Thesis Proposal

For

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Candidate for the Degree of

Master of Science in Aquaculture/Fisheries

TITLE: Relationships between largemouth bass *Micropterus salmoides* populations and off-channel habitat characteristics in the lower Arkansas River.

OBJECTIVES:

(1) To conduct a stock assessment of largemouth bass in different pools of the lower Arkansas River.

(2) To examine empirical relationships between largemouth bass population metrics from each pool and characteristics of river off-channel habitats from those same pools.

APPROVAL:

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Introduction

Off-channel habitats in large rivers play important roles in the population dynamics of many fishes (Junk et al. 1989). These habitats are often referred to as “backwater”, “extrachannel”, or “floodplain” habitats in the rivers literature and include habitats such as oxbow lakes, side (or secondary) river channels, dike pools, main channel margins, and tributary streams (Baker et al. 1991). Herein these habitats will be referred to as “off-channel” habitats (OCH), which is a reasonable compromise to various definitions listed in Armantrout (1998).

OCH in rivers serve as vital sources of nutrients and organic matter production for riverine biota. However, OCH serves many direct purposes for riverine fishes that include access to spawning sites, nursery areas for larvae and juveniles, and forage areas. In unregulated or otherwise unmodified river systems, fishes have evolved to exploit annual flood pulses (Junk et al. 1989). Fishes utilize off-channel habitats in rivers made accessible by flooding in order to maximize individual fitness and survival of offspring (Sparks 1995). This effect may be more dampened in large temperate rivers, which are highly modified and may contain a general asynchrony between flood pulses and water temperatures suitable for fish spawning, feeding, and growth (Eggleton and Schramm 2004). Furthermore, there is overwhelming evidence suggesting that the quantity and quality of off-channel habitats is degrading in highly modified rivers (Gore and Shields 1995; Poff et al. 1997; Karr 1999). Nevertheless, the ecological linkage between riverine fishes and the availability of OCHs in rivers is well documented, though better demonstrated in more natural rivers that are mostly unregulated (Welcomme 1979; Goulding 1980; Junk et al. 1989).

In addition to providing sources of organic matter and nutrients, OCH provides other characteristics that are beneficial to riverine biota. OCHs are typically characterized by low current and greater levels of productivity than main channel habitats (MCH) located in the river proper (Junk et al. 1989). With respect to fishes, low currents provide more suitable habitats for larval and juvenile fishes, while the enhanced productivity contained therein provides greater abundances of foods than are found in the main river channel (Junk et al. 1989). While MCHs in regulated rivers tend to be more physically homogeneous for fishes, OCHs tend to be fairly heterogeneous in that woody structure, aquatic vegetation, substrates, and hydrology can vary greatly across space and time (Johnson et al. 1995). The increased diversity of habitats associated with OCHs, coupled with the energetic benefits mentioned previously, has many positive effects on fishes and fisheries. All of these effects promote greater abundance, survival, and fitness of riverine fishes. The dependency of riverine fishes on these characteristics of OCH is especially noteworthy considering the tremendous loss of these habitats currently occurring in most large river systems due to regulation practices (Baker et al. 1991; Gore and Shields 1995). Unless critical linkages between fishes and OCHs are properly elucidated in more river systems, no appropriate guidelines or targets for river restoration efforts can be established.

The Arkansas River originates in the Rocky Mountains of Colorado, flows easterly through Kansas, and then southeasterly through Oklahoma and Arkansas, eventually flowing into the lower Mississippi River upstream of Arkansas City, Arkansas. While traversing Arkansas, the river flows northwest to southeast over a distance of 500 km (Limbird 1993), and with the exception of the lowermost 50 km, is contained entirely within the McClellan-Kerr Navigation (MKN) System (Limbird 1993). The present-day MKN System is a series of locks and dams designed to provide commercial navigation, hydroelectric power production, flood control, water supply, fish and wildlife habitat, environmental enhancement, and river channel stabilization for the lower Arkansas River Valley. While the system increases benefits for man, navigation systems such as these do not necessarily enhance benefits for aquatic biota, which are well-adapted to the highly variable and heterogeneous conditions characteristic of natural river systems. In recent history, four species of fishes are suspected to have been extirpated from the mainstem of the Arkansas River: plains minnow *Hybognathus placitus*, Arkansas River shiner *Notropis girardi*, suckermouth minnow *Phenacobious mirabilis*, and the speckled chub *Macrhybopsis aestivalis* (Limbird 1993). The loss of these species is likely due to regulation practices in the lower Arkansas River.

The earliest regulation efforts in the Arkansas River were dikes constructed of brush and stone near Fort Smith in 1878 (Limbird 1993). The current MKN lock and dam system was first begun at Dardenelle, Arkansas in 1959. By the late 1960s, the entire MKN System and the Arkansas Post Canal were completed making the river navigable for commercial barges upstream to Catoosa, Oklahoma (Limbird 1993). At the lower end of the system just above Dam No. 2, the Arkansas and White rivers are connected by the Arkansas Post Canal, by which commercial barge traffic exits the drainage into the Mississippi River. Although many of the common impacts on aquatic biota associated with dam systems are generally negative (Yeager 1993), few investigations have been conducted addressing fish community and/or fisheries changes within the Arkansas River since completion of the MKN project over 35 years ago.

The largemouth bass *Micropterus salmoides* (herein termed “bass”) is recognized as the most popular sport fish species in the United States (Heidinger 1975). The immense popularity of the species began following the massive reservoir construction efforts that occurred in the U.S. during the 1930s and 1940s. Largemouth bass angling in North America is economically important, generating many millions of dollars in revenues annually in most states by way of sales of fishing licenses, fishing tackle, boats, marine fuel, boating supplies, etc (U.S. Department of the Interior 2001). In turn, many millions of dollars in revenues are returned to individual states, much of which supports sport fish conservation and/or restoration efforts as well as other fisheries-related programs.

Largemouth bass angling in Arkansas is no exception to this rule. In 2003, 18,513 angler hours were spent tournament fishing for largemouth bass on the Arkansas River (ATIP). However, according to data compiled by the Arkansas Tournament Information Program (ATIP), the quality of the largemouth bass population in the river has been decreasing over the last decade. According to ATIP findings, the average number of angling hours required to catch a bass larger than 2.3 kg (5 lbs) in the Arkansas River was around 325 hours in 1994, but has now increased to over 1,500 hours in 2003 (ATIP). There also were decreases in number of fish caught per day, weight of fish caught per day, and percent success rate of tournament anglers. Largemouth Bass Virus (LMBV) may also play a part in this decline. Either way, according to ATIP, river-wide management designed to rehabilitate the bass fishery might be warranted.

In general, there is a conspicuous lack of studies that have focused on largemouth bass dynamics in river systems. For instance, Parkos and Wahl (2002) reported that 80%

of literature on largemouth bass recruitment was conducted in reservoirs compared to around 5% in rivers. These findings underscore that more studies are needed to assess black bass population dynamics in large river systems.

Current management of Arkansas River largemouth bass by the Arkansas Game and Fish Commission (AGFC) includes a 381-mm (15-inch) minimum total length limit on largemouth bass, with a creel limit of 10 black basses (all species pooled) per day (see Largemouth Bass Management Plan; AGFC 2002). In addition, AGFC sporadically stocks fingerling largemouth bass in some Arkansas River pools to enhance recruitment. AGFC and the U.S. Army Corps of Engineers have jointly implemented some habitat improvements. Improvements such as dike notching and pool dredging have been completed in the mouths of some backwaters. Although well-grounded in standard principles of largemouth bass management, this plan has not been active long enough to be ground-truthed or adjusted in an adaptive management scheme. A thorough stock assessment of largemouth bass throughout the Arkansas River could support such an adaptive management scheme, and would allow management that produces healthier populations and more satisfied anglers.

The main goal of this research project is to increase our understanding of the overall importance of off-channel habitats to largemouth bass population dynamics in the lower Arkansas River. This will be accomplished by completion of two main objectives. Specifically,

Objective One: To conduct a stock assessment of largemouth bass in different pools of the lower Arkansas River.

Objective Two: To examine empirical relationships between largemouth bass population metrics from each pool and the availability of river off-channel habitats for those same pools.

Additionally, there has been no comprehensive stock assessment done for largemouth bass in any pools of the Arkansas River within Arkansas, with the exception of Lake Dardanelle (Pool 10). This information will be valuable baseline data for the Arkansas River and serve to elucidate linkages between OCHs and largemouth bass in different pools of the river. Furthermore, results will be useful to AGFC personnel to support current management strategies in the lower Arkansas River.

Literature Review

Off-channel habitat in large rivers

Off-channel habitats have been shown to be important to largemouth bass (Raibley et al. 1997). Largemouth bass exist in many lotic systems, but evolved in floodplain and other slackwater habitats adjacent to large rivers (Page and Burr 1991). Largemouth bass are most abundant in lentic water bodies, and have thrived in man-made farm ponds and reservoirs (Heidinger 1975; Smith 1979). Largemouth bass in riverine systems are often strongly associated with low-current OCHs in order to successfully reproduce, feed, and overwinter (Raibley et al. 1997).

The widespread construction of dike fields during the past 75 years is common throughout large rivers in temperate North America. Although usually constructed to prevent river flow through an abandoned side channel, dike fields result in the formation of large upstream sand bars that redirect currents and induce continued scouring of the river thalweg (Pennington and Shields 1993). Coincident with dike field construction, side river channels become more isolated from the main river channel (and more lentic) and other isolated pockets of slackwater develop that provide some suitable OCHs for largemouth bass. In time, some of these habitats become structurally complex, as fallen timber accumulates and aquatic vegetation (both emergent and submergent) and woody plants become abundant in areas where flows are not limiting (Piegay and Salvador 1997). However, these positive impacts of river regulation are far outweighed by the negative aspects. Dike fields and bank revetments designed to maintain channel alignment (and thus, prevent channel meandering) greatly accelerate sedimentation rates in off-channel habitats (Regier et al. 1989). Thus, OCHs are disappearing at an alarming rate in many large river systems, essentially becoming terrestrialized habitats via natural successional processes in the river (Piegay and Salvador 1997).

Largemouth bass biology and life history

Fishes of the genus *Micropterus* are characterized as having an elongate body, a large mouth extending under or past the eye, having a moderately forked tail, three anal spines, and 55 or more lateral scales (Page and Burr 1991). The most well-known fish of this genus, the largemouth black bass, is characterized as having the first and second dorsal fins (spiny and soft, respectively) almost completely separated from one another, an upper jaw which extends well past the eye, and large cheek scales (Page and Burr 1991). The species is native from the St. Lawrence River in eastern Canada across through the Great Laurentian Lakes southward to Texas and Florida. They are found throughout the Mississippi River basin and its tributaries and all Atlantic slope river drainages in the southeastern U.S. Because of its immense popularity as a sport fish, largemouth bass also have been introduced almost everywhere in the U.S., northern Mexico, and southern Canada, as well as other nations abroad.

The largemouth bass is an extremely plastic species, existing in reservoirs, farm ponds, natural lakes, large rivers and their floodplains, and small creeks. The species exhibits a definite preference for more lentic or slackwater habitats, specifically vegetated oxbow lakes, clearer floodplain lakes, farm ponds, and reservoirs (Smith 1979). Spawning tends to occur in May or June when water temperatures reach 16°C, and usually occurs over constructed gravel nests found in the vicinity of vegetation or woody structure (Smith 1979).

First-year growth rates for age-0 bass averages about 104 mm total length (TL) for Arkansas (Carlander 1977). This number may be low because many of the Arkansas studies cited in Carlander (1977) were reported from coldwater reservoirs (e.g., Bull Shoals or Beaver Lake), and may not be comparable to growth in the Arkansas River. For ages 1-6, average growth in Arkansas was 202, 285, 346, 439, 501, and 542 mm TL respectively (Carlander 1977). Research has shown that largemouth bass reach sexual maturity on the basis of length, with most females being able to reproduce after reaching 250 mm TL (Nieman et al. 1979).

Largemouth bass adults are trophic generalists, in that individuals frequently target the most available food items. As larval fry, largemouth bass consume zooplankton and then switch to small insects and crustaceans as juveniles at a length of about 20 mm TL. At some point during their first year, bass switch to piscivory and growth accelerates rapidly (Adams and DeAngelis 1987). As adults, they are predatory and known to eat large quantities fishes, crustaceans, and aquatic insects, but a detailed listing of all food items consumed in a given year might include zooplankton, small mammals, algae, detritus, and even mollusks (Smith 1979; Etnier and Starnes 1993). Largemouth bass have such voracious appetites that they have been stocked in small ponds and lakes to control overabundant panfish such as bluegill *Lepomis macrochirus* and clupeids such as gizzard shad *Dorosoma cepedianum*. Having adopted such flexible life-history characteristics makes largemouth bass more adaptable and able to thrive in different types of aquatic environments.

Importance of largemouth bass

Largemouth bass are important to humans both recreationally and economically. Within human contexts, the largemouth bass is undoubtedly the most sought after sport fish in the freshwaters of North America. These fish are the source of a large amount of economic activity because of their popularity. In 2001, 28.4 million anglers fished a total of 467 million days and spent $21.3 billion while pursuing angling activities (U.S. Department of the Interior 2001). Of these anglers, 10.7 million anglers spent 160 million days attempting to catch black bass. In the state of Arkansas, according to this same report, 782,000 anglers fished about 13 million hours, and spent almost $450 million fishing for all species. As these data indicate, largemouth bass angling is an important industry in Arkansas that provides much needed revenue through license sales, boats, tackle, and other angling equipment.

River habitat alteration associated with river regulation

The present-day Arkansas River is much different from the way it would have appeared historically. The addition of locks and dams through construction of the MKN System, and the associated construction of numerous dike fields and bank revetments to maintain channel alignment, have had a large impact on the quality and quantity of the river's different habitats. The most striking impact, as in other river systems, has probably been the loss of suitable OCHs due to accelerated sedimentation. It has been observed that dams and the resultant sediment accumulation can lead to widespread destruction of nursery, shelter, spawning, and overwintering habitats of fishes (Yeager 1993). Given its basic life-history characteristics, the largemouth bass would seemingly be a species at particular risk to these impacts in the Arkansas River.

Methods

Study area

The study area for this project includes all of the lower Arkansas River within the state of Arkansas. This area encompasses 291 river channel miles beginning in northwestern Arkansas at Ft. Smith and ending at Lake Merrisach in the Arkansas Post Canal, which connects the Arkansas and White rivers for navigational purposes (Figure 1). The study area encompasses 11 pools – Arkansas River Pool 2 (Pendleton) upstream through Arkansas River Pool 13 (Ft. Smith) (there is no pool 11 in the MKN System).

These 11 pools range in size from 1,500 hectares (Pool 3) to 14,000 hectares (Pool 10, Lake Dardanelle) (Table 1). In terms of off-channel habitats, each pool has unique types, quantities, and qualities of OCH. In addition, these OCHs have other unique characteristics such as amount of emergent vegetation, surface area, width, and depth gradients. In addition, the largest pool, Lake Dardanelle, is more characteristic of a reservoir physically as opposed to the more riverine characteristics of the other pools. Another major difference is that the pools near Ft. Smith and Little Rock have some unique features because of their urban locations. These features include more bridges to accommodate vehicle traffic and trains, and larger amounts of artificial bank materials for increased stability. Overall, these 11 pools should offer a cross-section or "gradient" of off-channel characteristics that are hypothesized to be related to largemouth bass population dynamics (e.g., Garvey et al. 2002).

Fish collections

Largemouth bass will be collected by boat-mounted electrofishing during June-July and October-November 2004, and May 2005. Collections also will potentially be done in October-November 2005 following analysis of fall 2004 data. Sampling will be conducted using multiple 600-second electrofishing samples per pool. Sampling locations will be determined using a stratified random sampling scheme, with main channel and off-channel habitats representing the stratum. Equal sampling effort will be applied towards main channel and off-channel habitats. This scheme should allow adequate coverage of all areas of each pool and ensure that a minimum of 150 adult largemouth bass are collected for stock assessments. Increased sampling will be done as needed should the regular sampling scheme fail to produce enough bass for adequate stock assessments. Electrofishing will be conducted from approximately sunset to before sunrise. Electrofishing settings will be standardized based on water temperature and conductivity of each river pool to achieve a standard power output of 7-10 amps in all pools (Burkhardt and Gutreuter 1995). All largemouth bass collected during spring sampling will be returned on ice to the laboratory for processing. Bass collected during fall sampling will be measured for total length to the nearest mm in the field. All bass suspected to possibly be age-0 (specifically those <275 mm total length) will be returned to the laboratory for processing as above; all larger bass will be measured and released alive. This modified sampling scheme for fall is based on comparable research that suggests that the age-0 abundance during fall is an important predictor of future year-class strength (e.g., Adams and DeAngelis 1987; Fuhr et al. 2002).

Population metrics

In the laboratory, individual bass will be measured for total length to nearest mm and weighed for total weight to the nearest 0.1 g. Livers and stomachs will be excised and weighed to the nearest 0.01 g. Sagittal otoliths will be removed for age and growth analysis using standard methods (DeVries and Frie 1996). Fish gender will be determined and recorded.

Condition. Standard weight-length equations will be generated for largemouth bass in each pool using least-squares linear regression on $\log_{10}$-transformed total weights and total lengths. Standard condition indices including relative weight (Wege and Anderson 1978) and relative condition (LeCren 1951) will be calculated for each individual bass. Relative weight (W_r) is defined as:

$$Wr = \frac{W}{Ws} x100$$

where W = observed fish weight and W_s = predicted weight for the individual fish based on a standard weight-length equation for the species. Relative condition (K_n) is defined as:

$$Kn = \frac{W}{W'} x100$$

where W = observed fish weight and W' = predicted weight for the individual fish based on a stock- or population-wide weight-length equation. For relative weight, standard weight-length equations published for largemouth bass will be used in all calculations (Wege and Anderson 1978); for relative condition, a generalized weight-length equation will be developed for largemouth bass from all Arkansas River pools and used in all individual calculations. Basic descriptive statistics will be computed for each measure and compared across different pools. These two condition indices together will give a more complete picture of how largemouth bass condition in each pool compares to largemouth bass populations nationally (e.g., North America using relative weight) and regionally (e.g., Arkansas River using relative condition).

Liver weights will be used to calculate liver somatic index (LSI) values (Busacker et al. 1990) for each individual bass. This index is calculated as:

$$LSI = \frac{L}{W} x100$$

where L = liver weight and W = observed fish weight. Similarly, values will be averaged and descriptive statistics compared across pools. LSI statistics will offer another line of comparison of largemouth bass condition across pools. If possible, fat weights also will be used in a similar computation and comparison. If fat content of individual bass is small and not feasible to weigh, then a qualitative rating will be used to ascertain fat content and condition. For example, a largemouth bass with no visible fat will score zero, a bass with some visible fat will score a one, and a bass with much visible fat will score two. These values, though weak in scale, will still be averaged and descriptive statistics used to assess spatial patterns in bass condition.

Age structure and growth. Age and growth analyses will be conducted using the direct proportion (Dahl-Lea) method on otoliths read whole-view for bass up to age 2, and sectioned for age-3 and older bass (Schramm et al. 1992; Long and Fisher 2002) (Figure 2). Otoliths will be read twice by independent readers for verification purposes and assessment of reader bias. Appropriate checks and verification of new annuli formation will be done on June/July-collected bass to insure that bass are accurately aged. Resulting estimates of annual growth and mean age will be generated separately for each pool and compared across pools.

Once all bass are aged and ages have been verified, von Bertalanffy growth curves (von Bertalanffy 1938; Ricker 1979) will be constructed separately for each pool using least-squares nonlinear regression procedures. The formula for the von Bertalanffy growth curve is:

$$l_t = L_\infty * (1 - e^{-K(t - t_0)})$$

where l_t = fish length at age t, K = population growth parameter, $L\infty$ = population maximum possible total length, and t_o = theoretical time at which the fish would have a length of zero (usually a small negative number). von Bertalanffy growth parameters (i.e., K, $L\infty$, and t_o) will be generated separately for each pool and then compared across pools.

Size structure. Size structure of bass populations will be assessed using standard techniques, specifically proportional stock densities and relative stock densities for preferred-size fish. Proportional stock densities (PSD) will be calculated as:

$$PSD(\%) = \frac{number \geq quality\ size}{number \geq stock\ size} x100$$

with largemouth bass stock and quality sizes determined from Anderson and Neumann (1996). Relative stock densities of preferred-size fish (RSD_P) will be similarly calculated as:

$$RSD_P(\%) = \frac{number \geq preferred\ size}{number \geq stock\ size} x100$$

with largemouth bass stock and preferred sizes determined from Anderson and Neumann (1996). Values will be calculated separately for each sample in each pool and averaged for each pool, with descriptive statistics compared across pools.

Abundance. Average largemouth bass abundance as catch per hour (=CPUE) will be computed for each pool and used as a general index of bass density. Descriptive statistics for CPUE will then be compared across pools. Abundance of age-0 largemouth bass will be computed during fall samples only, when age-0 bass have recruited to boat-mounted electrofishing gear and are easily identifiable. Descriptive statistics will be tabulated and similarly compared across pools.

Mortality. Largemouth bass population total annual mortality will be assessed using standard catch-curve analysis (Van Den Avyle and Hayward 1996) done individually for each pool. Log-transformed bass catches (as CPUE + 1) will be used during generation of catch curves via least-squares linear regression analysis. Resulting mortality coefficients (Z) will be derived from slopes of catch curves (i.e., b = Z); actual annual mortalities (A) will then be derived as A = $1 - e^{Z}$ (Ricker 1975) and compared across different pools. Figure 3 below represents a conceptual example for a hypothetical pool.

Off-channel habitat characterization

Off-channel habitats in the Arkansas River will be characterized several different ways. Initially, surface areas of off-channels standardized to pool length or pool area will be used to an index of the general quantity of these habitats in each pool of the river. The general quality of off-channel habitats will be assessed using several measures. Qualitative habitat data visually estimated during each individual electrofishing sample and depth will be used to index the general quality of off-channel habitats in each pool. For instance, physical cover will be categorized as woody, vegetation, rock, other, or mixed, and rated on a scale of 0-10 with zero representing approximately 0% coverage and 10 representing approximately 100% coverage. Similar estimations will be made for overhead canopy cover. Additionally, supplementary data collections are planned for each pool during summer 2005 in order to create detailed profiles of channel and off-channel habitats. Data collected during this effort will include water quality measures such as Secchi reading, dissolved oxygen, water-column chlorophyll-*a*, turbidity, total dissolved solids, pH, and specific conductance. All measures will be used as indices of off-channel habitat quality. Related research being conducted at Mississippi State University using geospatial analyses of the Arkansas River and its off-channel waters also will be made available for analysis. These variables will encompass landscape measures that index the area, quality, and relative change in these habitats over the past

35 years in terms of depth, sedimentation, and physical macrohabitat (e.g., vegetation levels). These data are being generated from an ongoing study at Mississippi State University using Geographic Information Systems technology and should be available by March 2005.

Data analysis

In relating largemouth bass population statistics and OCH measures, it is anticipated that simple linear regression and multiple linear regression analyses will be emphasized. Measures used to characterize off-channel habitats are essentially independent (or predictor) variables that can be used in regression-type analyses. Similarly, stock assessment measures described before will serve as dependent (or response) variables in these same analyses. Figure 4 below represents a hypothetical analysis that might be constructed using data that are planned to be collected. The different points used in the scatterplot represent different Arkansas River pools. Thus, it is anticipated that 11 points will be available for most analyses. Additional data points might be available should some analyses be pooled between years. Although expected that linear regression analyses will be emphasized most, nonlinear regression and multivariate statistical approaches also will be considered when warranted.

Summary

The research proposed herein is unique in that it offers an in-depth examination of potential ecological linkages between largemouth bass population dynamics and off-channel habitats in a large river. Research from other river systems considers these linkages vital to the long-term survival and sustainability of fish populations. The data collected will be a valuable management aid for the Arkansas Game and Fish Commission, giving fisheries managers a detailed look at the current population status and providing guidelines to support current management and baselines to support future management in the river. In the future, results might be used to adjust harvest regulations, alter stocking schedules, and serve as baseline data for future monitoring of the river's largemouth bass population. Results may also provide an impetus for future studies of largemouth bass in the lower Arkansas River.

References

Adams, S.M., and D.L. DeAngelis. 1987. Indirect effects of early bass-shad interactions on predatory population structure and food web dynamics. Pages 103-117 *in* W. C. Kerfoot and A. Sih, editors. Predation: direct and indirect impacts on aquatic communities. University Press of New England, Hanover, New Hampshire.

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

AGFC (Arkansas Game and Fish Commission). 2002. Arkansas largemouth bass management plan. Arkansas Game and Fish Commission, Little Rock, AR.

Armantrout, N.B. 1998. Glossary of aquatic habitat inventory terminology. American Fisheries Society, Bethesda, Maryland.

Baker, J.A., K.J. Kilgore, and R.L. Kasul. 1991. Aquatic habitats and fish communities in the Lower Mississippi River. Reviews in Aquatic Sciences 3:313-356.

Burkhardt, R.W., and S. Gutreuter. 1995. Improving electrofishing catch consistency by standardizing power. North American Journal of Fisheries Management 15:375–381.

Busacker, G.P., I.R. Adelman, and E.M. Goolish. 1990. Growth. Pages 363-387 in C.B. Schreck and P.B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland.

Carlander, K.D. 1977. Handbook of freshwater fish biology. Vol. 2. Pages 218-225.

DeVries, D.R., and R. V. Frie. 1996. Determination of age and growth. Pages 483-512 *in* B.R. Murphy and D.W. Willis, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Eggleton, M.A. and H.L. Schramm, Jr. 2004. Feeding ecology and energetic relationships with habitat of blue catfish, *Ictalurus furcatus*, and flathead catfish, *Pylodictis olivaris*, in the lower Mississippi River, USA. Environmental Biology of Fishes 70:107-121.

Etnier, D.A. and W.C. Starnes. 1993. The fishes of Tennessee. University of Tennessee Press.

Fuhr, M.A., D.H. Wahl, and D.P. Philipp. 2002. Fall abundance of age-0 largemouth bass is more important than size in determining age-1 year class strength in Illinois. Pages 91-100 *in* D. P. Philipp and M. S. Ridgway, editors. Black bass: ecology, conservation, and management. American Fisheries Society Symposium 31.

Garvey, J.E., R.A. Stein, R.A. Wright, and M.T. Bremigan. 2002. Exploring ecological mechanisms underlying largemouth bass recruitment along environmental gradients. Pages 7-24 *in* D. P. Philipp and M. S. Ridgway, editors. Black bass: ecology, conservation, and management. American Fisheries Society Symposium 31.

Gore, J.A. and F.D. Shields, Jr. 1995. Can large rivers be restored? BioScience 45:142-52.

Goulding, M. 1980. The fishes and the forest, explorations in Amazonian natural history. University of California Press.

Heidinger, R.C. 1975. Life history and management of the largemouth bass. Pages 11-20 in H. Clepper, editor. Black bass biology and management. Sport Fishing Institute, Washington, D. C.

Johnson, B.L., W.B. Richardson, and T. J. Naimo. 1995. Past, present, and future concepts in large river ecology. Bioscience 45:134-141.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The flood pulse concept in river-floodplain systems. Pages 110-127 *in* D.P. Dodge, editor. Proceedings of the International Large River Symposium. Can. Spec. Publ. Fish. Aquat. Sci. 106.

Karr, J.R. 1999. Defining and measuring river health. Freshwater Biology 41:222-234.

Le Cren, E.D. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch Perca fluviatilis. Journal of Animal Ecology 20:201-219.

Limbird, R.L. 1993. The Arkansas River: a changing river. Pages 81-94 *in* L.W. Hesse, C.B. Stalnaker, N.B. Benson and J.R. Zuboy, editors. Restoration planning for rivers of the Mississippi River ecosystem. National Biological Survey, Washington, D. C.

Long, J.M. and W.L. Fisher. 2002. Precision and bias of largemouth, smallmouth, and spotted bass ages estimated from scales, whole otoliths, and sectioned otoliths. North American Journal of Fisheries Management 21:636-645.

Nieman, D.A., M.D. Clady, and G.E. Gebhardt. 1979. Sexual maturity of small yearling largemouth bass in Oklahoma. Proceedings of the Oklahoma Academy of Sciences 59: 51-52.

Page, L M. and B.M. Burr. 1991. A field guide to freshwater fishes. Houghton Mifflin Co.

Parkos, J.J. and Wahl, D.H. 2002. Towards an understanding of recruitment mechanisms in largemouth bass. Pages 25-45 *in* D.P. Philipp and M.S. Ridgway, editors. Black bass: ecology, conservation, and management. American Fisheries Society Symposium 31.

Piegay, H. and P. Salvador. 1997. Contemporary floodplain forest evolution along the middle Ubaye River, southern Alps, France. Global Ecology and Biogeography Letters 6:397-406.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47:769-784.

Pennington, C.H. and F.D. Shields, Jr. 1993. Dikes and levees. Pages 115-134 in C.F. Bryan and D.A. Rutherford, editors. Impacts on warmwater streams: guidelines for evaluation. Southern Division of the American Fisheries Society. Warmwater streams committee.

Raibley, P.T., K.S. Irons, T.M. O'Hara, K.D. Blodgett, and R.E. Sparks. 1997. Winter habitats used by largemouth bass in the Illinois River, a large river-floodplain ecosystem. North American Journal of Fisheries Management 17:401-412.

Regier, H.A., R.L. Welcomme, R.J. Steedman, and H.F. Henderson. 1989. Rehabilitation of degraded river ecosystems. Pages 86-97 in D.P. Dodge, editor. Proceedings of the International Large River Symposium. Canadian Special Publications in Fisheries and Aquatic Sciences 106.

Ricker, W.E. 1975. Computation and interpretation of biological statistics in fish populations. Fisheries Research Board of Canada Bulletin 191.

Ricker, W.E. 1979. Growth rates and models. Pages 677-743 *in* W.S. Hoar, D.J. Randall, and J.R. Brett, editors. Fish physiology, Volume 8. Academic Press, New York.

Schramm H.L., S.P. Malvestuto, and W.A. Hubert. 1992. Evaluation of procedures for back-calculation of lengths of largemouth bass aged by otoliths. North American Journal of Fisheries Management 12: 604-608.

Smith, P.W. 1979. The fishes of Illinois. University of Illinois Press.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their floodplains. Bioscience 45:168-182.

U.S. Department of the Interior, Fish and Wildlife Service and U. S. Department of Commerce, U. S. Census Bureau. 2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

Van Den Avyle, M.J. and R.S. Hayward. 1996. Pages 127-166 *in* C.C. Kohler and W.A. Hubert, editors. Inland fisheries management in North America. Second edition. American Fisheries Society, Bethesda, Maryland.

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Human Biology 10:181-213.

Wege, G.J., and R.O. Anderson. 1978. Relative weight (W_r): a new index of condition for largemouth bass. Pages 79-91 *in* G. D. Novinger and J. G. Dillard, editors. New approaches to the management of small impoundment. American Fisheries Society, North Central Division, Special Publication 5, Bethesda, Maryland.

Welcomme, R.L. 1979. Fisheries ecology of floodplain rivers. Longman Publishing Co.

Yeager, B.L. 1993. Dams. Pages 57-113 *in* C.F. Bryan and D.A. Rutheford, editors. Impacts on warmwater streams: guidelines for evaluation. Southern Division of the American Fisheries Society. Warmwater streams committee.

Table 1. Summary statistics for all pools in the lower Arkansas River used in this study.

Pool Number	Common Name	Area (acres)	Area (hectares)	Channel length (miles)	Approx # samples taken	#Samples per 500 h	#Samples per channel mile
2	Pendleton	10600	4290	36	18	2.1	2.0
3	Rising Star	3670	1485	16	10	3.4	1.6
4	Pine Bluff	5680	2300	20	12	2.6	1.7
5	Redfield	6680	2700	21	10	1.9	2.1
6	Little Rock	4710	1905	17	10	2.6	1.7
7	Murray	9700	3925	31	12	1.5	2.6
8	Toad Suck	4130	1670	21	8	2.4	2.6
9	Ormond	4910	1990	28	8	2.0	3.5
10*	Dardenelle	34300	13880	51	18	0.6	2.8
12	Ozark	8800	3560	35	12	1.7	2.9
13	Fort Smith	6820	2760	15	6	1.1	2.5

* There is no pool 11 in the MKN System.

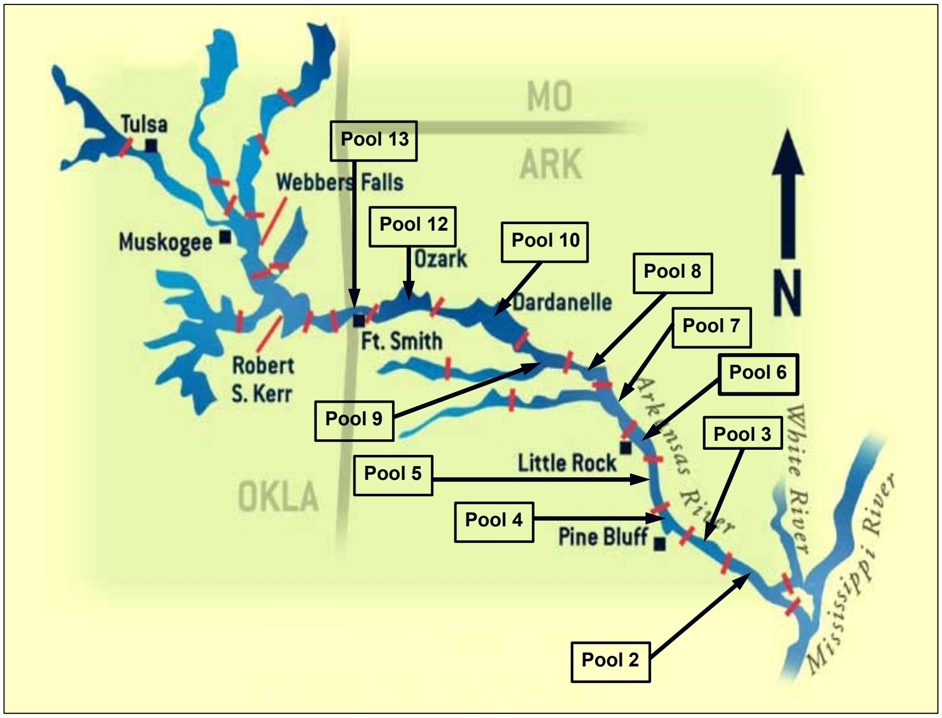

Figure 1. Lower Arkansas River pools used for this study.

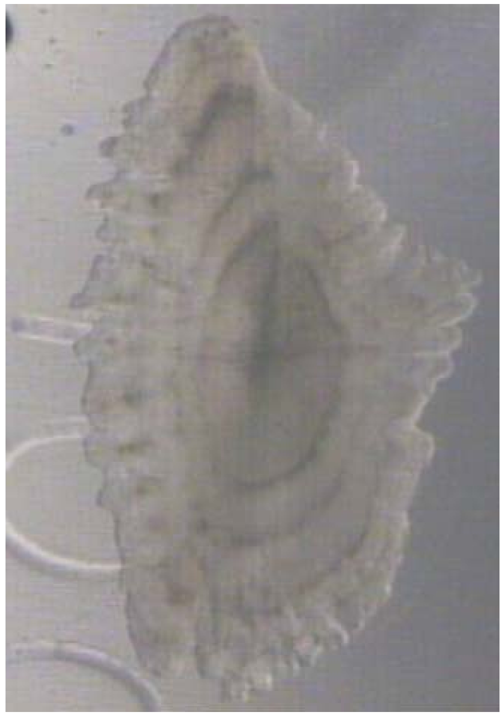

Figure 2. Sagittal otolith used for aging of largemouth bass.

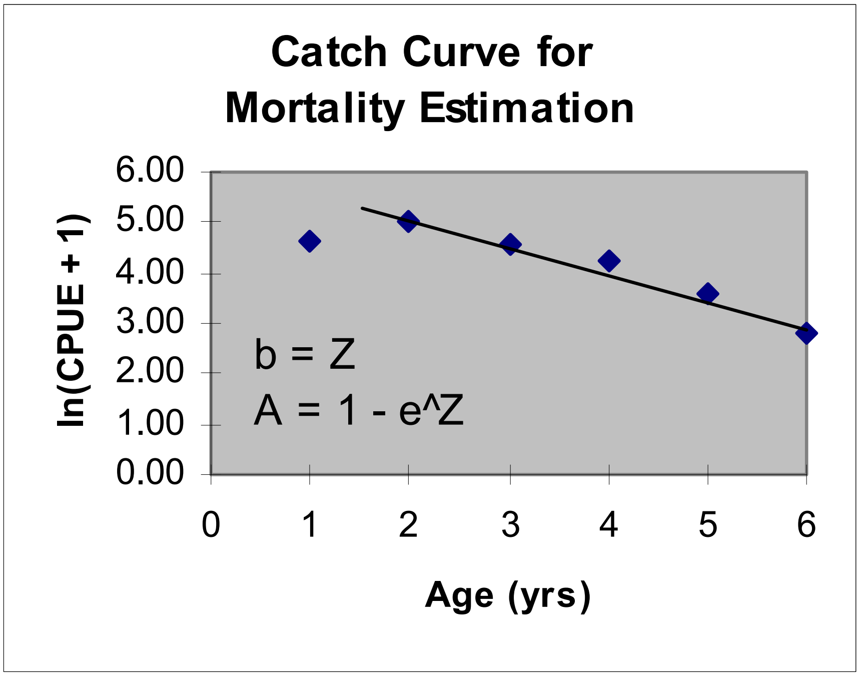

Figure 3. Catch-curve analysis used for estimation of total annual mortality for each pool on the Arkansas River.

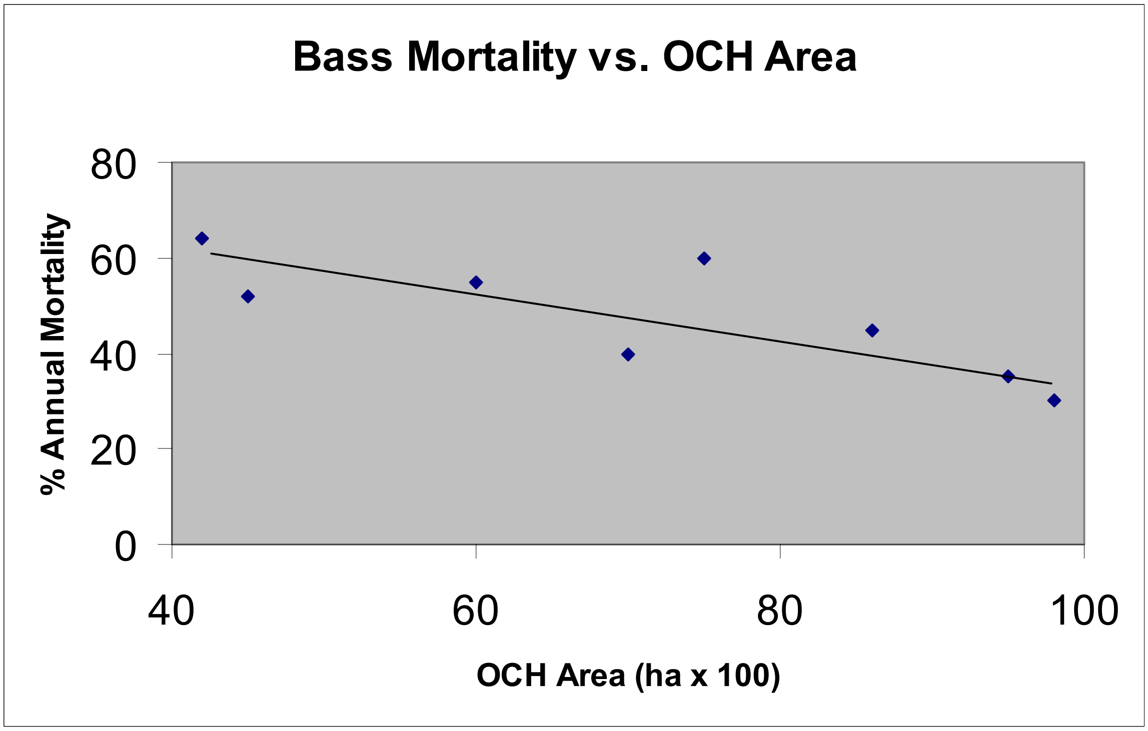

Figure 4. Hypothetical relationship between largemouth bass annual mortality and area of off-channel habitat in the lower Arkansas River.