Crappie population characteristics relative to inundation of floodplain habitats in reservoirs

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Catch rates of age-0 and adult crappies *Pomoxis* spp. were compared between floodplains and coves to determine if differences in densities existed between habitats, and to determine if water levels influenced density relationships. Habitat in a cove and a floodplain of Enid Reservoir was mapped to describe differences in vegetation. Adult crappies were collected with electrofishing and age-0 crappies were collected with trap nets. Coves had the greatest spring densities of adults in 2009 and 2010, whereas floodplains attracted adults earlier in the spawning season. Recruitment of age-0 crappies was related inversely to high water levels during months preceding the spawning period, but related directly to high water levels during the spawning period. Floodplains had the greatest densities of age-0 crappies in most years and reservoirs. These results suggest that management to improve recruitment could focus on timing of water level rises and protection of floodplain habitats.

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INTRODUCTION

Black crappie *Pomoxis nigromaculatus* and white crappie *P. annularis* provide important recreational fisheries in the midwestern and southeastern United States. In reservoirs, crappies often rank first or second in total biomass harvested (Jenkins and Morais 1971; Mitzner 1991). The 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation ranked crappies fourth most pursued regarding number of anglers and number of days targeting crappie (USFWS 2006). Likewise, in Mississippi, crappie populations in lakes and reservoirs support substantial recreational fisheries. The 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation for Mississippi ranked crappies fourth most pursued (number of anglers and days) in Mississippi (USFWS 2006).

Popularity of crappie angling is further substantiated in flood control reservoirs (Grenada Lake, Enid Lake, Sardis Lake and Arkabutla Lake) in northwest Mississippi. Since 2000, roving creel surveys on these reservoirs have estimated annual harvest by weight of crappies at 49.9 to 85.7% of total fish harvest (Table 1.1). Total statewide economic impacts from angling at Sardis Lake in 2006 and Grenada Lake in 2007 were estimated at $23.5 million and $12.0 million, respectively (Hunt et al. 2008). In the mid 1990s, a survey at Sardis Reservoir estimated annual crappie exploitation at 48%.

Although the current level of exploitation is unknown, anecdotal evidence suggests that annual crappie exploitation has increased due to increased fishing effort and more efficient angling techniques (multiple poles; Meals et al. *In Press*). A comparison of crappie catch rate and harvest rate between single-pole and multiple-pole anglers on Sardis, Grenada and Enid reservoirs provided evidence that multiple-pole anglers had greater catch rates and greater harvest rates. Single-pole anglers had a mean crappie catch rate of 1.2/h and harvested 0.9/h, whereas multiple-pole anglers had a mean catch rate of 3.1/h and harvested 1.8/h (Meals et al. *In Press*). Anecdotal evidence of the increasing demand for crappie angling on these reservoirs, the associated economic implications, and expected increase in exploitation warrant intensified efforts to develop management strategies that can maintain or enhance these crappie fisheries.

Dynamic rate functions (recruitment, growth, and mortality) are primary factors affecting fish population dynamics. For crappie, recruitment is often viewed as the governing and most variable of the 3 rate functions (Allen 1997). Variability associated with recruitment often results in uncertainty and increased complexity in managing crappie populations. Recruitment variation can affect estimates of other rate functions, which may hinder population responses to management actions. Consequently, an understanding of recruitment dynamics and factors affecting recruitment are of great importance to effective management of crappie populations.

Crappie recruitment is reported to be greatly variable (McDonough and Buchanan 1991; Webb and Ott 1991; Guy and Willis 1995; Allen and Miranda 1998; Pope and Willis 1998) and characterized as cyclic, with strong year classes reoccurring every 3 – 5 years (Swingle and Swingle 1967). Variable and cyclic recruitment often results in “boom-and-bust” crappie fisheries, where years of increased angler catch rates are followed by years of decreased catch rates (Colvin 1991; Webb and Ott 1991). Studies have shown that water-level manipulation is a useful management option for increasing likelihood of producing strong crappie year classes (Beam 1983; Mitzner 1991).

Variability in crappie recruitment has been attributed to density-dependent and density-independent factors, many of which are inter-correlated. Density-dependent factors affecting recruitment can include food availability (Ellison 1984; Pope and Willis 1998; Pine and Allen 2001), predation (Swingle and Swingle 1967; McDonough and Buchanan 1991; Pine and Allen 2001), and adult stock abundance (Miller et al. 1990; Dockendorf and Allen 2005). Density-independent factors affecting recruitment can include variables such as water temperature (Siefert 1968; McDonough and Buchanan 1991; Mitzner 1991), wind (Mitzner 1991; Guy and Willis 1995), discharge (Sammons and Bettoli 2000; Sammons et al. 2002), water level (Mitzner 1981; Ploskey 1986; Maceina and Stimpert 1998), chlorophyll-a (Dubuc 2002), spawning habitat availability (Pope and Willis 1998; Phelps et al. 2009), and turbidity (Mitzner 1991). McDonough and Buchanan (1991) and Allen and Miranda (2001) reported that variable crappie recruitment results from the interaction of density-dependent and density-independent factors. Magnitudes of the interactions vary over time and space, resulting in unpredictable fluctuations in recruitment (Allen and Miranda 2001).

Production of strong year classes of some species of fish in reservoirs is associated with periods of high water that inundates terrestrial vegetation during spawning and growing seasons (Shirley and Andrews 1977; Mitzner 1981; Ploskey 1986). Production of a strong year class during high water is stimulated by 1) inundation of terrestrial vegetation that increases allochthonous inputs and initiates decomposition of vegetation and release of nutrients (Godshalk and Barko 1985; Ploskey 1986; Northcote and Atagi 1997); 2) addition of invertebrates and small terrestrial animals that provide an abundant prey resource for spawning and age-0 fish; and 3) abundant spawning habitat and cover for littoral spawners and age-0 fish (Martin et al. 1981; Meals and Miranda 1991). An increase in water level also may create an area with decreased fish abundance, stimulating resident fishes to grow and reproduce to "fill the void" (Keith 1975).

Positive effects of increasing water levels can be depreciated by timing and duration of the water level increase. As duration of inundation increases, amount of bare substrate may decrease due to development of an epilithon cover (Probst et al. 2009). An early increase in water level may allow epilithon to cover substrates and reduce spawning areas for some species of fish. Gafny et al. (1992) found a negative relationship between epilithic growth and egg density and survival of lake sardines *Mirogrex terraesanctae*. Spawning success of Eurasian bream *Abramis brama* was reduced as epilithon cover reduced the eggs' ability to attach to substrates, therefore reducing egg survival (Probst et al. 2009). To my knowledge, effect of epilithon cover on crappie reproduction has not been studied, but could further explain effects of water level changes on reproduction. Vegetative decomposition also can occur if duration of the water level increase is too extended. Onset of decomposition depends on species of vegetation. Herbaceous vegetation is usually more tolerant of inundation than woody vegetation; however, if inundation lasts long, herbaceous plants also will begin to die and decompose (Godshalk and Barko 1985). Decomposition of vegetation could be detrimental to production of strong year classes, particularly fish that spawn near vegetation. Timing of water level increase also is important to successful reproduction. An increase in water level early in the spawning period may encourage spawning, but an increase during the spawning season may cause spawning adults to abandon nests that may be out of the preferred spawning depth range (Kohler et al. 1993). On the other end of the spectrum, an increase in water level after the spawning season would not provide spawning habitat for adults, but would provide refuge for age-0 fish (Ploskey 1986).

Numerous studies have examined the relationship between water level fluctuations and crappie recruitment and have indicated that in reservoirs with drastic water level fluctuations, crappie recruitment tends to be greatly variable among years. In a Kansas reservoir, management of water levels to increase inundated terrestrial vegetation during the crappie spawning season resulted in a 4-fold increase in year-class strength relative to 10 years pre-water level management (Beam 1983). Similarly, Mitzner (1981) reported a positive linear relationship (r^2=0.95) between juvenile crappie density and water volume in an Iowa flood control reservoir. Strong crappie year classes were produced in Lake Okeechobee, Florida, when lake level was above 4.1 m mean sea level during January through March. Conversely, weak year classes were produced when mean sea level was below 4.1 m (Schramm et al. 1985). McDonough and Buchanan (1991) reported that larval crappie densities in a Tennessee reservoir were greatest in years with higher water levels and lesser water discharge during spawning and larval growth periods. In several Southeastern reservoirs, strong year classes of crappies were produced when retention time was low (high discharge) prior to the spawning season (Sammons and Bettoli 2000) and retention time was high (low discharge) post-spawning season (Maceina and Stimpert 1998). High discharge prior to the spawning season provides increased current which may act as a spawning cue for adult crappie in which they respond to conditions that are similar to natural flooding (Sammons et al. 2002). Mechanisms explaining relationships between low discharge during the post-spawning season and strong crappie year classes may be related to survival of age-0 crappies in the limnetic zone. High discharge levels during the post-spawning season may increase turbidity (reducing feeding efficiency), reduce food availability, and increase entrainment of larval fish through the dam (Maceina and Stimpert 1998).

The 4 study reservoirs are located in northwest Mississippi (Figure 1.1). Reservoirs were constructed by the United States Army Corps of Engineers (USACE) during the 1940s and 1950s as part of the Yazoo Basin Headwater Project (USACE 2011). Plans for flood control reservoirs were initiated after the “Great flood of 1927” to prevent flooding in the Mississippi Delta Region. The impoundments are located on tributary streams of the Yazoo River, which drains into the Mississippi River. Arkabutla Lake impounds the Coldwater River, Sardis Lake impounds the Little Tallahatchie River, Enid Lake impounds the Yocona River, and Grenada Lake impounds the Skuna and Yalobusha rivers. Collectively, the impoundments in the Yazoo Basin Headwater Projects protect approximately 490,000 hectares of the Mississippi Delta Region (USACE 2011).

Study reservoirs range in size from 4,800 ha to 14,500 ha at summer pool, and have average depths ranging from 2.9 m to 5.6 m at summer pool. The 4 reservoirs have significant water level fluctuations ranging from 3.3 m in Arkabutla Lake to 7.3 m in Sardis Lake (Table 1.2; Meals and Miranda 1991). Water levels in the reservoirs are managed by rule curves developed and implemented by the USACE. The rule curve is a graph of water levels for regulating water elevation in a body of water. Each day of the year is assigned a target water elevation that was developed by the USACE. Target water elevations in the study reservoirs consist of winter pool and summer pool. During winter pool, water levels are kept low so that the reservoir can store spring precipitation. As precipitation is stored, water levels are raised until summer pool is attained. Water levels are held at summer pool until fall, when water is released until winter pool is attained. Full pool is attained when water level exceeds the spillway of the reservoir. Rule curves of Enid, Sardis, and Grenada reservoirs begin increasing water elevation around day-of-year (DOY) 15 (January 15), and reach summer pool by DOY 121 (May 1) after which they are held constant until DOY 213 (August 1). The rule curve of Arkabutla Lake does not begin increasing water elevation until DOY 121, reaches summer pool by DOY 135 (May 15) after which it is held constant until DOY 244 (September 1; Figure 1.2). Water levels often fluctuate above and below the rule curve depending on annual precipitation variability.

Flood control reservoirs exhibit large seasonal water level fluctuations (Wetzel 1990) that can affect amount and distribution of physical habitat available within the reservoir. Large water level fluctuations saturate previously unsaturated sediments, which may result in large land slides when water level is decreased (Fujita 1977). Erosion of littoral sediments into the water often leaves steep and unstable banks above the waterline that are devoid of suitable fish habitat. Erosion of reservoir shorelines also can be accelerated by wind and wave action. Shoreline erosion via wave action removes sediments near the waterline, resulting in an undercut bank (Marmulla 2001). Sediment deposits that have originated from shoreline erosion can impact reservoir storage capacity and biological processes. Sediment deposits impact biological processes through shallowing, creation of extensive mudflats, and loss of littoral habitats. Alteration of biological processes through these mechanisms can reduce productivity of littoral-dwelling fish species. Shorelines and mudflats devoid of vegetation do not provide habitats that are important for fish production (Meals and Miranda 1991). Shoreline erosion is greater in lower portions of reservoirs relative to upper portions due to steeper-gradient banks and increased exposure to wave action (greater fetch).

Reservoir basins can be separated into 3 macro-habitat zones which represent a longitudinal gradient in variables such as basin morphology, flow velocity, water residence time, suspended solids, and light and nutrient availability. Three macro-habitat types in a reservoir basin include the uplake riverine zone, the transition zone, and the down-lake lacustrine zone (Thornton 1990). The riverine zone has greater current velocity, brief water retention times, greater nutrient availability, greater concentration of suspended solids, and often expansive floodplains of the principal tributaries. The transition zone has decreasing current velocity and increasing water retention time. The lacustrine zone is characterized by little to no current velocity, longer water retention times, and decreased amounts of nutrients and suspended sediments. Boundaries of these reservoir zones are often not temporally static and therefore can be difficult to differentiate between.

For this study, I focused on 2 macro-habitat types, floodplains in the riverine zone and coves in the main-lake zone. These 2 macro-habitat types were selected because of distinct differences in habitat structure and functionality. Structurally, floodplains differ greatly from coves in vegetation coverage and shoreline slope. Functionally, floodplains within a reservoir are similar to floodplains of an unimpounded natural river system as outlined in the flood pulse concept (Junk et al. 1989). Shoreline slope is the angle of the shoreline relative to the water's surface. Floodplains are characterized as having low slopes, therefore inundating vast areas of habitat when water levels increase. Floodplains typically have terrestrial and aquatic vegetation communities which can provide optimal spawning and nursery habitat for several fish species given that the water regime is conducive during the reproductive season (Summerfelt 1999). In addition to complex vegetative communities, floodplains also contain diverse aquatic habitats such as sub-impoundments, sloughs, and oxbow lakes that provide habitat when water levels are high enough to connect them to the reservoir. Inundation of floodplains typically results in increased production within the system (Junk et al. 1989). Availability of habitat within floodplains is a function of precipitation, water management (rule curve), and reservoir use. Structure and composition of floodplains is greatly unstable because of sedimentation and meandering of stream and river channels. Conversely, cove areas within a reservoir generally contain physical habitat that is less complex and extensive than that of floodplains. The main-lake cove area is often characterized by banks with steep slopes devoid of inundated aquatic or terrestrial vegetation within the littoral area. High gradient, eroded banks found within this area are usually because of soil instability and erosion caused by water level fluctuations and wind (Fujita 1977; Allen and Wade 1991; Hellsten 1997). Physical habitat in the form of woody material and vegetation is usually limited in main-lake cove areas unless water levels exceed summer pool elevation.

Literature suggests that reservoir hydrology (water level and flow) is one of the important variables influencing crappie year-class strength. Effect of reservoir hydrology on crappie year-class strength has been studied numerous times in numerous aquatic ecosystems often reporting variable results; however, there are no data that examine this relationship in the study reservoirs. Floodplain habitats of flood control reservoirs may provide spawning habitat for adult crappie and nursery habitat for age-0 crappies when water levels are sufficient to inundate terrestrial and wetland vegetation. Availability of floodplain habitats during crappie spawning and developmental periods depends on water level of the reservoir. Failure to retain enough water to inundate floodplain habitats could decrease the likelihood of producing strong crappie year classes. Therefore, objectives of this study were to determine: 1) interaction between water level and extent of inundation of floodplains and main-lake coves; 2) patterns of use by reproductive-size white crappies differed between coves and floodplains in reservoirs; and 3) strength of the relationship between age-0 crappie relative abundance and inundation of floodplains and main-lake coves in reservoirs.

This thesis addresses each objective in manuscript form. Each chapter in the thesis is a separate manuscript that includes an introduction, methods, results, and discussion. The first objective is addressed in Chapter 2, where I describe and quantify vegetation that is inundated at different water levels in floodplains and coves of reservoirs. This chapter was descriptive, in that I organized observations about a single floodplain and cove without testing or validating cause and effect. The second objective was examined in Chapter 3 and was of interest to me because of marked differences in habitat found between floodplains and coves in the study reservoirs. Chapter 3 examined if utilization of floodplain and cove habitats by reproductive-sized crappies differed during later winter and spring. The third objective was explored in Chapter 4 and was of interest to me because of obvious differences in habitat found in floodplains and coves. Chapter 4 examined if age-0 crappie densities differed between floodplains and coves, and also examined whether a relationship existed between age-0 crappie abundance and pre-spawning period and spawning period water levels. A summary and synthesis of pertinent findings of this research and implications for management of crappie populations is provided in Chapter 5.

Table 1.1 Percentage of total annual harvest by weight of black crappie and white crappie in flood control reservoirs in northwest Mississippi from 2000 to 2008.

Year	Arkabutla	Enid	Grenada	Sardis	Source
2000	-	83.0	-	-	Meals and Dunn 2001
2001	-	-	85.7	-	Meals and Dunn 2002
2002	84.2	-	-		Meals and Dunn 2003
2003	-	-	-	49.9	Meals and Dunn 2004
2004	-	77.3	-	-	Meals and Dunn 2005
2005	-	-	86.0	-	Mississippi Wildlife, Fish and Parks 2006
2006	-	-	-	80.8	Mississippi Wildlife, Fish and Parks 2007
2007	-	-	79.0	-	Mississippi Wildlife, Fish and Parks 2008
2008	57.6	-	-	-	Mississippi Wildlife, Fish and Parks 2009

Table 1.2 Characteristics of the study reservoirs in northwest Mississippi (Meals and Miranda 1991).

	Reservoir			
Characteristic	Arkabutla	Enid	Grenada	Sardis
Year of Impoundment	1941	1952	1954	1940
Elevation (m)				
Winter Pool	63.7	70.1	58.8	71.9
Summer Pool	67.1	76.2	65.5	79.2
Full Pool	72.5	81.7	70.4	86.3
Surface area (ha)				
Winter Pool	2,056	2,477	3,970	3,996
Summer Pool	4,804	6,528	14,496	12,991
Full Pool	13,537	11,311	25,160	23,675
Average depth (m)				
Winter Pool	1.9	2.9	2.6	2.9
Summer Pool	2.9	5.1	4.7	5.6
Full Pool	4.8	7.2	6.3	8.2
Annual Depth Fluctuation (m)	3.3	6.1	6.7	7.3

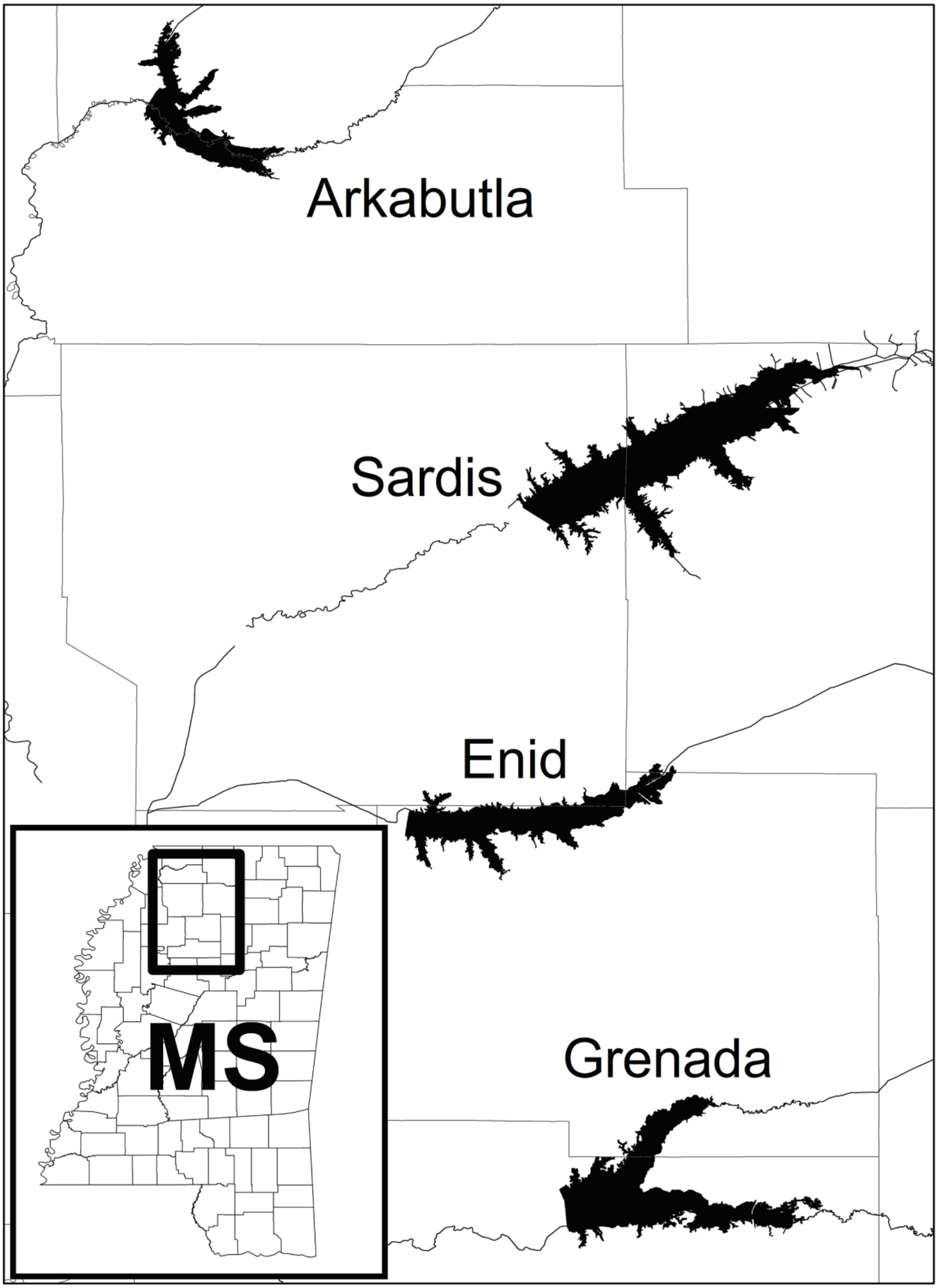

Figure 1.1 Map showing location of study reservoirs in northwest Mississippi during 2009 and 2010.

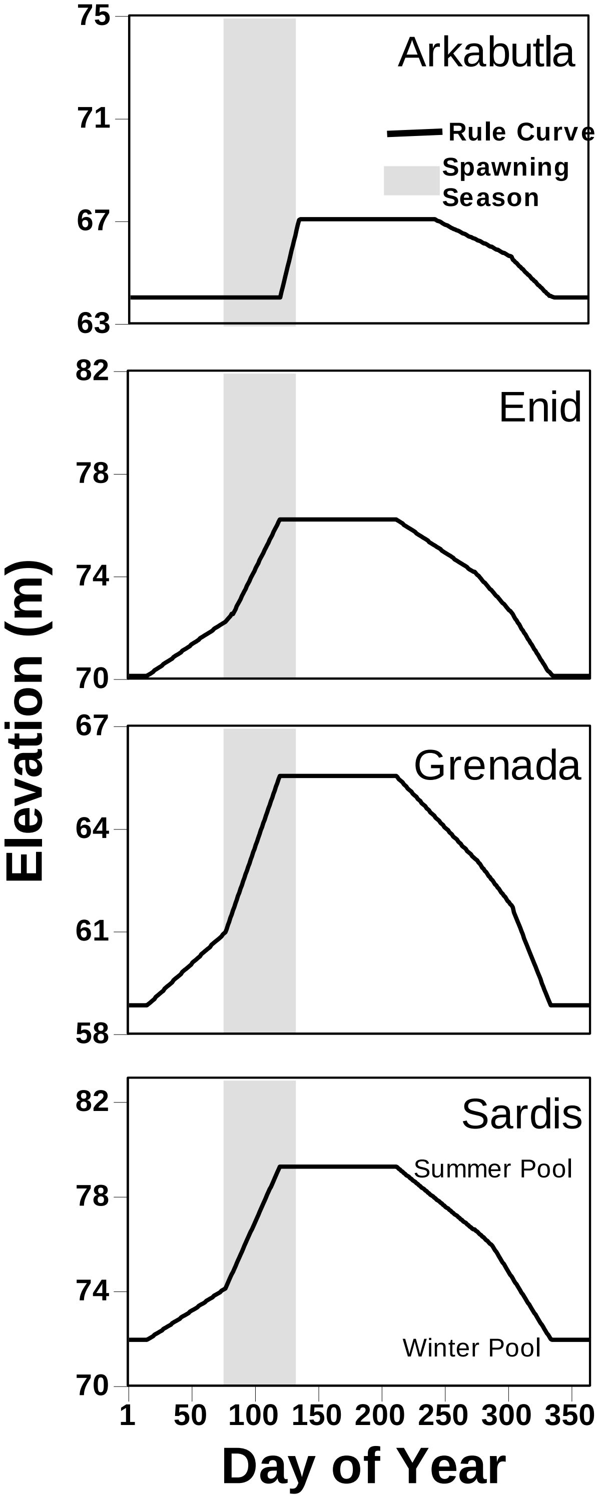

Figure 1.2 Current rule curves established in 1989 and maintained by the United States Army Corps Engineers for 4 flood control reservoirs in northwest Mississippi, showing Day-of-year (DOY) of the beginning of spring rise and fall drawdown.

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CHAPTER II

DIFFERENCES IN HABITAT COMPOSITION BETWEEN A FLOODPLAIN AND A COVE OF ENID RESERVOIR

Introduction

Many reservoirs include extensive floodplains in the area where the main tributary enters the reservoir. Extent and timing of inundation of these floodplains, particularly in reservoirs with large annual water level fluctuations, should be of great importance to biologists responsible for managing fish populations (Ploskey 1986). Floodplains in reservoirs often provide habitat that can be used by many fish species if timing and duration of inundation corresponds with critical life-history stages (Clark et al. 2008). Nevertheless, extent and timing of flooding, as well as type of habitat flooded, has not been investigated sufficiently.

Evidence suggests that crappie populations in reservoirs may benefit from periodic connection to sloughs, manmade sub-impoundments, and oxbow lakes found in extensive floodplains of tributary streams and rivers feeding the reservoirs (Meals and Miranda 1991; Slipke and Maceina 2007). Inundation of floodplains allows adult crappies access to floodplains for spawning (depending on timing of flooding), which could in time result in export of juveniles back into the reservoir (Junk et al. 1989;

Schultz et al. 2007). Thus, timing of connectivity between floodplains and the reservoir may be vital to maintaining crappie populations in reservoirs with extensive floodplains.

Perhaps the most common littoral habitats in most reservoirs are coves. Compared to floodplains, coves generally contain habitat that is less complex. High gradient, eroded shorelines in coves result from soil instability caused by water level fluctuations and wind (Fujita 1977). Habitat is limited in coves because bank instability prevents most aquatic and terrestrial vegetation from colonizing the fluctuation zone (Allen and Wade 1991).

Four similar flood control reservoirs in northwest Mississippi provide nationally renowned crappie fisheries and have significant economic impacts on the region (Hunt et al. 2008). These reservoirs have extensive floodplains and large annual water level fluctuations that affect extent of available habitat during crappie spawning and developmental periods. Limited spawning or nursery habitat during low water levels may hinder crappie spawning success and recruitment, resulting in a weak year-class (Mitzner 1981). The objective of this chapter was to describe major differences in habitat composition in a floodplain and a cove relative to water levels in Enid Reservoir.

Methods and Materials

Study Site

Enid Reservoir is located in northwest Mississippi (Figure 2.1). Its primary purpose is to provide flood protection to the Mississippi Delta Region, an extensive agricultural area. Because it is a flood control reservoir, it experiences large annual water level fluctuations of approximately 6.1 m, where water is stored during the wet season and then discharged later in the year during the dry season. Water level is managed according to a rule curve implemented and maintained by the United States Army Corps of Engineers (USACE). Water levels often deviate from the rule curve depending on amount of precipitation received in the watershed or in the region downstream for which flood protection is being provided. Water level fluctuations alter the extent and type of habitat available for fish in Enid Reservoir.

For this study, the reservoir basin was separated into 2 zones, a floodplain and a cove. The floodplain was selected because it was the largest contiguous floodplain in the study reservoir. The cove (Longbranch Creek) was selected because of its proximity to the dam and because its surface area was similar to that of the floodplain. Moreover, the study cove and floodplain were part of a concurrent study designed to assess crappie reproduction in Enid Reservoir and similar reservoirs in the region (Chapter 4; Figure 2.1). Separating lines between the main-lake and the study sites were drawn through the 74.7-m mean sea level (msl) isobath, because at this elevation the reservoir begins inundating the floodplain. The floodplain has complex terrestrial and aquatic vegetative communities and contains diverse aquatic habitats such as sloughs, oxbow lakes, manmade sub-impoundments, main river channels, and side channels. The floodplain is characterized as having a low gradient; therefore vast areas are inundated when water levels increase. Structure and composition of the floodplain is unstable because of sedimentation and meandering of stream and river channels. Habitat in the cove is less complex and not as extensive as habitats found in the floodplain. The cove is characterized as having a high gradient shoreline slope that is primarily because of erosion caused by wave action and water level fluctuations (Fujita 1977). High gradient, unstable shorelines in the cove prohibit aquatic and terrestrial vegetation from establishing, therefore, limiting the amount of habitat available in these areas.

Study Design

A Geographic Information System (GIS) is well suited for determining effects of water level changes on extent of fish habitats in aquatic ecosystems (Rowe et al. 2002). Spatial analysis with a GIS was used to estimate differences in percentage of habitats inundated at various water levels in the cove and floodplain. This analysis was designed to calculate percentage of 5 habitat classes inundated at simulated water levels using a Digital Elevation Model (DEM). Estimation of percentage of habitat classes at various water levels allowed for comparisons of habitat composition between a cove and a floodplain.

Land Cover

Land-cover classes were delineated from satellite imagery using unsupervised classification procedures. Classified satellite imagery was obtained from the USACE Vicksburg District office. Selection of satellite images to be used for classification was influenced by cloud cover, imagery availability, time of year, and reservoir water level. An April 22, 2007 image was selected because water levels were low, imagery was clear, and it was taken after approximately 31 weeks of water levels below 74.7 m that allowed for extensive vegetation growth.

Unsupervised classification creates clusters based on pixel spectral characteristics using the Iterative Self-Organizing Data Analysis Technique (ISODATA) clustering algorithm. ISODATA technique uses minimum spectral distance to assign a cluster for each pixel (ERDAS, Inc. 1999). The process begins with a specified number of arbitrary cluster means, and then processes repetitively so that those means shift to the means of the clusters in the data (ERDAS, Inc. 1999). Unsupervised classification resulted in numerous land-cover classes, but classes were further combined into 5 land-cover classes. Thus, this study was focused on mapping macro-habitats, such as herbaceous vegetation or woody vegetation, but did not map micro-habitats (i.e., patches of individual plant species).

Five land-cover classes were used to describe habitat in the reservoirs including 1) herbaceous, 2) shrub, 3) forest, 4) non-vegetated, and 5) wetlands. Vegetation types present in class 1 were composed of grasses, legumes, herbs, and row crops. Herbaceous vegetation has no woody stem above the ground and therefore dies down to soil level at the end of the growing season. Woody material was sparse or absent. Although herbaceous vegetation in the cove and the floodplain were classified into the same class, differences likely existed in species of vegetation present in each area. Herbaceous vegetation in the floodplain is likely composed of wetland plant species (Johnson 2002), and herbaceous vegetation in the cove is likely composed mostly of upland terrestrial species (Liu et al. 2009). Vegetation types present in class 2 included those in class 1 with addition of shrub and shrub-like vegetation (i.e., vegetation with woody stems and less than 5 m tall). Vegetation types in class 3 were composed of forest vegetation, which included several species of trees, but primarily oaks *Quercus* spp. and pines *Pinus* spp.

Herbaceous and shrub-like vegetation also occurred under the forest canopy. Non-vegetated habitat in class 4 was composed primarily of bare substrate including sand and clay, and minimal amounts of gravel and bedrock. Habitat in class 5 included bodies of water that are disconnected from the main reservoir when water level is at winter pool, such as sloughs, oxbow lakes, and manmade sub-impoundments and are referred to as "wetlands" in this thesis.

Water Level Modeling

Digital Elevation Models (10 m; MARIS 2010) were used to estimate total area of the floodplain and cove at 0.3-m water-level increments beginning at 74.7 m msl and ending at 78.9 m msl. DEMs were imported into ArcGIS's ArcMap. Each 0.3-m increment was selected in the raster by using the raster math tool in ArcGIS Spatial Analyst (ESRI 2006). For example, selecting all of the raster cells ≤ 74.7 m msl gave the extent of the floodplain and cove when water level was at 74.7 m msl. The raster was then converted to a vector polygon using geoprocessing tools. I created 15 polygons representing 15 0.3-m water level increments between 74.7 and 78.9 m msl. Polygons that were not connected to the main lake were removed. A bathymetric contour map was created by merging 15 polygons into one data layer using geoprocessing tools.

GIS Modeling

Geospatial Modeling Environment (GME; Beyer 2009) was used to estimate area of land-cover classes in each polygon. The GME tool package allowed me to produce a summary of raster cell values that are contained in a polygon. The summary contains counts of number of pixels of each land-cover class contained in each 0.3-m water level polygon. The land-cover raster had a resolution of 30 m so total area of land-cover classes was calculated by multiplying the land-cover class count for each polygon by 900 m^2. Percentages of each habitat class were calculated in the floodplain and the cove at each modeled water level.

Crappies and most nesting species construct nests and spawn in areas that are ≤ 1.5 m deep (Ross 2001). Therefore, percentage composition of habitat type was calculated for 1.5-m depth bands around the perimeter of the floodplain or cove for each 0.3-m increase in water level. Thus, percentage composition of habitat types in the first depth band included estimates of habitat percentages from water levels 74.7 – 75.9 m msl. The second depth band included estimates of habitat percentages from water levels 75.0 – 76.2 m msl, and so on. In total, percentage composition of habitat types was estimated for 11 depth bands. Using 1.5-m depth bands allowed for estimation of habitat types within the range of preferred spawning depths.

Results

Estimates of habitat composition for the study cove and floodplain were obtained for water levels 74.7 to 78.9 m msl. Total area of the cove and floodplain were 258 and 151 ha at 74.7 m msl, respectively; 431 and 255 ha at 76.2 m msl (summer pool); and 620 and 741 ha at 78.9 m msl (Figure 2.2). Total area of the floodplain increased at a greater rate than the cove, suggesting that the study cove had a greater shoreline slope than the floodplain. Thus, area of shoreline inundated with a rise in water level was less in the cove than in the floodplain.

Habitat composition in the cove and floodplain was dominated by herbaceous vegetation. The cove tended to have greater percentages of non-vegetated areas and forest than the floodplain. The floodplain was characterized as having greater percentages of shrub habitat and permanent wetlands (Figure 2.3).

Percentage of non-vegetated areas decreased as water level increased in the floodplain and the cove. Percentage of non-vegetated areas in depth bands was almost twice greater in the cove than in the floodplain and varied from 0.1 to 37% (19 to 571 ha) in the cove and 0.4 to 18% (10 to 147 ha) in the floodplain (Figure 2.3). The greatest percentage of non-vegetated areas for the cove and floodplain occurred in the first depth band (74.7 – 75.9 m msl).

Herbaceous vegetation was the most abundant habitat type present in the floodplain and the cove in all depth bands (≥54%; Figure 2.3) and did not show a trend relative to increasing water level in the floodplain (r^2=0.01, P=0.98) or cove (r^2=0.20, P=0.17). Coverage of herbaceous vegetation in depth bands varied from 56 to 72% (488 to 1,101 ha) in the cove, and 54 to 74% (571 to 1,857 ha) in the floodplain. In the cove, the greatest percentage of herbaceous vegetation occurred in depth band 75.6 – 76.8 m msl. Significant amounts of terrestrial vegetation were not inundated in the cove until water level reaches summer pool (76.2 m msl). In the floodplain, the greatest percentage of herbaceous vegetation occurred in depth band 75.3 – 76.5 m msl, immediately before and after summer pool.

Shrub habitat was limited in the cove making up less than 5% (49 ha) of the composition. Shrub habitat was more abundant in the floodplain, accounting for 7 to 20%

(62 to 516 ha) of the habitat depending on depth band. Percentage of shrub habitat was greatest in the floodplain in depth band 76.2 – 77.4 m msl (Figure 2.3).

Forest habitat increased as water level increased in the cove and floodplain. Percentage of forest habitat was greater in the cove than in the floodplain in all depth bands. Percentage of forest was greatest in depth band 77.7 – 78.9 m msl in the floodplain (22%; 461 ha) and the cove (37%; 330 ha).

Wetlands were limited in the cove, accounting for less than 3% (28 ha) of the composition of all depth bands. The floodplain contained a greater percentage of wetlands than the cove (Figure 2.3). Wetlands were most abundant in depth band 75.6 – 76.8 m msl, at which point a relatively large permanent wetland became connected to the main reservoir (655 ha). As water levels exceeded 77.7 m msl, wetlands were limited in the floodplain and cove (less than 2%).

Discussion

My results indicated that herbaceous vegetation is the most abundant habitat class in the floodplain and cove, as it comprised at least one-half of habitat composition in all depth bands. The unsupervised classification procedure classified herbaceous vegetation in the floodplain and the cove into the same class, even though distinct differences likely exist. Although a list of species of herbaceous vegetation present in the floodplain and the cove of Enid Reservoir is not available, studies in other reservoirs have reported differences in species richness and composition in upstream and downstream areas in the reservoir basin. Liu et al. (2009) reported that species richness in an upstream riparian area of Danjiangkou Reservoir, China, was significantly greater than in areas closer to the dam. In impoundments of the Missouri River, reservoir floodplains supported several species of wetland vegetation whereas areas closer to the dam were almost devoid of wetland vegetation (Johnson 2002). Floodplains in Enid Reservoir resemble the floodplain of a natural river system, which are comprised of complex aquatic habitats and vegetative communities (Bayley 1995; Johnson 2002), and are expected to include mainly wetland/floodplain species of vegetation. A decrease in species richness in areas closer to the dam suggests that vegetative communities in coves are composed of upland species that are less tolerant of inundation (Liu et al. 2009). Effect of type (wetland or upland species) of herbaceous vegetation on quality of habitat is unclear; however, extensive use of floodplains by crappies (Slipke and Maceina 2007) provides evidence that crappies may seek areas with wetland vegetation.

Floodplains appear to provide a greater percentage of spawning and nursery habitats for adult and age-0 white crappies relative to the cove. Crappies construct nests in areas <1.5 m in depth (Ross 2001) with sand or clay substrates (Phelps et al. 2009) and with abundant aquatic or terrestrial vegetation (Siefert 1968). Pope and Willis (1997) suggested that black crappies selected nesting sites in areas with wetland vegetation (cattails, *Typha* spp.) and woody vegetation. My results indicate that the cove tended to have roughly twice the percentage of non-vegetated areas and forest habitats relative to the floodplain. Steep and unstable banks, long fetches, and fluctuating water levels result in increased erosion and preclude growth of riparian vegetation in the fluctuation zone of reservoir shorelines (coves; Fujita 1977; Johnson 2002). Lower gradient shorelines in floodplains not only increase the area ≤ 1.5 m deep but also may decrease amount of erosion, therefore allowing establishment of vegetation. Forested habitat is likely suitable spawning habitat for crappies as under the canopy there is often substantial woody debris, shrubs, and herbaceous vegetation. However, a significant percentage of forest is not inundated in the cove or floodplain until water level substantially exceeds summer pool. The floodplain tended to have greater percentages of wetlands and shrub habitat relative to the cove. Crappies have evolved as a floodplain species and readily move into floodplain oxbow lakes and sloughs when these habitats become connected to the reservoir (Slipke and Maceina 2007). Greater percentages of shrub habitat also may positively affect crappie recruitment. Earlier studies have reported that crappies construct nests or congregate around woody vegetation or debris (Markham et al. 1991; Pope and Willis 1997). Shrub habitat in the floodplain provides a class of habitat not readily available in the cove.

Error associated with GIS applications needs to be acknowledged to understand limitations and application of my estimates. In GIS applications, principal sources of error are in data acquisition, processing, and in user interpretation, with the latter being the largest source (Lunetta et al. 1991). Ways in which these errors interact are not fully understood (Lunetta et al. 1991). The DEM’s were constructed from original 1:24,000 USGS topo maps and inherently are less accurate than original maps (MARIS 2010). In this study, one of the largest sources of error that could influence estimates of area of the reservoir at different water levels is vertical accuracy of DEM’s. Another source of error in this study could be attributed to the accuracy of classified satellite imagery. Moreover, I used a single point in time for this analysis, whereas vegetative composition probably changes with time and can be altered by water level fluctuations. Ground-truthing of classified imagery allows for an estimate of the accuracy of the image (Fosado 2009).

This study did not assess accuracy of the classified image; however, ground-level visual observation (Heumann 2011) of habitat at Enid Reservoir verified that accuracy was sufficient to meet the objective of this study, (i.e., describe major differences in habitats between a floodplain and a cove).

This study provides a starting point for future research designed to understand and manage habitat in floodplains and coves of Enid Reservoir. Future research should focus on describing the vegetation community present in floodplains and upland areas within the reservoir basin. Additional research is also needed to fully understand tolerances of different vegetation types to inundation magnitude and duration. Information about vegetative communities in the reservoir basin and their tolerance to inundation would provide a basis for managing water levels that may help preserve and enhance vegetation communities to benefit fish and other wildlife.

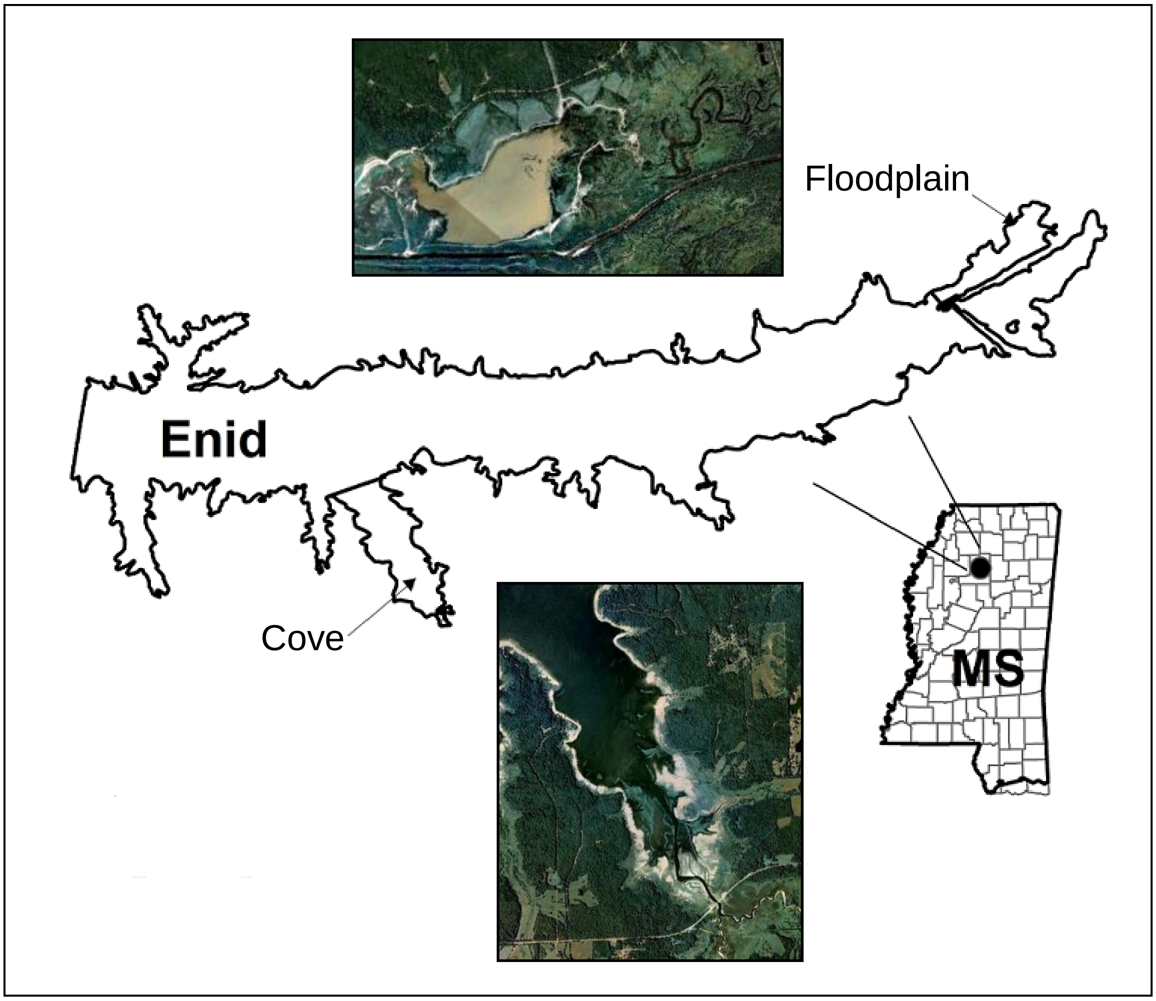

Figure 2.1 Map of Enid Reservoir in northwest Mississippi depicting location of the floodplain and cove study areas in 2009 and 2010.

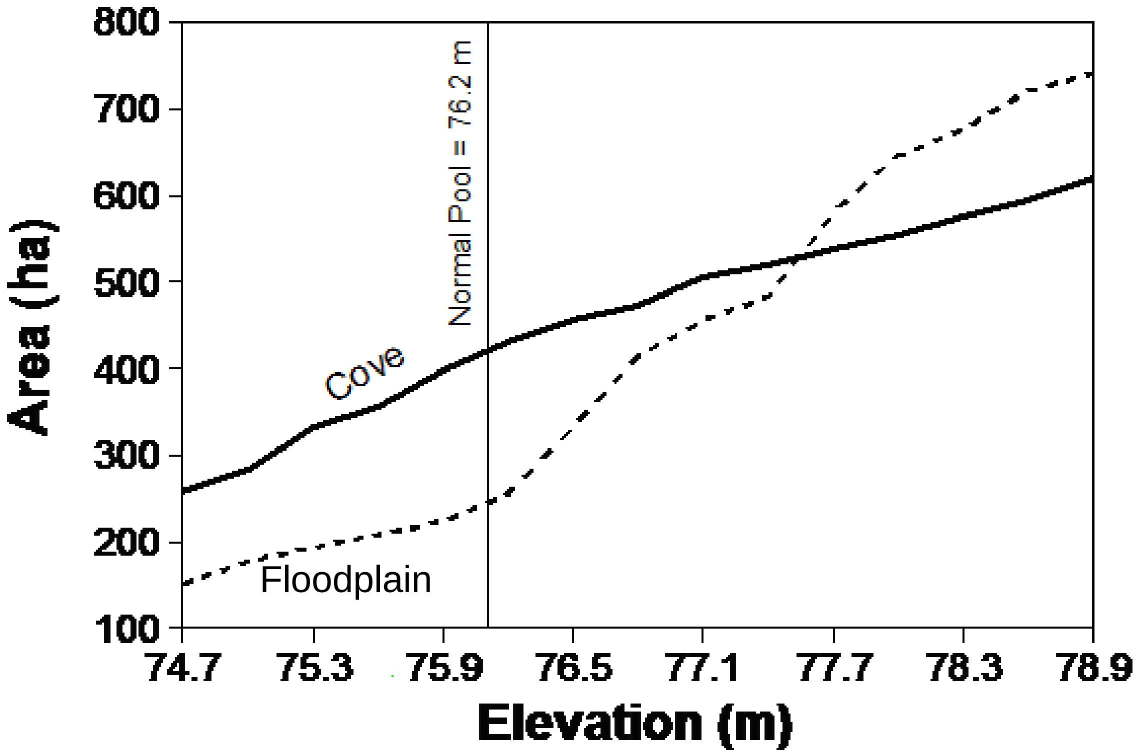

Figure 2.2 Total area (ha) of a cove and a floodplain relative to water levels in Enid Reservoir, Mississippi, in 2009 and 2010.

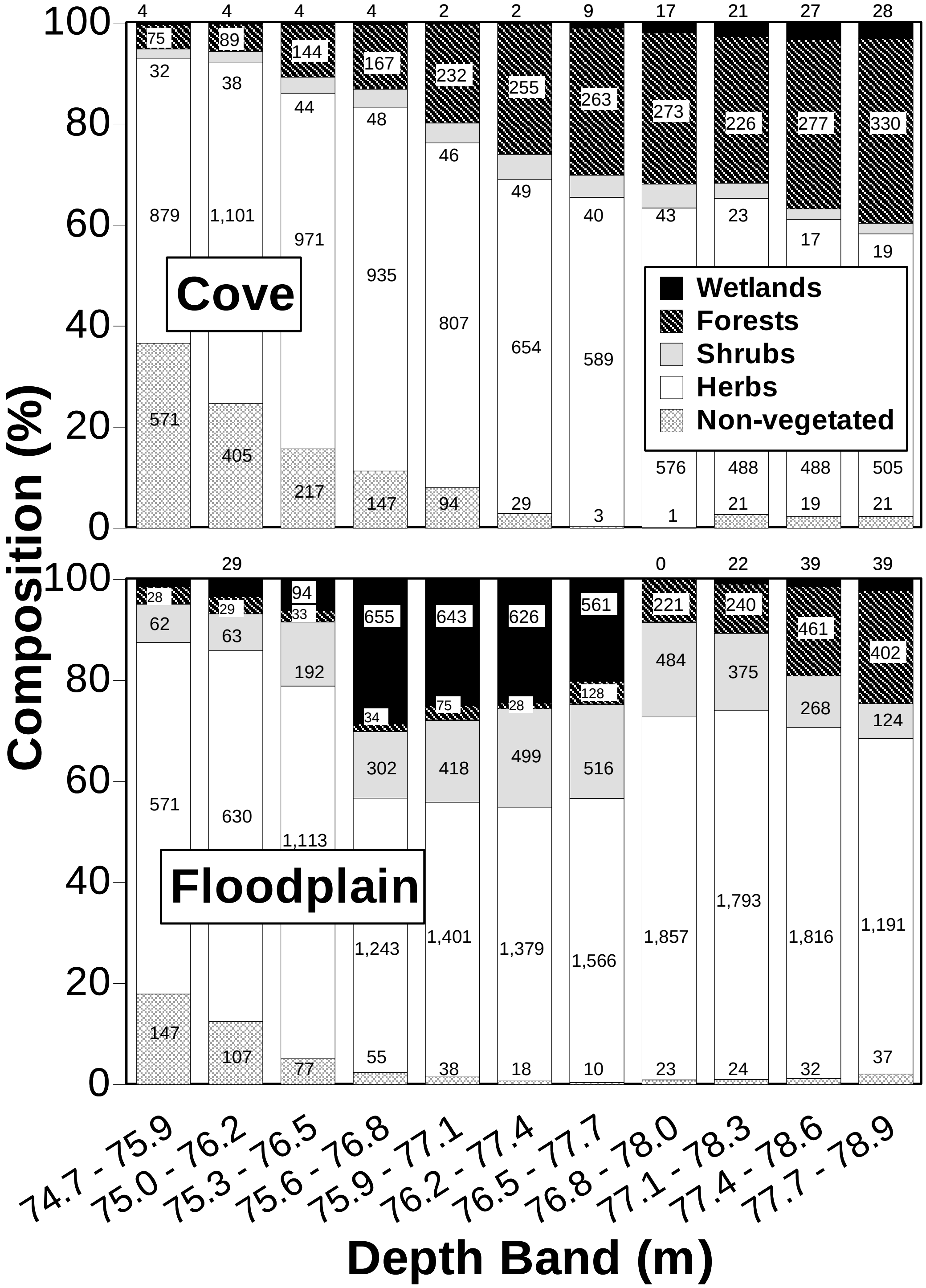

Figure 2.3 Percentage composition of habitat of 1.5 m depth bands in a floodplain and a cove of Enid Reservoir, Mississippi in 2007. Percentage composition was calculated for depth bands at 0.3 m increments. Numbers on the figure represent area of habitat type (ha). Summer pool = 76.2 m mean sea level.

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CHAPTER III

TEMPORAL USE OF RESERVOIR COVES AND FLOODPLAINS BY WHITE CRAPPIES DURING SPAWNING

Introduction

White crappies have evolved as a floodplain species capable of exploiting abundant resources adjacent to rivers during annual flooding cycles (Hocutt and Wiley 1986). This species roams in and out of these environments to exploit changing conditions in habitat and food availability (Slipke and Maceina 2007). White crappies are often associated with floodplain habitats such as sloughs, oxbow lakes, and newly flooded terrestrial vegetation (Markham et al. 1991; Ross 2001) and use these habitats for feeding and reproduction (Slipke and Maceina 2007). Crappies spawn in nests often associated with vegetation, brush, or other submerged woody structures (Siefert 1968; Pope and Willis 1997; Phelps et al. 2009), and juveniles survive initially by feeding on plankton and eventually on macroinvertebrates (Mathur and Robbins 1971; O’Brien et al. 1984; Pope and Willis 1998) that are often abundant in vegetated habitats.

Dams alter natural floodplain environments favored by crappies, yet crappies persist and often thrive in reservoirs. Within the main body of a reservoir, floodplains become submerged and are replaced by shallow-water coves. These coves flood previously upland environments, except near tributary inlets where some floodplain environments may remain. For a few years after impoundment cove environments provide abundant flooded terrestrial vegetation equivalent to that periodically flooded in natural floodplains. These flooded uplands provide ample food and cover for floodplain species (Ploskey 1986; Bayley 1995). However, over time flooded terrestrial vegetation is unable to persist in a wet or submerged environment (Godshalk and Barko 1985). Therefore, cove habitat becomes devoid of terrestrial vegetation, turning into mudflats and barren banks, with vegetation mainly persisting above summer pool elevation where flooding occurs irregularly. Also, coves are different than floodplains in that they tend to have a higher gradient shoreline and therefore loss of vegetation is exacerbated by erosion caused by wind-induced wave action (Fujita 1977).

In reservoirs impounding floodplain rivers, natural floodplain habitat may remain in major tributaries in upper reaches of the reservoir. If the reservoir experiences large water level fluctuations, these floodplains are inundated periodically and may continue to function as a natural floodplain. Unlike coves, these floodplains have lowland, wetland, and aquatic plant communities able to withstand extensive periodic flooding (Johnson 2002). In aging reservoirs, such floodplains and associated plant communities may provide key habitat for crappies and other fish species where coves have lost their vegetation (Slipke et al. 2005). Also unlike coves, these floodplains support a greater diversity of habitats that include sloughs, permanent side channels, and oxbow lakes (Chapter 2).

Distinct differences in habitat can exist between floodplains and coves within a reservoir. These differences may result in unequal use of these habitats by crappies, differences that can potentially be exploited by fishery managers in older reservoirs where fish habitat degradation can limit strength of crappie year classes. The objective of this chapter was to determine if patterns of use by reproductive-size white crappies differed between coves and floodplains in reservoirs. I hypothesized that white crappies would be more abundant in floodplains than in coves and that crappies would use floodplains earlier than coves. To this end, I monitored relative abundance of reproductive-size white crappies in these habitats during late winter and spring in flood-control reservoirs.

Methods and Materials

Study Reservoirs

This study was conducted in floodplains and a cove of Grenada Reservoir in 2009 and Grenada, Enid and Sardis reservoirs in 2010. These flood control reservoirs are located in northwest Mississippi and provide flood protection in the western Yazoo Basin. Floodplains occur in the upper reaches of the reservoir, near the mouth of the main tributary river, and are characterized as having shallow areas that are connected to or disconnected from the tributary river or reservoir and have reduced or no current velocity. Floodplains have complex terrestrial and aquatic vegetative communities and contain a diversity of aquatic habitats such as sloughs, oxbow lakes, manmade sub-impoundments, main river channel, and side channels. Gently sloping basins allow vast areas of land to be inundated when water levels increase. Coves occur mainly in the lower half of the reservoirs. Coves typically have a high gradient bank slope, intensified by erosion from wave action and water level fluctuations that virtually have homogenized littoral habitats.

Crappie spawning habitat is limited in coves, as unstable shorelines and water level fluctuations prevent establishment of vegetation below summer pool. Water levels are managed according to rule curves established by the U.S. Army Corps of Engineers (USACE).

Fish Collections

White crappies were sampled using daytime boat electrofishing in shallow areas (< 2-m deep) of floodplains and a cove in Grenada, Enid, and Sardis reservoirs. Adult crappies were sampled weekly or bi-weekly, depending on stability of water levels, from DOY 91 to 135 in 2009 and from DOY 46 to 145 in 2010. A commercially available electrofishing unit (MBS series, ETS Electrofishing, Verona, Wisconsin) was used to generate pulsed DC current at 60 Hz and maintain 10 – 15 peak amperes of output adjusted to water conductivity that ranged from 30 – 130 μ S/cm. Four to 5 transects were sampled for 0.25 h in floodplains and in coves per sampling day. Transects were selected arbitrarily, but occasionally selection was restricted by presence of anglers and excessive wind action on some shores. Crappies collected were identified to species, counted, and measured for total length to the nearest centimeter. In the southeastern United States, crappies typically reach sexual maturity between age 1 and 2 (Carlander 1977). Total length of white crappie in Grenada and Ross Barnett reservoirs, and Moon Lake, Mississippi averaged 11.4 and 17.1 cm at age-1 and age-2, respectively (Hammers and Miranda 1991); therefore, white crappies 15.0 cm or longer were assumed to be sexually mature and were included in analyses.

Catch rates (catch per hour) were used to estimate relative abundance of adult white crappies in floodplains and coves during the sampling period. Black crappies were not included in the analyses because of small sample sizes. Catch rates ($\hat{R}$) of adult white crappies were calculated for each habitat (floodplains or coves) and sampling day as the mean of ratios:

$$\hat{R} = \frac{\sum_{i=1}^{n} \left(\frac{c_i}{h_i} \right)}{n} \tag{3.1}$$

Where c_i is total catch in the i^{th} transect, h_i is total effort (h) in the i^{th} transect, and n is total number of transects sampled in each habitat and day. A Shapiro-Wilk test (Univariate Procedure; SAS Institute 2008) indicated catch rates in the 3 study reservoirs were not distributed normally in 2009 or 2010, so catch rates were $\log_e$-transformed [$\log_e$(catch rate + 1)] to normalize their distributions. General linear models (GLM Procedure; SAS Institute 2008) were used to test if white crappie catch rates differed between floodplains and coves, while accounting for reservoir (Enid, Grenada, Sardis) and time period (DOY 60 – 150). Separate models were developed for years (2009 and 2010). Catch rate was the dependent variable; habitat and reservoir were class variables, and DOY was a covariate. I assumed that the relationship between $\log_e$(catch rate + 1) and DOY was dome-shaped, so a quadratic term of DOY also was included. The relationship was assumed to be dome-shaped because crappies migrate inshore from deep water to spawn in shallow areas and then move back to deep water after spawning (Guy et al. 1992; Guy et al. 1994). The following model was fitted separately for 2009 and 2010 adult white crappie catch rates:

$$\hat{Y}_{ijk} = \hat{\beta}_0 + \hat{\beta}_1(DOY_{ik}) + \hat{\beta}_2(DOY_{ik})^2 + \hat{\beta}_3(HAB_i) + \hat{\beta}_4(DOY_{ik} \times HAB_i) + \hat{\beta}_5(RES_k) + \hat{\beta}_6(DOY_{ik} \times RES_k) \quad (3.2)$$

where,

$\hat{Y}_{ijk}$ = log(catch rate+1) predicted for the j^{th} observation, i^{th} habitat and k^{th} reservoir,

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

$\hat{\beta}_1$ = slope for DOY,

$\hat{\beta}_2$ = slope for DOY^2,

$\hat{\beta}_3$ = slope for habitat (HAB; floodplain or cove),

$\hat{\beta}_4$ = slope for DOY × habitat interaction,

$\hat{\beta}_5$ = slope for reservoir (RES; Enid, Grenada, Sardis), and

$\hat{\beta}_6$ = slope for DOY × reservoir interaction.

In 2009, the reservoir term was excluded from the model because only one reservoir was available for analysis.

Water temperature is recognized as an important factor controlling timing of crappie spawning. Spawning activity of white crappies typically begins when water temperatures reach 15°C and subsides when water temperatures approach 20 °C (Siefert 1968). Differences in depth associated with differences in basin morphology between floodplains and coves may potentially produce temporal differences in water temperature that affect use of floodplains and coves. Therefore, I measured seasonal water temperatures and tested for differences between habitats. Water temperature was recorded at 0.5 m below the water surface in floodplains and coves during each sampling period. I used analysis of covariance to test whether water temperature (dependent variable) differed between habitat (class variable), reservoir (class variable), sampling day of the year (covariate), and the interaction of habitat and sampling day of year. A statistically significant habitat effect or interaction would suggest that temperatures differed between floodplains and coves.

Results

Water temperatures during the sampling period increased through the sampling season. Water temperature between DOY 91 and DOY 125 ranged from $14.5^{o}C$ to $21.2^{o}C$ in floodplains and from $13.4^{o}C$ to $21.9^{o}C$ in coves. There were no statistical differences in temperature between habitats (F=0.31, P=0.59) and no habitat × DOY interaction (F=0.34, P=0.57).

2009

In 2009, 145 adult white crappies were collected from floodplains and coves of Grenada Reservoir. Catches of adult white crappies ranged from 0 to 16 fish per transect in floodplains and 0 to 24 fish per transect in coves. Total length of crappies captured in coves ranged from 20 to 39 cm and averaged 32.5 cm (SD=4.2; N=54), and in floodplains ranged from 20 to 39 cm and averaged 32.2 cm (SD=4.5; N=92). A Kolmogorov-Smirnov test indicated no significant differences in total length distributions of white crappies between habitats in 2009 (KSa=0.53, P=0.95).

White crappie catch rates in floodplains and coves increased through the spawning season, peaked, and then decreased. The 2009 model for adult white crappie catch rates was statistically significant (*F*=7.23, *P*=0.009) and accounted for 78.3% of the variation in catch rates at Grenada Reservoir. The final model included terms DOY, DOY^2, habitat, and habitat × DOY (Table 3.1). Catch rates of white crappies differed significantly between floodplains and coves of Grenada Reservoir in 2009, indicated by the significant habitat effect (*F*=12.50, *P*=0.007). Peak abundance of white crappies predicted by the model was greater in coves than in floodplains at 22.5 and 21.1 fish/ hour, respectively. The habitat × DOY interaction effect also was statistically significant (*F*=12.56, *P*=0.007), indicating that time of peak catch rate differed between habitats. Peak abundance of white crappies occurred earlier in floodplains (DOY 91) than in coves (DOY119; *t*=-3.54, *P*=0.007; Figure 3.1). Nevertheless, peak abundance in floodplains may have occurred earlier. Because sampling did not begin until DOY 91, catch rates may not have accurately identified peak concentration of white crappies in floodplains.

2010

In 2010, 642 adult white crappies were collected from floodplains and coves of Grenada, Enid, and Sardis reservoirs. I collected 49% (N=313) of crappies at Grenada Reservoir, 28% (N=183) at Enid Reservoir, and 23% (N=146) at Sardis Reservoir. Catches of adult white crappie ranged from 0 to 35 fish per transect in floodplains, and 0 to 27 fish per transect in coves across all reservoirs and sampling days. Total length of white crappies in floodplains averaged 32.8 cm (SD=4.6; N=215) and ranged from 16 to 40 cm, and total length of white crappies in coves averaged 31.0 cm (SD=3.7; N=425) and ranged from 21 to 40 cm, across all reservoirs and sampling days. A Kolmogorov-

Smirnov test indicated that total length distribution of reproductive-sized white crappies in 2010 differed significantly between floodplains and coves in Grenada (KSa=2.69, *P*<0.001) and Enid reservoirs (KSa=1.80, *P*=0.003), but not in Sardis Reservoir (KSa=0.36, *P*=0.999). In Grenada Reservoir, mean total length of reproductive sized white crappies was greater in floodplains than in coves, averaging 33.9 cm (SD=4.6 cm) and 30.9 cm (SD= 4.81 cm), respectively. In Enid Reservoir, mean total length of reproductive sized white crappies was shorter in floodplains than in coves, averaging 29.8 cm (SD=4.36 cm) and 30.3 cm (SD=2.26 cm), respectively.

Catch rates of white crappies increased through the spawning season, peaked, and then decreased. The 2010 model was statistically significant and accounted for 65% of the variability in adult white crappie catch rates (*F*=10.20, *P*<0.001). The final model included the terms DOY, DOY^2, habitat, reservoir, habitat × DOY, and reservoir × DOY (Table 3.2). The significant habitat effect indicated that catch rates differed between floodplains and coves (*F*=4.64, *P*=0.037). Catch rates in coves were significantly greater than in floodplains (*t* =-2.15, *P*=0.037; Figure 3.2). Peak abundances of white crappies predicted by the model in coves of Grenada, Enid, and Sardis reservoirs were 50.0, 13.9, and 16.6 fish/hour, respectively. In floodplains, predicted peak abundances of white crappies were 12.6, 5.8, and 5.0 fish/ hour, respectively.

The habitat × DOY interaction effect was statistically significant (*F*=8.94, *P*=0.004) indicating that the magnitude of differences in catch rates between habitats varied with time. Peak abundances of white crappies occurred earlier in floodplains than in coves in all reservoirs (*t*=2.99, *P*=0.004; Figure 3.2). In floodplains in Grenada, Enid, and Sardis reservoirs, peak abundances predicted by the model occurred on DOY 119, DOY 96, and DOY 107, respectively. In coves, predicted peak abundance of white crappies occurred approximately 2 – 3 weeks after floodplains (Grenada DOY 137, Enid DOY 116, and Sardis DOY 127).

The reservoir effect on catch rates was not statistically significant (F=2.97, P=0.062) indicating that catch rates of adult white crappie did not differ among reservoirs. Timing of peak abundance of adult white crappies differed among reservoirs, as indicated by the significant reservoir × DOY interaction effect (F=4.25, P=0.021). Timing of peak abundance differed between Grenada (DOY 130) and Enid reservoirs (DOY106; t=2.92, P=0.005), but did not differ between Grenada and Sardis reservoirs (t=1.38, P=0.175), or Enid and Sardis reservoirs (t=1.37, P=0.179; Table 3.2).

Water temperature between DOY 46 and DOY 145 ranged from 2.8^{o}C to 28.8^{o}C in floodplains and from 5.6^{o}C to 26.9^{o}C in coves. There were no statistical differences in temperature between habitats (F=0.22, P=0.64) and no habitat by DOY interaction (F=0.22, P=0.64). This pattern was consistent across the 3 reservoirs studied in 2010.

Discussion

Catch rates of adult white crappie in floodplains and coves suggested movements in and out of these habitats over the length of the sampling season, conforming to expectations about usage of these habitats for spawning activity. These movements coincided with predefined spawning temperature ranges for white crappie. Nevertheless, whereas temperatures did not differ between habitats, timing of usage did differ between habitats as evidenced by differences in peak catch rates. Moreover, contrary to my expectations, at peak densities catch rates of white crappies in coves were greater than in floodplains.

Various studies have reported that crappies spawn in shallow areas that have abundant aquatic or inundated terrestrial vegetation and woody material (Pope and Willis 1997; Phelps et al. 2009). When inundated, floodplains in the study reservoirs provide abundant spawning habitat for adult crappies. Therefore, I hypothesized that floodplain habitat would attract more spawning crappies and hence have greater catch rates of white crappies than cove habitats. In contrast, my results indicated that catch rates during peak usage by white crappies were significantly greater in cove habitats in Grenada Reservoir in 2009 and Grenada, Enid and Sardis reservoirs in 2010. These results were unexpected because coves tend to have greater percentages of non-vegetated areas relative to floodplains (Chapter 2). I conjecture that this contradiction may be a function of differing capture efficiencies between the 2 habitat types. In coves, spawning habitat may be limited which concentrates spawning crappies into limited spawning habitat close to shore, which may result in greater catch rates over narrow bands along the perimeter of the cove. Hilborn and Walters (1992) termed this concept “hyperstability.” Hyperstability occurs when sampling is extremely efficient because effort is concentrated in areas of great densities. Because spawning habitat is limited in coves, crappies tended to be concentrated in these suitable spawning areas, likely causing catch rates to be inflated. In floodplains, white crappies were likely more dispersed because of abundant and widespread distribution of spawning habitat, therefore reducing capture probability relative to coves.

This study indicated that peak catch rates of spawning crappie occurred significantly earlier in floodplains than in coves. Peak catch rate of reproductive-size white crappies occurred approximately 2 - 3 weeks earlier in floodplains than in coves in the study reservoirs. Differences in timing of peak catch rates could be caused by differences in temperature regimes. However, no differences in temperature were detected, and given the broad range of temperature when white crappie spawn, differences in temperature between habitats would have to be substantial before they would create the observed effect.

Alternatively, differences in timing of peak catch rates could be attributed to differences in availability of spawning habitat. In the study reservoirs, floodplain habitats begin to be inundated when water levels are -1.5 m (Grenada), -1.5 m (Enid), and -3.0 m (Sardis) from summer pool. In contrast, terrestrial vegetation in coves does not begin to be inundated until water levels exceed summer pool elevation, unless water levels have been below summer in previous years allowing terrestrial vegetation to colonize mudflats below summer pool. Therefore, in floodplain habitats, suitable spawning habitat normally becomes available at lower water elevations earlier in spring.

Floodplain habitats are important to white crappie populations in the study reservoirs, as they provide access to spawning habitat at lower water levels. There are at least 2 benefits to having access to suitable spawning habitat at lower water levels. First, in years of below-average precipitation the reservoirs may not store enough water to flood adequate vegetated habitat along the edge of coves but may still flood floodplain habitats. In those years, much of the spawning activity and recruitment of age-0 white crappies may depend on access to floodplains. Second, by providing access to spawning habitat earlier in the year, juveniles hatched in floodplains may experience increased survival. Individuals of other centrarchid species hatched early in the growing season are reportedly able to achieve greater lengths during age-0, which could reduce their vulnerability to predation and starvation (Gutreuter and Anderson 1985; Miranda and Hubbard 1994; Cargnelli and Gross 1995). This growth advantage may be a function of the longer growing season, or could be intensified by reduced competition for prey resources that may occur early in the growing season (Phillips et al. 1995).

Management efforts to enhance white crappie populations in the study reservoirs may need to give consideration to preserving and enhancing floodplain habitats. Watershed scale management efforts to control suspended sediments in runoff would help preserve floodplain habitats by decreasing amount of sediments settling in floodplains. Management efforts also may focus on developing sub-impoundments in upper reaches of reservoirs, which may trap sediments. Natural floodplain habitats such as sloughs or oxbow lakes that retain water throughout the year and that become connected to the main reservoir during white crappie spawning season, may require maintenance to remove sediments. Additionally, timely water level fluctuations including dewatering to allow wetland vegetation to recolonize and grow, and ensuring that annual inundation of floodplains coincide with spawning temperatures, should be critical components of management plans.

Table 3.1 Parameter estimates for the 2009 white crappie general linear model describing white crappie movements at Grenada Reservoir, Mississippi. Parameters correspond to those described in equation 3.2.

Parameter	Estimate	SE of Estimate	*P*-value
β_0 intercept	-20.17255	22.4	0.394
β_1 DOY	0.5169	0.4184	0.251
β_2 DOY^2	-0.0029	0.0019	0.177
β_3 Habitat			
Cove	-17.0117	4.812	0.007
Floodplain	0	0	-
β_4 DOY × Habitat			
Cove	0.1637	0.0462	0.007
Floodplain	0	0	-

Table 3.2 Parameter estimates for the 2010 white crappie general linear model describing white crappie movements at Enid, Grenada, and Sardis reservoirs, Mississippi. Parameters correspond to those described in equation 3.2.

Parameter	Estimate	SE of Estimate	*P*-value
β_0 intercept	-3.7492	1.5295	0.018
β_1 DOY	0.1181	0.0305	<0.001
β_2 DOY^2	-0.00062	0.00015	<0.001
β_3 Habitat			
Cove	-1.8322	0.8508	0.037
Floodplain			
β_4 DOY × Habitat			
Cove	0.0247	0.0082	0.004
Floodplain			
β_5 Reservoir			
Grenada	-2.4081	1.0005	0.021
Sardis	-1.5553	1.0960	0.163
Enid			
β_6 DOY × Reservoir			
Grenada	0.0288	0.0099	0.005
Sardis	0.0142	0.0104	0.179
Enid			

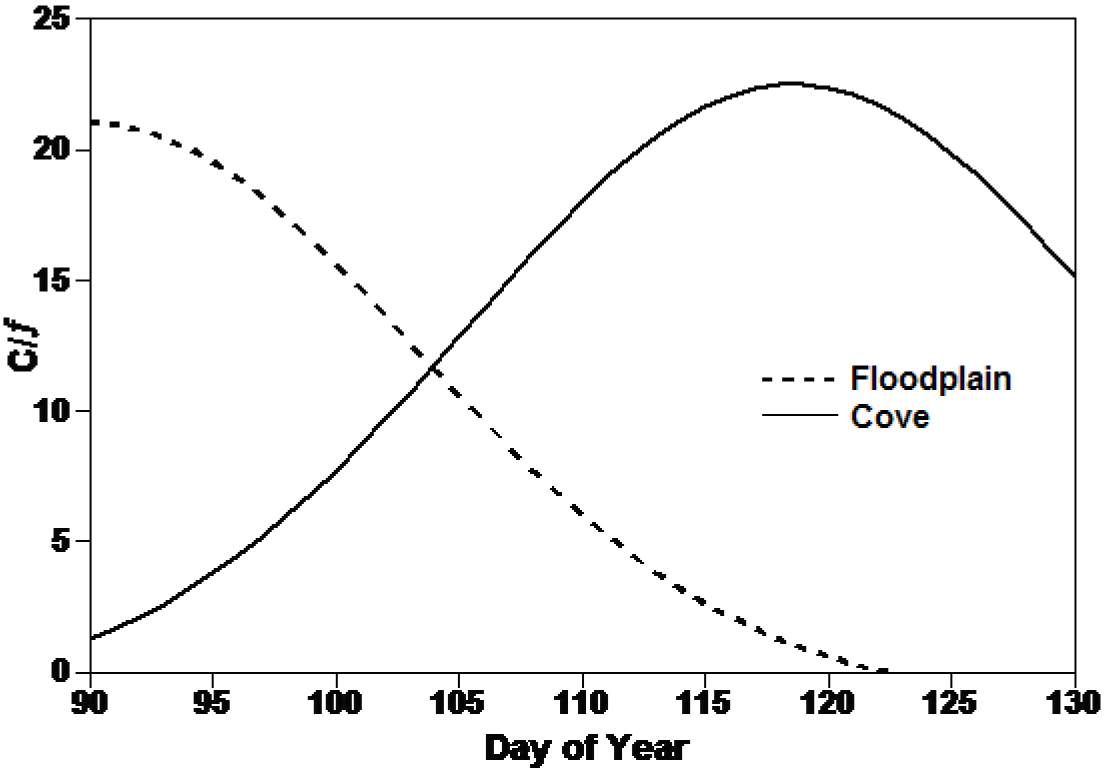

Figure 3.1 General linear model estimates of adult white crappie relative abundance (catch per unit effort – C/*f*) in floodplains and coves of Grenada Reservoir, Mississippi, in 2009.Values were predicted with equation 3.2 and estimates listed in Table 3.1.

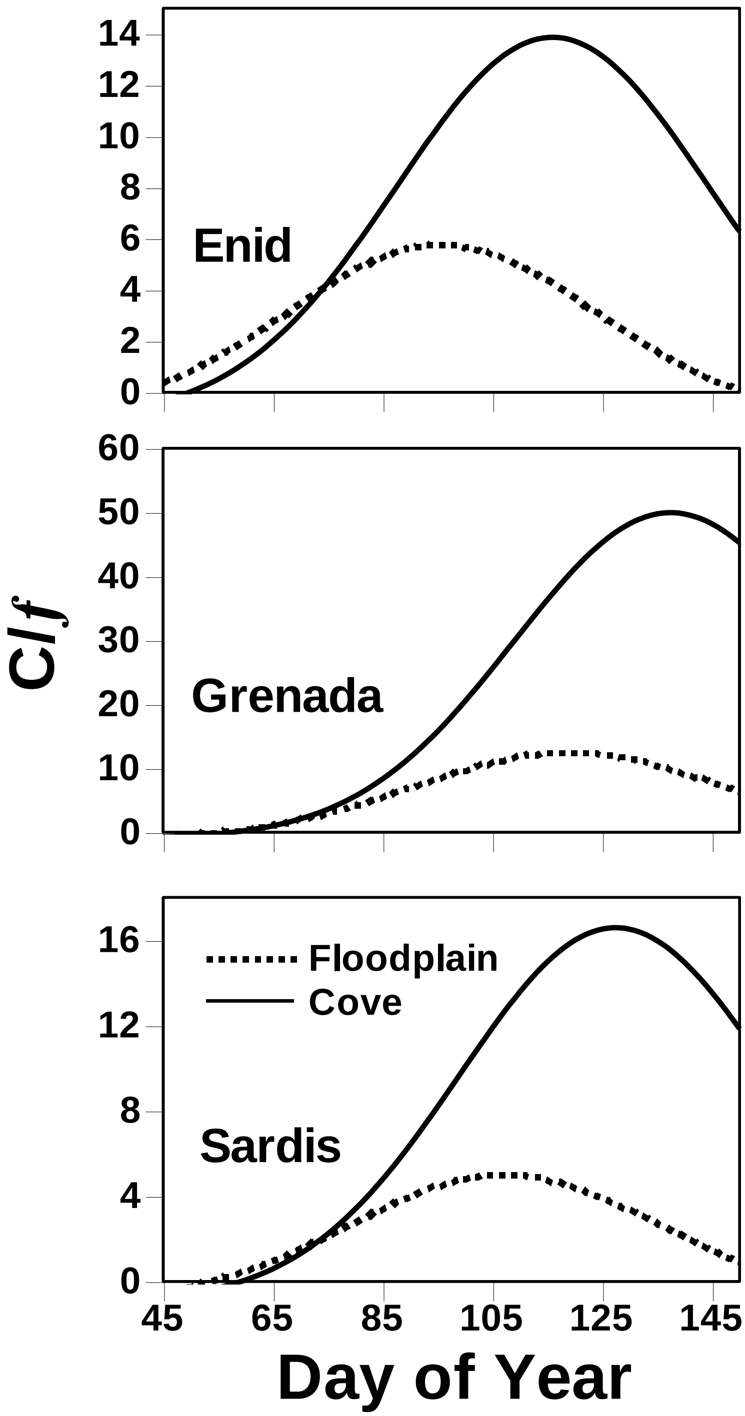

Figure 3.2 General linear model estimates of adult white crappie relative abundance (catch per unit effort – C/*f*) in floodplains and coves of Enid, Grenada, and Sardis reservoirs, Mississippi, in 2010. Values were predicted with equation 3.2 and estimates listed in Table 3.2.

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CHAPTER IV

FLOODPLAINS IN UPPER REACHES OF RESERVOIRS CONTRIBUTE GREAT DENSITIES OF AGE-0 CRAPPIES

Introduction

Understanding factors affecting crappie recruitment (number of fish to survive to a certain threshold) is essential to successful management of crappie populations (Quist 2007). Crappie recruitment is reportedly influenced by numerous environmental factors including wind (Mitzner 1991), water temperature (Siefert 1968), chlorophyll-a (Dubuc and DeVries 2002), spawning habitat availability (Mitzner 1981), and hydrology (Maceina and Stimpert 1998; Sammons et al. 2002). Numerous studies have suggested that annual variation in crappie recruitment in reservoirs is primarily a function of water levels or hydrology (Mitzner 1981; Beam 1983; McDonough and Buchanan 1991; Sammons et al. 2002). High water levels in reservoirs often enhance recruitment of many warmwater fish species if timing of the water level rise and ensuing flooding corresponds with the spawning and growing seasons of the species (Ploskey 1986). Crappies construct nests in flooded areas that contain aquatic or terrestrial vegetation or woody material (Pope and Willis 1997; Phelps et al. 2009). Reproduction and recruitment of crappies during years with high water levels and extensive flooding can be enhanced through increased access to vegetated spawning habitat for adult fish, an action that can also provide protective cover for juvenile fish (Martin et al. 1981; Ploskey 1986).

Managing water levels to flood vegetated habitat may have different outcomes in different reaches of a reservoir. Littoral habitat composition in flood control reservoirs with large annual water level fluctuations typically varies with proximity to the impounding structure (Wetzel 1990). Lower-lake (i.e., close to the dam; coves) littoral habitats are characterized as having high-gradient, greatly-eroded and barren shorelines resulting from wind, wave action, and water level fluctuations (Fujita 1977). Littoral habitat in main-lake coves is limited until water levels exceed summer pool. Upper-lake floodplains are characterized as having low-gradient slopes, complex terrestrial and aquatic vegetation communities, and diverse aquatic habitats such as sloughs, and oxbow lakes, but are only available if water levels are high enough.

Chapter 2 examined differences in habitat distribution and composition relative to increasing water levels in one of the study reservoirs. Given distinct differences in habitat distribution and composition within floodplains and coves, and inter-annual differences in hydrology, objectives of this chapter are to determine: 1) if relative abundance of age-0 crappies differed between floodplains and coves, 2) if reservoir water levels regulate any possible habitat differences in fish density between floodplains and coves, 3) frequency with which floodplains and coves have been inundated in time for crappie spawning in the study reservoirs over the last 2 decades, and 4) what types of reservoirs in the southeastern United States tend to have extensive floodplain areas. I hypothesized that floodplains would have greater densities than coves and that density would be related to pre-spawning and spawning waterlevels.

Methods and Materials

Study Reservoirs

Objectives 1-3 were examined in floodplains and coves of flood control reservoirs in northwest Mississippi (Arkabutla, Enid, Grenada, and Sardis reservoirs). Floodplains occur near the mouth of the main tributary and coves (e.g., reservoir arms or embayments) occur in the main body of the reservoir. The reservoirs were impounded in the 1940s and 1950s as part of the Yazoo Basin Headwater Project, designed to prevent flooding in the western Yazoo basin. At summer pool, the reservoirs range in surface area from approximately 4,600 to 14,500 ha and have mean depths ranging from 2.9 to 5.6 m. All 4 reservoirs have significant annual water level fluctuations ranging from 3.3 to 7.3 m (Table 4.1). Aquatic vegetation is limited in these systems due to turbid water and large annual water level fluctuations.

Water levels in these reservoirs are managed by rule curves implemented and maintained by the United States Army Corps of Engineers (USACE). Rule curves of Enid, Sardis, and Grenada reservoirs begin increasing water elevation around day-of-year (DOY) 15 (i.e., January 15), and reach summer pool by DOY 121 after which they are held constant until DOY 213. The rule curve of Arkabutla Reservoir does not begin increasing water elevation until DOY 121, reaches summer pool by DOY 135, after which it is held constant until DOY 244. Water levels often deviate from rule curve depending on amount of precipitation received in the watersheds where the reservoirs are located or in the region for which flood protection is being provided.

Fish Collections

Age-0 crappies were sampled in floodplains and main-lake coves in late summer (DOY 205 to 230) in 2009 and 2010 using modified fyke nets. Boxrucker and Ploskey (1988) concluded that trap nets provide a relative index of year-class strength useful for spatial and temporal comparisons. Late summer was selected for sampling based on 2 criteria, 1) sampling before fall drawdown of the reservoirs, and 2) delaying sampling until age-0 crappies could not escape through the mesh during net retrieval. The trap nets have 0.9 x 1.8-m rectangular frames spaced 0.6-m apart, a 0.9 x 15-30 m lead equipped with a float line and lead line, and a 13-mm bar nylon mesh (Miranda and Boxrucker 2009). Twelve trap nets per habitat (floodplain and cove) were fished over a 24-h period in each reservoir and in each year. However, because occasional wave action would collapse a net, or a hole would be ripped in a net, some nets had to be excluded from analysis. Trap nets were deployed perpendicular to obstructions (e.g., tree lines, shrub lines, and shoreline) at sites selected at random based on accessibility via a boat and angler density. Areas 1 – 3 m in depth with abundant terrestrial or wetland vegetation and with gently sloping bottoms were targeted. Age-0 crappies were fixed in 10% formaldehyde, preserved in 90% ethanol, counted, and measured for total length (TL) in the laboratory. Identification of age-0 crappies to species using meristic characteristics can be unreliable (Smith et al. 1995); therefore, I combined black crappies and white crappies for analysis and dismissed any possible species-specific differences in recruitment.

Objective 1 - Coves vs. Floodplains

Catch rates (fish per net night) estimated relative abundance in floodplains and coves. A mean catch rate was calculated for floodplains and for coves for each of the 4 reservoirs. A Shapiro-Wilk test (Univariate Procedure; SAS Institute 2008) indicated catch rates in the 4 study reservoirs were not distributed normally in 2009 or 2010, so catch rates were $\log_e$-transformed [$\log_e$(catch rate + 1)] to normalize the distribution and meet assumptions of the statistical test. A 3-factor (habitat, reservoir, year) analysis of variance (ANOVA; GLM Procedure; SAS Institute 2008) was used to test for differences in catch rates between habitats while controlling for differences across years and reservoirs. A multiple comparisons procedure (LSMEANS option of GLM Procedure; SAS Institute 2008) was used to separate means if effects and interactions were significant. All statistical tests were considered significant if *P*-values were less than 0.10. Increasing the probability of committing a type I error (detecting differences in catch rates between habitats or relationships with water level when they do not exist) to α=0.10 reduced the probability of making a type II error (failing to detect differences in catch rates between habitats or relationships to water level when they do exist). Reduction of type I error was of concern in this study because failing to recognize effects of habitat or water level could hinder implementation of potentially beneficial management strategies. Means reported are geometric means.

Objective 2 - Effects of Water Level

Water levels during spawning season influence abundance of habitat available to spawning crappie and to the new year class. Analysis of covariance (ANCOVA; GLM

Procedure; SAS Institute 2008) was used to test for relationships between reservoir water levels and $\log_e$-transformed catch rates of age-0 crappies in floodplains and coves. Catch rate was the dependent variable; habitat was a class variable (floodplain or cove); and covariates were pre-spawn water level and spawning water level. Water level was described as reservoir percentage fullness, where the reservoir was considered 0% full when water level was at winter pool, and 100% full when at flood stage (spillway crest). It would have been preferable to relate age-0 catch rates to habitat estimates discussed in Chapter 2 of this thesis; however, habitat estimates reported in Chapter 2 were only available for one of the 4 study reservoirs. The percentage fullness metric assumes that there is a positive 1:1 relationship between reservoir percentage fullness and amount of vegetation inundated. Mean reservoir percentage fullness was calculated for 2 periods relevant to crappie recruitment, the pre-spawn period (DOY 1 to 74) and the spawning period (DOY 75 to 135). Spawning period was estimated based on day-of-year when water temperatures reached 15º C (DOY_{15}), the water temperature at which crappie reportedly begin spawning (Siefert 1968). Because DOY_{15} occurred on or after DOY 75 in approximately 90% of the years in 1950-2009 (Miranda et al. 2010), DOY 75 was selected as the beginning of the spawning season. Water levels prior to DOY 75 (i.e., pre-spawn period) can affect availability of inundated terrestrial and wetland vegetation. Water levels during the pre-spawn period were considered because high water levels during the pre-spawn period may prevent growth or drown submerged terrestrial or wetland vegetation, which may affect amount of crappie spawning habitat available during the spawning period. Water level data for the study reservoirs were obtained from the USACE Vicksburg District office (USACE 2010).

Objective 3 - Flooding Frequency

Flooding was defined in terms of water level elevation and timing. For coves, flooding elevation was set at +0.6 m from summer pool elevation (Table 4.1), which would result in expansion of water into terrestrial vegetation. For floodplains, flooding elevation was set at -0.9 m from summer pool at Grenada and Enid reservoirs, -2.4 m from summer pool at Sardis Reservoir, and +0.6 m from summer pool at Arkabutla Reservoir. Floodplain elevations were determined empirically to represent +0.6 m above the elevation at which water from the reservoir begins inundating vegetation. Timing was established based on if the elevations listed above were reached by DOY_{15}. This analysis was limited to the 1989 – 2010 period, as current rule curves were established in 1989. Percentage of years in 1989 – 2010 when vegetation in floodplains and coves was inundated by the time water temperatures reached 15º C was calculated according to reservoir and habitat type (floodplains and coves).

Objective 4 - Floodplains in Southeastern Reservoirs

The relevancy of this research to other reservoirs in the southeastern United States was examined. Reservoirs of various sizes and distributed over 12 states (Alabama, Arkansas, Georgia, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia) were selected for analysis. Using the ruler tool in Google Earth, I measured length of the reservoir and length of the floodplain zone within the reservoir. Length of the reservoir was measured from the dam to the mouth of the main tributary river (identified using Google maps). Criteria to identify floodplains included areas that appeared to have complex vegetation communities and a diversity of aquatic habitats including sloughs, and oxbow lakes. Floodplain habitats at upper end of reservoirs typically transition gradually from lacustrine to riverine habitat. For the purposes of this analysis, a single artificial point of transition was selected at a location where the criteria listed above began to become noticeable. The proportion of length of floodplains to length of reservoir (floodplain percentage) was used to index extent of floodplain habitats in the reservoir.

Along with this percentage, various additional reservoir morphometry descriptors were obtained from the 1988 version of the National Reservoir Research Database (Turner and Cornelius 1989). Descriptors available in this database included area, maximum depth, mean depth, elevation, drainage area, volume, storage ratio, thermocline depth, water level fluctuation, and shoreline development index. Two additional variables were created by dividing water level fluctuation by mean depth and water level fluctuation by maximum depth, which effectively relativized fluctuation. Principal component analysis was applied to these 12 variables in addition to reservoir length and floodplain percentage (14 variables total) to identify characteristics of reservoirs exhibiting least and greatest floodplain availability.

Results

Fish Collections

In 2009 and 2010, 2,099 age-0 crappies were collected in the 4 reservoirs. Catch rates in 2009 and 2010 were variable within and among reservoirs (Table 4.2). Trap net catches ranged from 0 to 325 fish per net, with 34% of trap nets (n=57) having zero catches. Total length of age-0 crappies ranged from 43 to 106 mm, and averaged 67 mm (SD=8.3 mm).

Objective 1 - Coves vs. Floodplains

The habitat (coves and floodplains) effect on catch rates of age-0 crappies was significant in 2009 and 2010 (F=64.13, P<0.001). The reservoir × habitat interaction effect also was significant, indicating that effect of habitat depended on reservoir (F=3.31, P=0.022). In 2009, catch rates of age-0 crappies in floodplains of Sardis, Enid, and Grenada reservoirs were significantly greater than cove catch rates, but no difference was detected in Arkabutla Reservoir (Figure 4.1), which accounted for the significant reservoir × habitat interaction. In 2010, catch rates were significantly greater in floodplains than in coves of all reservoirs.

Objective 2 - Effects of Water Level

Mean reservoir percentage fullness during the pre-spawning (DOY 1 – 74) and spawning (DOY 75 – 135) periods varied among lakes and between years. Pre-spawning period water levels in 2009 were low ranging from 3.4% full in Arkabutla Reservoir to 9.8% full in Grenada Reservoir (Table 4.2). Pre-spawning period water levels in 2010 were greater (37.1 to 40.9% full) except for Arkabutla Reservoir, which had a mean pre-spawning period water level of 6.6% full. Spawning period water levels were more similar across years than those in the pre-spawning period (Table 4.2). Also, they were as variable across reservoirs in 2009 (19.5 – 39.6% full) as in 2010 (17.1 – 38.8% full).

The model (Table 4.3) that examined the relationship between catch rates of age-0 crappies and pre-spawn water level, spawning water level, and habitat type was statistically significant (*F*=7.1, *P*=0.005), and explained 64% of the variation in observed age-0 catch rates. The model indicated that floodplain and cove catch rates differed significantly, with floodplains having significantly greater catch rates of age-0 crappies than coves (*F*=13.9, *P*=0.003). The pre-spawning period water level effect on age-0 crappie catch rates was significant, with an inverse effect of water level on age-0 crappie catch rates (*F*=7.0, *P*=0.022); thus, as pre-spawning period water level increased age-0 crappie catch rates decreased. The spawning period water level effect on age-0 crappie catch rates also was statistically significant (*F*=3.2, *P*=0.097), and suggested a direct relationship between spawning period water level and age-0 crappie catch rates.

Objective 3 - Flooding Frequency

From 1989 through 2010 vegetation in floodplains was inundated on average 92% of the years and in coves 75% of the years. The DOY when vegetation in floodplains was inundated varied annually and among reservoirs (Figure 4.2), but the mean was on DOY 90 at Arkabutla, 84 at Enid, 80 at Grenada, and 56 at Sardis. Conversely, mean DOY when terrestrial vegetation was inundated in coves was 90 at Arkabutla, 108 at Enid, 127 at Grenada, and 95 at Sardis. Thus, there was no difference at Arkabutla Reservoir between mean DOY when vegetation in floodplains and coves were inundated, but at Enid Reservoir vegetation in floodplains was flooded on average over 3 weeks earlier than in coves, over 6 weeks earlier at Grenada, and over 5 weeks earlier at Sardis.

Ideally, flooding of vegetated areas should occur briefly before DOY_{15} to provide spawning crappie with freshly-inundated vegetation. Although vegetation was flooded almost yearly, years when flooding occurred by DOY_{15} were fewer. On average, floodplains were inundated 47% of the years by DOY_{15} including 41% of the years at Arkabutla, Enid, and Grenada reservoirs, and 64% of the years at Sardis Reservoir. Coves were inundated by DOY_{15} on average 28% of the years, including 41% of the years at Arkabutla Reservoir, 27% at Enid and Sardis reservoirs, and 18% at Grenada Reservoir. Thus, floodplains were flooded on time to coincide with crappie spawning roughly half of the years in floodplains, but roughly one-third of the years in coves. Nevertheless, these percentages do not reflect the fact that in some years flooding of vegetation occurred many weeks before DOY_{15} (Figure 4.2), which potentially could have reduced quality of the flooded vegetation.

Objective 4 - Floodplains in Southeastern Reservoirs

In total, 53 reservoirs representing a wide diversity of morphometry descriptors and 3 use types were included in this analysis (Table 4.4). Drainage area, total area, volume, storage ratio, and ratio of fluctuation to maximum depth were the most variable descriptors having coefficients of variation greater than 100. Other variables had lesser coefficients of variability yet were still relatively variable with values ranging between 50 and 100. Of particular importance to this analysis is variability of percentage floodplains, which ranged from 0 to 50% with a coefficient of variation of 81. Use type included 47% hydropower, 42% flood control, and 11% navigation, although many of the study reservoirs were multi-purpose reservoirs.

The first 4 principal components had eigenvalues greater than one and accounted for over 84% of the variability in reservoir morphometry descriptors. Principal component 1 and principal component 2 accounted for over 60% of the variability in reservoir morphometry and were the only principal components considered because loadings for percentage floodplains, the descriptor of interest, were greatest in these principal components. This analysis indicated that presence of a greater percentage of floodplains in reservoirs was generally inversely related to mean and maximum depth, storage ratio, thermocline depth, and elevation, but directly related to relative water level fluctuation (Figure 4.3). This analysis also suggested that percentage floodplains was not associated strongly with variables descriptive of reservoir size, such as area, length, volume, or drainage area.

The PCA ordination also showed that reservoir use type separated best mainly along principal component 1 (Figure 4.3). Flood control reservoirs tended to ordinate to the left of principal component 1, navigation reservoirs near the center, and hydropower reservoirs to the right. However, there was substantial overlap, particularly between navigation and hydropower reservoirs. These results suggest that these reservoir types have different characteristics, but that flood control reservoirs tend to have the greatest percentage of floodplains, followed by navigation, and by hydropower reservoirs. Mean percentage floodplains in flood control reservoirs was 24% (N=22 reservoirs), 19% (N=6 reservoirs) in navigation reservoirs, and 12% (N=25 reservoirs) in hydropower reservoirs.

Discussion

An important assumption of this study was that densities of age-0 crappies in mid-summer reflected events prompted by habitat availability several months earlier. The validity of this assumption depends on extent of crappie dispersals into or out of the study areas. Briefly after absorbing the yolk-sac, crappie larvae passively or actively disperse to offshore areas (i.e., areas in which light does not penetrate to the bottom) to feed on offshore zooplankton (Seifert 1968; O'Brien et al. 1984). After a few weeks of this offshore stage, juveniles shift to a more benthic habitat, and occupy offshore and littoral areas (Pine and Allen 2001; Bunnell et al. 2003). I could neither validate nor invalidate this assumption. However, size of the floodplains and arms included in this study was large and contained extensive offshore and littoral habitats suitable for supporting all life stages of crappies. Therefore, I suggest that in these floodplains and coves, juvenile crappie densities in mid-summer are likely well correlated with events that took place weeks earlier during the spawning period.

My results suggest that floodplains in northwest Mississippi flood control reservoirs provide essential spawning habitat for adult crappies and nursery habitat for age-0 crappies. Catch rates of age-0 crappies were greater in floodplains of all 4 reservoirs in each year except for Arkabutla Reservoir in 2009. The study years presented scenarios in which water levels during the pre-spawning period were low in 2009 and high in 2010. In each scenario, catch rates of age-0 crappies were greater in floodplains than coves. When inundated during the crappie spawning season, floodplains provide abundant vegetated habitat for spawning crappies at lower water levels than coves. Floodplains would therefore flood earlier and remain flooded longer than coves and provide prolonged nursery habitat for age-0 crappies. An exception was Arkabutla Reservoir in 2009, where catch rates of age-0 crappies were greater in coves than in floodplains, although not significantly different. Greater catch rates in coves was apparently attributed to extremely high water levels (average of 1.5 m over summer pool) during the spawning period, which produced conditions in coves analogous to those created at lower water levels in floodplains. Abundant terrestrial habitat becomes inundated in coves only when water levels exceed summer pool elevations. At extremely high water levels, inundated vegetation becomes more similar between floodplains and coves, reducing differences in effects of habitat.

Similar to my results, other studies have reported positive relationships between crappie year-class strength and high water levels during the crappie spawning period (Mitzner 1981; Beam 1983; McDonough and Buchanan 1991). High water levels during the spawning period increase amount of preferred habitat available for spawning crappie (Martin et al. 1981). High water levels also have been linked to increased allochthonous inputs and nutrient releases from inundated vegetation and sediments, resulting in a brief increase in productivity likely to enhance food availability for juvenile fish (Godshalk and Barko 1985; Ploskey 1986; Northcote and Atagi 1997). High water levels increase food availability for age-0 crappies through addition of terrestrial invertebrates that succumb to inundation (Mullan and Applegate 1968). My results add to this list of benefits by suggesting that high water levels facilitate access to floodplain habitats that provide desired spawning substrates and juvenile rearing areas.

This study suggested that crappie recruitment in northwest Mississippi flood control reservoirs is negatively affected by high water levels during the 2 – 3 months preceding the spawn. Potentially, vegetation may be degraded if inundation prior to the spawn is long enough to drown vegetation or allow epilithon cover to grow on spawning surfaces. Spawning habitat can be degraded if duration of flooding kills or prevents growth of terrestrial vegetation (Northcote and Atagi 1997). Seasonal flooding will kill many species of trees, though there are some tolerant tree species, such as willows *Salix* spp. and some shrubs that can survive partial inundation (Godshalk and Barko 1985). Woody plants need to be periodically emerged to allow for aerobic root respiration (Godshalk and Barko 1985). Most herbaceous plants are less tolerant of flooding than woody plants and die more rapidly than woody vegetation (Whitlow and Harris 1979). Riis and Hawes (2002) found that vegetation diversity in the littoral zone of a lake was greatest when inundation lasted less than 30 days, suggesting that inundation beyond 30 days would have detrimental effects on species intolerant of inundation. Relative to epilithon buildup, Gafny et al. (1992) found that egg density and survival of lake sardines, a substrate spawner, decreased as epilithon cover increased. Similarly, spawning success of Eurasian bream was reduced as epilithon cover reduced the eggs ability to attach to substrates, therefore reducing egg survival (Probst et al. 2009). Crappies construct nests on sand or clay substrates that are free of silt or other fine sediments that if present, may create anoxic conditions for crappie eggs (Phelps et al. 2009). Hansen (1965) reported that crappie eggs adhered to clay substrates and vegetation present in or around the nest. Epilithon cover may prevent adhesion of eggs to the surface of the nest, potentially decreasing egg viability. Effect of epilithon cover on crappie reproduction has not been documented, but may provide insight into how pre-spawning period water levels affect crappie recruitment.

Recruitment of littoral spawning fish species is influenced not just by extent of flooding but also by its timing (Aggus and Elliot 1975). Flooding of vegetation that corresponds with the spawning season of littoral spawning species may result in a stronger year class (Ploskey 1986). My analyses indicated that vegetation is inundated almost yearly in the study reservoirs; however, inundation of vegetation prior to DOY_{15} occurred in substantially fewer years. Because of differences in elevation, vegetation in floodplains was flooded on time for crappie spawning in about one-half of the years, but only about one-third of the years in coves. In some years inundation occurred too early. Inundation of floodplain and cove vegetation would ideally occur 1 – 2 weeks prior to DOY_{15}. If inundation occurs much earlier, or water level remains high through the previous fall and winter, amount and/or quality of vegetation may be reduced.

Wetlands in floodplains of reservoirs provide unique spawning and nursery habitat for crappies, many species of centrarchids (Meals and Miranda 1991), and other reservoir species (Slipke et al. 2005). Extent of floodplain habitats in reservoirs varies, dictating composition of the fish assemblage. Reservoirs throughout the southeastern United States have been constructed for many purposes including flood control, navigation, water supply, hydropower, and recreation all of which differ in extent of floodplain availability due to where they are built and how they are managed. Reservoirs with large relative water level fluctuations (flood control reservoirs) tend to have more floodplains than deep reservoirs located in high elevations (hydropower reservoirs) where floodplains are constricted. Location of a reservoir along the reservoir cascade and its primary use dictates habitat representation in the reservoir (Jenkins 1970; Miranda et al. 2008). A hydropower reservoir located high in a reservoir cascade would likely have a smaller fraction of littoral habitat and reduced connectivity to floodplains compared to a reservoir located downstream (Miranda et al. 2008). Many fish species rely on or are benefited by presence of floodplains to complete portions, or all, of their life history stages. Recognition of importance of floodplains and an understanding of how floodplains relate to other reservoir physical characteristics could allow managers to adjust species specific management objectives based on the species dependence on floodplain habitats.

Management Implications

Currently, water levels do not reach summer pool until DOY 121 in Grenada, Enid, and Sardis reservoirs, and DOY 135 in Arkabutla Reservoir. Thus, summer pool is attained near or at the end of the crappie spawning season and that of other fish species, thereby limiting amount of habitat available for spawning. A rise in water level briefly before DOY_{15} may benefit crappie populations. Since 1950, DOY_{15} occurred after DOY 75 in approximately 90% of the years (Miranda et al. 2010), indicating that vegetation should be inundated by approximately DOY 75 to be available for spawning crappies.

Water levels in northwest Mississippi flood control reservoirs and possibly similar reservoirs elsewhere, may best benefit crappies if they were held at winter pool during fall and winter to allow for growth of vegetation and then gradually raised to flood floodplains and coves 1 – 2 weeks prior to the onset of crappie spawning season (about DOY 75). Flooding vegetation in floodplains by this target date is more achievable than flooding vegetation in coves because floodplains are positioned at lower elevations and can be flooded while water level is below summer pool. Vegetative communities in floodplains (wetland species) are able to tolerate annual flooding or readily re-establish after inundation (Liu et al. 2009), and thus can sustain more regular flooding. Since 1989, floodplain vegetation in the study reservoirs has been inundated in 92% of the years, but in time for crappie spawning only 47% of the years. Conversely, flooding vegetation in coves by the crappie spawning season is more difficult because it requires raising the water level above summer pool. As a result, since 1989 the study reservoirs have been flooded 0.6 m above summer pool in 75% of the years, but in time for crappie recruitment in only 28% of the years. Upland vegetation typically flooded in coves is less tolerant of annual inundation (Liu et al. 2009) and if drowned usually requires 2 – 3 years to re-establish post inundation (Strange et al. 1982). Limiting inundation of upland vegetation to the current frequency of 75% of the years would preserve the current assemblage of vegetation. Conceivably, flooding in these reservoirs may be moved ahead so that floodplains are flooded on time for spawning another 40 – 50% of the years while still preserving existing vegetation assemblages. Nevertheless, additional monitoring and research is needed to ensure that vegetation assemblages will not be damaged.

Table 4.1 Characteristics of study reservoirs in northwest Mississippi (Meals and Miranda 1991).

	Reservoir			
Characteristic	Arkabutla	Enid	Grenada	Sardis
Year of Impoundment	1941	1952	1954	1940
Elevation (m)				
Winter Pool	63.7	70.1	58.8	71.9
Summer Pool	67.1	76.2	65.5	79.2
Full Pool	72.5	81.7	70.4	86.3
Surface area (ha)				
Winter Pool	2,056	2,477	3,970	3,996
Summer Pool	4,804	6,528	14,496	12,991
Full Pool	13,537	11,311	25,160	23,675
Average depth (m)				
Winter Pool	1.9	2.9	2.6	2.9
Summer Pool	2.9	5.1	4.7	5.6
Full Pool	4.8	7.2	6.3	8.2
Annual Depth Fluctuation (m)	3.3	6.1	6.7	7.3

Table 4.2 Fyke net catches of age-0 crappies in floodplains (FP) and coves (CO) of Mississippi flood control reservoirs and mean percentage fullness during the pre-spawning and spawning periods in 2009 and 2010.

Lake	Habitat	Year	Pre-spawning % Full	Spawning % Full	Crappie	Net Nights	Geometric Mean	CV
Arkabutla	FP	2009	3.4	39.6	233	11	5.6	85
		2010	6.6	17.1	200	8	10.5	38
	CO	2009	3.4	39.6	383	11	13.9	69
		2010	6.6	17.1	37	11	2.4	58
Enid	FP	2009	6.3	25.3	86	12	3.8	69
		2010	40.9	38.8	417	11	8.4	68
	CO	2009	6.3	25.3	13	11	0.5	180
		2010	40.9	38.8	0	11	0.0	.
Grenada	FP	2009	9.8	34.7	404	10	27.2	29
		2010	40.7	32.0	58	11	3.0	76
	CO	2009	9.8	34.7	100	8	6.7	58
		2010	40.7	32.0	3	11	0.2	229
Sardis	FP	2009	3.7	19.5	68	11	4.7	45
		2010	37.1	34.9	88	11	5.8	45
	CO	2009	3.7	19.5	5	11	0.3	185
		2010	37.1	34.9	4	11	0.2	237

Table 4.3 Parameter estimates for the model relating reservoir water level to age-0 crappie catch rates in northwest Mississippi flood control reservoirs in 2009 and 2010. The following model was applied

$$C/f = \beta_0 + \beta_1 Habitat + \beta_2 \mathrm{Pr}espawnWL + \beta_3 SpawningWL$$

Parameter	Estimate	SE of Estimate	F-value	P-value
β_0 Intercept	0.1131	0.6869	.	0.87
β_1 Habitat			13.9	
Floodplain	1.2500	0.3357		<0.01
Cove	0.0000	.		.
β_2 Pre-spawn WL	-0.0309	0.0117	7.0	0.02
β_3 Spawning WL	0.0429	0.2386	3.2	0.10

Table 4.4 Description and distribution of variables included in the principal components analysis. Statistics represent summaries over all 53 southeastern reservoirs included in the analysis. Data were collected by Turner and Cornelius, 1989.

Variable	Description	Min	Mean	Max	CV
Drainage area (ha)× 100	Total area from which runoff drains into the reservoir	293	37,001	397,993	230
Elevation (m)	Elevation of reservoir above mean sea level	23	140	327	63
Area (ha)	Total surface area of the reservoir	554	12,164	73,491	114
Volume (ha-m)	Total volume of the reservoir	3,230	92,827	560,001	126
Storage ratio	Ratio of volume to discharge	0.01	0.50	3.23	136
Mean depth (m)	Mean depth of the reservoir	1.8	7.9	35.7	77
Max depth (m)	Maximum depth of the reservoir	4.6	26.2	112.8	74
Thermocline depth (m)	Depth at which the thermocline develops	0.0	4.3	13.7	99
Fluctuation (m)	Annual change in water level	0.6	3.7	9.1	76
Shoreline development index	Ratio of the length of the shoreline to length of the circumference of a circle of equal area to the reservoir	2	12	38	68
Reservoir length (km)	Length of the reservoir from the dam to its main tributary	8	35	142	82
Percentage floodplains	Proportion of length of floodplains to length of reservoir	0	20	50	81
Fluctuation 2	Ratio of fluctuation to mean depth	0.02	0.20	0.80	98
Fluctuation 3	Ratio of fluctuation to max depth	0.05	0.70	3.60	114

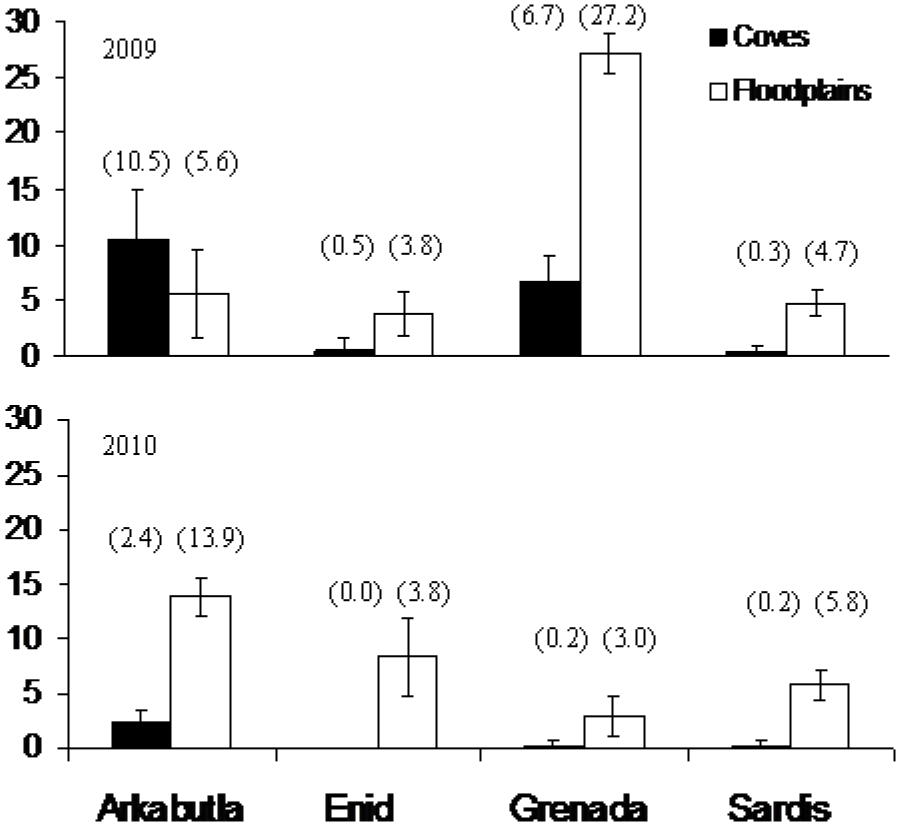

Figure 4.1 Catch rates of age-0 crappies in coves and floodplains of 4 northwest Mississippi flood control reservoirs in 2009 and 2010. Error bars represent standard deviation. Mean catch rate is in parentheses above its respective bar.

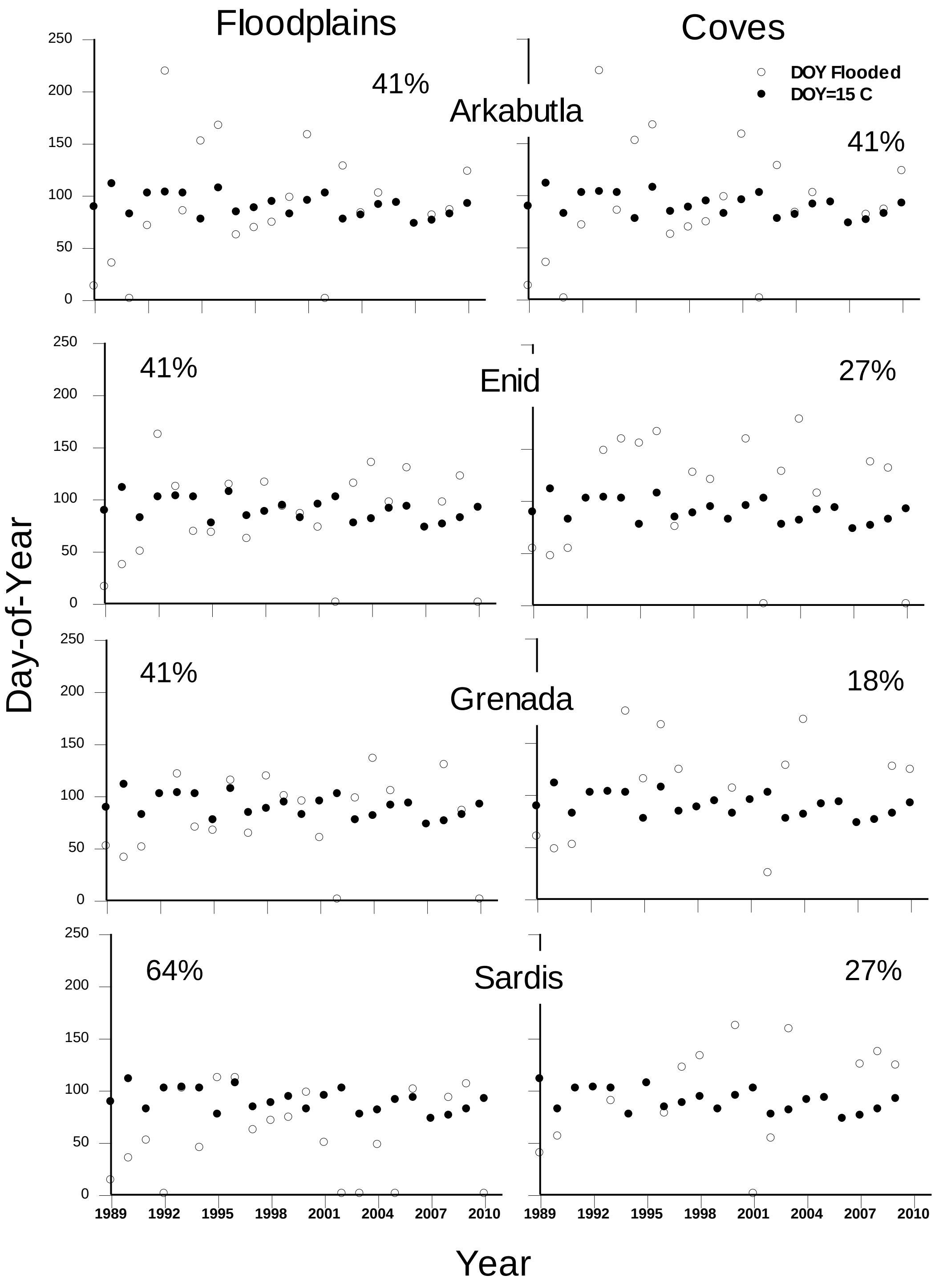

Figure 4.2 Percentage of years from 1989 to 2010 in which floodplain and cove vegetation was inundated prior to water temperatures reaching 15º C in 4 flood control reservoirs in northwest Mississippi. White dots represent day-of-year when vegetation is flooded and black dots represent day-of-year when water temperature reaches 15º C.

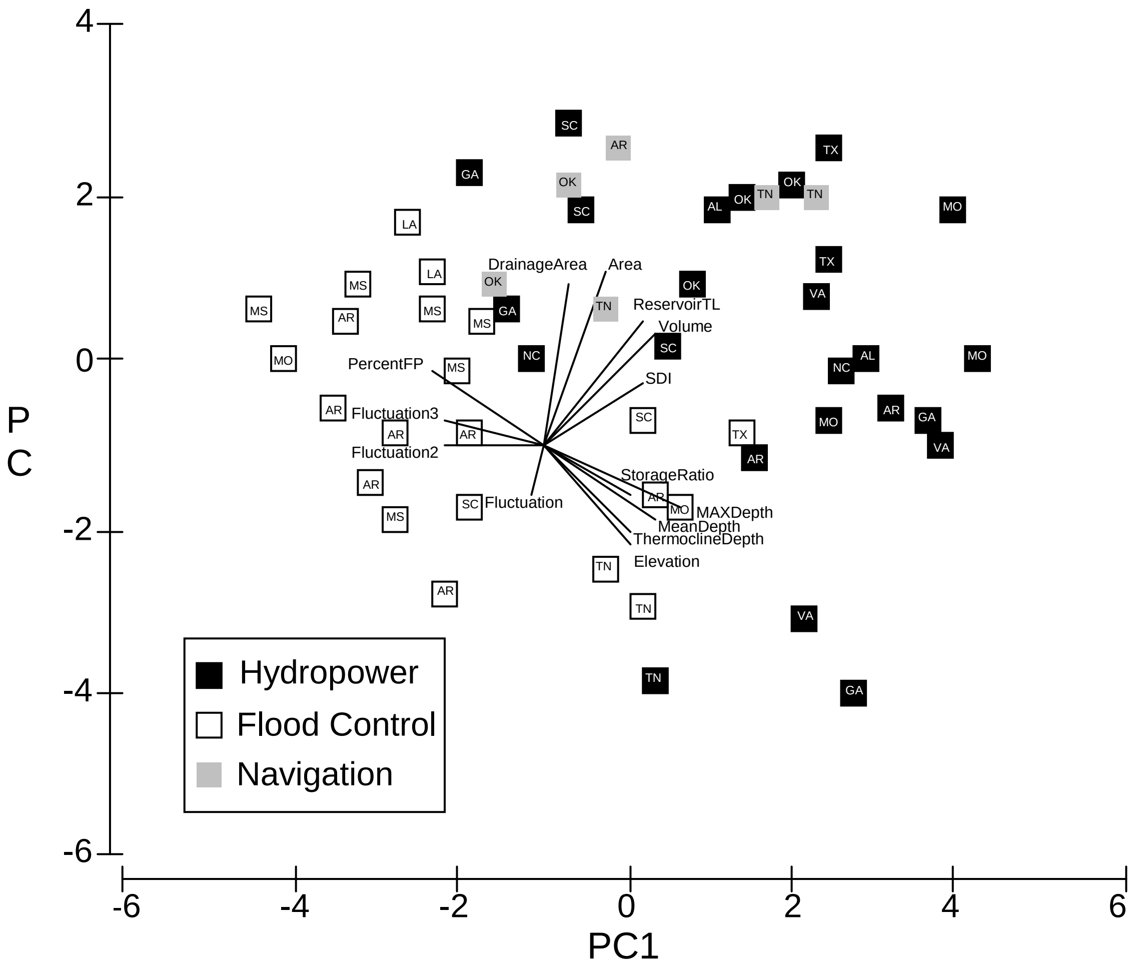

Figure 4.3 Principal component analysis results of reservoir morphometry descriptors from 53 southeastern reservoirs. State abbreviations are in each square. Different shade squares represent reservoir use type. Data were collected by Turner and Cornelius (1989).

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CHAPTER V

SUMMARY AND CONCLUSIONS

The overarching goal of this study was to provide fisheries managers with additional insight into how to inundate floodplain habitats in reservoirs to benefit crappie populations. The objective of Chapter 2 was to quantify and describe how vegetation composition changed with increasing water levels, and then compare vegetation composition of 2 dissimilar areas in the reservoir, a floodplain and a cove. The results suggest that herbaceous vegetation was the most common vegetation in coves and the floodplains, as it comprised at least one-half of the habitat composition over various depth bands. However, coves tended to have roughly twice the amount of non-vegetated areas and forest habitats relative to floodplains. Floodplains tend to have greater percentages of wetland and shrub habitats relative to coves. The objective of Chapter 3 was to examine if use of floodplain and cove habitats by reproductive-sized crappies differed during late winter and spring. I hypothesized that crappies would use floodplains to a greater degree than coves; in contrast, I found that coves had greater catch rates in each year and all reservoirs sampled. Peak abundance of reproductive sized crappies occurred nearly 2 – 3 weeks earlier in floodplains than in coves. The objectives of Chapter 4 were to determine 1) if age-0 crappie densities differed between floodplains and coves, and 2) whether a relationship existed between age-0 crappie abundance and pre-spawning period and spawning period water levels. Abundance of age-0 crappies was greater in floodplains than in coves in all but one of the years and reservoirs sampled, suggesting that floodplains may provide habitat important to sustaining crappie populations. Additionally, age-0 crappie density was affected negatively by high pre-spawning period water levels and affected positively by high spawning period water levels, suggesting that timely increases in water level could be a useful management tool.

Although results of Chapter 3 suggest that catch rates (fish/hour of electrofishing) of reproductive-sized crappies were greater in coves than in floodplains during the spawning period, I suspect that crappie abundance (fish/ha) in floodplains may be greater. Catch rates in coves were potentially biased high because of differing capture probabilities in the 2 habitats. In coves, lack of suitable habitat seemed to concentrate crappies around what little habitat there was, potentially inflating catch rates. Conversely, in floodplains suitable habitat was in great abundance which tended to disperse crappies, potentially deflating catch rates.

This thesis provides evidence that floodplains in the study reservoirs produce greater densities of age-0 crappies and may be important in sustaining crappie populations. From a habitat perspective, floodplain habitats contained greater percentages of wetlands, which are conducive to crappie spawning. Additionally, one could argue that floodplains contain higher quality crappie spawning and nursery habitat. From a recruitment perspective, habitat in floodplains is inundated earlier than habitat in coves, which may allow spawning to occur earlier depending on the reservoir. By providing access to spawning habitat earlier in the year, juveniles hatched in floodplains may experience increased survival because of their greater size. Finally, in years of below-average precipitation, water levels are lower and vegetation in coves may not be inundated, whereas vegetation in floodplains may be. If this was the case, much of the spawning activity and recruitment of white crappies may depend on access to floodplains. In high water years, vegetation in the coves and the floodplains would be inundated, thereby decreasing importance of floodplain inundation.

Management of water levels in these reservoirs could be a useful tool for sustaining crappie populations. Water levels in northwest Mississippi flood control reservoirs, and possibly similar reservoirs elsewhere, may best benefit crappies if they were held at winter pool during fall and winter to allow for growth of vegetation, and then gradually raised to flood floodplains and coves 1 – 2 weeks prior to the onset of crappie spawning season (about DOY 75). Flooding vegetation in floodplains by this target date is more achievable than flooding vegetation in coves because floodplains are positioned at lower elevations and can be flooded while water level is below summer pool. Additionally, vegetative communities in floodplains (wetland species) are able to tolerate annual flooding or readily re-establish after inundation and thus can sustain more regular flooding.

Management strategies for littoral zones in coves and floodplains could focus on providing additional spawning habitat. In coves, construction of sub-impoundments to function as wetlands would provide habitat that could be exploited by crappies. Moreover, planting of vegetation in the winter drawdown zone may provide additional habitat, although this vegetation would likely have to be replanted annually (Strange et al. 1982). Efforts to increase bank stability may include rip-rapping eroded sections of shoreline. Decreasing erosion would potentially allow vegetation to re-colonize otherwise unstable shoreline areas. In floodplains, habitat management strategies could focus on protection and restoration. Some sub-impoundments currently exist in floodplains of the study reservoirs, but many are too deep to support wetland vegetation. Additional shallow sub-impoundments to function as wetlands may benefit crappie populations in floodplains. Also, watershed-scale management efforts to control suspended sediments in runoff would help preserve floodplain habitats by decreasing amount of sedimentation.

This study provides managers with additional information regarding crappies and floodplain inundation, but there are several areas that still need research. Although differences in vegetation communities in floodplains and coves were observed during sampling, there are no data to validate these observations. A description of vegetation species richness, diversity, and composition in floodplains and coves and an understanding of their tolerances to inundation may prove to be beneficial in formulating water management objectives. In addition, a study to assess the contribution to the crappie population by age-0 crappies that originate in coves and floodplains may provide managers with an improved framework of where to focus habitat preservation and restoration efforts.

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