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Enhancing our Understanding of Age-0 Crappies in Northwest Mississippi Flood Control Reservoirs: A Study on Distribution and Size

Levi Joseph Kaczka

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Enhancing our understanding of age-0 crappies in Northwest Mississippi flood control
reservoirs: A study on distribution and size

By

Levi Joseph Kaczka

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master's of Science
in Wildlife and Fisheries Science
in the Department of Wildlife, Fisheries, and Aquaculture

Mississippi State, Mississippi

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2013

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reservoirs: A study on distribution and size

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Crappie fisheries in northwest Mississippi flood control reservoirs are valued from social and economic standpoints. To mitigate variable recruitment rates of these recreationally valuable species, I sought to gain a better understanding of the population dynamics of these fish during their first year of life. My analyses indicate that embayment habitats in the study reservoirs display a longitudinal distribution gradient of both habitat composition and age-0 crappie abundance during late summer. Additionally, age-0 crappies inhabiting uplake floodplain areas grow to a larger size than downlake embayment-inhabiting conspecifics. The results from this study provide direction on potential management strategies to promote annual recruitment of age-0 crappies in these reservoirs

DEDICATION

I would like to dedicate this work to my family, particularly my wife, Courtney, who provided a daily source of motivation during my time in graduate school.

ACKNOWLEDGEMENTS

I would first like to thank Dr. Miranda for providing the opportunity to further my education in the fisheries field, and also for helping me take full advantage of this opportunity by providing guidance along the way during my graduate career. I would also like to thank my graduate committee members for their advice and guidance on designing and carrying out my research. I am very thankful for Jonah Dagel, Sky Wigen, Ted Alfermann, and Ethan Mower who all helped with collecting the data used in my research.

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CHAPTER I

INTRODUCTION

White crappies (*Pomoxis annularis*) and black crappies (*Pomoxis nigromaculatus*) provide the United States with an angling resource valuable from social and economic standpoints. The 2011 national survey of fishing, hunting, and wildlife-associated recreation indicated that a total of 27.5 million anglers spent an estimated 456 million days fishing freshwaters, with total expenditures in excess of \$27 billion (U.S. Fish and Wildlife Service 2011). Of these anglers, almost a quarter (23%) targeted crappies (*Pomoxis* spp.), accounting for 102 million days of fishing. Crappie fisheries are particularly important within the state of Mississippi. The same survey reported that, of the 651 thousand anglers in the state, approximately 46% targeted crappies in 2011, falling second only to anglers targeting catfish (54%).

Within Mississippi, flood control reservoirs provide some of the best crappie fishing in the state. Arkabutla, Sardis, Enid, and Grenada reservoirs were constructed in the 1940s and 1950s as part of the Yazoo Basin Headwater Project. These reservoirs, located in the northwest section of the state (Figure 1.1), provide a consistent influx to the state's economy and are regarded as being among the top crappie fisheries in the country. Hutt et al. (2013) estimated the total economic impacts of Sardis Reservoir in 2006 and Grenada Reservoir in 2007 to be \$5.83 and \$2.15 million, respectively. Popular fishing websites such as www.OutdoorLife.com and www.FishHound.com rank the quality of

crappie fishing in Grenada Reservoir as number one in the country, with the other three being among the top crappie fisheries as well. Despite their reputations Mississippi crappie fisheries, like most crappie fisheries, are susceptible to variable year-class strength that can substantially affect fishery characteristics from year to year.

Year-class strength in fish populations is determined during the early stages of life, often in the weeks following hatch (Diana 1995). Much of the literature concerning juvenile crappies has recognized the issue of variable recruitment (Mitzner 1981; McDonough and Buchanan 1991; Maceina and Stimpert 1998; Sammons et al. 2001), yet conclusive results suggesting strategies to mitigate this variation remain elusive. Several studies have suggested that water level management may be one of the most influential factors in determining recruitment rates (e.g., Sammons et al. 2002; Maceina 2003). If water level does in fact play the influential role in crappie recruitment as evidenced in the literature, then it is conceivable that northwest Mississippi reservoirs would be a prime example of such recruitment variation. The hydrologic regime in each of the reservoirs is managed according to “guide curves”, which indicate a target elevation to maintain water level throughout the year (Figure 1.2). Guide curves are fixed and do not change year to year; however, annual variability in precipitation often causes water levels to deviate from the guide curves. These reservoirs were constructed to provide flood control for the downstream agricultural area; as such they experience drastic annual water level fluctuations ranging 3.3-7.3 m. Such water level fluctuations may be a driving factor influencing the quality and quantity of seasonal nursery habitat for age-0 fishes.

Water level fluctuations within the regulated zone provided by the guide curve over the life of the reservoirs have caused degradation of littoral zones valued as

spawning and rearing grounds for crappie populations (Meals and Miranda 1991). Dagele and Miranda (2011) described downstream embayments in Enid Reservoir as having highly eroded shorelines that were devoid of vegetation. In contrast, upstream floodplains were typified by wetland habitats that experienced far less erosion due to flatter bottom profiles and a seedbank of floodplain vegetation. Dagele and Miranda (2012) suggested the floodplains provided better habitat over embayments to juvenile crappies and reported greater abundances of age-0 crappies in the wetland-type habitats. Furthermore, Dagele and Miranda (2011) found that vegetated habitat in embayments was unlikely to become available to age-0 crappies unless water levels rose above normal pool in a given year. Although reservoirs represent man-made systems, impounding a high order river at lower elevations often results in maintaining seasonal flooding in the river's expansive natural floodplain. As such, seasonal flooding in these upstream areas mimics the "moving littoral" as described in the flood-pulse concept of Junk et al. (1989). Because of the higher gradient shorelines in embayments, and a seedbank composed mainly of upland vegetation less tolerant of prolonged inundation, the "moving littoral" effect does not become noticeable until water levels rise above normal pool and is much less pronounced than in upstream floodplains. Given the obvious physical differences in habitat characteristics between embayments and floodplains of northwest Mississippi reservoirs, and the importance of these systems to crappie populations, my research was aimed at gaining a better understanding of how these common habitat types may affect age-0 crappies.

My research focused on two aspects of age-0 crappie dynamics in flood control reservoirs. First, I wanted to determine if embayments did in fact lack the nursery habitat

for age-0 crappies that was previously suggested in the literature. Previous studies on reservoir fisheries have occurred on a spatial scale that may prohibit detection of small, but important, variations in population dynamics. To my knowledge, none of the literature on reservoir centrarchid populations has described juvenile abundance on a scale smaller than the macrohabitat (e.g., embayments). Because embayments are lateral projections of the main reservoir and formed by an incoming tributary, it is conceivable that the upstream ends of embayments would mimic the upstream floodplains of the main reservoir, albeit on a smaller scale. If so, taking a holistic approach to classifying the value of nursery habitat in embayments may not benefit management strategies. Additionally, the relatively small size of embayments makes them more manageable than larger areas in reservoirs. To that end, the first objective of my research was to determine if reservoir embayments display longitudinal gradients in habitat composition, and if such gradients are paralleled by gradients in age-0 crappie distribution.

The second aspect of my research was to determine the biotic/abiotic interactions that may influence body size of age-0 crappies. It has been shown in the literature that survival of age-0 sportfishes is often size-dependent (Oliver et al. 1979; Miranda and Hubbard 1994; Nilsson and Brönmark 2000), yet only one study to my knowledge has looked at body size of age-0 crappies as a dependent variable (Sammons et al. 2001). This void in the literature warrants the need for research that helps to increase our knowledge of the factors affecting body size in age-0 crappies since body size plays a key role in survival, and thus recruitment. To that end, the second objective of my research was to determine if differences existed in age-0 crappie total length between embayment

and floodplain habitats while accounting for potential confounding effects of water level, species, and abundance.

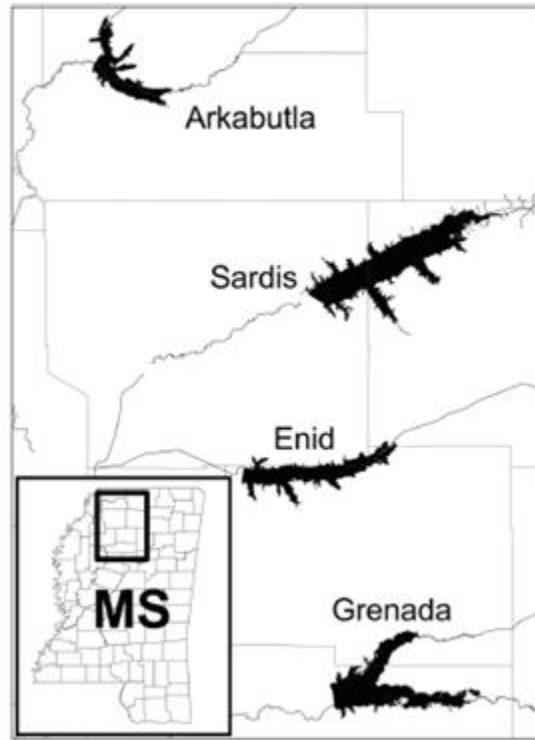


Figure 1.1 Location of the study reservoirs in northwest Mississippi

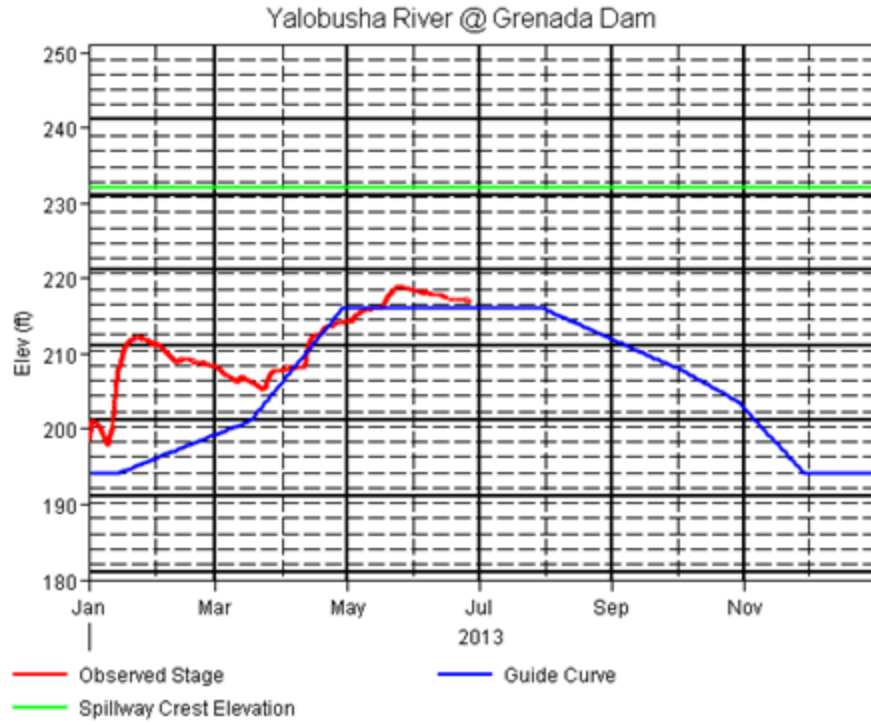


Figure 1.2 Example of a guide curve and water level for Grenada Reservoir

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CHAPTER II
GRADIENTS OF MICROHABITAT AND CRAPPIE *POMOXIS* SPP.
DISTRIBUTIONS IN RESERVOIR EMBAYMENTS

Introduction

Embayments are conspicuous macrohabitats in reservoir systems. They are formed when the impounding structure causes flooding into small lateral tributaries to the reservoir. Embayments are often characterized as having high gradient and eroded shorelines associated with annual water level fluctuations and wind action (Fujita 1977). It is generally accepted that the highest production in lentic systems occurs within the littoral zone (Kalff 2002), and in reservoirs the highest proportion of littoral to pelagic area is generally found in embayments. Moreover, physicochemical characteristics of embayments can be heavily influenced by their tributaries (Kennedy and Walker 1990). Thus, embayments may often represent separate ecosystems from the main body of a reservoir as they provide a contrasting representation of shallow water that is conducive to development of distinct abiotic and biotic environments.

With respect to fish, embayments serve as important habitats that harbor fish assemblages often different from main lake-areas (Van Winkle et al. 1981; Jackson et al. 1991; Meals and Miranda 1991). Most lentic fish utilize littoral areas at some point in their life for spawning habitat, forage source, or predator avoidance (Hayes et al. 1999). In summer, reservoir embayments can be dominated by juveniles of various lentic species

often influential in reservoir fish assemblages (Meals and Miranda 1991). In spring, embayments attract a diversity of shallow-water species that, temporally over several months, take turns in using available spawning microhabitats in response to gradients in temperature, photoperiod, and possibly water levels (Miranda et al., 2013). Availability of embayment habitat can be greatly affected by the extent and timing of water level fluctuations (Hayes et al. 1999). Fluctuations control factors such as embayment depth, area, substrate composition, water quality, and magnitude and composition of the land-water ecotone, all of which can influence an embayment's habitat suitability for fish. Moreover, embayments may display a gradient of fish microhabitats shaped by lowland riparian zones at the entrance of tributaries, favoring specialist riverine and wetland plant species, shifting to microhabitats shaped by upland environments as the embayment progresses towards the main lake, favoring terrestrial plant species.

Despite the apparent value of embayments to various species/life stages of reservoir fishes, relatively little research has specifically examined how these habitats may influence recruitment success of juvenile fish. Previous research on centrarchids, mainly crappies (*Pomoxis* spp.) and largemouth bass (*Micropterus salmoides*), has used spatial scales too coarse to detect potential patterns that may compliment the aforementioned gradients in embayment microhabitats. Studies conducted on reservoirs mostly quantify estimates of population dynamics at the reservoir scale (e.g., Mitzner 1981; Guy and Willis 1991; Maceina and Stimpert 1998), some quantify them according to the upper, middle, and lower sections of reservoirs (Bryant et al. 1999; Sammons et al. 2002) and fewer have reduced spatial scale to the macrohabitat level (e.g., embayments) (Irwin et al. 1997). The spatial scales commonly used in reservoir fisheries research

prohibit detecting potential intra-habitat variation in population dynamics. A better understanding of embayments as fish habitat can be beneficial to reservoir managers because their relatively small size make them more manageable than main-lake areas. Considering this void in the reservoir literature, I sought to gain a better understanding of the distribution of microhabitats within embayments, their relationship to water levels, and distribution of age-0 crappies *Pomoxis* spp. along habitat gradients. Crappies receive a significant amount of angler effort in many reservoirs in the southeastern U.S., and increasing our understanding of the mechanisms behind their variable recruitment rates may lead to improved management of this economically and socially valuable species. Specific objectives of this study included 1) determine if embayment macrohabitats within four northwest Mississippi reservoirs showed a longitudinal (i.e., main-lake to rear of embayment) gradient in habitat composition; and 2) determine if an accompanying gradient in relative abundance of age-0 crappies existed at the same scale.

Methods

Study sites

This study was carried out within embayments of Arkabutla (34°45'26" N, 90°07'28" W), Enid (34°09'28" N, 89°54'14" W), Grenada (33°48'32" N, 89°46'14" W), and Sardis (34°24'21" N, 89°47'25" W) reservoirs in northwest Mississippi. These 4,600-14,500 ha flood-control reservoirs are 60-70 years old and their littoral zones have been extensively affected by annual water level fluctuations that range 3.3-7.3 m. As a result of these fluctuations, embayments in the study reservoirs commonly have barren shorelines that require above normal water levels to inundate mostly upland vegetation, but some wetland vegetation occurs towards the rear of embayments (Miranda et al.,

2013). These embayments typically have high sloping shorelines near the main-lake but slopes generally subside towards the entrance of tributaries. The changing shoreline slopes are generally susceptible to differing erosion levels that influence the establishment of moist-soil and wetland plants; due to water level fluctuations, almost no aquatic plants are present. The reservoirs are within a 50-km radius and are similar in physiography, size, and function so that knowledge gained in one reservoir is likely transferable to the other three.

Sample referencing

Sampling locations for habitat composition and fish data were referenced within embayments using a coding system that scored location from 0 to 1. A value of 0 represented a location upstream in an embayment at the entrance of the tributary. Conversely, a value of 1 represented a location downstream where the embayment opens to the main lake. For objectives 1 and 2, locations were fixed based on reservoir water levels modeled at full pool (i.e., spillway crest elevation); therefore, a location value represented the distance from the entrance of the tributary as a percentage based on the maximum potential length of the given embayment. Objective 1 incorporated remotely sensed data (described below), so location values included an entire embayment and ranged from 0 to 1; objective 2 (described below) involved field collections; because during the study years water levels never reached full pool, location values ranged from 0.3 to 1. Although water levels rarely reach full pool elevation in the study reservoirs, modeling water level at this elevation provided a reference suitable for standardizing sample locations in embayments of different lengths. Thus, the coding system indexed relative position within an embayment.

Habitat gradients

Three embayments were selected at Enid Reservoir to analyze longitudinal changes in habitat descriptors including habitat composition, water depth, and shoreline slope. Availability of usable remotely-sensed images limited my analyses of habitat gradients (i.e., objective 1) to Enid Reservoir. Each embayment was analyzed using a Geographic Information System (GIS, ESRI 2006), Digital Elevation Model (DEM, MARIS 2010), and a classified land-cover image obtained from the U.S. Army Corps of Engineers (USACE), Vicksburg District. Land-cover composition (percentage of non-vegetated mudflat, herbaceous, forest, shrub, and wetland) was determined within 500-m cross-sections positioned perpendicular to the longitudinal axis of the embayment (Figure 2.1). Composition was estimated along two elevation contour bands including the band below normal pool and that between normal and full pool. Average depth and shoreline slope within each cross-section was derived using the GIS and DEM for the contour band between normal and full pool only, because DEMs were incomplete below normal pool. Cross-sections were referenced from 0 to 1 longitudinally along the embayment with the coding system described earlier.

I applied an analysis of covariance to test if habitat composition (%) changed with cross-section location (covariate), while accounting for differences among embayment lengths (covariate) and pool elevation (class variable; up-to-normal, normal-to-full). Preliminary analyses with a Shapiro-Wilk test (univariate procedure; SAS Institute 2008) indicated habitat percent compositions were not normally distributed due to a large number of zeros for some cover types, and transformations were not able to adequately normalize distributions. Thus, I applied a nonparametric permutation analysis of

covariance (permanova procedure; Anderson et al. 2008) because it relies on the distribution of the data for significance testing rather than on the normal distribution. The following model was fitted to habitat composition:

$$\hat{d}_{ijk} = \hat{\beta}_0 + \hat{\beta}_1 (\text{location}_i) + \hat{\beta}_2 (\text{pool elevation}_j) + \hat{\beta}_3 (\text{embayment length}_k) \quad (2.1)$$

where,

\hat{d}_{ijk} = similarity in habitat composition between cross-sections (a similarity matrix for every possible pair was constructed with the Bray-Curtis coefficient),

$\hat{\beta}_0$ = intercept,

$\hat{\beta}_1$ = slope for location along the embayment,

$\hat{\beta}_2$ = effect of pool elevation (i.e., full and normal pool),

$\hat{\beta}_3$ = effect of embayment length.

I also considered all possible interactions but sequentially eliminated non-significant interactions one at a time starting with the highest P -value until all interactions remaining in the model were statistically significant ($P \leq 0.10$) based on 10,000 permutations.

Fish gradients

Age-0 crappies were sampled from a single embayment on each of the four study reservoirs over four years (2009-2012), except in Arkabutla Reservoir in 2009.

Collections were made in late summer (day of year 205 to 230) using trap nets (i.e., modified fyke nets). Boxrucker and Ploskey (1988) reported that trap nets effectively sampled age-0 crappies and provided adequate data for making spatial and temporal

comparisons. Sampling in late summer addressed two concerns: 1) sampling was carried out prior to scheduled decreases in water level that would limit motorboat access to the length of an embayment, and 2) age-0 fish were large enough to be retained by the net's mesh and small enough to easily separate from age-1 fish based on their length-frequency distributions. Trap nets had 0.9 x 1.8 m rectangular frames spaced 0.6-m apart, a 0.9 x 30-m lead equipped with a float line and lead line, and a 13-mm nylon bar mesh (Miranda and Boxrucker 2009). At least 10 nets were fished for a 24-h period in each embayment and year. Trap nets were deployed roughly equidistant from front to rear of each embayment, perpendicular to the shoreline, and in areas where the bottom sloped to about 1-2 m in depth. Location of the trap nets within an embayment were referenced from 0 to 1 as described earlier. All types of discernible microhabitats were targeted. Black crappies *Pomoxis nigromaculatus* and white crappies *P. annularis* were combined for analysis.

Catch rates (catch per net) were used to estimate relative abundance of age-0 crappies according to location within reservoir embayments. I applied an analysis of covariance to test if catch rates changed with net location (covariate) along the embayment while controlling for differences across reservoir (class variable; fixed) and water level (class variable; random). Catch rates were not normally distributed due to a large number of zero catches, thus I applied permutation analysis of covariance. The following model was fitted to catch rates:

$$\hat{d}_{ijk} = \hat{\beta}_0 + \hat{\beta}_1 (\text{location}_i) + \hat{\beta}_2 (\text{reservoir}_j) + \hat{\beta}_3 (\text{water level}_k) \quad (2.2)$$

where,

\hat{d}_{ijk} = similarity in catch between two trap nets (a similarity matrix for every possible pair was constructed with the Bray-Curtis coefficient after $\log_e x+1$ transforming catch to

reduce skewness),

$\hat{\beta}_0$ = intercept,

$\hat{\beta}_1$ = slope for location along the embayment,

$\hat{\beta}_2$ = effect of reservoir,

$\hat{\beta}_3$ = effect of water level.

I also considered all possible interactions but sequentially eliminated non-significant interactions one at a time starting with the highest P -value until all interactions remaining in the model were statistically significant ($P \leq 0.10$) based on 10,000 permutations.

Results

Habitat gradients

The image used for Enid Reservoir was taken on April 22, 2007. Although the guide curve for Enid Reservoir targets summer pool on May 1, water levels during the spring of 2007 were far below the guide curve (i.e., approximately 3.8 m below summer pool on the date the image was taken). Using an image that represented unusually low water levels, I was able to index how potential age-0 crappie habitat would change longitudinally along embayments during a low water year when late summer water levels

increased to normal pool or above. The USACE water level records indicated that this image reflects conditions that have occurred in less than a third (28%) of years since Enid Reservoir was created under the current hydrograph.

Thirty-two 500-m cross-sections were analyzed on three embayments of Enid Reservoir that ranged in area from 330 to 700 ha and in length from 4.5 to 6.5 km, at full pool elevation; embayment 1 included 9 cross-sections, embayment 2 included 13 cross-sections, and embayment 3 included 10 cross-sections. Depth and bank grade in the front of embayments between normal and full pool averaged 3.6 m and 7.7%, respectively. The rear of embayments had an average depth of 1.1 m and bank grade of 1.2%. Up to normal pool, mudflats accounted for an average 71.2% of the cover, herbaceous plants for 26.2%, forested lands for 1.9%, shrub vegetation for 0.6%, and wetland plants for 0.1%. Between normal pool and full pool, mudflats accounted for an average 7.4% of the cover, herbaceous plants for 49.6%, forested lands for 37.3%, shrub vegetation for 4.4%, and wetland plants for 1.3% (Figure 2.2).

Analysis of covariance indicated that similarity in habitat composition between cross-sections differed depending on location of cross-sections, pool elevation, and embayment length. There was a significant main effect of location (pseudo-F = 24.4, df = 1, $P < 0.01$) suggesting that habitat composition changed along the embayment but similarity was greatest in proximal sites. There was also a significant main effect of pool elevation (pseudo-F = 80.9, df = 1, $P < 0.01$) and embayment length (pseudo-F = 2.6, df = 1, $P \leq 0.05$). The former effect indicated that the degree of habitat similarity between proximal sites depends on water level, while the latter effect indicated that the degree of habitat similarity between cross-sections depends on embayment length. Additionally,

there was significant interaction between embayment length and cross-section location (pseudo-F = 3.4, df = 1, $P = 0.03$) indicating that the extent to which similarity in habitat composition changed between proximal sites depended on the length of the embayment. Significant interaction was also detected between cross-section location and pool elevation (pseudo-F = 19.5, df = 1, $P < 0.01$) indicating that the extent of habitat similarity between proximal sites depended on water level. No other interactions were evident.

Fish gradients

The four embayments included in the fish gradients objective of the study ranged in area from 290 to 700 ha and in length from 1.7 to 6.5 km, at full pool elevation. In all, 1,010 age-0 crappies were collected in 147 nets fished in the four study reservoirs, represented by 82% white crappies and 18% black crappies. Catch rates ranged from 0 to 160 fish per net. Crappies were collected in all embayments except for one at Enid Reservoir in 2010; nevertheless, this embayment was included in all analyses. In general, the number of crappies collected was lowest near the main body of the reservoir and increased towards the rear of embayments (Figure 2.3); however, this pattern was variable.

Similarity in trap net catches differed depending on net location within an embayment, depending on reservoir, and depending on water level. There was a significant main effect of location (pseudo-F = 8.6, df = 1, $P < 0.01$) indicating that similarity in catch rate increased in proximal sites and that relative abundance of age-0 crappies generally increased towards the rear of embayments. There was no significant main effect of reservoir (pseudo-F = 1.6, df = 3, $P = 0.19$) suggesting that catch rates

were similar across reservoirs. There was also no main effect of water level (pseudo-F = 0.9, $df = 1$, $P = 0.36$). However, there was a significant interaction between location and water level (pseudo-F = 3.4, $df = 1$, $P = 0.06$), between reservoir and water level (pseudo-F = 7.2, $df = 3$, $P < 0.01$), and between reservoir and location (pseudo-F = 4.8, $df = 3$, $P < 0.01$). The interaction between location and water level indicated that the degree of catch rate similarity between proximal sites depended on water level. The reservoir and water level interaction indicated that similarity in catch rates between reservoirs depended on water level. The reservoir and location interaction suggested that the pattern of increasing catch rate towards the rear of the embayment showed different rates of increase, likely due to differing embayment characteristics. No other interactions were evident.

Discussion

The lack of vegetation in the littoral zones of many reservoirs can be attributed to continual water level fluctuations and erosion-induced sedimentation (Miranda 2008). These mechanisms prevent littoral zones from establishing a seed bank. Since 1954, water levels in Enid Reservoir reached normal pool in 77% of years, supporting the idea that consistent inundation and erosion below this depth contour has prevented a seed bank from establishing. Therefore, this portion of embayments will show little vegetative growth even in years of low water levels. A similar study by Dagel and Miranda (2011) found that significant amounts of vegetation in a reservoir embayment did not become inundated until water levels reached normal pool. Although normal pool is reached about every 3 of 4 years, water levels do not often go far above this level. In Enid Reservoir the elevation difference between normal and full pool is 5.5 m. Water levels have stayed

within the lower quarter of this range (i.e., < 1.4 m above normal pool) in 65% of years. This indicates that the majority of land between normal and full pool is inundated only every 1 of 3 years, allowing for diverse vegetative growth.

This study is the first to my knowledge that has analyzed how microhabitat shifts longitudinally within a single reservoir macrohabitat; however, past studies have found results similar to mine, but on a larger scale. Johnson (2002) found upstream floodplain habitats supported a high abundance of wetland plant species, whereas this vegetation type was nearly absent in areas of the downstream portion of the reservoir. While wetland species were the most limited vegetation type in the three study embayments on Enid Reservoir, the occurrence of this vegetation type was restricted to the areas upstream in embayments. Likewise, Liu et al. (2009) suggested that the lack of vegetative diversity in downstream areas of reservoirs is attributed to having a seed bank of upland species intolerant of consistent inundation. Although distinguishing plant species was not possible with the land cover image I used, the upper third of the study embayments included herbaceous, forested, shrub, and wetland cover, versus downstream areas that were limited to herbaceous coverage only at normal pool, and herbaceous and forested coverage at full pool.

Adding to the observed patterns, average depth and shoreline slope decreased towards the rear of embayments, likely from a combination of natural topographic characteristics as well as sedimentation consequences associated with impounding riverine systems. From a topographic standpoint, tributaries that feed embayments in lowland reservoirs have a natural riparian zone associated with their banks. After lowland zones near the front of embayments become inundated water begins flooding

upland areas with steeper gradient shorelines resulting in greater depth. Processes associated with river impoundment also add to the shoreline slope and depth differences observed. The greatest amount of sedimentation occurs in the transition zone in the upper portion of reservoirs (Thornton 1990). This represents the area where flowing water meets the standing waters of the reservoir, and the sediment load associated with the main channel is deposited. Similarly, tributaries that feed embayments bring with them an associated sediment load and this load is deposited in the upper reaches of embayments, reducing depth and shoreline slope. In Lake Texoma, Texas-Oklahoma, depositional shorelines in embayment rears had significantly lower slopes than non-depositional shorelines (Patton and Lyday 2008). A progression from mudflats to dense vegetation is often represented in areas where depositional filling has occurred (Patton and Lyday 2008).

Crappie catch rates differed across net locations, reservoirs, and water levels. The location effect indicated that relative abundance of age-0 crappies generally increased towards the rear of embayments. I suspect this trend is associated with habitat gradients within embayments. Given that crappies have been documented as being relatively mobile during the juvenile stages of life (Siefert 1968; Travnichek et al. 1996; Pine and Allen 2001), it is conceivable that they would actively seek habitats in an embayment favorable to survival. Because trap nets are a passive gear, they depend on fish movement to collect a sample. I operated under the assumption that movement by age-0 crappies was constant over the gradient of microhabitats existing over the length of an embayment. However, if movement, and thus catchability, of age-0 crappies increased in unappealing microhabitats (i.e., possibly front of embayments) and decreased in

appealing microhabitats (i.e., possibly rear of embayments), then the true distribution pattern of age-0 crappies in the study embayments could have been misestimated as the front-to-rear gradient may be more pronounced than my results indicate. The interaction between location and water level likely resulted from water level variations causing differences in habitat composition for the same location. Because I used standardized locations to represent net position in an embayment, two nets could have been fished in the same relative position within an embayment, but in different habitats because of differences in water level. Further inspection of the interaction indicated that abundance gradients were most pronounced in low water years. This observation parallels habitat composition that is longitudinally very different during low water, but more uniform during high water. Thus, water level could influence the pattern of catch rates as fish distribution along the embayment may shift due to habitat availability changes. Besides water level, the longitudinal patterns in catch rates along embayments were affected by embayment morphometric peculiarities, as suggested by the location \times reservoir interaction. Nevertheless, the general pattern was that of increasing densities of crappies towards the rear of embayments. Studies by Borawa et al. (1979) and Moxley and Langford (1985) corroborate my findings as both of these studies noted an increase in younger fish as plant density increased.

Embayments in the study reservoirs presented longitudinal habitat patterns that potentially affected crappie distribution and conceivably other species not targeted by my study but that orient relative to habitat structure. My results can help inform management efforts designed to improve fish habitat. A major characteristic of the study reservoirs is their pronounced annual water level fluctuations. Depending on water level, a large

percentage (90-95%) of an embayment can be dewatered. The effect of the drawdown on embayment habitat depends on timing. Early drawdowns are preferred to allow sufficient time for vegetation growth before the first frost in late autumn. Because drawdowns can take several weeks, and considering the flatter bottom profiles in the rear of embayments compared to the front, large areas become dewatered near the rear of the embayment early, whereas smaller areas become dewatered near the front of the embayment later. Thus, habitat enhancement through planting of annual grasses may be most beneficial if done early near the rear of embayments. Strange et al. (1982) found that seeding shorelines of Lake Nottely, Georgia, increased age-0 black bass (*Micropterus* spp.) abundance during early summer as well as increased growth and condition of age-0 fish compared with those in unseeded control sites. Ratcliff et al. (2009) found that juvenile black bass abundance in reservoir littoral habitats was 54 times greater at sites with planted beds of cereal barley *Hordeum vulgare* than at non-planted control sites. That study suggested that grassbed treatments are a cost-effective method for large-scale habitat enhancement projects to improve juvenile fish survival in reservoirs. Azami et al. (2012) reported successful seeding of willow trees (*Salix* spp.) along a reservoir shoreline when seeding occurred during the annual drawdown period. Despite these findings it should be noted that the degree of success for shoreline seeding is variable among studies, and benefits would be unlikely to last for multiple years as long as flooding lasts for weeks and months. Introduction of structures such as woody debris (Brouha and von Geldern 1979; Wege and Anderson 1979; Miranda and Hubbard 1994) may be best accomplished in winter and positioned near the front of embayments where terrain is steeper and annuals are less abundant because of the shorter growing season.

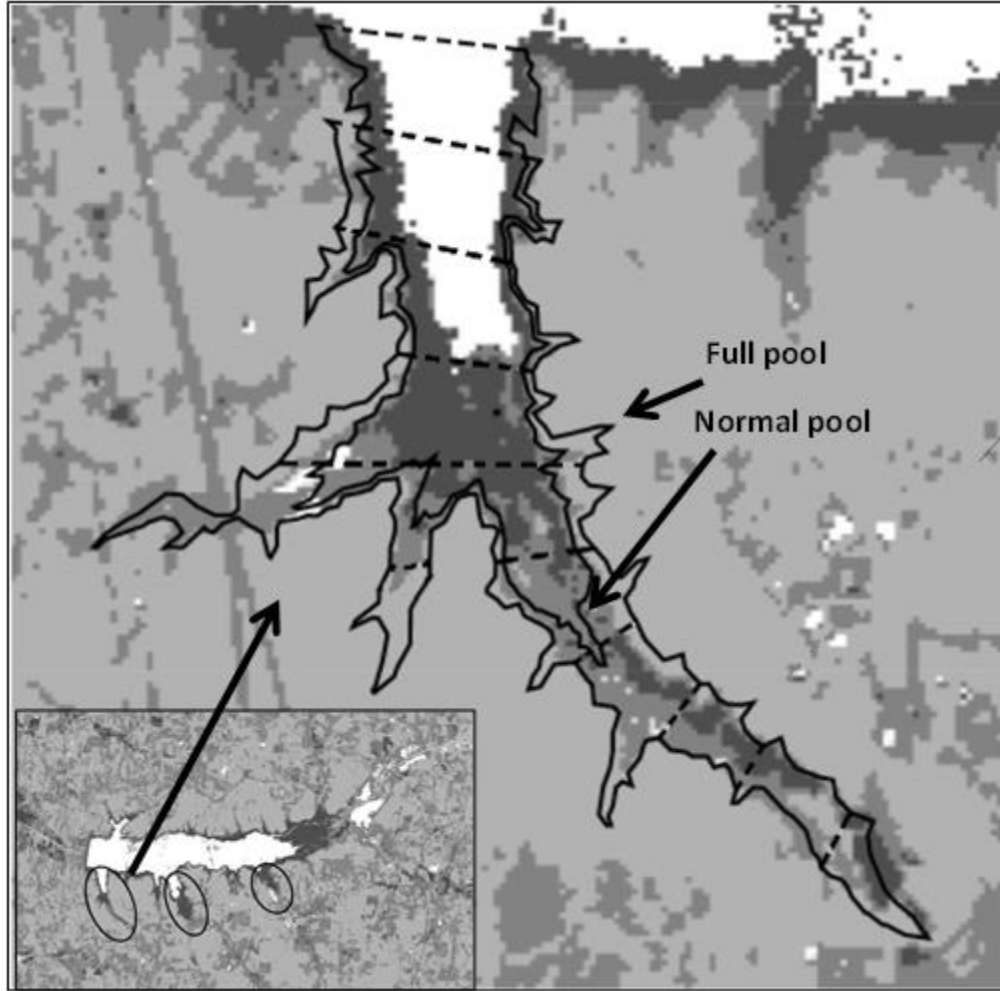


Figure 2.1 Depth bands indicating full and normal pool levels in an embayment of Enid Reservoir.

The dashed lines represent 500-m cross-sections. The three embayments analyzed for habitat composition gradients are indicated by the black ovals in the inset image of the reservoir.

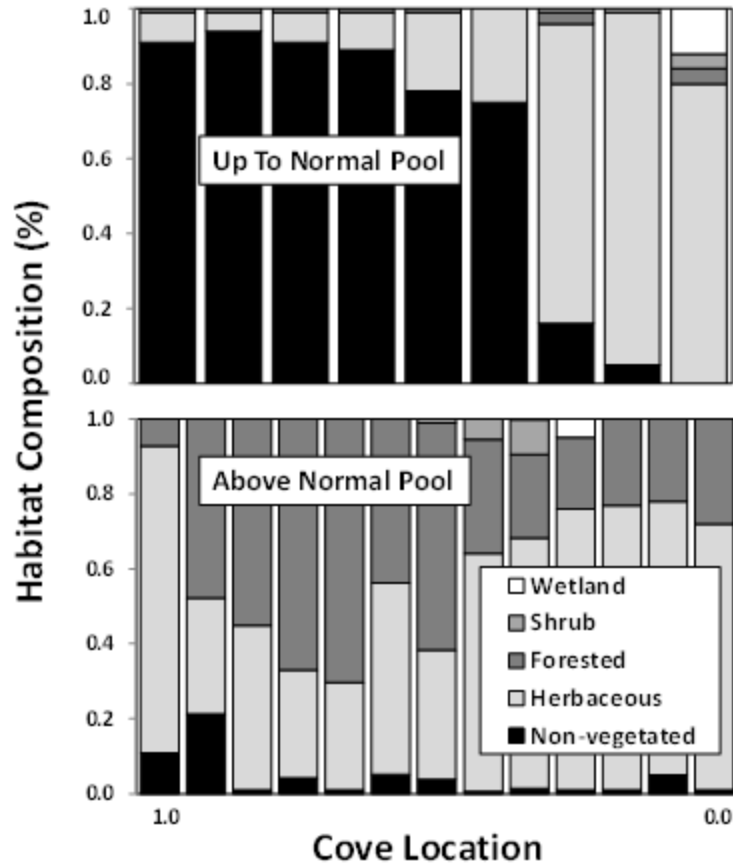


Figure 2.2 Habitat composition within 500-m cross-sections at two pool levels in an embayment of Enid Reservoir.

Location indicates relative position of the cross-section from front of the embayment (1) to rear of the embayment (0).

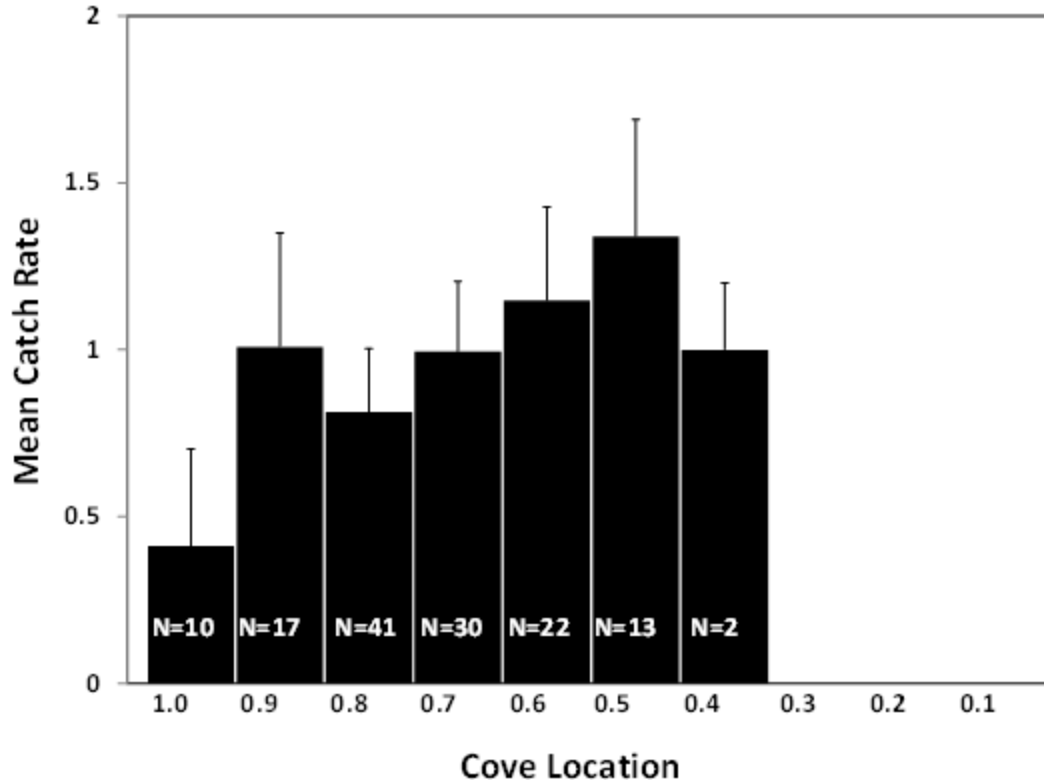


Figure 2.3 Mean catch rates ($\log_e x+1$) for crappies collected in trap nets fished longitudinally along reservoir embayments.

Location indicates relative position of the trap net from front of the embayment (1) to rear of the embayment (0). Water levels during the course of the study remained below full pool, thus preventing upstream access beyond a location of 0.3. The vertical lines represent standard error and N represents the number of nets fished within a given embayment location over the course of the study.

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CHAPTER III
SIZE OF AGE-0 CRAPPIES *POMOXIS* SPP. RELATIVE TO HABITAT,
ABUNDANCE, AND RESERVOIR WATER LEVEL

Introduction

Crappie (*Pomoxis* spp.) populations are dynamic, often influenced by many factors that affect their stability. One such factor that is widely recognized, yet poorly understood, is highly variable recruitment of age-0 crappies (McDonough and Buchanan 1991; Maceina and Stimpert 1998; Sammons et al. 2000). Inconsistent recruitment of reservoir crappie populations and the importance of these fisheries in the US warrant further research on factors affecting survival of age-0 crappies. Relatively few studies have focused on this topic, and even fewer have looked at habitat as a main influence. Former research has looked at feeding behaviors (Gebhart and Summerfelt 1978; Ellison 1984; O'Brien et al. 1984) and influence of water level (Mitzner 1981) on abundance of age-0 crappies, while others have looked at water quality parameters such as turbidity (Spier and Heidinger 2002), temperature (St. John and Black 2004), and dissolved oxygen (Hale 1998) to explain growth and recruitment. Although most of these studies produced inconclusive results, those studies by Hale (1998), Spier and Heidinger (2002), and St. John and Black (2004) suggested that factors other than water quality are likely to be most influential on age-0 crappie growth and recruitment.

Several studies have used seasonal reservoir hydrology to explain crappie recruitment. Maceina and Stimpert (1998) found that crappie recruitment was positively related to pre-spawn water levels in several Alabama impoundments. That study suggested recruitment was not related to spawning and post-spawn hydrologic conditions. Sammons et al. (2002) found similar results in Tennessee reservoirs, suggesting that high discharge during the pre-spawn period was consistently related to higher crappie recruitment rates. Conversely, Dagel and Miranda (2012) found that age-0 catch rates in four Mississippi reservoirs were inversely related to pre-spawn water levels, suggesting that early inundation of terrestrial vegetation caused senescence of these plants prior to peak spawning periods. None of these studies, however, looked at how water level affects fish size, which is likely a contributing factor to age-0 recruitment.

Large body size for age-0 fishes entering their first winter of life would conceivably provide survival advantages over their smaller-bodied conspecifics. High overwinter mortality among smaller age-0 fish has been attributed to energy reserve depletion during extended periods of cold water temperature (Oliver et al. 1979; Gutreuter and Anderson 1985; Miranda and Hubbard 1994). More recently, predator-prey interactions have been used to explain size-specific mortality in age-0 fishes as a function of predator gape limitations (Nilsson and Brönmark 2000) and increased predator avoidance by larger fish (Lundvall et al. 1999). Although the causal factors influencing size-specific mortality among age-0 fishes are likely interdependent, research has shown that body size, to a large extent, directly relates to greater survival of age-0 fishes.

Habitat may also play an important role in shaping body size of age-0 fish (Tupper and Boutiller 1995). Reservoirs impounded over floodplain rivers are unique because they may include in their upper reaches extensive shallow water representing the exposed floodplain of the impounded river (Miranda 2008). Reservoirs that experience large seasonal water level fluctuations as part of their operational objective (i.e., flood control) mimic, to an extent, the natural seasonal inundation of upstream floodplain areas. This seasonal flooding likely benefits crappies, which have evolved to rely on seasonal access to these areas in order to complete their life cycle (Siefert 1968). In years when floodplains are not inundated, rearing areas in reservoirs may be restricted to shallow waters in embayments. Embayments of aging reservoirs are characterized as having high gradient, eroded banks, often including broad bands of mudflats with no or little vegetation (Fujita 1977; Kaczka and Miranda 2013), and therefore provide inferior habitat for juvenile crappies.

Given this background, continued research on the interactions of habitat and age-0 crappie size may improve understanding of how to enhance potential control over year-class strength in reservoirs. Thus, the objective of this study was to determine differences in age-0 crappie total length between embayment and floodplain habitats, while accounting for potential confounding effects of water levels, species, and abundance.

Methods

Study sites

This study was carried out within embayments and inundated upstream floodplain areas of Arkabutla (34°45'26" N, 90°07'28" W), Enid (34°09'28" N, 89°54'14" W), Grenada (33°48'32" N, 89°46'14" W), and Sardis (34°24'21" N, 89°47'25" W) reservoirs

in northwest Mississippi. The four reservoirs were constructed in the 1940s and 1950s as part of the Yazoo Basin Headwater Project. The primary use of these reservoirs is for floodwater storage; as such, these systems experience extreme annual water level fluctuations (3.3 to 7.3 m) following guide curves established by the U.S. Army Corps of Engineers. However, variation in annual precipitation may cause water levels to exceed or fall below the pre-determined guide.

All four reservoirs are similar due to their close geographic proximity (within a 50 km radius), age, and large water level fluctuations. Annual fluctuations over the past 60 to 70 years have caused habitat degradation of littoral zones valuable to the reservoirs' fish communities (Meals and Miranda 1991). However, habitat degradation is not uniform throughout these reservoirs. Downstream embayments are often characterized as having high gradient, eroded shorelines that are devoid of vegetation due to wind and wave action and continual water level fluctuations (Dagel and Miranda 2011). Conversely, upstream reaches of the study reservoirs are typified by low gradient bottom profiles and wetland habitats as the wide floodplains of tributary rivers meet the reservoirs. These upper reaches are flooded during the crappie growing season in approximately 90% of years to provide seasonal fish habitat valued as spawning and rearing grounds for floodplain oriented species (Miranda et al. 2013). Due to their morphometric differences, these two habitats are affected by water level increases differently. Depending on reservoir, floodplains become inundated when water levels are as low as 2-3 m below normal pool, whereas vegetation in embayments does not become inundated until water levels are at or above normal pool.

Fish collections

Age-0 crappies were collected from embayments and floodplains in the four study reservoirs in late-July to mid-August, 2009-2011 (day of year 205 to 230) using trap nets (i.e., modified fyke nets). Boxrucker and Ploskey (1988) reported that trap nets effectively sampled age-0 crappies and provided adequate data for making spatial and temporal comparisons. Sampling in late summer addressed two concerns: 1) sampling was carried out before scheduled decreases in water level that would limit motorboat access to sampling sites, and 2) age-0 fish were large enough to be retained by the net's mesh and small enough to easily separate from age-1 fish based on their length-frequency distributions. Trap nets had 0.9 x 1.8 m rectangular frames spaced 0.6-m apart, a 0.9 x 30-m lead equipped with a float line and lead line, and a 13-mm nylon bar mesh (Miranda and Boxrucker 2009). At least ten nets were fished over a 24-hour period (i.e., a collection) in one embayment and one backwater in each reservoir and each year, for a total of 24 collections (i.e., 2 habitats, 4 reservoirs, and 3 years). Embayments and floodplain areas sampled remained fixed over the course of the study, but individual net locations within these two habitat types were chosen haphazardly and changed year to year. Embayments ranged 115-440 ha in surface area, and floodplains ranged 970-1,815 ha. Netted crappies were preserved on ice and later identified to species and measured for total length (nearest 1 mm) at a laboratory.

Water levels

I downloaded daily water levels in the study reservoirs from the website www.rivergages.com. Reservoir water level was described as mean deviation (m) from normal pool during the post-spawning season (Julian day 136-230, Miranda et al. 2010).

Because normal pool in the study reservoirs occurs at different elevations, setting normal pool to zero and describing water level as the mean deviation from zero in each reservoir provided a standardized metric for my statistical analyses.

Statistical analyses

An analysis of covariance (ANCOVA; glmselect procedure, SAS Institute 2012) was used to test if median total length of age-0 crappies differed according to habitat (class variable; fixed), species (class variable; fixed), post-spawning season water level (covariate), and age-0 crappie abundance (covariate). The main effects and all possible 2-, 3-, and 4-way interactions were considered by the glmselect procedure; the model was chosen with a stepwise selection process that retained the model with the lowest Akaike's Information Criterion score corrected for small sample size. Crappie abundance was indexed as the number of age-0 crappies collected per net night and was \log_{10} -transformed to rein in a right-skewed distribution and linearize relationships. Additionally, I weighted each median length by its sample size to give more influence to values derived from large samples. Reservoir and year were not part of the model as reservoirs were considered replicates because of their similarity, and year was represented by the different water levels. Adding reservoir and year into the model would improve the coefficient of determination of the final model but would reduce the generality of my conclusions and most likely produce an overfit model.

Results

In all, 258 trap-net samples collected 3,682 age-0 crappies over the three years of study. Floodplains produced 76% of the total catch versus 24% from embayments.

White crappies represented 90% of the total catch versus black crappies representing 10%. Distribution of white crappies favored floodplain habitats which produced 77% of the total white crappie catch versus 23% from embayments. Black crappie distribution was slightly more similar between habitats with floodplains producing 69% of the total catch versus 31% from embayments. Total length ranged 43-106 mm for white crappies and 45-91 mm for black crappies.

Catch per trap net ranged from 0 to 55 and averaged 19 fish per net; a single collection (i.e., at least ten trap nets fished concurrently for a 24-hour period) collected no age-0 crappies and was excluded because no fish lengths were available. Abundance and post-spawning season water levels both varied among reservoirs and years. Deviation from normal pool ranged from -0.09 to 4.12 m. The observed variability in densities and water levels allowed adequate assessment of the effects of these covariates.

Analysis of covariance with median total length of age-0 crappies identified a statistically significant model ($F = 28.6, P < 0.01$) that included habitat, post-spawn water level, and abundance (Table 3.1) with an R^2 of 0.68. A main effect of habitat ($F = 5.9, P = 0.02$) indicated that fish from floodplains were longer than those collected in embayments. A significant abundance effect ($F = 25.9, P < 0.01$) indicated that median length of crappies was density dependent. Furthermore, a significant water level by abundance interaction ($F < 83.4, P < 0.01$) indicated that the nature of the density-dependence relationship changed with water level. There was no statistically significant species effect ($P > 0.10$).

Thus, median length of crappies regardless of species was consistently larger in floodplain than embayment habitats. The interaction indicated that crappie size was

inversely related to density during years of low water levels; that in years with intermediate water levels the effect of density became gradually less important until there was no density-dependence effect (near 2.3 m above normal pool and 85-90th percentile of observed water levels during study period); and that in years of higher water levels (i.e., > 2.3 m above normal pool) increased density was associated with larger median lengths (Figure 3.1). The interaction between density, size, and water level also suggests that the effects of density on length were generally most pronounced at lower densities (i.e., steeper slopes at lower densities in Figure 3.1), and that differences in median length among water levels and habitats were least at low densities (curves converge at low densities in Figure 3.1).

Discussion

This study provides information about first-year growth of crappies, an aspect of crappie ecology that has received limited attention in the published literature. Most previous studies researching early population dynamics of crappies have focused on how recruitment is affected by larval/juvenile abundance (Mitzner 1981; St. John and Black 2004; Bunnell et al. 2006), reservoir hydrology (Maceina and Stimpert 1998; Sammons et al. 2002; Maceina 2003), or a combination of the two. Other than Sammons et al. (2001), I could not find published analyses of biotic/abiotic interactions to explain observed variation in age-0 crappie size. The rather extensive amount of literature recognizing size-specific overwinter mortality of age-0 fishes supports the value of those studies that seek to better understand factors affecting size gains during the first year of life (reviewed by Sogard 1997).

I observed larger age-0 crappies in floodplain habitats across the range of water levels observed over the course of this study. Differing habitat characteristics between embayments and floodplains may account for this effect. Embayments include primarily upland vegetation maladapted to the fluctuations in water level occurring in the study reservoirs. As a result, most upland vegetation has disappeared from the regulated zone of these reservoirs over their 60-70 years life, producing a wide band of mudflats between conservation and normal pool elevations (Kaczka and Miranda 2013). Only above normal pool, where flooding occurs less often and for shorter periods, terrestrial vegetation remains that provides suitable habitat, cover, and harbors food for juvenile crappies when inundated (Dagel and Miranda 2011). Conversely, floodplain habitats represent lowland environments with flatter bottom profiles and an extensive seedbank of wetland plants better suited to withstand the reservoir's water level fluctuations. These habitats allow for a "moving littoral" as described by the flood-pulse concept of Junk et al. (1989); in embayments, the moving littoral effect is essentially non-existent until water levels rise above normal pool. Moreover, as water levels rise through the spring, floodplain habitats in the study reservoirs are flooded when water levels are below normal pool, allowing juveniles access to suitable habitat earlier than in embayments. Access to vegetated floodplains with increased primary productivity relative to embayment mudflats likely translates into increased secondary production by age-0 crappies. The advantages provided by increased nursery habitat in floodplains are likely a synergetic effect of nutrient availability, cover, and macroinvertebrates associated with submerged vegetation not as readily available to age-0 crappies inhabiting embayments.

My results suggested an overall negative effect of density on age-0 crappie size at low water levels, no density dependence at mid-to-high water levels, and a positive effect at high water levels (i.e., as density increased size increased). These effects are likely due to resource availability (e.g., space and food). I suspect that at low water levels size is inversely related to density because of limited resource availability. Age-0 white crappies also exhibited negative density-dependent growth in Texas reservoirs (Pope et al. 2004), and age-0 black crappies in an impoundment and a natural lake in South Dakota (Pope and Willis 1998). At low densities, there were only small or no differences in size regardless of habitat or water level, likely because resource availability was not limiting. However, as density increased size changed rapidly but the rate of change diminished. In the study reservoirs, higher density was directly related to higher water levels that amplify space and food availability. Thus, while abundance is increasing due to higher water levels, so is resource availability, to the extent that the factors that contribute to producing abundant year classes also contribute to producing large juveniles. This effect was also reported in Normandy Reservoir, Tennessee, where high densities of larval crappies were associated with high mean total lengths (Sammons et al. 2001). Whereas this effect is uncommon in the ecological literature, the observed relationship provides evidence that in years with highly favorable environmental conditions, factors that enhance post-spawn survival may also enhance growth and size.

My study indicated differences in median total length of crappies occupying different habitats of flood control reservoirs. While the differences in length appeared small, they could represent substantial differences in energy reserves. For example, median total length of crappies in floodplain habitats was 5% longer than their

embayment-inhabiting conspecifics, but this 5% difference in length translated into a 16% difference in weight (Pope and DeVries 1994). Various studies of overwinter survival of age-0 fishes have shown that small fish depleted their energy reserves sooner than large fish (e.g., Oliver et al. 1979; Miranda and Hubbard 1994), although such effects have not been consistent (Johnson and Evans 1990). Thus, small differences in length by late summer could potentially translate into differential recruitment to age-1 of fish from different habitats.

My study suggests that habitat, density, and reservoir water level interact to play important roles in determining age-0 crappie size in flood control reservoirs. Strategies to enhance median length of a new cohort may focus on enhancing habitat and enhancing access to habitat. Seedbanks in uplake floodplain areas are largely comprised of wetland plants that are tolerant of prolonged inundation and can more readily establish themselves soon after water levels are dropped. Because of this, water level management should allow for late summer drawdowns, which will rejuvenate the vegetation in the floodplain, followed by water level increases several months later to inundate floodplain vegetation synchronous with the crappie spawning season. Retaining water at a high level throughout the crappie growing season may translate to increasing the overall size of age-0 fish before entering their first winter, but will shorten the time available for plant growth. Thus, water management policy may include a system that produces high and low water levels during summer and fall over a period of multiple years.

Because embayment habitats have experienced an increased amount of littoral habitat degradation relative to floodplains, and because seedbanks in these downlake habitats are comprised of a higher proportion of upland vegetation not resistant to

prolonged inundation, management activities may include shoreline seeding in addition to the aforementioned water level management. Kaczka and Miranda (2013) found that areas upstream in embayments of the study reservoirs display abundant amounts of herbaceous vegetative growth after water levels are decreased during late summer/early fall. Shoreline seeding may be a cost-efficient and ecologically effective method of supplementing this growth and extending nursery habitat to the littoral areas downstream in embayments closer to the main lake (Ratcliff et al. 2009). Age-0 black bass (*Micropterus* spp.) displayed increased abundance, growth, and condition in areas of seeded versus unseeded sites along the shorelines of Lake Nottely, Georgia (Strange et al. 1982). Such management actions may allow for enhancement of crappie recruitment rates and help mitigate the negative effects of habitat degradation in flood control reservoirs.

Table 3.1 Parameter estimates for a model relating habitat, species, age-0 crappie density, and water level to median total length of age-0 crappies as defined in text.

Variables	Estimate	SE	F	P
β_0 Intercept	66.40	1.84	1302.5	< 0.01
β_1 Habitat			5.9	0.02
floodplain	3.48	1.43		
embayment	0	0		
β_2 Abundance	-7.32	1.44	25.9	< 0.01
β_3 Water level \times abundance	3.16	0.35	83.4	< 0.01

The main effects and all possible 2-, 3-, and 4-way interactions were considered by the glmselect procedure; the variables listed were chosen with a stepwise selection process that retained the model with the lowest Akaike's Information Criterion score corrected for small sample size.

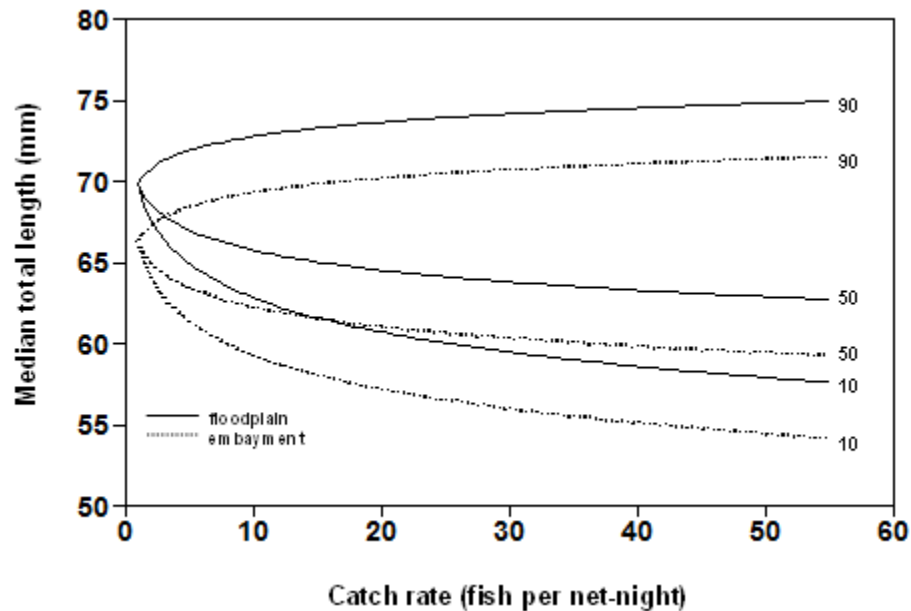


Figure 3.1 Relationship between age-0 crappie median total length and abundance indexed as catch per net night, derived with the model listed in Table 3.1

Relationships are illustrated for floodplain and embayment habitats and for the 10th, 50th, and 90th percentiles of the observed water levels during the study period, corresponding to 0.1, 1.0, and 3.25 m above normal pool, respectively

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