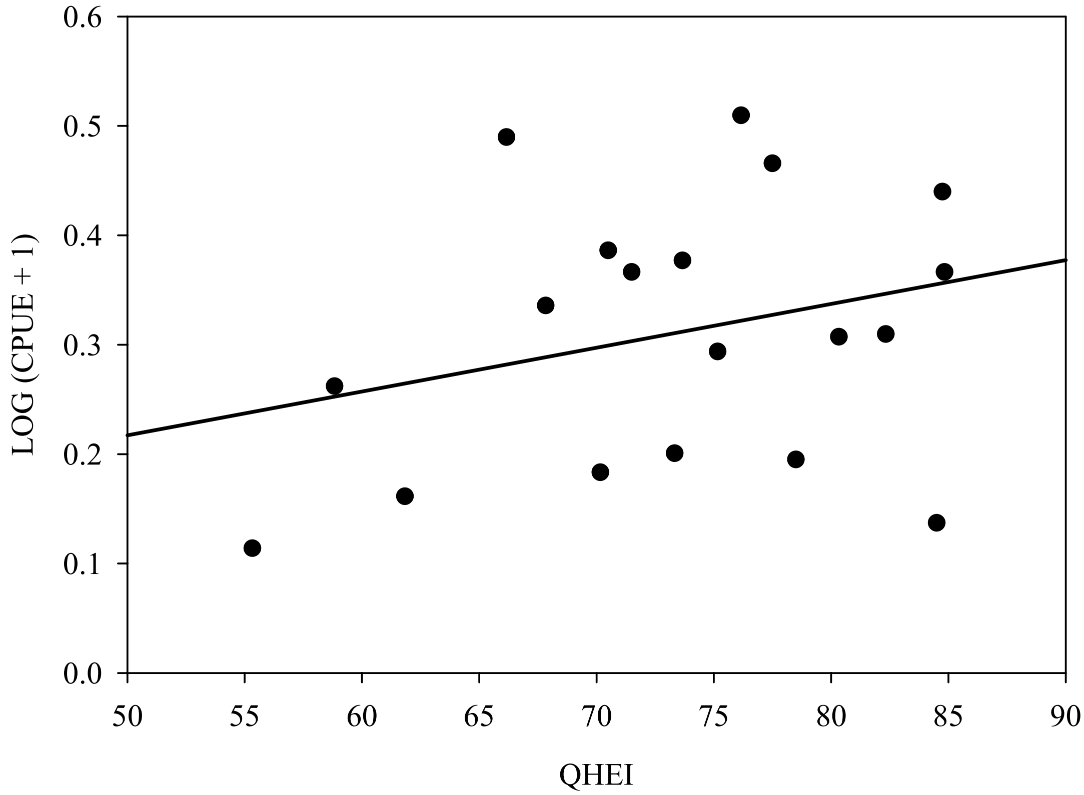

Figure 40. Relationship between QHEI and mean hoop net CPUE of channel catfish (Log (CPUE + 1) = 0.004 * QHEI + 0.017; $r^2 = 0.08$; $P > 0.05$) sampled during fall 2001 through 2004 in the Wabash River.

CHAPTER FIVE

ASSESSMENT OF THE COMMERCIAL FISHERY

INTRODUCTION

There is a substantial commercial fishery on the Wabash River with more than 300 commercial licenses issued annually (Stefanavage 1999, Maher 2001). These licenses require the commercial fishers to provide a yearly estimate of their total harvest by weight. Managers currently lack information regarding the gear used, effort, location and size structure of harvested channel catfish. These data could provide insight into the impact of harvest on the length frequency distribution of catfish in the commercially treatment reaches of the Wabash River. The Indiana Department of Natural Resources sought to obtain this information; however, logistic problems did not allow for sufficient observer effort.

METHODS

During springs 2001 and 2004, a member of Indiana DNR (INDNR) accompanied both an Indiana and Illinois commercial fisher during their fishing trips. During spring 2003 data were collected from an Illinois commercial fisher only. In 2002, no data were collected by INDNR personnel from commercial fishers. The INDNR observers did not record information regarding the effort or gear used; however, they did collect information on catfish species caught, their lengths and weights, and when time permitted, the sex and reproductive stage of each catfish.

RESULTS

A total of 408 catfish were caught with hoop nets in the spring by commercial fishers in the presence of the INDNR observer. The observers did not collect any information regarding the mesh size used by the commercial fishers. Of these, channel catfish accounted for 78% of the catch. Illinois commercial fishers caught 75% of the catfish in the sample. Illinois commercial fishers harvested larger channel catfish than did the Indiana commercial fishers (Figure 41). The mean length of catfish harvested by the Illinois commercial fisher (541 mm) was substantially greater than the mean of either the 25.4-mm hoop nets (257 mm) or 32-mm hoop nets (343 mm) that were used in my fall surveys. Although the fish captured by the Indiana fisher had a larger mean length (394 mm) than did my samples, the difference was not great. The mode of the length frequency distribution of fish harvested by the commercial fishery occurred at a point similar to where there was a decline in distributions generated by my fall sampling survey (Figure 42).

A total of 363 channel catfish were sexed, with males comprising 73% of the sample. Because most of the fish sampled came from an Illinois commercial fisher subjected to a 381-mm length limit, 97% of the fish had reached sexual maturity. The smallest mature catfish was a 241-mm female channel catfish, the only individual less than 330 mm that was staged as mature. All immature fish ranged from 309 to 445 mm except for one 551 mm individual. Mature fish ranged from 330 to 940 mm except for one 241 mm female.

DISCUSSION

The lengths of channel catfish harvested by Indiana commercial fishers were much smaller than those of the Illinois commercial fishers, likely influencing size distributions in the IN & IL and IN treatment reaches. Variations in the gear used by the commercial fishers may contribute to the difference in lengths of catfish harvested between the states. The Illinois commercial fisher captured catfish of a mean length that was greater than either of our hoop nets suggesting a different compliment of mesh sizes. The spring commercial harvest of these fishers in the Wabash River selectively harvested male catfish, perhaps due to the proximity to the spawning season. Anecdotal evidence suggests a gear bias towards males when a single female is captured in the net, leading to high catch rates of males (John Cooper, Wabash commercial fisherman, *personal communication*). This gear bias has prompted some commercial fishers to bait hoop nets with female catfish to attract males during the spring spawning season. There does seem to be a seasonal selection towards males in the commercial harvest; however, the sex ratio as estimated by my fall sampling remained one to one (Chapter 2).

Although we now have some insight into the impact of commercial fishing on catfishes of the Wabash River, many gaps in our knowledge still exist. For example, we lack information on the female maturation schedule, which is necessary to model the impact of exploitation on the reproductive potential (Goodyear 1993) of this population. In addition, both Indiana and Illinois need to elicit more information from their commercial fishers to better understand how these fisheries differ. Specifically, commercial fishers should provide details regarding the gear used, effort, and reach-specific harvest. Lastly, the length frequency distribution and sex ratio harvested by the commercial fishery needs to be quantified at other times of the year to determine if these trends are similar during the entire year. Researchers must also gather information regarding the recreational harvest of catfish in the Wabash including the use of trotlines, limb lines, and jugs. Some of these questions are currently being addressed by the INDNR (Tom Stefanavage, INDNR, personal communication).

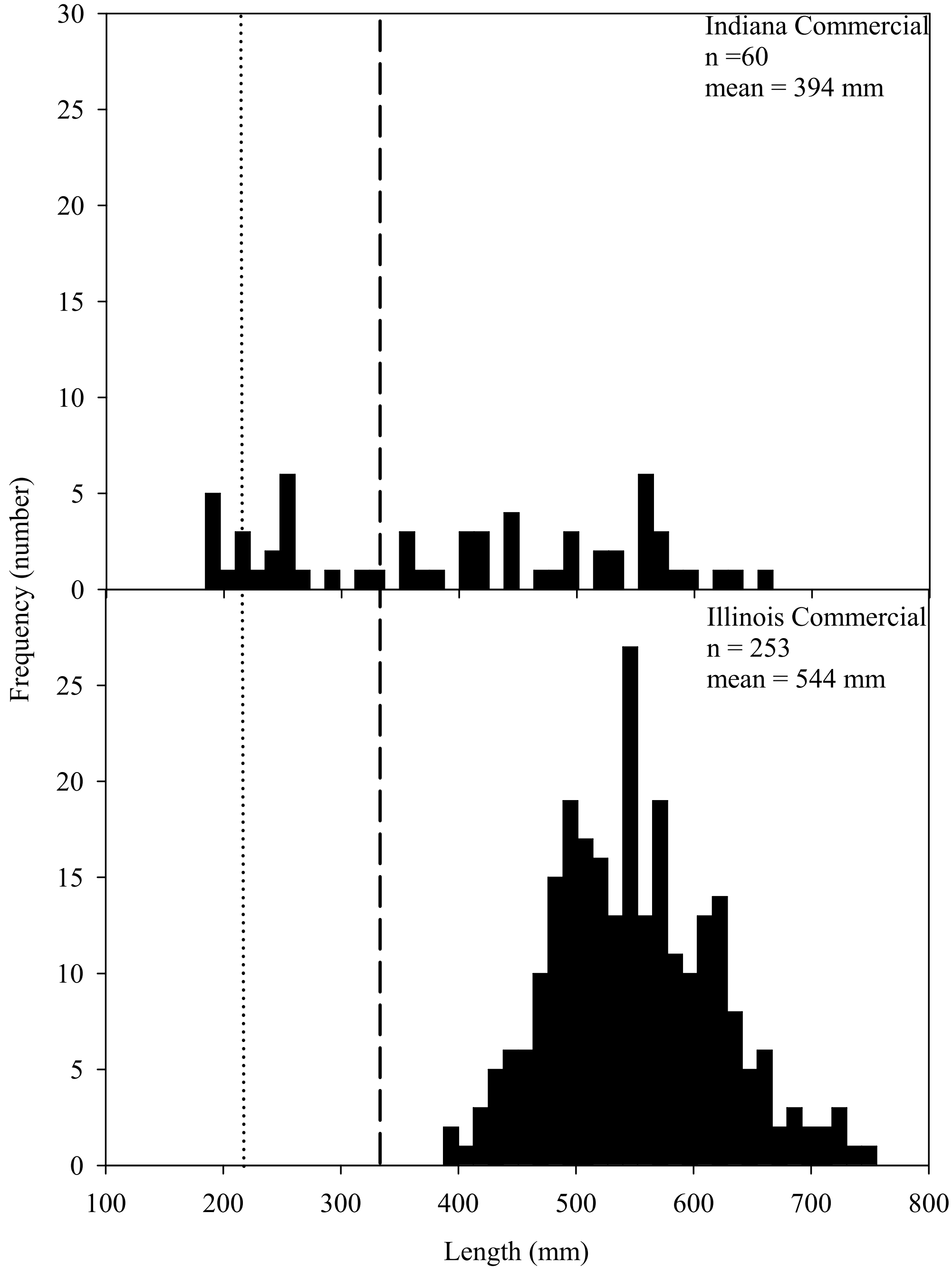

Figure 41. Length frequency histograms for channel catfish harvested by commercial fishers in the presence of an INDNR observer during spring 2001 through 2004.

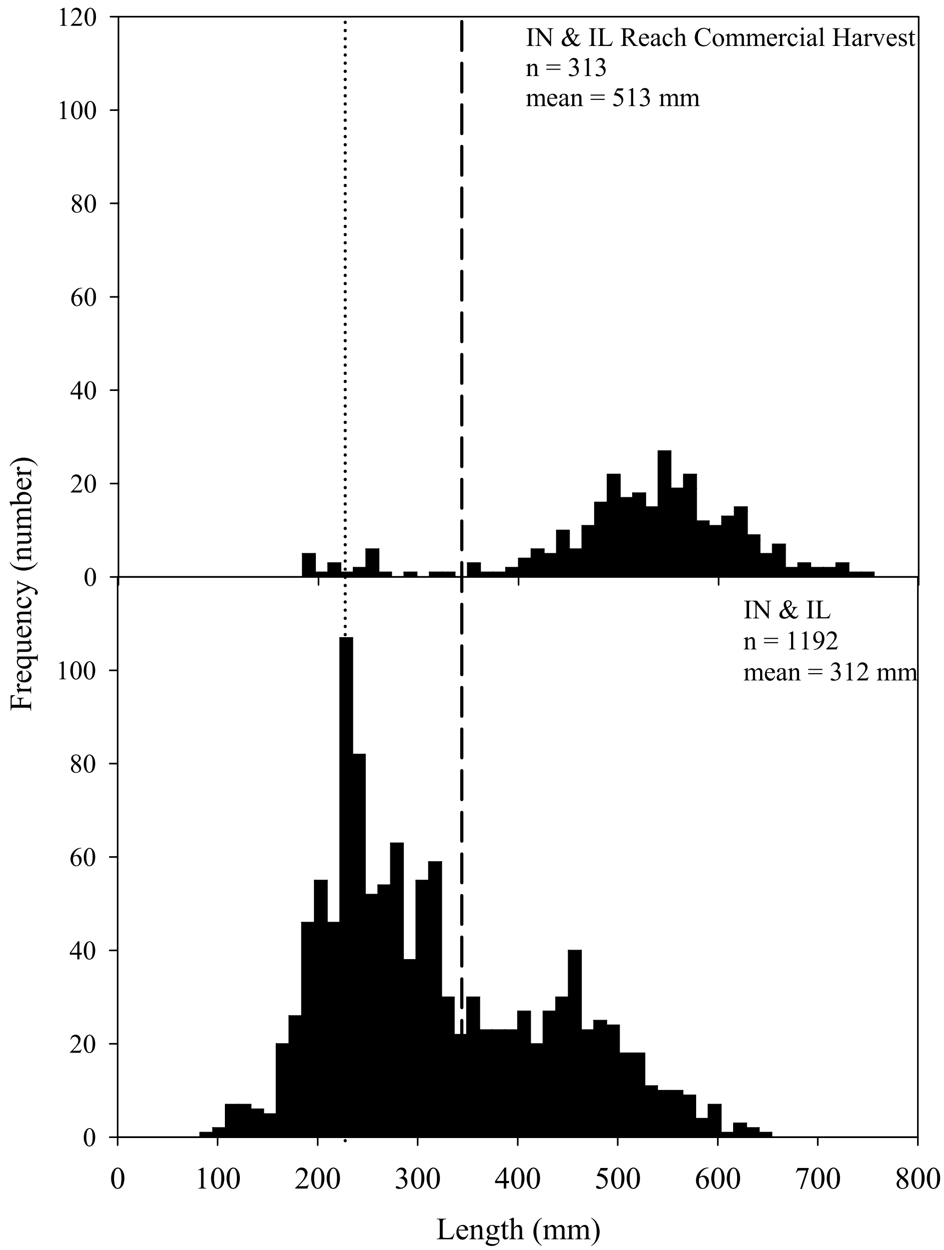

Figure 42. Length frequency histograms for channel catfish sampled by commercial fishers in the presence of an INDNR observer during spring 2001 through 2004 (top panel) and sampled in the IN & IL during the sampling conducted by SIUC during fall 2001 through 2004 (bottom panel).

CHAPTER SIX

PREDICTING THE IMPACT OF HARVEST ON THE YIELD OF CHANNEL AND FLATHEAD CATFISH IN THE WABASH USING POPULATION MODELING

ABSTRACT

Beverton-Holt yield-per-recruit modeling was used to predict impact of harvest on the channel and flathead catfish populations of the Wabash River. I separated the populations into two treatment reaches: one occurring in the boundary fishery (IN & IL) and one occurring entirely within the state of Indiana (IN). Both treatment reaches are subjected to commercial fishing. The populations were modeled at three different minimum length limits to estimate how the population yield would change with differences in the management practices of Indiana and Illinois. Under the first management scenario, the current Indiana minimum length limit (254-mm total length) is adopted by both states. With this management strategy, both populations were predicted to become overfished at low levels of fishing mortality (< 40%). Because this is the current length limit in Indiana, care must be given to monitor the population in the IN treatment reach in order to avoid overfishing. The second management strategy is an intermediate length limit (330-mm), which is between the length limit of Indiana (254-mm) and Illinois (381-mm). At this length limit, the population could withstand a larger amount of harvest before it became overfished. This management strategy would allow for a sustainable commercial fishery and still provide some sport fishing opportunities. The third management strategy has both agencies adopting the current Illinois minimum length limit (381-mm). At this length limit, the population of channel catfish did not

reach overfishing at any simulated level of fishing mortality (up to 60%). The 381-mm management option would allow for the development of a larger commercial and or sport fishery on the Wabash River. Finally, the model suggested that at the current level of harvest, the channel catfish commercial fishery is likely sustainable at any minimum length limit ≥ 254-mm. However, modest increases in harvest at a 254-mm minimum length regulation may lead to both growth and recruitment overfishing. For the flathead catfish population, the fishery was not predicted to be sustainable at any minimum length limit modeled.

INTRODUCTION

The Wabash River currently sustains a large catfish commercial fishery with an unknown level of sport fishing. An interesting attribute of this river is that it is a boundary fishery, with the lower 322 km forming the southern border of Indiana and Illinois. Currently, two minimum length limits are in effect in this boundary fishery. In Indiana, the catfish fishery is managed as a "fiddler" fishery (254-mm) allowing the commercial fishers to harvest the smaller catfish. This is contrasted with the current 381-mm minimum size limit in Illinois. Recently the harvest of the catfish has been similar between the two states, with Indiana fishers harvesting approximately 20 tons (Stefanavage 1999) and the Illinois commercial fishers harvesting 22 tons annually (Maher 2002); this equates to 84 kg of catfish harvested per river kilometer.

Understanding how commercial harvest affects populations is essential for effective management of sustainable stocks. If left unchecked, catfish populations can become overfished, leading to reductions in yield and recruitment (Pitlo 1997). Fisheries yield modeling is one approach that has been used to determine the influence of commercial exploitation of exploited fish stocks (Quist et al. 2002, Colombo et al. 2007) Models such as the Beverton-Holt yield per recruit model have been used to estimate the yield of populations as a function of alternative management strategies (Maceina et al. 1998, Slipke et al. 1998, Slipke et al. 2002, Quist et al. 2002, Colombo et al. 2007). These models require information on the growth and mortality of the population, both of which are currently available for the channel catfish in the Wabash River (Chapter 2 and 3).

The spawning potential ratio (SPR) is used to assess how harvest affects the reproductive potential of females in a population (Slipke et al. 2002). The SPR estimates the potential proportion of eggs a recruit will produce in an exploited population compared to that of an unexploited one. As fishing mortality increases the SPR declines towards zero. For many marine fisheries, a SPR of 30% is considered the critical value below which the population reaches recruitment overfishing (Goodyear 1993). The critical SPR of the commercially exploited population of channel catfish in the Upper Mississippi River was determined to be between 10 and 20% (Slipke et al. 2002). Information is needed on the sex ratio, female's maturation schedule and fecundity to determine the SPR for Wabash River stocks. Exclusive of the sex ratio, these specific data are currently lacking. However, this is information available for similar populations in large midwestern rivers (Pflieger 1997, Slipke et al. 2002). Although these data do not substitute for ones derived directly from the Wabash River population, they do provide a good starting point.

The current commercial regulations in the Wabash River do not distinguish between species of catfishes. The proportion of flathead catfish collect during this study was different than the proportion in the two states commercial harvest reports, suggesting that differential harvest of flathead catfish in the Wabash River may occur. Flathead catfish comprised 8% of the total catch during the fall sampling of this study; however, flathead catfish comprise 26% of the commercial harvest (Maher 2002, Stefenavage 1999). Because of their life history flathead catfish may be more susceptible to over harvest compared to the channel catfish. Flathead catfish reach maximum size slowly, mature late, and when unexploited have high annual survival and are long lived (Jackson 1999, Jackson and Jackson 1999, Kwak et al. 2004, Makinster 2006). Therefore, it is also important to determine how these length limits may be affecting the flathead population in the Wabash.

In this chapter, I predict the impact that commercial fishing is having on the channel and flathead catfish populations in the Wabash River using yield-per-recruit modeling. These models predict how different length limits would affect the population yield. The results of these models were used to determine the level harvest mortality the channel catfish fishery could withstand while remaining sustainable. Finally, I also predicted how harvest affected sustainability of the flathead catfish populations under the current length limits.

METHODS

Channel catfish populations of the two commercially exploited treatment reaches (IN & IL and IN) along with the flathead catfish population of the Wabash River were modeled using the Beverton-Holt equilibrium yield model (Ricker 1975) in the yield-per-recruit function in Fishery Analysis and Simulation Tools (FAST) software (Slipke and Maceina 2000). The FAST yield per recruit model is actually a modification of the original Beverton-Holt model (Ricker 1975; Slipke et al. 2002), but it is similar to yieldmodels of other programs (Quist et al. 2002). The Beverton-Holt yield-per-recruit model estimates yield using the following formula (Slipke and Macenia 2000):

$$Y = \frac{F * N_t * e^{Zr} * W_\infty}{K} * [\beta(X, P, Q)] - [\beta(X_1, P, Q)]$$

where F = instantaneous fishing mortality; N_t = the number of recruits entering the fishery at some time t; Z = instantaneous mortality rate; r = time to recruitment ($t_r - t_0$); W_∞ = maximum theoretic weight estimated from L_∞ and the Log_{10} length against Log_{10} weight regression; K = the Brody growth constant from the von Bertalanffy model; β() = the incomplete beta function; X = e^{-Kr}; $X_1 = e^{-K(\text{Max Age} - t0)}$, Max Age is the maximum age from the sample and t0 = the theoretic time at which length equals zero; P = Z/K; and Q = slope of the length-weight regression +1.

Several parameters are needed to run the simulation models using FAST. Information regarding the growth rate, longevity, and the length-weight regression was calculated from the data collected during this study (Table 17) (Chapters 2 and 3). For the minimum length limits I used 254, 330, and 381-mm coinciding with the Indiana, intermediate, and Illinois length limits respectively (Table 17). The mortality estimate from the NON treatment (Chapter 3) provided an estimate of conditional natural mortality. This value is well within levels reported for other populations of channel catfish (Hubert 1999; Slipke et al. 2002).

To estimate how yield was affected by harvest, I modeled the populations over varying conditional fishing mortality (F). For the IN & IL treatment reach, the lowest minimum conditional fishing mortality was 15 %, which was the difference in mortality between the NON and IN & IL treatment reaches (Table 17). As a starting point for the

IN treatment 8% fishing mortality was used, which was the difference in mortality between the non-commercially fished (NON) and adjacent commercially fished (IN) treatment reach (Table 17). A value of 60% conditional fishing mortality was used as the maximum mortality for both populations (Table 17).

In the yield-per-recruit models, the inflection point in the conditional fishing mortality against yield plot (F_{max}) was considered the point at which growth overfishing began to occur. The 10% rule ($F_{0.1}$ = fishing mortality that leads to a slope 10% of the slope at F = 0, King 2001) was used to determine the level of mortality that maintained a sustainable fishery (Hilborn and Walters 1992, Haddon 2001, King 2001). The 10% rule is more conservative than F_{max} and has been shown to produce sustainable levels of harvest (Hilborn and Walters 1992, Haddon 2001, King 2001).

The effect of harvest on the reproductive potential of the population was estimated by simulating the spawning potential ratio (SPR). The SPR has been used extensively in marine systems (Goodyear 1993) and has recently been used to determine the point of recruitment overfishing in freshwater systems (Quist et al. 2002, Slipke et al. 2002). The SPR estimates the number of eggs produced in an exploited fishery compared to an unexploited one by estimating the fecundity potential of the recruits using the formula (Goodyear 1993):

$$P = \sum_{i=1}^{n} E_i \prod_{j=0}^{t=1} S_{ij}$$

where n = number of age classes in an unfished population; E_i = the mean fecundity of females of age i; $S_{ij} = e^{-(Fij+Mij)}$, the density-independent annual survival probabilities of females age i; F_{ij} = instantaneous fishing mortality rate of females age i; and Mij = instantaneous natural mortality rate of females age i.

Calculation of SPR requires estimates of age at sexual maturation, length at fecundity, and percentage of females spawning annually. These parameters based on studies from other populations of channel catfish in midwestern rivers. Age at sexual maturation (3 years) of females was taken from Pflieger (1997) (Table 17). The relationship between length and fecundity and the percentage of females spawning annually were derived from Slipke et al. (2002). Because the sex ratio of channel catfish in the Wabash River did not differ from one to one (Chapter 2) the percentage of females in the population was set at 50%. I used a critical SPR level of 20% (i.e., allowing fish to meet 20% of their maximum expected reproductive potential) as the minimum level of SPR that was necessary to avoid recruitment overfishing of channel catfish (Slipke et al. 2002).

Demographic information was limited for flathead catfish; however, I was able to estimate the annual mortality rate (33%), and a length weight regression from the fish sampled during this study (Appendix B; Table 17). Because I did not remove the pectoral spines of the largest flathead catfish, a von Bertalanffy model was developed from 311 flathead collected by INDNR during spring 2005 in which the spines of all fish were removed (Colombo et al. *unpublished data*) (Table 17, appendix B). Conditional natural mortality was set at 0.15 which was similar to an unexploited population of flathead catfish (Kwak et al. 2004) (Table 17). Reproductive information regarding the flathead catfish was not available so, the spawning potential ratio was not calculated.

RESULTS

The Boundary Fishery (IN & IL treatment reach)

Across the levels of conditional fishing mortality that were used in this model, the only length limit that resulted in the channel catfish population approaching growth overfishing (i.e., individuals were harvested before contributing to the population's maximum potential yield) was the 254-mm (Indiana) limit (Figure 43). This level was approached at a conditional fishing mortality of 33% (Figure 43). With a 254-mm length limit the fishery was sustainable ($\leq F_{0.1}$) until fishing mortality reached 25%, compared to fishing mortalities of 35% and 42% for the 330 and 381-mm length limits respectively (Figure 43). The mean length of fish harvested decreased most rapidly over the range of fishing mortalities modeled with the 254-mm limit compared to the 330 and 381-mm limits (Figure 44). Mean length harvested at the 254-mm length limit declined by 17% across the range of fishing mortality (Figure 44). The mean length of fish harvested declined by 11% and 8% in the 330 and 381-mm length limits respectively across the range of conditional fishing mortality (Figure 44). Reducing the minimum length limit reduced the mean size harvested and the total population yield, with the 254-mm limit incurring a much greater effect at moderate increases relative to current fishing mortality.

Both the 254 and 330-mm length limits caused the fishery to decline below the critical SPR value of 0.20 (20%), with increasing conditional fishing mortality (Figure 45). At the 254-mm minimum length limit, the critical limit was reached at 33% conditional fishing mortality (Figure 45). This coincided with the reduction in yield found at the 254-mm minimum size requirement for $F > 0.35$ (Figure 43). At the 330-mm minimum length limit, the critical SPR was reached at a conditional fishing mortality of 48% (Figure 45). However, there was no reduction in yield over the entire range of fishing mortality. When subjected to the 381-mm minimum length limit the population did not decline to the critical SPR of 0.20 (Figure 45).

The Indiana Fishery (IN treatment reach)

I obtained similar results occurred in the IN treatment reach. With a 254-mm minimum length limit, yield was maximized at 33% fishing mortality compared to 52% at the 330-mm minimum length limit (Figure 46). For the IN treatment reach, the fishery remained sustainable over a narrower range of fishing mortalities compared to the IN & IL treatment reach (Figure 43 and 45). With a 254-mm length limit, the fishery was sustainable ($F_{0.1}$) to 21% conditional fishing mortality compared to 27% and 33% for the 330 and 381-mm length limits (Figure 46). As was the case for the IN & IL treatment reach the 381-mm minimum length limit produced the highest maximum yield (Figure 46). With increasing fishing mortality, there was a large decline in the mean length of fish harvested with the 254-mm length limit (Figure 47). Over the entire range of fishing mortalities the 254-mm limit resulted in a 22% reduction in mean total length harvested (Figure 47). With the 330 and 381-mm limits there were reductions of 16% and 12% respectively and higher overall mean lengths harvested (Figure 47).

Results for the SPR for the IN treatment reach were similar to that of the IN & IL treatment reach. Again SPR within the 254-mm limit declined to the critical value at fairly low levels of harvest (32%) (Figure 48). The population subjected to a 330-mm limit reached the critical SPR value of 0.20 at a conditional fishing mortality of 47% (Figure 48). With a 381-mm limit, the critical SPR was not reached over this range of conditional fishing mortalities. The lowest SPR reached with a 381-mm limit was 0.26 (Figure 48). As in the IN&IL treatment reach, the current length limit of 254-mm will likely lead to both growth and recruitment overfishing with modest increases in harvest.

Flathead Catfish

The Beverton-Holt model suggested at the current level of mortality (33%) the flathead catfish population would be overfished if there was a 254-mm minimum length limit (Figure 49). The same was true if both states adopted a 330-mm minimum length limit (Figure 49). Additionally, based on an annual mortality rate of 33% the population of flathead catfish in the Wabash River is approching Fmax for a 381-mm minimum length limit (Figure 49).

DISCUSSION

Based solely on biomass yield, the channel catfish populations of the Wabash River do not appear to be overfished at the current minimum length limits and harvest level. However, the models predicted that increases in harvest under the current 254-mm limit would potentially lead to both overfishing of young fish that have not yet contributed fully to population biomass as well as to overfishing of females that are critical to reproductive success. Several outcomes are possible under the modeling scenarios presented herein. If both agencies adopted a 254-mm minimum length limit, I predict that a modest increase in commercial harvest would occur, although the maximum yield would be unattainable due to growth and perhaps recruitment overfishing. If both Indiana and Illinois adopted a 330-mm minimum length limit, the models predicted that fishery would yield a higher maximum biomass with increased harvest. At the current fishing intensity, the third management scenario where both Indiana and Illinois adopt a 381-mm minimum length may lead to a reduction in the overall biomass harvested. However, a much higher fishing intensity could be supported which would produce a larger maximum biomass yield.

I would not recommend that both state agencies adopt a 254-mm minimum length limit. With the 254-mm minimum limit, the population would likely become overfished with a modest increase in harvest. Such an increase in harvest would likely occur if Illinois adopted a 254-mm minimum limit. Judging by the sentiment of the Illinois commercial fishers the current demand for fiddler catfish in Illinois would cause an increase in the harvest of catfish in the Wabash River. Selective harvest of intermediate-sized individuals in the IN&IL treatment reach may lead to a channel catfish population with high PSD values similar to what is occurring in the IN treatment reach currently. Although the PSD would increase due to the fish recruiting out of the gear, the tradeoff would be reduced catch rates and perhaps greater susceptibility to collapse. This is currently not a concern in the IN treatment reach because of the apparently low commercial harvest rate.

At the intermediate combined minimum length limit of 330-mm, both mean length and sustainable harvest increased appreciably. This option represents a balance between commercial and sport fishing, still allowing for take of some desirable small-sized individuals by commercial fishers. Due to a reduction in the impact on small, young fish with a high, unachieved reproductive potential, the population abundance should increase, leading to higher angler catch rates in the river.

The final scenario would be a change of Indiana's regulation to that of 381-mm. The models predicted that this type of limit would allow for the greatest amount yield by commercial fishing. With a 381-mm limit the catfish populations in the Wabash River could withstand a 45% increase in the conditional fishing mortality and still not be overfished. Mean length of the fish harvested would theoretically increase, perhaps leading to improved recreational fishing satisfaction. However, the harvest of desirable fiddler sized catfish would be curtailed. It is also important to note that increased competition for large individuals between commercial and recreational interests might occur. Hence, the availability of the largest catfish for anglers may decline because they would be increasingly removed by the commercial harvest.

Channel catfish populations in the Wabash River are responsive to fishing. Harvest appears to be sustainable under the present scenario. However, increases in the current level of harvest, particularly of small individuals near the 254-mm Indiana limit, may lead to a rapid decline in reproductive potential of the population. Further, catch per unit effort will most likely decline with increased harvest rates because the maximum yield of the population under the current minimum length limit is quite low compared to larger length limits. Hence, harvest needs to be closely monitored to prevent overfishing from occurring. Further, many of these recommendations are founded in assumptions about the reproductive capacity of the population. A refined understanding of reproductive potential of the catfish in Wabash River and their subsequent recruitment success is needed to determine how resilient the current stocks are to changes in harvest.

Commercial fishers are harvesting flathead catfish at a disproportionate rate compared to their availability, based on my fall sampling. Yield-per-recruit modeling for flathead catfish suggests that the population in the Wabash River is currently being overfished. Using similar length limits as those for channel catfish did not provide for a sustainable flathead fishery, due to the life history of the flathead catfish having slow growth, long life spans, and low rates of natural mortality (Kwak et al. 2004, Makinster 2006). More research into the population dynamics of the flathead catfish in the Wabash River needs to be accomplished so that an estimate of the sexual demographics can be made to determine if the population is undergoing recruitment overfishing. The results for flathead catfish make apparent the need for a better understanding of the blue catfish demographics, as blue catfish are also disproportionately harvested compared to my standardized sampling. Furthermore, if the harvest of flathead catfish is not sustainable under any of the proposed minimum length limits, different species of catfish may need differing management regulations. As the life history of the threes species of catfish differ markedly differing management regulations may be advisable.

Table 17. Life history parameters used to model the channel and flathead catfish populations from the two treatment reaches of the Wabash River. Where L_∞ = maximum length from the von Bertalanffy model (mm); K = Brody's growth coefficient from von Bertalanffy model; t_0 = length at time equal to zero; b = slope of the length weight regression; a = y-intercept of the length weight regression; *m* =slope of the fecundity length relationship; *b* = y-intercept of the fecundity length relationship.

	Channel		Flathead
Parameter	IN & IL	IN	Rkm 0-500
Von Bertalanffy Growth Parameters			
L_∞	569 mm	663 mm	1127
K	0.24	0.17	0.142
t_0	0.17	-0.26	0.37
Conditional natural mortality	0.25	0.25	0.20
Conditional fishing mortality	0.15 – 0.60	0.08 – 0.60	0 - 0.60
Log (weight) : Log(length) coefficients	a = -5.5; b = 3.1	a = -5.9, b = 3.3	a = -5.2, b = 3.1
Age at sexual maturity	3[a]	3[a]	na
Fecundity : length relationship	*m* = 2.8; b = -3.2[b]	*m* = 2.8; b = -3.2[b]	na
Percent of females spawning			na
3 to 4 year olds	30%[b]	30%[b]	na
5 to 15 year olds	75%[b]	75%[b]	na
Sex Ratio	1:1	1:1	na
Maximum age	15.5	15.5	18
Minimum length limits (mm)	254, 330, 381	254, 330, 381	254, 330, 381

[a] - from Pflieger (1997)
[b] - from Slipke et al. (2002)
n/a – no available information

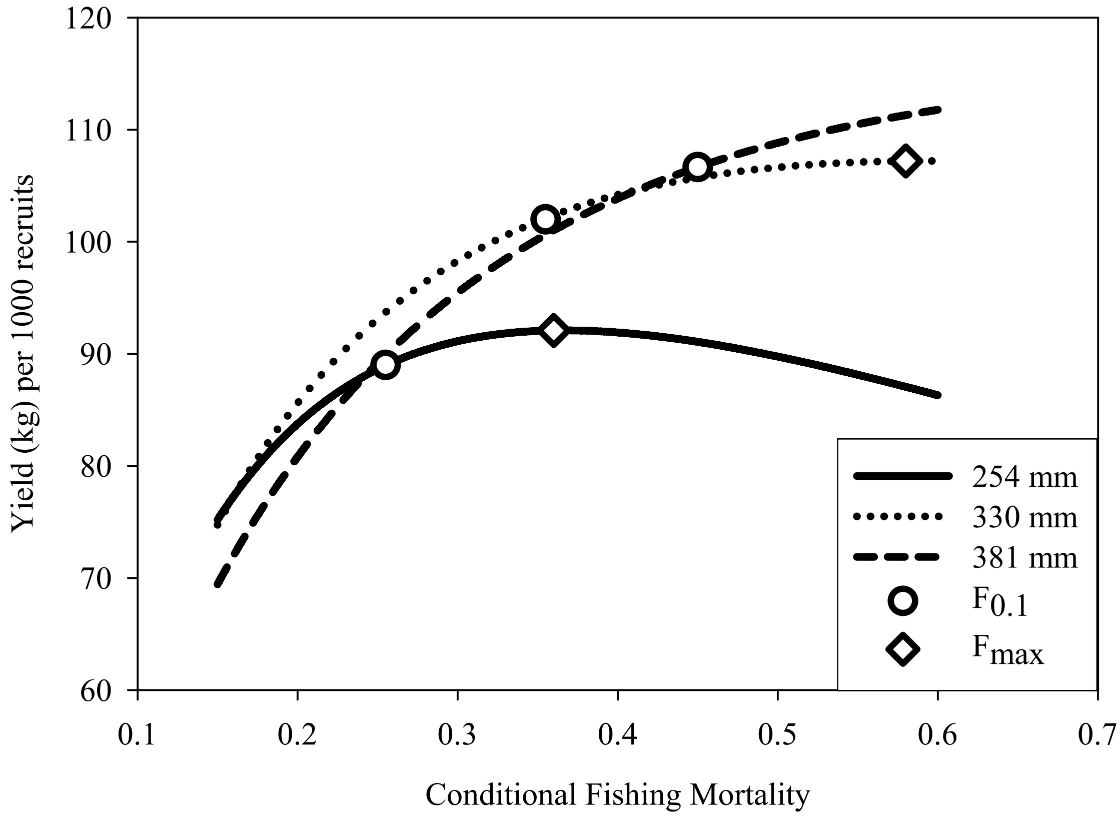

Figure 43. Predicted yield per 1000 channel catfish recruits versus conditional fishing mortality for three different length limits of the IN & IL treatment reach of the Wabash River. Open circles = $F_{0.1}$, open diamonds = Fmax.

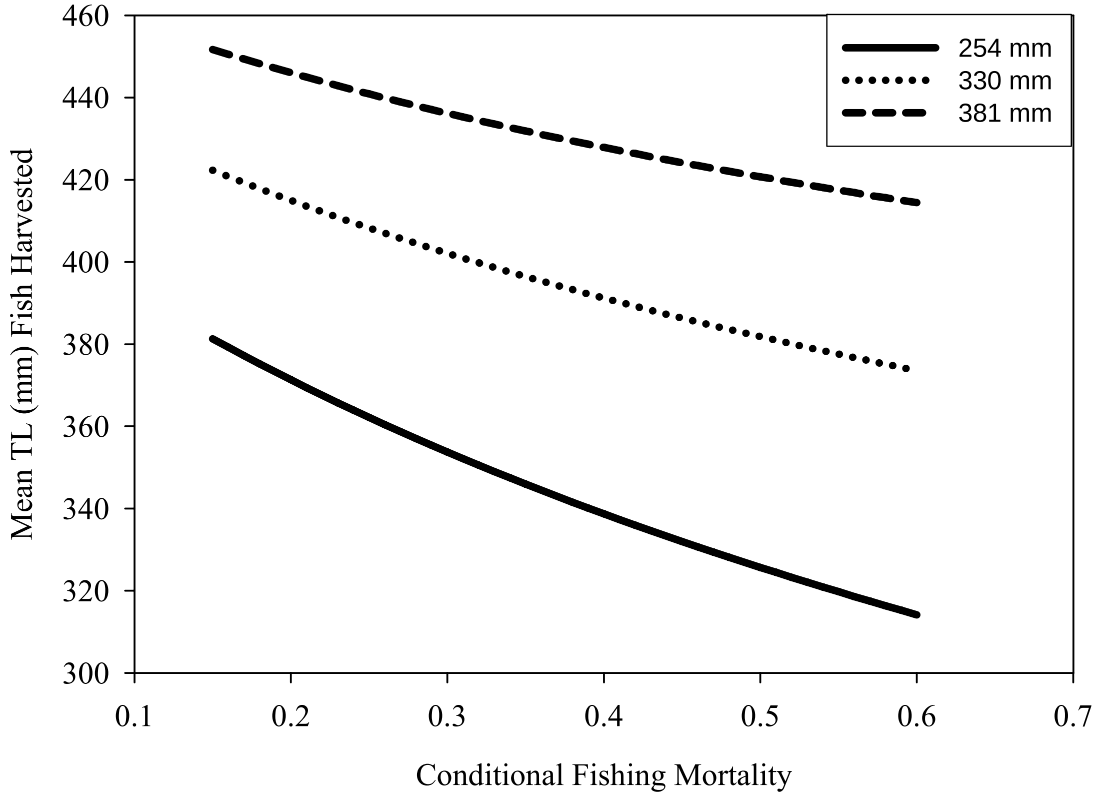

Figure 44. Predicted changes in mean length of channel catfish harvested with increasing conditional fishing mortality at three different length limits for the IN & IL treatment reach of the Wabash River.

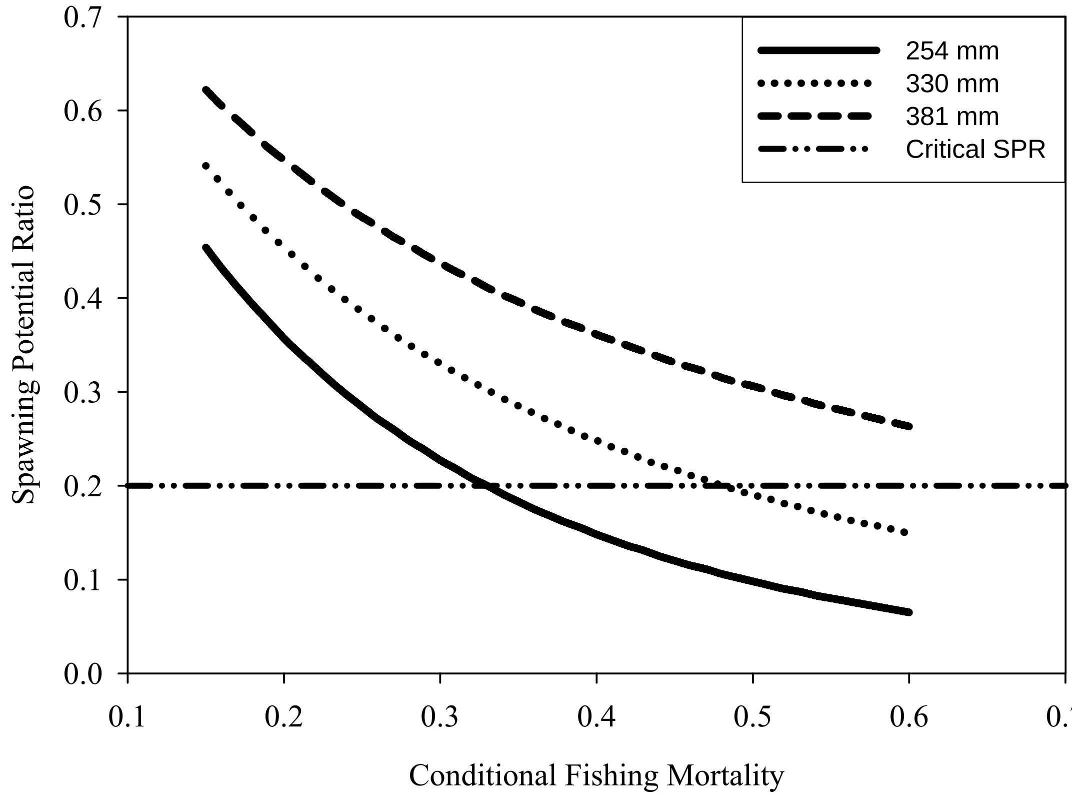

Figure 45. Predicted spawning potential ratio versus conditional fishing mortality of channel catfish at three different length limits for the IN & IL treatment reach of the Wabash River. Horizontal line represents the critical SPR level.

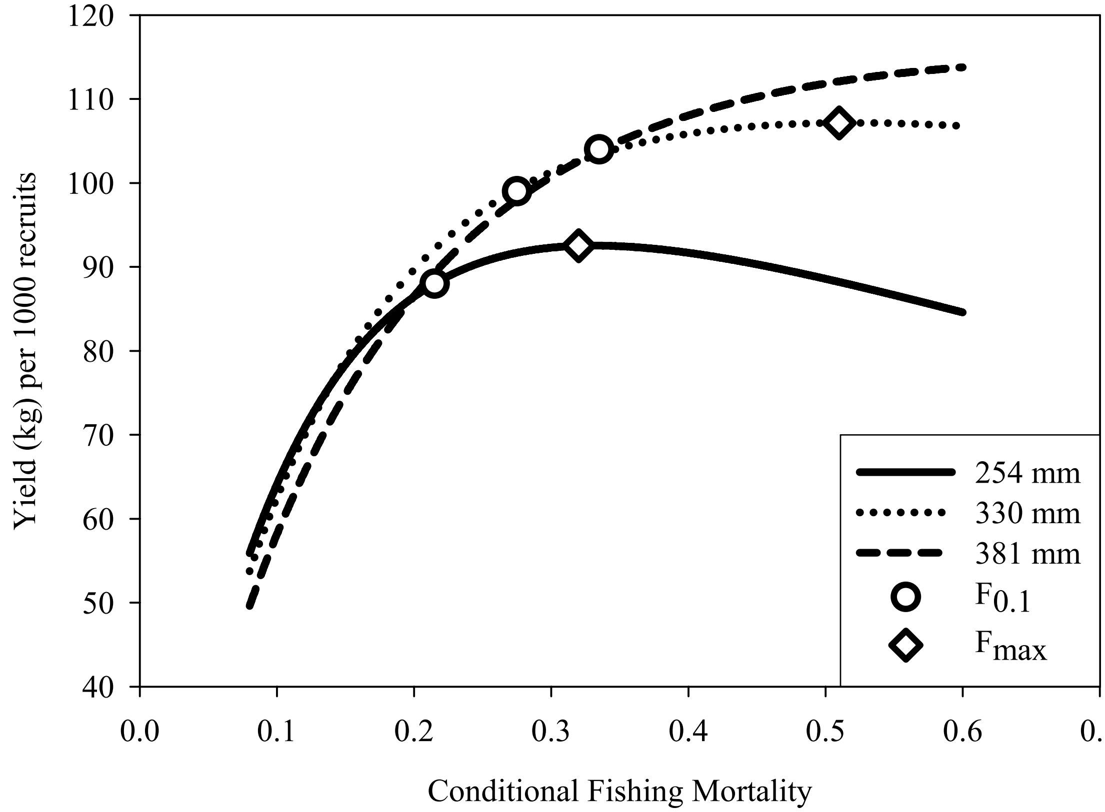

Figure 46. Predicted yield per 1000 channel catfish recruits versus conditional fishing mortality for three different length limits for IN treatment reach of the Wabash River. Open circles = $F_{0.1}$, open diamonds = Fmax.

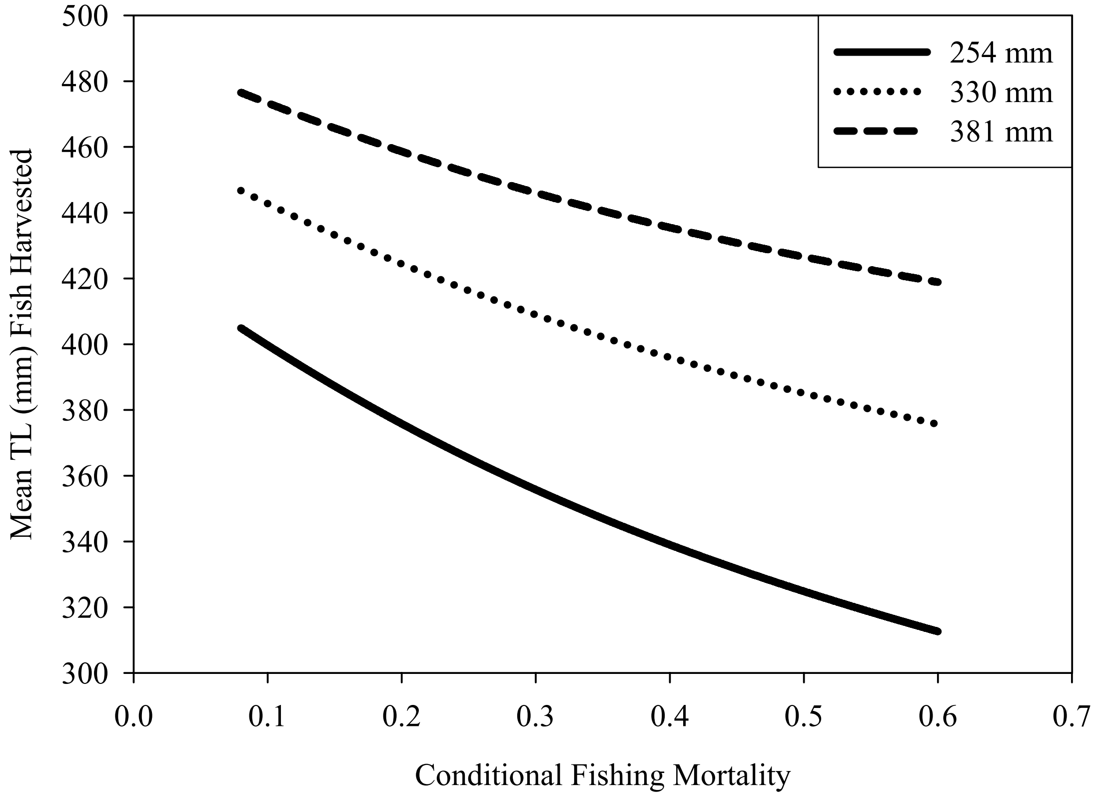

Figure 47. Predicted changes in mean length of channel catfish harvested with increasing conditional fishing mortality at three different length limits for the IN treatment reach of the Wabash River.

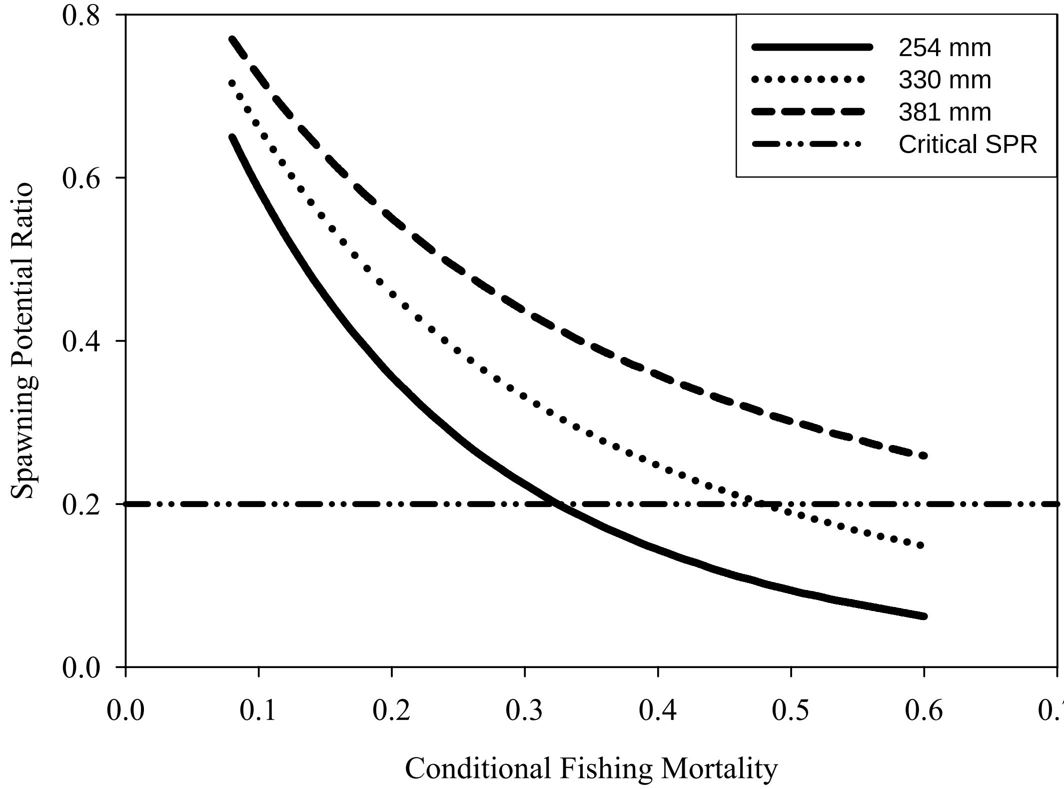

Figure 48. Predicted spawning potential ratio versus conditional fishing mortality of channel catfish at three different length limits for the IN treatment reach of the Wabash River.

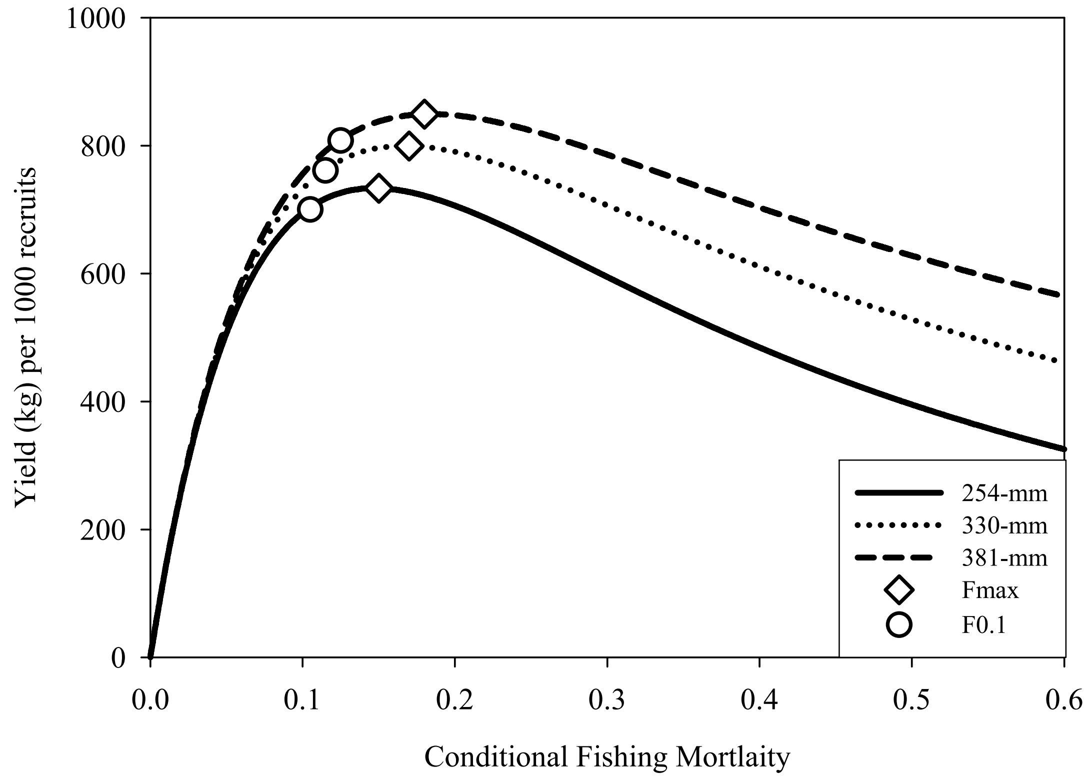

Figure 49. Predicted yield per 1000 flathead catfish recruits versus conditional fishing mortality for three different length limits for all treatment reaches of the Wabash River. Open circles = $F_{0.1}$, open diamonds = Fmax.

CHAPTER SEVEN

CATFISH FROM A FOOD WEB STANDPOINT

INTRODUCTION

Channel catfish are among the most numerically abundant and productive in terms of fish biomass in the Wabash River ecosystem (Gammon 1998). Channel catfish are habitat generalists (Layher and Maughen 1985) making them prolific in all areas of the Wabash and because they are omnivorous they are important in transferring energy throughout the food web. Because of their widespread distribution and broad diet breadth catfish may occupy different levels of the food web based on the surrounding ecosystem. For instance, in relatively simple systems catfish may take on a predatory role as compared to more complex systems in which they may feed at a lower trophic level, with most of their energy being derived from macroinvertebrates.

Stable isotopes of nitrogen have been effective at determining the trophic status of a species. The trophic status of species can be compared due to enrichment of $\delta^{15}N$, which increases by an average 3 to 4 $^{0}/_{00}$ from prey to consumer (Cabana and Rasmussen 1994, Vander Zanden et al. 1997, Vander Zanden and Rasmussen 1999). Enrichment of $\delta^{15}N$ allows the trophic position of a species to be characterized using a method which integrates diet over time (Vander Zanden and Rasmussen 1999). Although stable isotopes of nitrogen allow for comparing trophic positions of two groups, they provide little information regarding autotrophic source of energy.

Stable isotopes of carbon have been used to track the different sources of autotrophic production contributing to a food web (Darnaude et al. 2004, Vander Zanden and Rassmussen 1999), with the major assumption to this being different sources of carbon have distinct isotopic signatures (Thorp et al. 1998, Vander Zanden and Rassmussen 2001, Darnaude et al. 2003). If this assumption is met, sources of autotrophic production can be tracked through an aquatic ecosystem. Tracking autotrophic sources is particularly important from the standpoint of riverine systems. Because freshwater riverine systems are among the most imperiled ecosystems on the planet (Vitousek et al. 1997, Fitzsimmons and Robertson 2005), it becomes apparent that determining the source of energy to the system can have profound impacts on the conservation of riverine systems.

The three most common riverine ecosystem models vary in the source of the carbon hypotheses can be made to determine the function of riverine systems. The flood pulse concept suggests that the source of primary energy to a riverine system comes from the floodplain (Junk et al. 1989) in this case the carbon signature would have a terrestrial riparian signature. The source of carbon in the riverine productivity model is local instream production (Thorp and Delong 1994) and therefore has an aquatic signature. Finally, the river continuum concept suggests that the inefficiencies upstream provide energy (Vannote et al. 1980). In a river operating along the predictions of the river continuum concept the carbon source will be a mixture of both terrestrial and instream sources.

I sought to determine whether the trophic position channel catfish changes along the river gradient. Further, I sought to determine whether any of the three riverine ecosystem models could explain the source of energy in the Wabash River. I attempted to answer these questions by analyzing the stable isotopes of carbon and nitrogen in various food web constituents.

METHODS

Sample Collection

During fall 2004, all samples (organic matter and fish species) were collected from three sites along the Wabash River for stable isotope analysis. Samples were frozen in the field and taken back to the Southern Illinois University Fisheries and Illinois Aquaculture Center for processing. Once processed the samples were sent to the University of Alaska at Fairbanks for the analysis of $\delta^{15}N$ and $\delta^{13}C$.

Terrestrial Organic Matter

I collected organic matter from the most numerically abundant terrestrial autotrophs. Leaves both abscised and attached were collected from trees and grasses in the adjacent riparian zone. Leaves were dried at 110°C for at least 36 hours and then ground to a powder using a Dremel® high speed rotary tool. Powdered samples were weighed to 0.01 – 0.04 mg and sealed in aluminum canisters.

Instream Organic Matter

Instream benthic coarse particulate organic matter was collected by dip net from areas of deposition (i.e., pools, woody debris). Instream organic matter samples were dried at 110°C for at least 36 hours. Dried organic matter was ground to a powder using a dremel® high speed rotary tool. Powdered samples were weighed to 0.01 – 0.04 mg and sealed in aluminum canisters.

Fish Species

I collected muscle tissue from seven abundant species of fishes using electrofishing. These were: channel, flathead and blue catfish, gizzard shad (*Dorosoma cepedianum*), freshwater drum (*Aplodinotus grunniens*), river carpsucker (*Carpiodes carpio*) and shortnose gar (*Lepisosteus platostomus*). Whole fish were frozen in the field and taken to the laboratory at the Fisheries and Illinois Aquaculture Center. A sample of the dorsal musculature was removed from each individual and dried at 80°C for at least 72 hours. Dried muscle tissue was ground to a powder and weighed to 0.01 – 0.04 mg.

Statistical Analysis

One-way ANOVA was used to determine whether catfish differed in either $\delta^{15}N$ or $\delta^{13}C$ along the river gradient. Regression was used to determine whether channel catfish length was related to either $\delta^{15}N$ or $\delta^{13}C$. One-way ANOVA was used to determine whether species / organic matter differed in either $\delta^{15}N$ or $\delta^{13}C$. Finally, ANOVA was used to assess differences in stable isotope concentration among river reaches.

RESULTS

A total of 49 channel catfish was analyzed for $\delta^{13}C$ and $\delta^{15}N$ from the three treatment reaches of the Wabash River (NON: N = 20, IN: N = 7, IN & IL: N = 22). These fish ranged in length from 188 to 535 mm total length with a mean of 369 mm. There was no difference in either $\delta^{13}C$ ($F_{2,46} = 1.44$, $P > 0.05$) or $\delta^{15}N$ ($F_{2,46} = 5.65$, $P > 0.05$) among treatment reaches (Figure 50). There was no detectable relationship between catfish length and either $\delta^{13}C$ ($r^2 = 0.19$, $P > 0.05$) (Figure 51) or $\delta^{15}N$ ($r^2 = 0.16$, $P > 0.05$) (Figure 52).

There were no apparent differences in stable isotopes among river reaches ($P > 0.05$) with any species or organic matter, so these results were combined. Overall there was a significant effect of species/autotroph group (abscised, live terrestrial, aquatic organic matter) on $\delta^{15}N$ ($F_{6, 132} = 10.25$, $P < 0.001$; Figure 53). All three autotroph groups differed from the consumers and aquatic organic matter differed from live terrestrial organic matter in $\delta^{15}N$. For consumers, the multiple comparisons test suggested that both gar and flathead catfish differed from gizzard shad in nitrogen. All other multiple comparisons among consumers were non significant. There was also a significant effect of consumer species on $\delta^{13}C$ ($F_{6, 132} = 9.74$, $P < 0.05$); however, all pairwise comparisons were non significant.

Although significant relationships were scarce there were some interesting trends in these data. When plotted, groups clustered over both $\delta^{15}N$ and $\delta^{13}C$ (Figure 53). The signatures for $\delta^{15}N$ show three consumer levels. The gizzard shad had the lowest $\delta^{15}N$ of consumers, with carpsuckers, blue and channel catfish, and freshwater drum showing an intermediate $\delta^{15}N$ (Figure 53). Gar and flathead catfish seemed to cluster over $\delta^{15}N$, both acting as piscivores (Figure 53). For consumers, there seems to be three clusters when looking at $\delta^{13}C$ (Figure 53). Shortnose gar and shad seem to show a terrestrial signature in $\delta^{13}C$, blue catfish and river carpsucker show a similar $\delta^{13}C$ to the aquatic organic matter, and channel catfish flathead catfish and freshwater drum show a $\delta^{13}C$ signature that seems to be displaced from a terrestrial organic matter signature towards values for $\delta^{13}C$ that are indicative of instream primary producers (Thorp et al.1998) (Figure 53).

DISCUSSION

The results of this study suggest channel catfish occupy the same level in the food web in all areas along the Wabash River. There was no apparent difference in the stable isotope signature based on catfish size suggesting that although the catfish may become more piscivorous as they grow (Hubert 1999), they remain generalists through life. This study provides some preliminary evidence that organisms within a large unimpounded river might derive their baseline energy from several autotrophic sources. Gizzard shad and shortnose gar showed a terrestrial signature in their carbon isotopic signatures suggesting that the riparian influx is an important source of organic matter to the stream. This type of signature would be prevalent in streams operating under the flood pulse concept. River carpsuckers and blue catfish showed a carbon signature that resembled the aquatic organic matter shifted towards the terrestrial. This would be similar to a system operating under the river continuum concept in that terrestrial matter that falls into the system is altered in the stream by low level consumers and made available to higher consumers. Finally, channel and flathead catfish coupled with freshwater drum seem to have a signature in carbon that is shifted from the terrestrial signature towards the aquatic producer signature. This type of signature would be indicative of a stream operating under the riverine productivity model. This chapter presents preliminary results only that require further attention by a study that would sample a greater proportion of the food web (i.e. macroinvertebrates, instream primary productivity, other fish species) and integrate a temporal contingent as these results may be season specific (Yoshioka et al. 1994, Perga and Gerdeaux 2005).

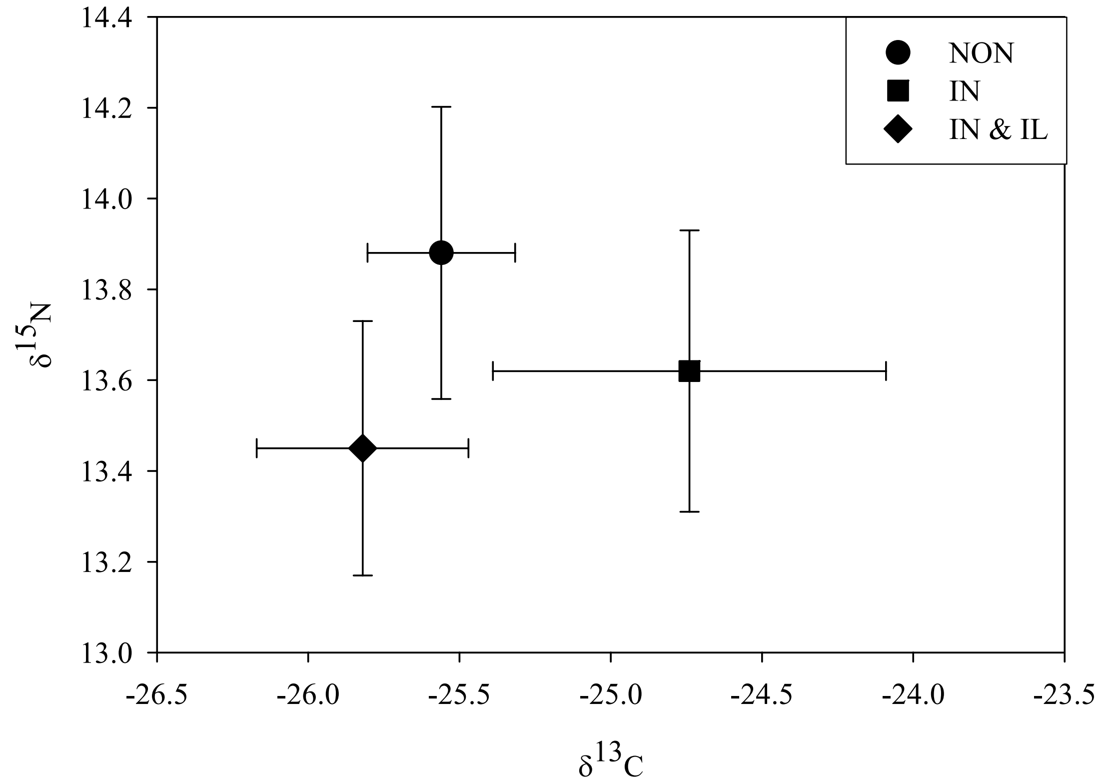

Figure 50. Mean (± 1 S.E.) $\delta^{13}C$ and $\delta^{15}N$ values for channel catfish sampled from the three different treatment reaches of the Wabash River with electrofishing during fall 2004. Mean values for did not differ among treatment reaches for either $\delta^{13}C$ or $\delta^{15}N$ ($P > 0.05$).

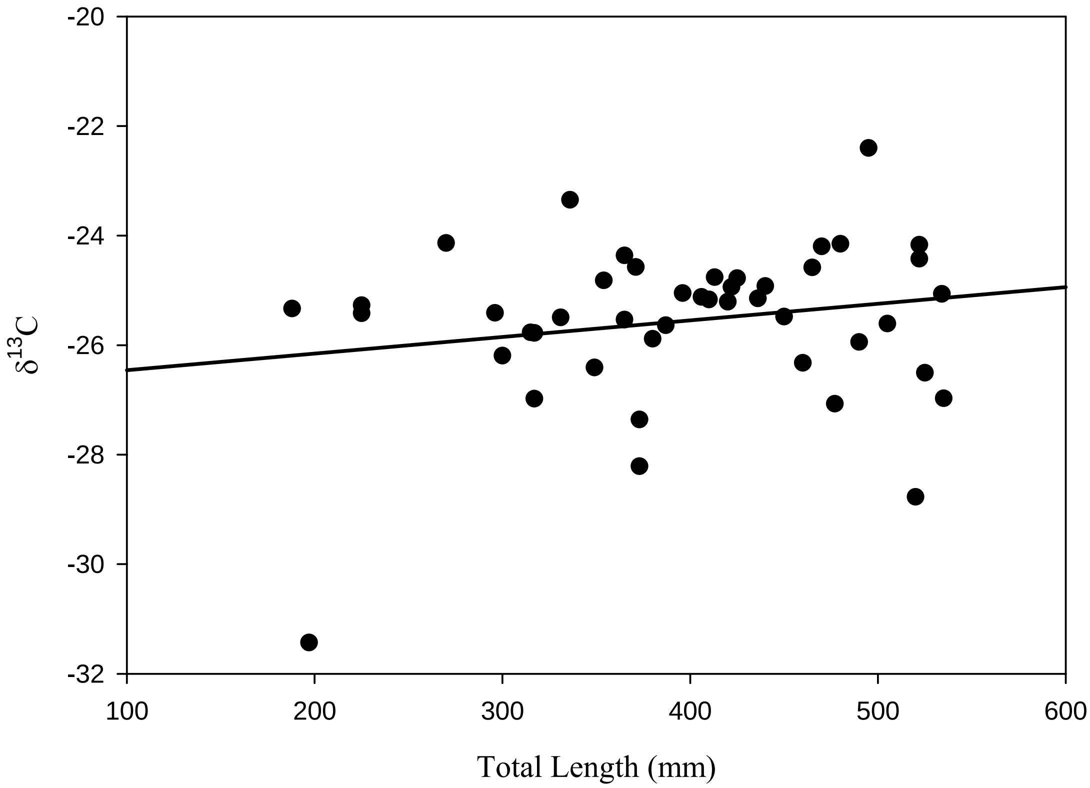

Figure 51. Channel catfish $\delta^{13}C$ by length for fish sampled from all treatment reaches of the Wabash River during fall 2004.

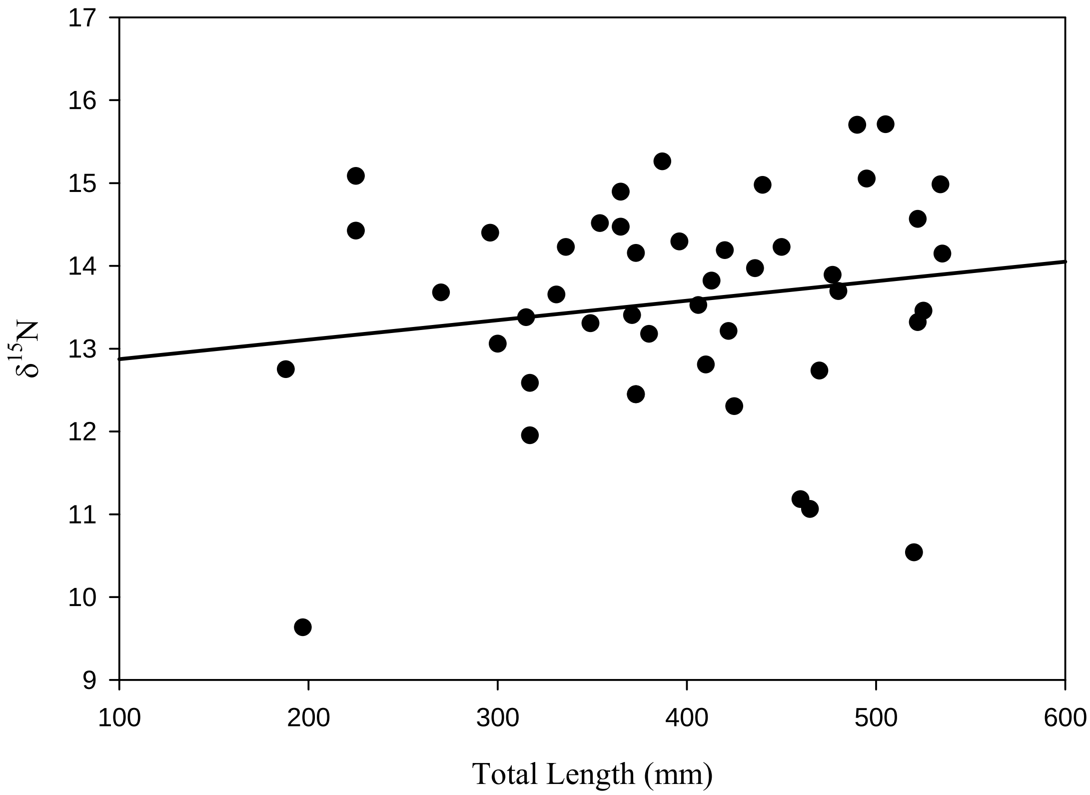

Figure 52. Channel catfish $\delta^{15}N$ by length for fish sampled from all treatment reaches of the Wabash River during fall 2004.

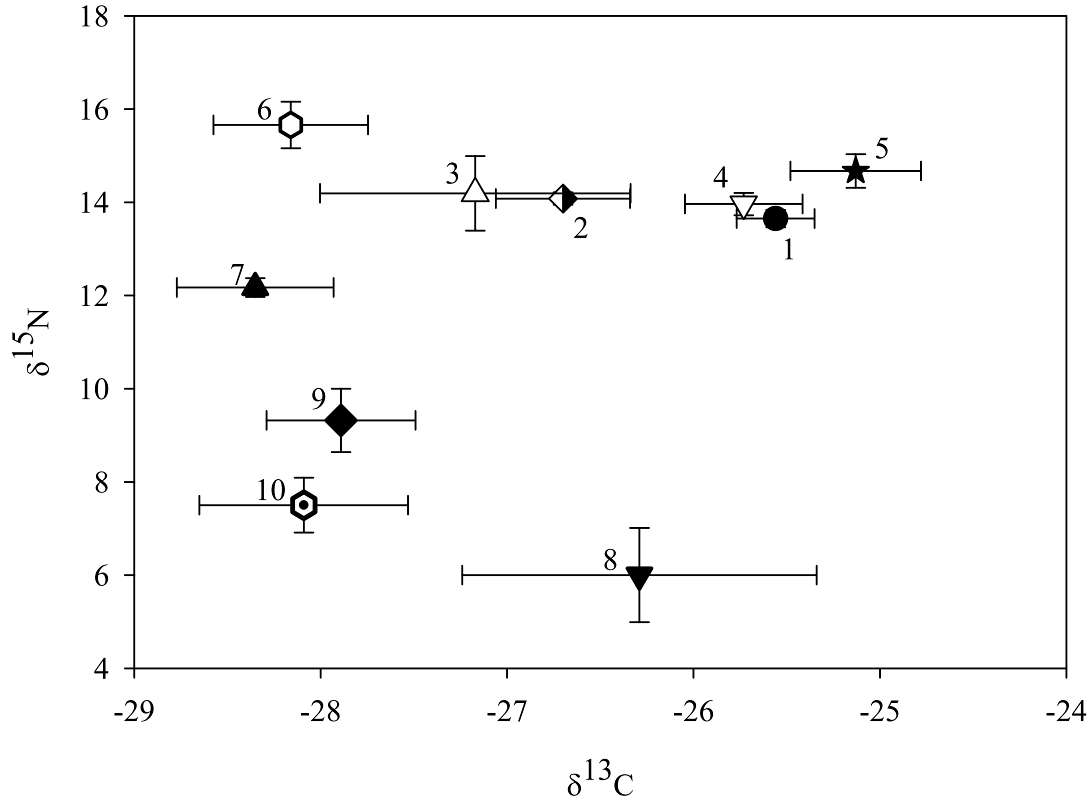

Figure 53. Mean (± 1 S.E.) $\delta^{13}C$ and $\delta^{15}N$ values for different fish consumers: 1. channel catfish, 2. blue catfish, 3. river carpsucker, 4. freshwater drum, 5. flathead catfish, 6. shortnose gar, 7. gizzard shad; and autotrophic sources: 8. instream organic matter, 9. live terrestrial organic matter, 10. abscised terrestrial sampled during fall 2004 from all treatment reaches of the Wabash River.

CHAPTER EIGHT

GENERAL CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Populations of channel catfish provide important recreational and commercial fisheries throughout the United States. Catfish are considered moderately or highly important to anglers in 32 states and are managed in 34 states (Michaletz and Dillard 1999), leading to high stocking rates of channel catfish by both federal and state agencies (Heidinger 1999). Although harvest of these fisheries has declined since the early 1980s (Heidinger 2000, FAO 2003), commercial catfish fisheries remain in 28 states (Michaletz and Dillard 1999). In the Midwestern US, commercial catfish fisheries are particularly important. For example in Illinois, catfish account for 25% of the fish biomass harvested annually from rivers by commercial fishers (Maher 2002). Commercial exploitation of catfish populations in the Mississippi River has led to recruitment overfishing (Pitlo 1997, Slipke et al. 2002). It is therefore essential to monitor catfish populations in systems where commercial exploitation occurs.

Catfish are a major component of the Wabash River fish assemblage and are commercially fished below river kilometer (Rkm) 500. From Rkm 322 through 499, the commercial fishery is subjected only to Indiana regulations, which stipulate a 254-mm minimum length limit on both sport and commercially harvested catfish. Below RM 322, the Wabash forms the state boundary of Indiana and Illinois and there are two different length limits on commercially harvested catfish. Indiana maintains its 254-mm total length limit, while Illinois commercial fishers are subjected to a 381-mm minimum size limit; however, there is no length limit on sport harvest of catfish by Illinois anglers. The primary objective of this study was to assess the general population dynamics of the channel catfish, and determine how their demographics differ under various sport and commercial fishing regulations.

Gear Selectivity

Numerous studies have documented that an individual gear type may bias simple populations metrics such as age structure (Essington et al. 2002), growth (Lucena and O'Brien 2000), size structure (Sullivan and Gale 1999, Robinson 1999), and mortality (Beamesderfer and Rieman 1988). Hoop nets are commonly used to sample catfish populations in lentic and lotic environments (Gerhart and Hubert 1989; Pugibet and Jackson 1989; Holland and Peters 1992; Stopha 1994; Robinson 1999; Vokoun and Rabeni 1999; and Sullivan and Gale 1999; Jackson 2004). However, these gears vary in size selectivity and catch rates. Different mesh sizes produce differing length-frequency distributions (Holland and Peters 1992), which may result in incorrect estimates of population metrics. Alternating current (AC) and direct current (DC) electrofishing also have been used to sample catfish (Jacobs and Swink 1982; Santucci et al. 1999; Vokoun and Rabeni 1999). These gears have been shown to produce conflicting measures of efficiency (Heidinger et al. 1983) and size selectivity (Reynolds 1996, Santucci et al. 1999). Therefore, a multi-gear approach may be beneficial when determining size and age structure of the population.

Both three-phase AC electrofishing and baited hoop nets (both 25- and 32-mm bar mesh) were used to sample fish during each fall of each year. Each gear type had size-specific bias. Within each treatment reach, three-phase AC electrofishing sampled larger fish compared to either of the two meshes of hoop nets. One-inch mesh hoop nets sampled the smallest catfish among the gear types. Similarly, other studies have shown that hoop net mesh size may influence length-frequency distributions with smaller mesh nets sampling smaller catfish (Holland and Peters 1992; Vokoun and Rabeni 1999). Alternating-current electrofishing sampled the largest channel catfish most efficiently, but may have underestimated relative abundance of channel catfish smaller than 300 mm. These results differ markedly from previous research which suggested small channel catfish were more susceptible to electrofishing than large catfish (Santucci et al. 1999).

In summary hoop nets sampled more small, young catfish, but few large or old individuals leading to reduced PSD values, a strongly skewed age structure, increased mortality rates, and reduced growth compared with electrofishing. The 32-mm bar mesh hoop nets sampled larger catfish than did the 25-mm mesh hoop nets; however, the catch rate of all sizes of catfish was low. Electrofishing sampled many large channel catfish, but failed to sample young, small catfish. Electrofishing may have best estimated adult mortality (age > 5 years), because the gear collected the largest number of adult age classes. Therefore, to develop sound sampling designs for river catfish, the apparent size- and age-related biases associated with each gear must be considered.

Because all three gear types portrayed different population characteristic estimates of channel catfish, an individual gear may result in incorrect management decisions. However, these issues could be resolved with multiple years of data and knowing the limitations of the gears. Care must be given to use multiple gear types that will provide the best estimates of size and age structure. For example, I suggest using 25-mm hoop nets for indexing relative abundance and mortality of young catfish, and AC electrofishing to determine growth, mortality, and an index of adult density. This multiple gear approach differs from previous research on channel catfish which suggested using hoop nets to assess population demographics (Vokoun and Rabeni 1999). Using multiple gears will allow managers to make informed management decisions and gather accurate and precise measures of population metrics. However, I caution that the use of AC electrofishing may provide different results than DC electrofishing, and using different complements of hoop-net mesh sizes may alter results. With the contradictory estimated population metrics among gears, I recommend future researchers "ground truth" accuracy of each gear by comparing with rotenone samples or some other technique that provides an unbiased estimate of population structure.

Density, size structure and condition

Commercial exploitation typically leads to a reduction in population density (Schram et al. 1985, Law 2000). If this change in density is large, the population can become overfished. In catfish populations, harvest can cause recruitment overfishing (Pitlo 1997). Increasing the minimum length limit in these populations caused an increase in the spawning potential ratio (Slipke et al. 2002) increasing the recruitment level and allowed the population to recover (Pitlo 1997). Understanding the impact that exploitation is having on the population density is paramount when making management decisions.

To determine the impact of commercial exploitation on the density of catfish populations in the Wabash River, I compared size structure and condition among river treatment reaches (Chapter 2). The density of the largest channel catfish was lower in the commercially fished treatment reaches compared to the unfished treatment reach.

However, no difference in the density of the small, young channel catfish occurred among the river treatment reaches. Length frequency distributions differed among treatment reaches, with the unfished treatment reach having the highest mean length. These differences were reflected in the stock indices. The PSD and RSD-P indices were higher in the non-commercially fished treatment reach (NON) than either the IN & IL and the IN treatment reaches which were both commercially fished. Potentially, more abundant large fish in the NON treatment reach reduced individual growth due to intraspecific competition. Similarly, condition of channel catfish was lower in the NON treatment reach where the density of large individuals was high. Commercial exploitation in the Wabash River altered the density and size structure which may have lead to an increase in the condition of individuals in exploited treatment reaches due to competitive release.

Because harvest is often size selective, changes in these populations can be expected. In fisheries that target the largest individuals, directional selection favors the survival of small, slow-growing individuals (Walsh et al. 2006). Selecting for the largest individuals can cause a reduction in the ability of a population to rebound after overharvest (Walsh et al. 2006). A reduction in population density may also lead to a decrease in the intraspecific competition leading to increased condition and growth (Walters and Post 1993, Law 2000, Grift et al. 2003). This becomes apparent when a fishery is opened to harvest (Schramm et al. 1985) or when a reserve is used as a management tool (Fabrizio et al. 2001, Bene and Tewfick 2003, Gardmark et al. 2006).

I examined the age structure, growth and mortality of channel catfish in the Wabash River to determine the impact of commercial exploitation on these processes

(Chapter 3). The articulating process of the spine agreed well with the otolith and depicted similar growing pattern in the channel catfish. Because removing the articulating process is a non lethal technique, it provides an adequate alternative to otoliths. The proportion of old channel catfish in the commercially exploited treatment reaches was low compared to the NON treatment reach. Samples of channel catfish obtained by both electrofishing and hoop netting revealed higher mortality rates in the commercially fished treatment reaches. Judging by the higher mortality in the IN & IL treatment reach than in the IN reach, harvest is likely greatest in this treatment reach shared by Indiana and Illinois. Compared to the Upper Mississippi River population of channel catfish, the mortality in all treatment reaches of the Wabash River was fairly low. The population of channel catfish in all reaches of the Wabash River showed fast somatic growth compared to other midwestern catfish populations (Table 18). Interestingly the catfish somatic growth differed among reaches in the Wabash River. Catfish from the un-exploited treatment reach grew slower but reached a larger body size than in the exploited treatment reaches. Increased mortality and reduced density in the commercial fishing treatment reaches apparently enhanced individual growth rates in these reaches. Reduced intraspecific competition, a compensatory population response, likely was responsible for the increased growth rate.

Habitat quality

Freshwater ecosystems are among the most imperiled on the planet (Vitousek et al. 1997, Fitzsimmons and Richardson 2005). Therefore, it is important to monitor water and habitat quality. Although adult channel catfish can be described as habitat generalists

(Layher and Maughen 1985) they display ontogenetic shifts in requirements (Macdonald 1990), making it important for a system to contain all critical habitats to maintain population sustainability. I quantified the water and habitat quality of the Wabash River (Chapter 4). All water quality parameters (temperature, dissolved oxygen, conductivity, ph, and secchi depth) were within the tolerance limits for the three species of catfish inhabiting the Wabash (McMahon et al. 1982).

I quantified the habitat quality using the Qualitative Habitat Evaluation Index (QHEI). Habitat quality estimated using the QHEI varied among treatment reaches. The highest QHEI scores for habitat occurred in the most upstream treatment reach (NON), followed by the boundary fishery (IN & IL). Abundance of large individuals estimated from electrofishing correlated positively with habitat quality. The QHEI has also been shown to be positively correlated with the index of biotic integrity scores for other midwestern ecosystems (Rankin 1989). Because no commercially fished treatment reach with equivalent habitat quality to the NON treatment reach was sampled it is difficult to tease apart the impact of habitat quality and fishing on the density among treatment reaches. Furthermore, the QHEI was not developed to assess the habitat requirements for channel catfish. Rather, it was developed as an index of the habitat quality of wadable streams (Rankin 1989). Based on habitat suitability models developed specifically for channel catfish, the Wabash River seems to have ample suitable catfish habitat in all river reaches (McMahon et al. 1982).

For many harvested fish populations recruitment can become limiting, it is therefore essential to understand those abiotic characteristics that may be correlated with recruitment strength. As evident by the age frequency distributions there were no missing age classes; however, year classes were underrepresented in 1993 and 2000. These two weak year classes both took place in high summer discharge years. Several strong year classes were also apparent. The 1999 and 2001 year classes were over represented in the sample which took place in low summer discharge years. Preliminary evidence suggests that year class strength of channel catfish is related to summer discharge. If this relationship can be elucidated further managers may be better equipped to change regulations during a string of poor recruitment years.

Commercial exploitation

The spring commercial harvest was assessed by INDNR's personnel during three of the four years of the study (Chapter 5). Overall, Illinois commercial fishers harvested larger channel catfish than did their Indiana counterparts. Differing length limits on the Wabash River (IN&IL treatment reach: combined 254-381 mm minimum between states; IN treatment reach: 254-mm minimum only) were responsible. Mean length of channel catfish harvested by the Illinois commercial fishers occurred at 543 mm, which coincided well with the sharp decline in the frequency of catfish of greater than or equal to this length in the shared IN & IL treatment reach. The mean length of channel catfish harvested by Indiana commercial fishers (394 mm) was lower than the Illinois commercial fishers; however only 10% of the harvest data was from the Indiana commercial fishers. Although IN harvest data were limited, selective harvest for intermediate sized channel catfish in the IN treatment reach likely allowed a greater proportion of individuals to survive to larger sizes and older age classes. There is currently no information regarding harvest from recreational anglers.

Yield modeling

The Beverton-Holt yield-per-recruit model has been used extensively to understand how different management strategies affect size-dependent population yield, mean length of fish harvested, and spawning potential ratio (SPR), (Maceina et al. 1998, Slipke et al 1998, Slipke and Maceina 2000, King 2001, Slipke et al. 2002, Quist et al. 2002, Colombo et al. 2007). To determine the impact of altering the minimum length limits on the commercial fishery of channel and flathead catfish, I explored the potential effects of 254-, 330, and 381-mm minimum length limits (Chapter 6). At the current level of harvest and size limits, harvest of channel catfish appears to be sustainable. The model suggested that if both Indiana and Illinois adopted a 254-mm minimum length requirement for sport and commercial fishing, recruitment and growth overfishing may occur with even a moderate increase in harvest. If a 330-mm minimum length limit was implemented by both states, a larger range of harvest and a greater mean length could be sustained before the population became overfished. At this length limit, maximum yield would increase by about 10%, while producing larger catfish for the sport fishery. At the modeled 381-mm minimum length limit, recruitment overfishing was not reached at any of the conditional fishing mortalities and harvestable mean lengths were the greatest. With the current minimum length limits occurring in the Wabash River, total yield would decline with modest increases in harvest rates. As such, all harvested treatment reaches require monitoring so that overharvest of reproductively viable adults does not occur.

Although the three species of catfish in the Wabash differ markedly in their life histories (Hubert 1999, Jackson 1999, Pflieger 2001) the current regulations treat all three species the same. Commercial harvest reports suggested that blue and flathead catfish are harvested disproportionably compared my standardized sampling protocol (channel catfish: harvest = 56%, sampling = 91%, flathead catfish: harvest = 28%, sampling = 8%, blue catfish: harvest = 18%, sampling = 1%). Although the difference in the proportion may be a function of a gear bias, it is essential to determine how the current length limits are affecting these species. Flathead catfish harvest was not sustainable under any length limit up to 381-mm. Because of the differences between flathead and channel catfish in response to harvest, these two species may need to be managed independently. Furthermore, demographic information regarding blue catfish needs to be determined so sustainability can be assessed.

None of these modeling scenarios incorporate compensatory responses (e.g., dynamic changes in recruitment and growth rates) as a function of changes in density. The comparison across treatment reaches suggests that demographic parameters are highly responsive to density changes, which may alter modeling responses. Further, the current modeling scenario assumes equal harvest probability of all individuals above the minimum length limit, although it is likely that intermediate-size "fiddler" catfish may be selectively removed by commercial fishers. More detailed information about size-dependent harvest rates would improve model predictions.

Stable Isotopes

Based on stable isotope analysis, the food webs of the different treatment reaches of the Wabash River were similar. Furthermore, channel catfish did not differ in their trophic state among river reaches. Although differences in biomass among treatment reaches was not assessed, the stable isotope results do provide some additional support to the hypothesis that differences in growth and condition of the channel catfish is a function of density differences among treatment reaches.

Final Conclusions

My results suggest that commercial exploitation is affecting the channel catfish population in the Wabash River. Harvest seems to have caused a decrease in the density of fish in the commercially exploited treatment reaches. This change in density was coupled with a apparent shift in the length frequency distributions in the different treatment reaches. Further, the reduction in density resulted from an increase in the population level mortality. As the density has decreased the remaining catfish have experienced a competitive release allowing for better condition and faster growth. The modeling suggested that the fishery is currently sustainable under the current management scenarios. These populations would be susceptible to overharvest if Illinois would adopt a length limit similar to that of Indiana.

A final interesting finding of this study is the un-exploited treatment reach acted similar to that of other fisheries reserves. I found that on this reserve the density of fish was higher. Similar to other studies (Fabrizio et al. 2001, Gadmark et al. 2006), this high density led to catfish in poorer condition that grew slower. The effect that this treatment reach may have as a source of colonists is unknown, but, would be an interesting parameter to incorporate into future models.

Several questions have been answered during this study. And, of course, new gaps in the knowledge have been uncovered. A refined, reach-specific maturation schedule and size-dependent fecundity relationships for channel catfish in the Wabash

River are needed to better refine my predictions. Furthermore, reach-specific sport and commercial fishing effort and harvest will allow for the determination of reach-specific management protocols. Teasing apart the contribution of commercial and recreational harvest to fishing mortality will improve estimates of fishing and natural mortality and allow refinement of the models. All of my interpretations rely on the assumption that catfish remain largely stationary within each treatment reach, which a preliminary tagging study supports (Colombo *unpublished data*). Size-dependent movement among the treatment reaches and between the Wabash River and adjacent systems (e.g., the White River and the Ohio River) would greatly alter my conclusions and recommendations. Furthermore the preliminary model of the flathead catfish yield suggests one length limit for all species of catfish may be undesirable. More research needs to be done to target the demographics of blue and flathead catfish in the Wabash River. Stable isotope analysis provided preliminary evidence suggesting that the consumers in the Wabash may be deriving their energy from different autotrophic sources; however, more information on the lower consumers as well as instream primary production sources needs to be evaluated. Many of these questions are currently being addressed by the Indiana Department of Natural Resources which will lead to an improved understanding of the dynamics of catfish populations in the Wabash River.

Table 18. Back-calculated mean length at age for channel catfish in midwestern river systems. For the Wabash River mean length at age are from all years in the three treatment reaches combined.

	Mean total length (mm) at age			
System	3	6	9	Source
Mississippi River	234	373	457	Pitlo 1997
Ohio River	211	371	n/a	Schoumacher 1973
Missouri River	262	381	n/a	Hesse et al. 1982
Wabash River	262	414	495	This Study

n/a – not available.

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APPENDICES

APPENDIX A

SATELITE IMAGES OF THE NINETEEN SITES SAMPLED DURNING FALL 2001 THROUGH FALL 2004

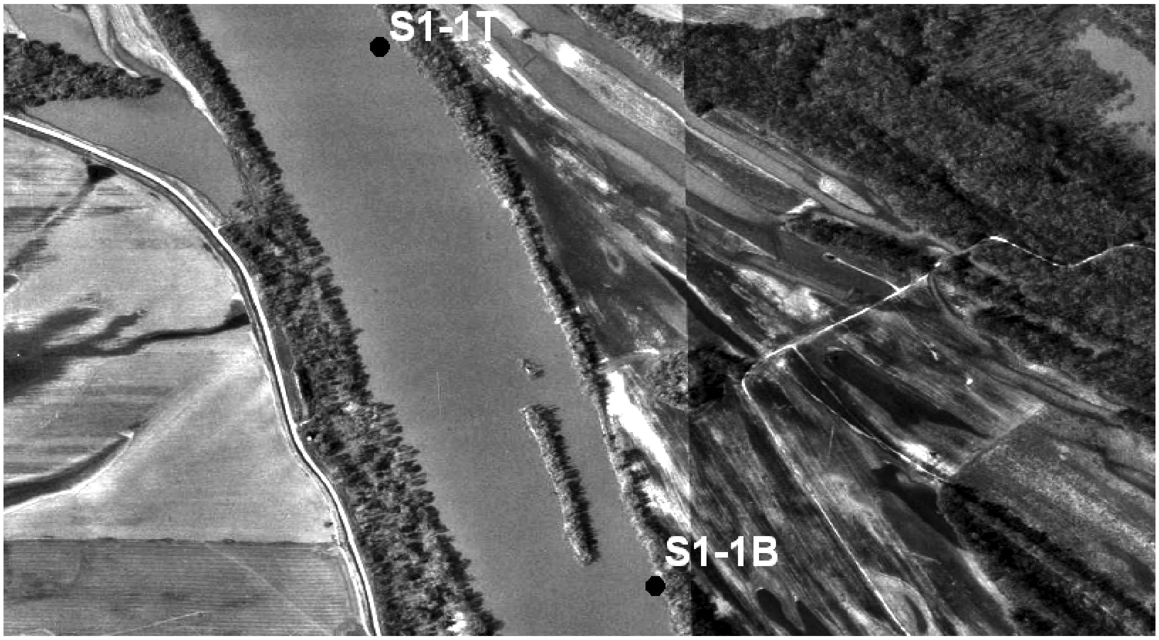

Figure A1. Map of site S1-1 from the IN & IL treatment reach of the Wabash River.

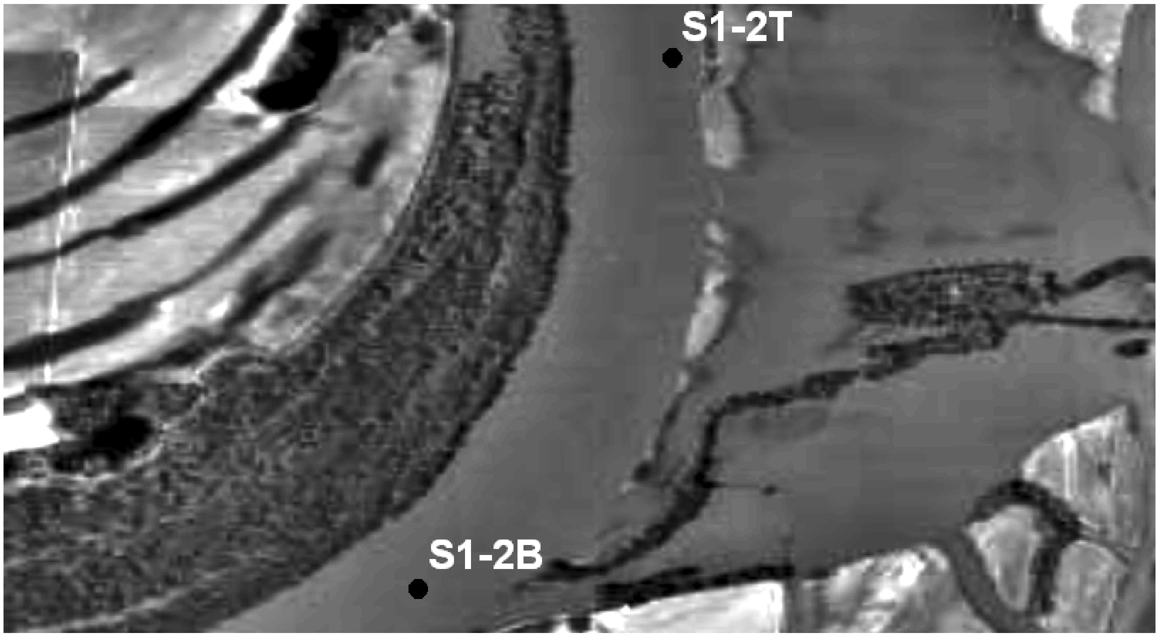

Figure A2. Map of site S1-2from the IN & IL treatment reach of the Wabash River.

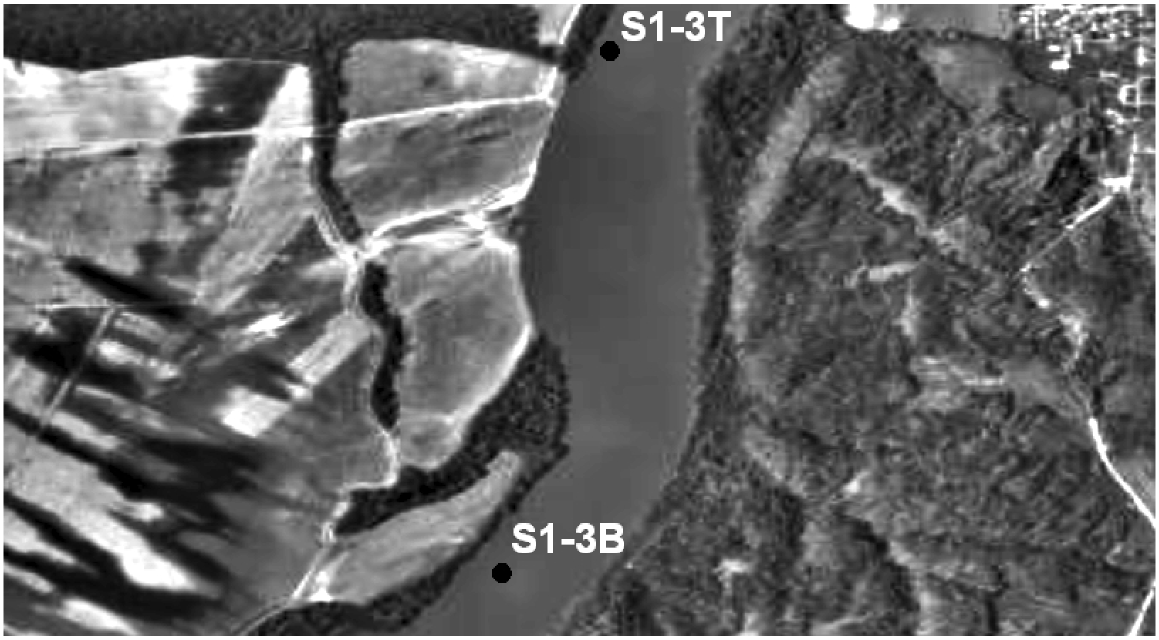

Figure A3. Map of site S1-3 from the IN & IL treatment reach of the Wabash River.

Figure A4. Map of site S2-1 from the IN & IL treatment reach of the Wabash River.

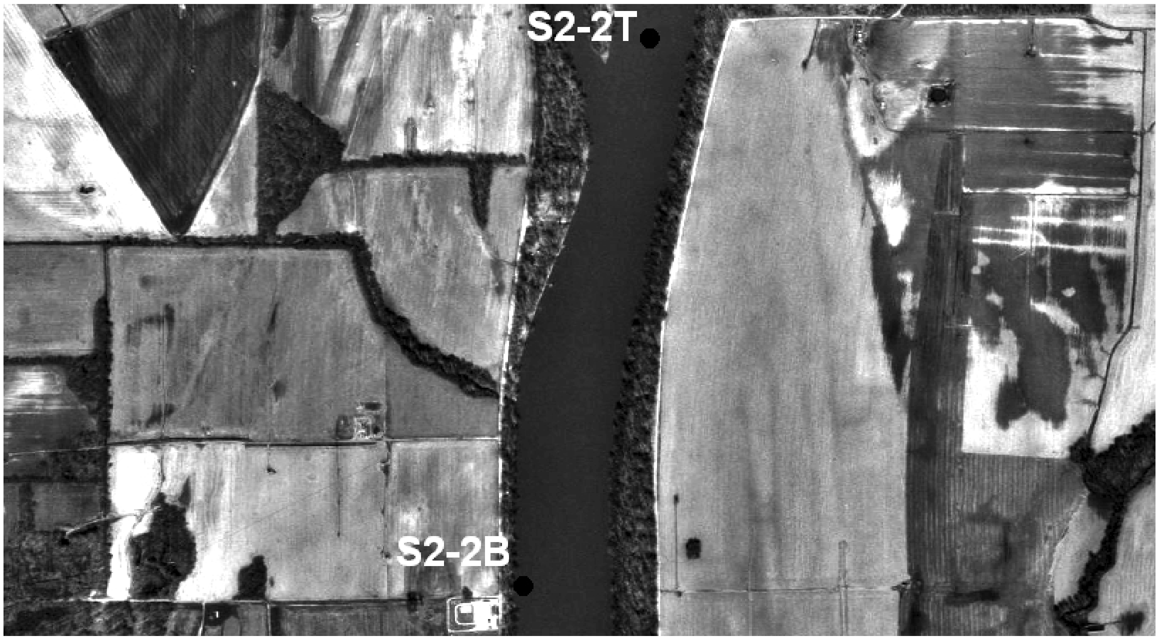

Figure A5. Map of site S2-2 from the IN & IL treatment reach of the Wabash River.

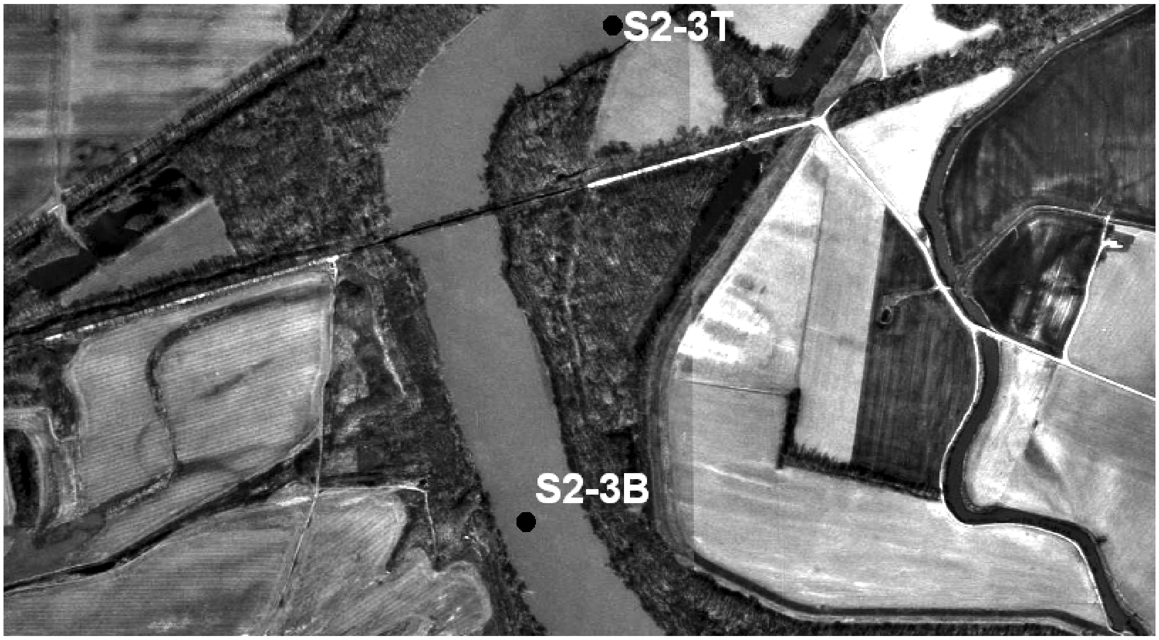

Figure A6. Map of site S2-3 from the IN & IL treatment reach of the Wabash River.

Figure A7. Map of site S3-1 from the IN & IL treatment reach of the Wabash River.

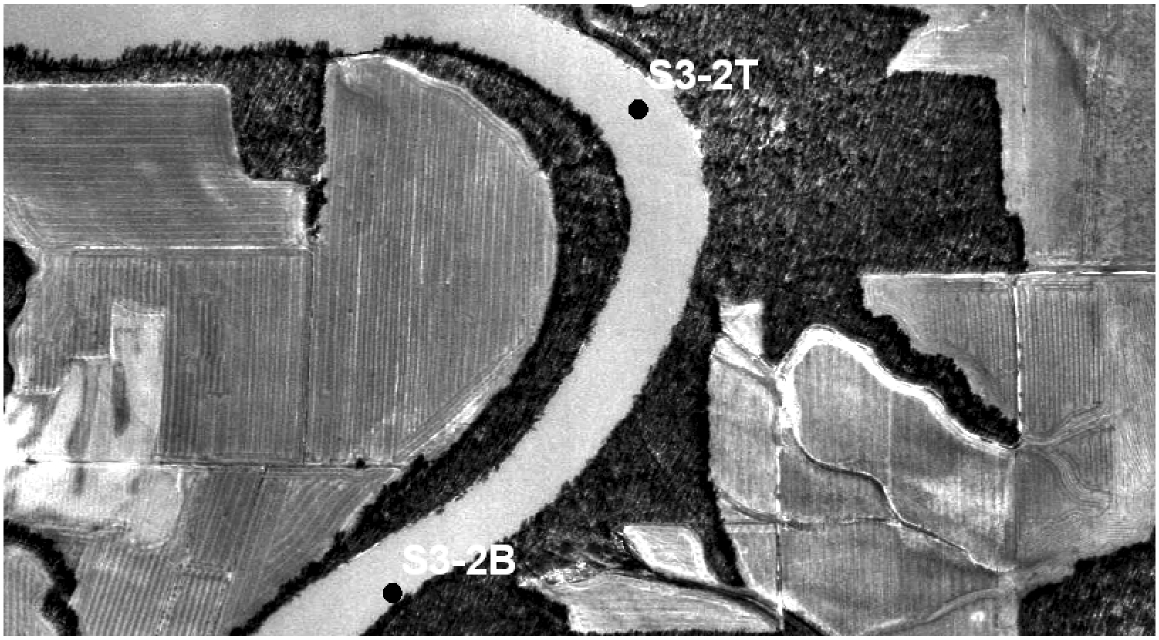

Figure A8. Map of site S3-2 from the IN & IL treatment reach of the Wabash River.

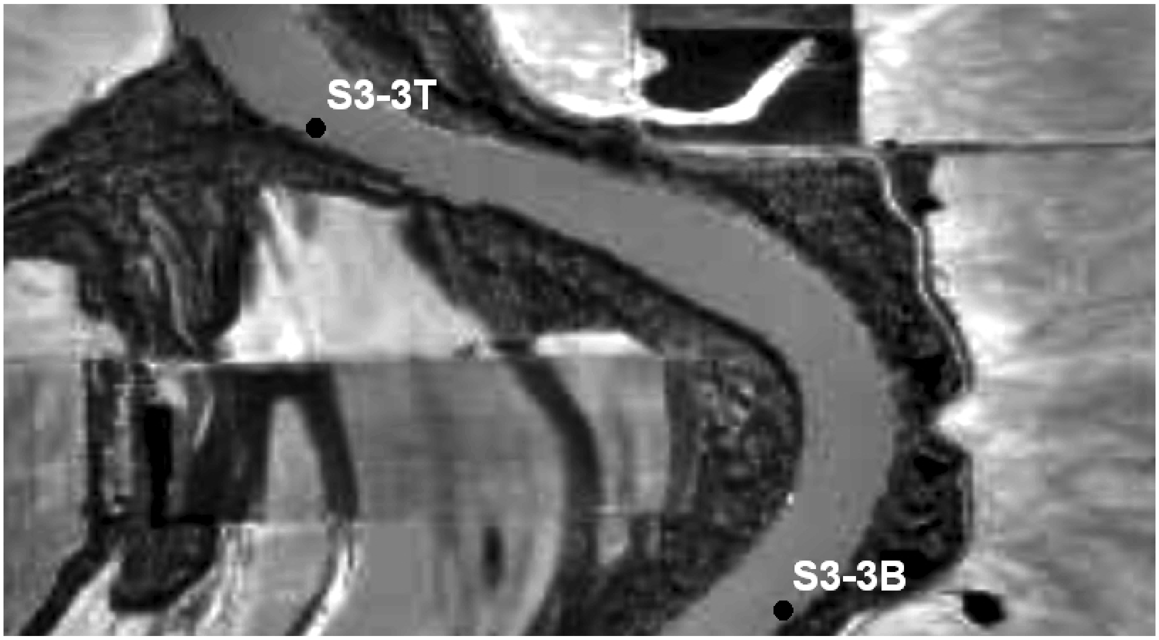

Figure A9. Map of site S3-3 from the IN & IL treatment reach of the Wabash River.

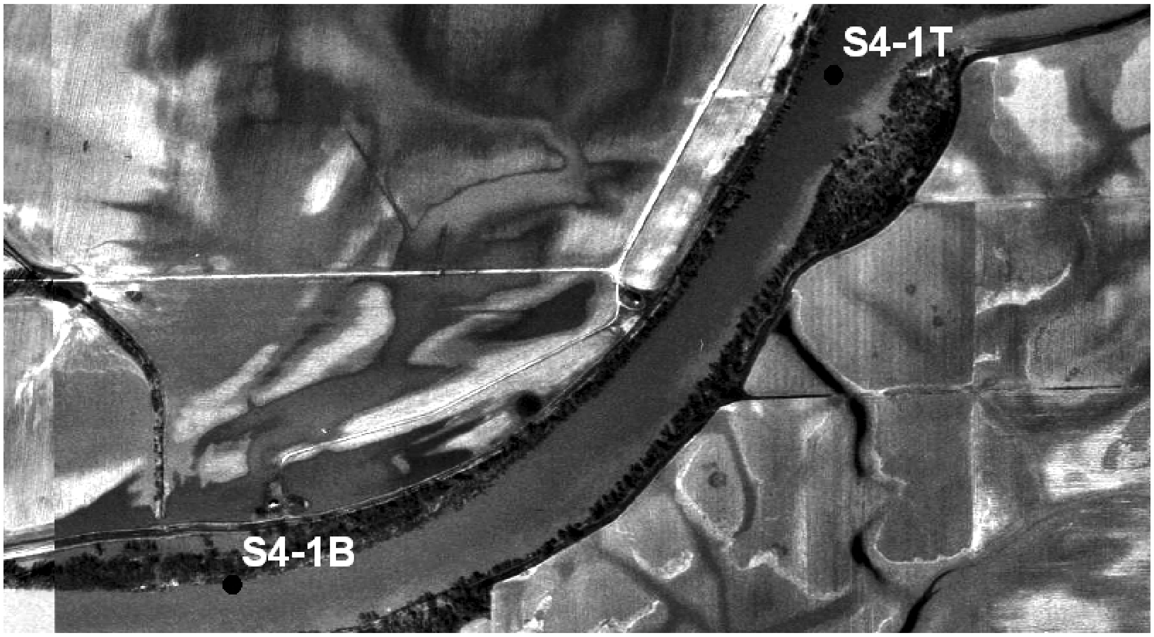

Figure A10. Map of site S4-1 from the IN treatment reach of the Wabash River.

Figure A11. Map of site S4-2 from the IN treatment reach of the Wabash River.

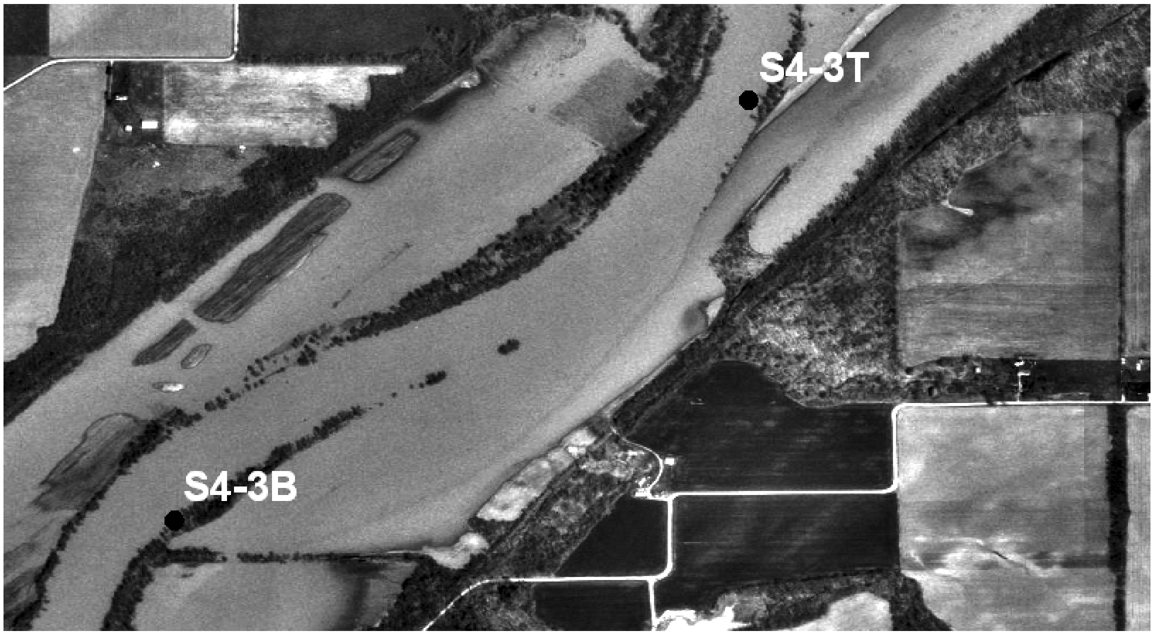

Figure A12. Map of site S4-3 from the IN treatment reach of the Wabash River.

Figure A13. Map of site S4-4 from the IN treatment reach of the Wabash River.

Figure A14. Map of site S5-1 from the NON treatment reach of the Wabash River.

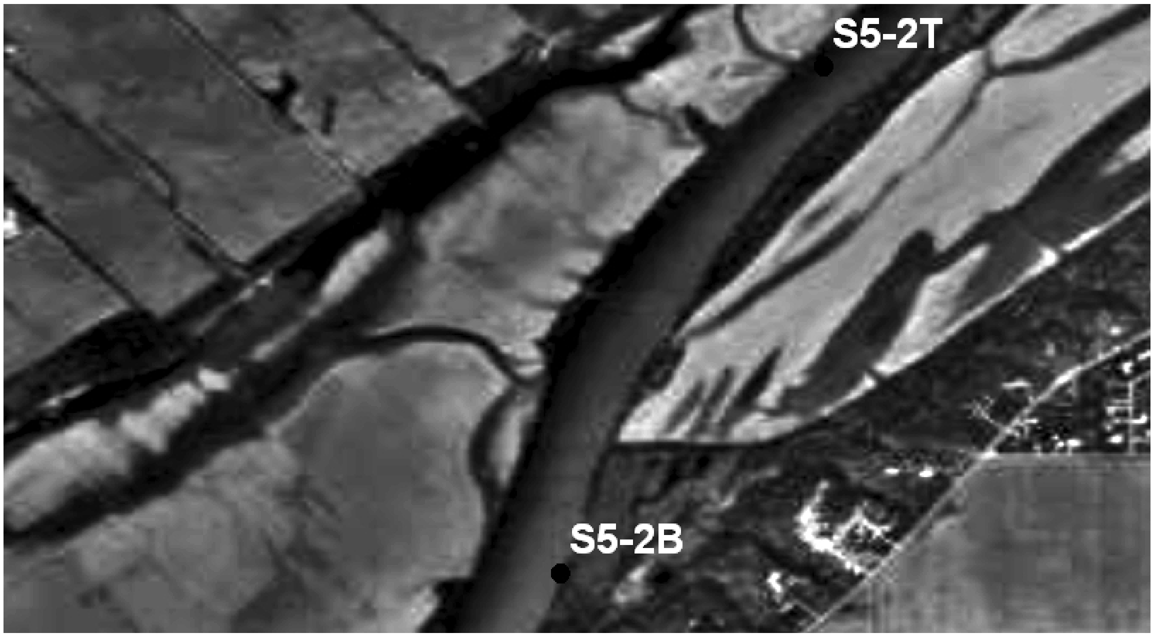

Figure A15. Map of site S5-2 from the NON treatment reach of the Wabash River.

Figure A16. Map of site S5-3 from the NON treatment reach of the Wabash River.

Figure A17. Map of site S5-4 from the NON treatment reach of the Wabash River.

Figure A18. Map of site S5-5 from the NON treatment reach of the Wabash River.

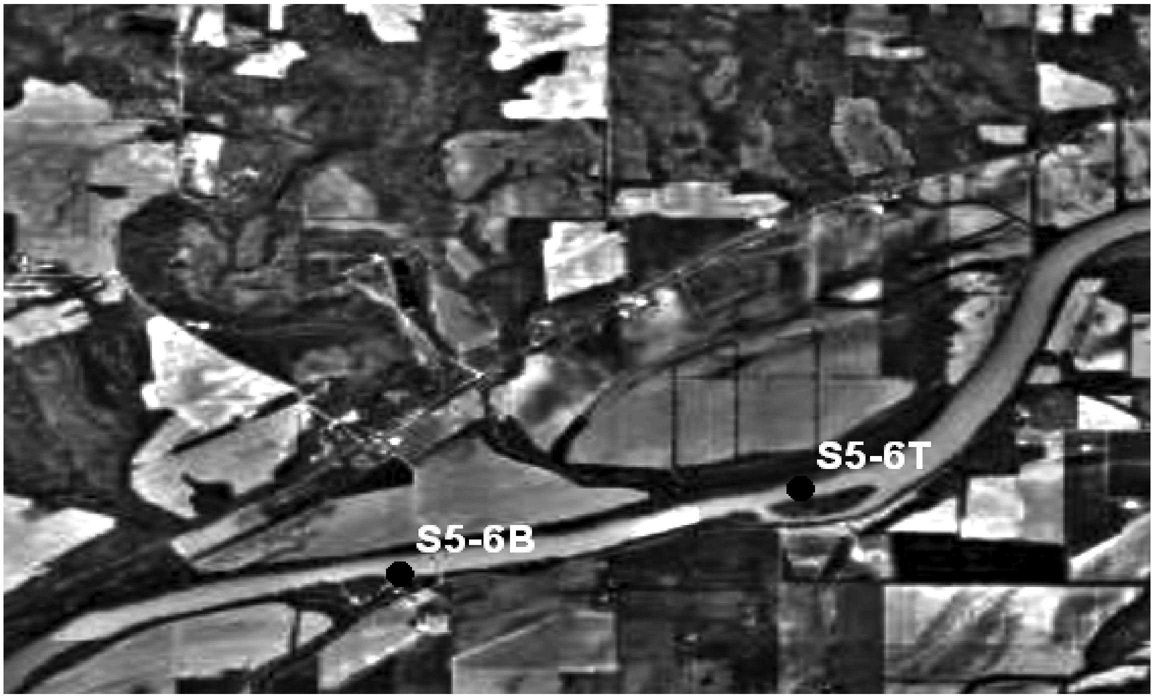

Figure A19. Map of site S5-6 from the NON treatment reach of the Wabash River

APPENDIX B

SUMMARY OF FLATHEAD AND BLUE CATFISH SAMPLED FROM ALL THREE TREATMENT REACHES DURING FALL 2001 THROUGH FALL 2004

The following presents results for flathead and blue catfish that were sampled during the four years of the study. Although, due to small sample sizes they were not reported in the body of the dissertation there are some elements of the flathead catfish data that are robust.

Flathead and Blue Catfish

A total of 218 flathead catfish was sampled during the four years of this study, resulting in lower CPUE compared to channel catfish among all treatments reaches (Table 13). Both proportional stock density (PSD) and relative stock density of preferred size fish (RSD-P) stock indices were calculated for flathead catfish (stock = 356 mm., quality = 508 mm., and preferred = 711 mm) using the length classes defined in Anderson and Neumann (1996). The stock indices in both the NON and IN treatment reaches were high (Table B1) attributable to the high proportion of large flathead catfish present (Figure B1). In the IN & IL treatment reach, a large proportion of flathead catfish were small (Figure B1) leading to low PSD and RSD-P values. For flathead catfish, I used a Ws of Log_{10} Ws = -5.542 + 3.230 Log_{10} TL (Quist 1998). The condition of the flathead catfish was similar in all treatment reaches (Table B1). A total of 33 blue catfish were sampled during the four years of this study. Mean length of blue catfish was 404 mm and ranged from 180 to 871 mm. Due to their low numbers only length at age was calculated for this species.

Flathead Catfish

Because I did not remove the spines of the largest flathead catfish, only 180 of the 218 captured were aged during this study. Therefore, I combined data across all treatment reaches and gears. Mean age of flathead catfish sampled was 3 years, with 2 year old fish making up the largest age class (Figure B2). Mortality of flathead catfish was estimated as 33% (Figure B2). Mean length at age was similar for flathead catfish among years (Figure B3). The von Bertalanffy model for flathead catfish showed fast growth with a maximum length of 610 mm (Figure B4). This is an underestimation of true maximum length within the population because I did not remove the spines of the largest fish sampled in the field. The mean length at age data for flathead and blue catfish are summarized in Table B2. The mean length at age of capture for 311 flathead catfish sampled by Indiana Department of Natural resources is summarized in Table B3. Based on a fishery observer the mean length of flathead catfish harvested by an Illinois commercial fisherman was 625 mm (Figure B5).

Table B1. Mean CPUE, stock index values, and relative weight for flathead catfish sampled from the Wabash River during fall 2001 through 2004. SE = Stnadard error of the mean. IN & IL = Illinois and Indiana commercially exploited treatment reach (Rkm 0-322), IN = Indiana commercially exploited treatment reach (Rkm 394-500), NON = un-exploited treatment reach (Rkm 500-552). (Stock = 350 mm, Quality = 510 mm, and Preferred = 710 mm)

	Treatment Reach		
Parameter	IN & IL	IN	NON
CPUE			
Electrofishing	1.72	1.08	0.76
S.E.	*0.20*	*0.32*	*0.17*
25-mm Hoop net	0.04	0.04	0.03
S.E.	*0.01*	*0.02*	*0.01*
32-mm Hoop net	0.01	0.06	0.03
S.E.	*0.01*	*0.03*	*0.01*
Stock Indices			
PSD	30	44	51
RSD-P	7	19	14
Condition			
Wr	94	91	92
S.E.	*1.35*	*1.35*	*1.74*

Table B2. Mean back-calculated length (mm) at age for flathead and blue catfish sampled from all treatment reaches of the Wabash during fall 2001 through 2004.

	Age									
	1	2	3	4	5	6	7	8	9	10
Flathead Catfish[a]	138	227	318	399	475	487	568	623	573	547
Blue Catfish[b]	182	256	340	401	470	500	575	615	652	720

[a] Log_{10} (length) = 2.83 * Log_{10} (weight) – 4.73; $r^2 = 0.79$
[b] Log_{10} (length) = 3.46 * Log_{10} (weight) – 6.26; $r^2 = 0.96$

Table B3. Mean length (mm) at age of capture for flathead sampled from all treatment reaches of the Wabash during spring 2005 by Indiana Department of Natural resources.

	Age (Years)								
	1	3	6	9	10	11	13	14	18
Flathead Catfish	190	328	537	721	864	1034	1058	1029	1063

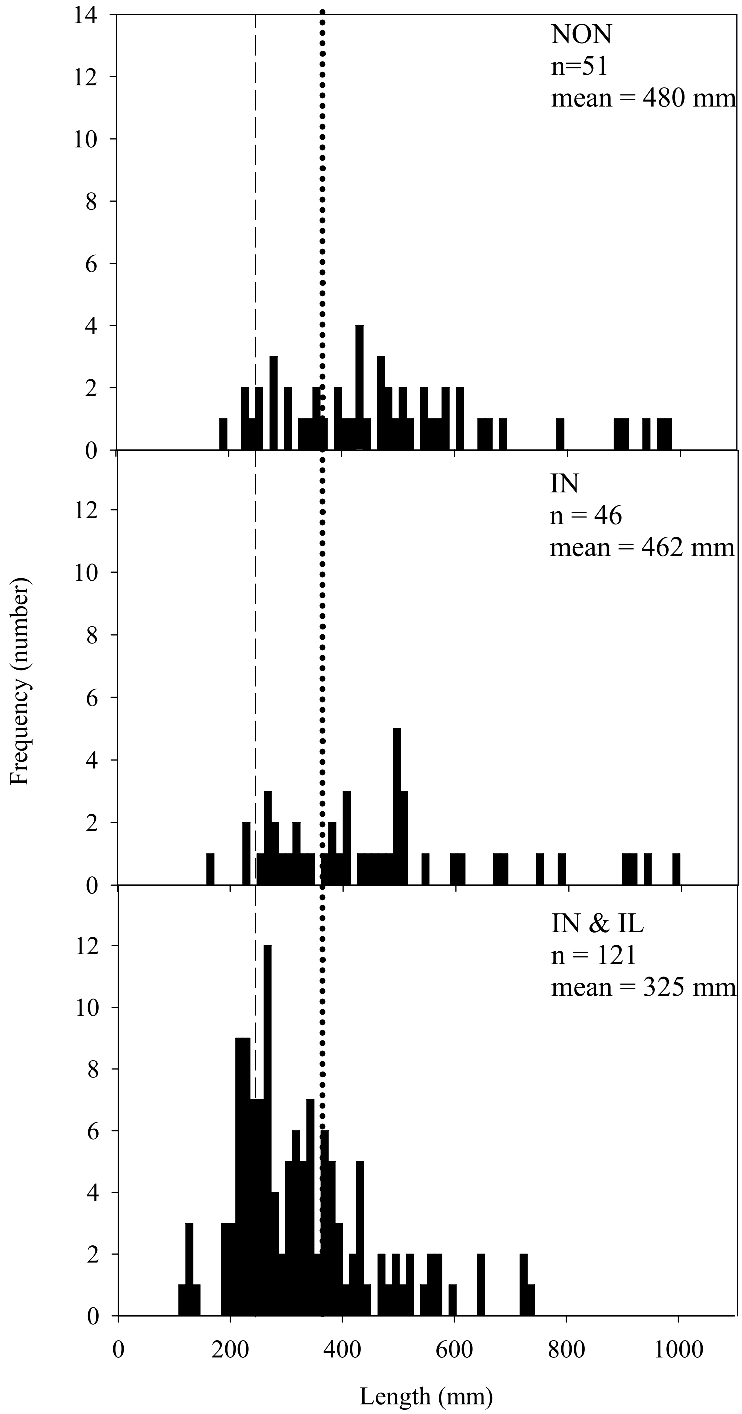

Figure B1. Length frequency distributions by treatment reach for flathead catfish sampled from the Wabash River during fall 2001 through 2004.

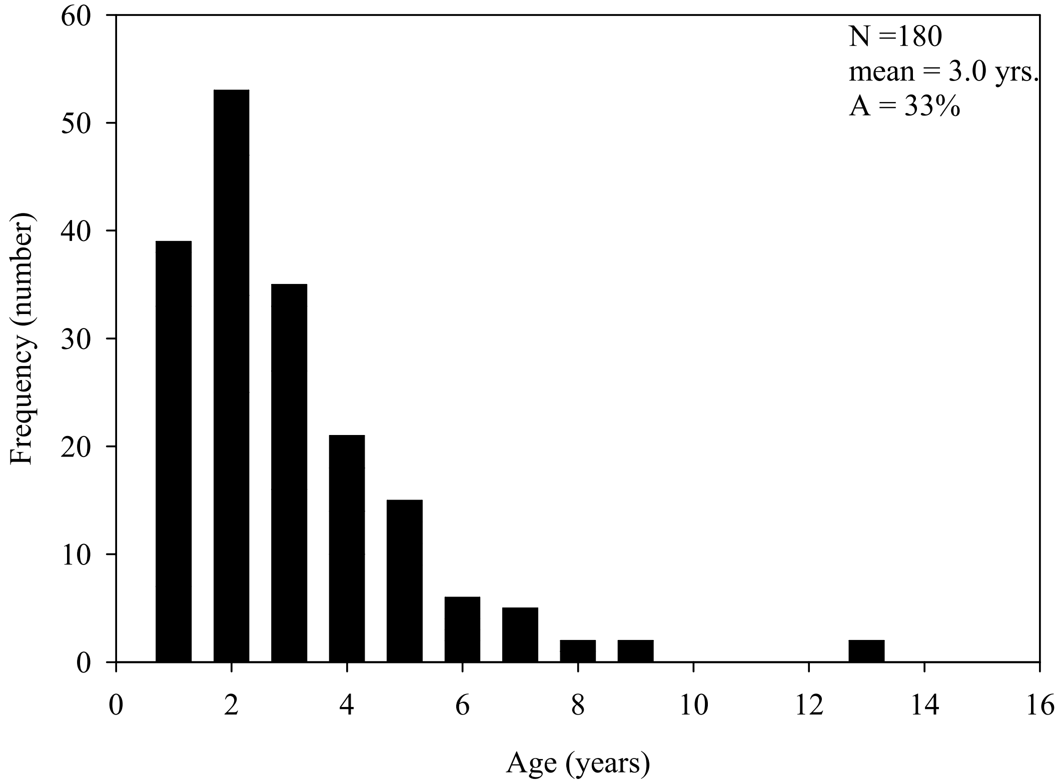

Figure B2. Pooled Age frequency distribution for all flathead catfish aged from the Wabash River during fall 2001 through 2004. Total annual mortality indicated by (A).

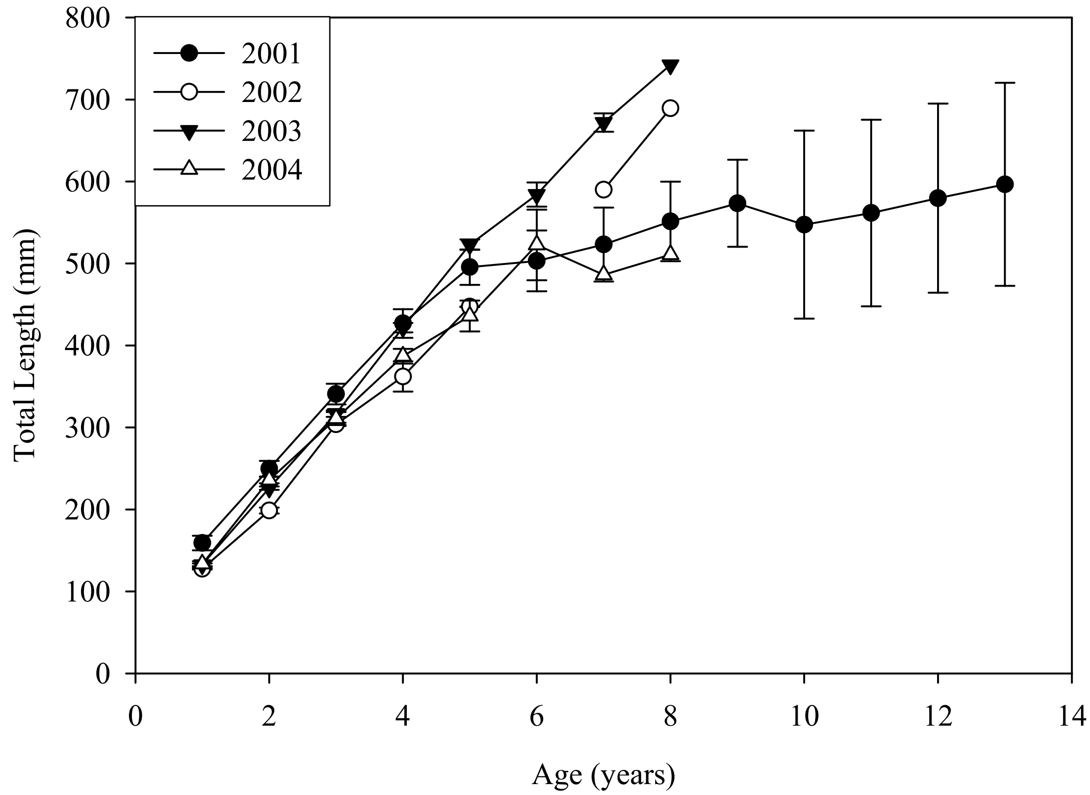

Figure B3. Mean length at age (±1 S.E.) by year for all flathead catfish aged in the Wabash River during fall 2001 through 2004 (2001, n = 73; 2002, n = 57; 2003, n = 33; 2004, n = 17).

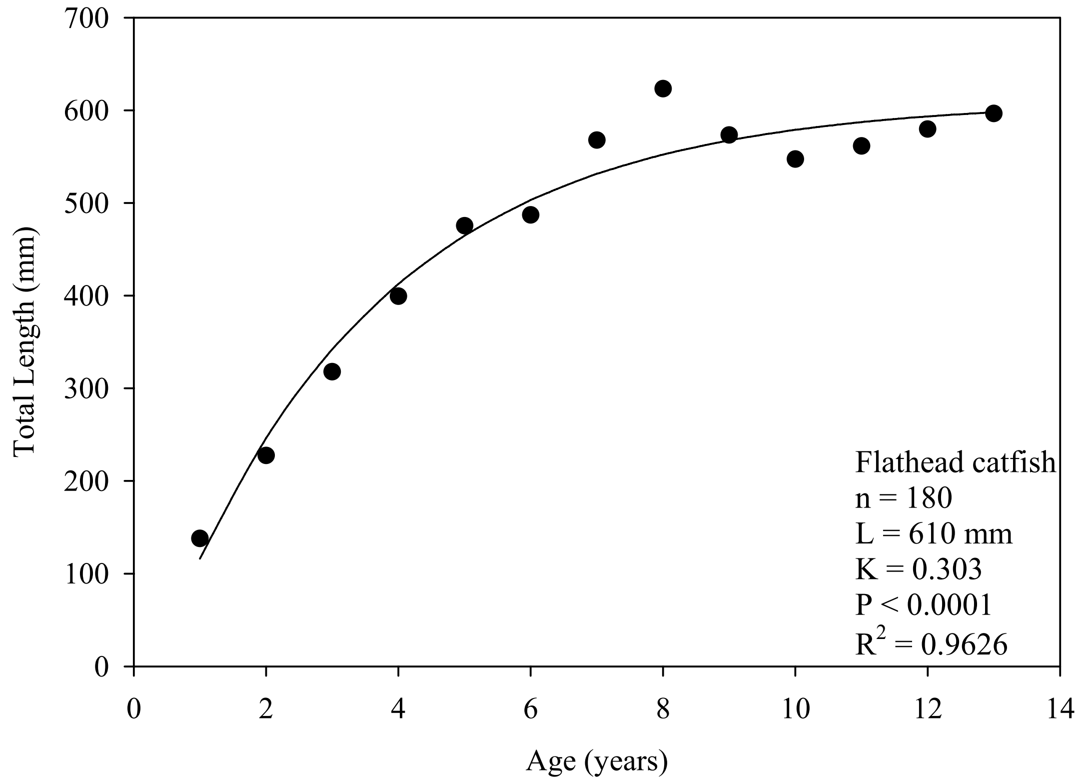

Figure B4. Flathead catfish mean length at age and von Bertalanffy model for all flathead catfish aged in the Wabash River during fall 2001 through 2004

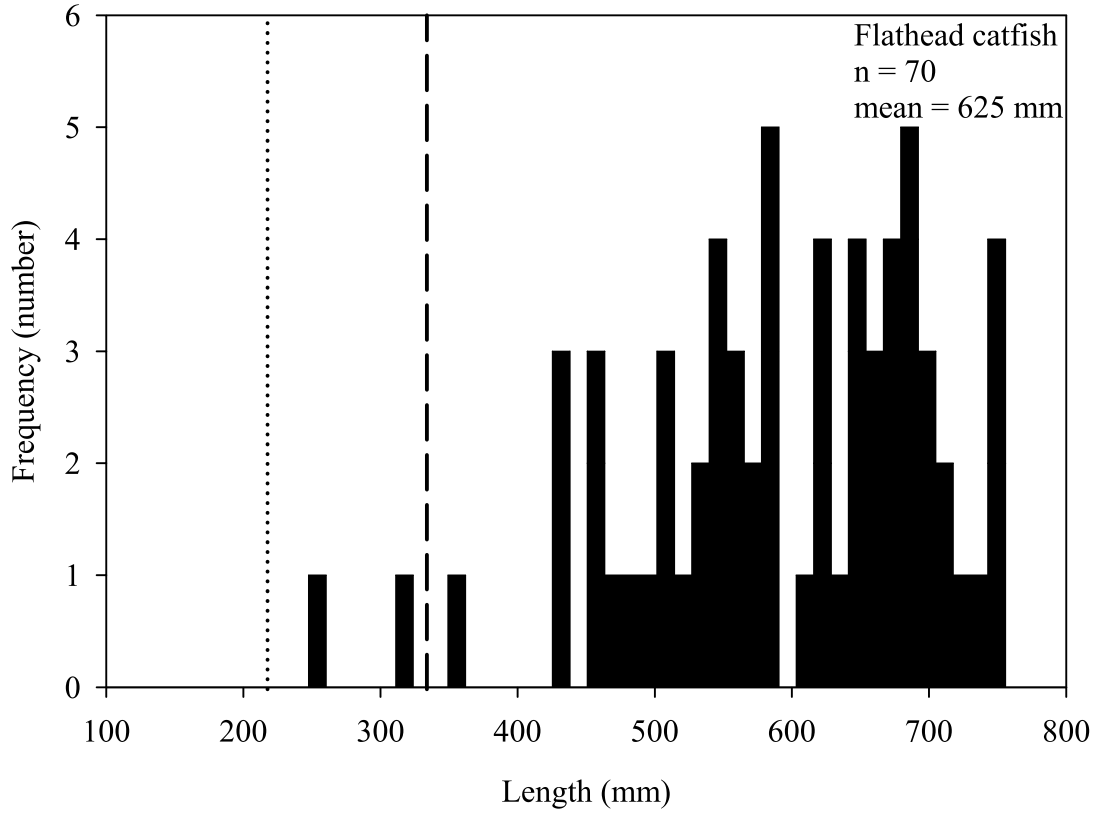

Figure B5. Length frequency histograms for flathead catfish harvested by commercial fishers in the presence of an INDNR observer during spring 2001 through 2004.

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