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Habitat Associations of Lower Mississippi River Floodplain Fishes on St. Catherine Creek National Wildlife Refuge

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HABITAT ASSOCIATIONS OF LOWER MISSISSIPPI RIVER FLOODPLAIN FISHES ON ST. CATHERINE CREEK NATIONAL WILDLIFE REFUGE

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ABSTRACT

Each year, floodplain habitats are inundated and dewatered throughout the lower Mississippi River during the flood pulse. Many organisms, particularly fishes, are facultative or obligate users of inundated floodplain habitats for foraging and reproduction. The abundance and distribution of these fishes are influenced by annual floods, ranging from weeks to months depending on intensity and duration of the pulse. One major consequence of anthropogenic alterations to the river has been the sequential loss of connectivity of floodplain habitats. In light of these changes, a concentrated effort has been made to restore the integrity of the LMR floodplain. An integral part of restoration efforts depends on understanding characteristics of aquatic habitats that promote reproduction, growth, and survival of floodplain species. In collaboration with USFWS and GCPOLCC, this project investigated fish-habitat relationships and identified aquatic habitat conditions that promote healthy alligator gar populations. My objectives for this study were to: 1) identify floodplain habitat features associated with desired fish assemblage characteristics based on the role of Alligator Gar as a surrogate species; and 2) develop a sampling protocol for surveying alligator gar with side-scan sonar. The sampling program involved collecting fishes with gill nets throughout the flood pulse and documenting species and sizes of fishes collected in relation to habitat characteristics. A total of 373 fishes representing 14 species were sampled across 62 sites during two pulse periods (2013-2014). The most frequently caught species was Smallmouth Buffalo, which made up approximately half of the total catch followed second by Bigmouth buffalo. Considering two species of conservation concern that were present, Paddlefish (n=8) were found strictly in OPWA and FLVG. Conversely, Alligator Gar (n=31), which were caught at 22 sites with 6 sites producing multiple fish. These sites also yielded significant abundances of other fish species, including Gizzard

Shad (53.8%; n=13), Common Carp (45.5%; n=22), and Longnose Gar (60.0%; n=5). Analyses revealed that fish assemblage structure was strongly related to habitats in REWA and OPWA, distance to river, sample year, and river stage. Alligator gar were reliably detected with side-scan sonar, yielding 788 images collected and a total estimate of 515 gar with approximate total lengths > 1m. These data will assist in developing sound conservation strategies throughout the LMRV to identify areas that fit the USFWS's needs in prioritization of conservation and floodplain restoration projects and the Service's initiative for strategic habitat conservation. A better understanding of this floodplain system and the characteristics that contribute to its habitat value will hopefully provide the basis for development of management programs to enhance floodplain fish diversity and accessibility of floodplain habitats to riverine species.

CHAPTER 1. GENERAL INTRODUCTION

1.1 INTRODUCTION

The annual flood pulse in the Mississippi River inundates an extensive floodplain area in the lower river for periods ranging from a few days to several months. Numerous fishes are facultative or obligate users of inundated floodplain habitats for foraging and reproduction (Welcomme 1979, Kwak 1988, Junk et al. 1989). However, alterations to river-floodplain connectivity over the past century, including levee construction, channel training, weir placements, and bank armoring, have changed the hydrology and behavior of the river (Baker et al. 1991, Agostinho et al. 2004, Schramm et al. 2009, Piazza et al. 2014) as well as the accessibility and biotic value of flooded bottomland forests, lakes, and agricultural lands (Barko et al. 2004, Harmar and Clifford 2006, Lasne et al. 2007).

Water has been historically managed to control the timing, duration, and magnitude of river discharge, whether for flood control, agriculture, industry, or municipal and domestic use (Poff et al. 1997, Tockner and Stanford 2002). The use of dams and levees to alter the natural flow of riverine systems results in severe changes to floodplain hydrology that can significantly affect availability and use of essential fish habitat (Bunn and Arthington 2002, Ickes et al. 2005). These changes lead to decreased floodplain inundation (Schramm et al. 2009), disconnection of floodplain channels and access from river channels, and reduced floodplain use by fishes inhabiting the river (Lasne et al. 2007). Such changes can have substantial impacts on the distribution and abundance of floodplain-dependent fishes, reducing or eliminating access to habitats that are essential for movement, migration, reproduction, feeding, and growth (Ross and Baker 1983, Kwak 1988, Ferrara 2001, Mendoza et al. 2002, Springer 2002, Robertson et al. 2008).

The Mississippi River has lost 90 percent of its floodplain habitat due to human alterations, prohibiting vital exchanges of water, nutrients, fishes, food supplies, and debris (Baker et al. 1991, Postel and Richter 2003, Piazza et al. 2014). Historically, river management has been based solely on water quality/quantity and navigable use, with little consideration of the biotic effects of channel training and floodplain isolation (Mitsch and Gosselink 2007, Ickes et al. 2005). Examining interactions between riverine systems, floodplains, and their associated fish assemblages is essential for improving management policies and addressing problems that have been created from past river alterations. A management approach that considers the ecology of the entire river system and focuses on maintaining the ecological integrity of floodplain ecosystems and their connectivity to the main stem river environment is critical (Ickes et al. 2005); this should be the overarching theme in river restoration water management (Burgess et al. 2012). Management of these waterways should focus more on allowing natural flow of the river rather than restricting and controlling water for human use. Without accessible floodplains, riverine fish populations across the world may continue to decline, riparian agricultural lands may continue to be degraded without nutrient replenishment, and coastal habitat quality may decline without the natural flushing of coastal marshlands (Aarts and Nienhuis 2003, Aarts et al. 2004).

The lower Mississippi River (LMR) has undergone tremendous anthropogenic changes over the last century, including an extensive levee system that has eliminated thousands of square kilometers of historic floodplain habitat (Criss and Kusky 2008, Ickes et al. 2005). Numerous fishes take advantage of flooded bottomlands along the river for feeding and reproduction, the Alligator Gar (*Atractosteus spatula*), which is one of the largest, most easily recognized freshwater fishes in tributary rivers of the Gulf of Mexico (Mendoza et al. 2002).

Alligator Gar are a species of conservation concern and have suffered population declines and historic range contractions across the United States, likely due to sport and commercial fishing pressure and loss and alteration of critical habitat (Ferrara 2001, Mendoza et al. 2002). Channelization has resulted in sandy substrates and little habitat structure in most large systems, including the LMR, where associated levees have kept spring floods from inundating bottomlands that function as primary Alligator Gar spawning habitat (Springer 2002).

Located near river kilometer 578 on the LMR, St. Catherine Creek National Wildlife Refuge (SCCNWR) comprises 8,499 hectares (21,000 acres) of floodplain and supports a diverse fish assemblage that includes Alligator Gar (Allen et al. 2014) and Paddlefish (*Polyodon spathula*; R. Campbell, USFWS, pers. comm.). Alligator Gar restoration projects have been underway for the past ten years, but these efforts have been hindered by the lack of information on Alligator Gar habitat requirements and life history characteristics, particularly those related to floodplain use. The lack of life history data for LMR Alligator Gar have contributed to its listing as a species of concern by the U.S. Fish and Wildlife Service (USFWS) and the Gulf Coastal Plain Ozarks Landscape Conservation Cooperative (GCPOLCC).

In collaboration with USFWS and GCPOLCC, this project identified aquatic habitat conditions that promote healthy alligator gar populations. My objectives for this study were to identify floodplain habitat features associated with desired fish assemblage characteristics based on the role of alligator gar as a surrogate species (Campbell 2012), and develop a sampling protocol for surveying alligator gar with side-scan sonar (Kaeser and Litts 2010). A better understanding of this floodplain system and the characteristics that contribute to its habitat value will hopefully provide the basis for development management programs to enhance floodplain fish diversity and accessibility of floodplain habitats to riverine species.

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CHAPTER 2. THE FLOODPLAIN FISH ASSEMBLAGE

2.1 INTRODUCTION

Flooding can contribute significantly to the availability of trophic and reproductive resources for fishes in both tropical and temperate riverine systems (Junk et al. 1989, Junk 1999, Kingsford 2000, Petry et al. 2003, Ickes et al. 2005). Flood pulses provide seasonal increases in food availability in periodically connected floodplain lakes and ponds, including vegetation, insects, detritus and abundant forage fishes, for migrating adult fishes as well as larval and juvenile fishes produced on the floodplain (Junk et al. 1989, Winemiller and Jepsen 1998). Floodwaters also wash floodplain-derived food, woody debris, and detritus into the main river channel, increasing availability of food and cover to fishes that do not access flooded habitats (Humphries et al. 1999). Levee systems typically reduce or eliminate floodplain connectivity in developed systems such as the LMR (Criss and Kusky 2008, Baker et al. 1991, Tockner and Stanford 2002, Ickes et al. 2005), eliminating vast areas of potential fish habitat and interrupting the natural exchange of water, sediment, nutrients, and organic debris that are vital resources for riverine and floodplain organisms (Bayley 1991, Poff et al. 1997, Bunn and Arthington 2002, Burgess et al. 2012).

Flood-driven seasonal movements are common for fishes in large river systems (Bodensteiner and Lewis 1992, Rodríguez and Lewis 1994), and lateral movements onto the floodplain are important for maintaining the species composition and genetic diversity of riverine fish assemblages (Tockner and Stanford 2002, Ickes et al. 2005). In unregulated large rivers, the annual flood pulse increases lateral connectivity and allows immigration and emigration of fishes to isolated lakes and ponds for feeding and reproduction (Welcomme 1979, Ickes et al. 2005, Lasne et al. 2007). Accessible habitats vary in depth, structural complexity (flooded vegetation

and timberlands), and substrate (e.g., gravel areas, flooded agricultural fields), with variable water quality depending on water movement and habitat type (Poff et al. 1997, Humphries et al. 1999, Harmar and Clifford 2006). Several studies have documented rapid movements of riverine fishes into the flooded riparian zone (e.g., days to weeks; Lonzarich et al. 1998, King et al. 2003), suggesting that such movements are important in maintaining the productivity of riverine fish assemblages (Bodensteiner and Lewis 1992, Olden et al. 2001). The ecological benefits associated with maintaining or restoring natural flow regimes in floodplain rivers are based on the idea that natural flow conditions maximize the ability of native species to fill available ecological niches (Burgess et al. 2012)

Riverine floodplains are important spawning and nursery grounds for a variety of fishes, which is likely related to the availability of structurally complex backwaters, low current velocities, warmer water temperatures, and high densities prey for larvae and juveniles (Junk et al. 1989, Baker et al. 1991, Robertson et al. 2008). Spawning in numerous fish species, including two species of conservation concern in the LMRV Paddlefish (*Polydon spatula*) and Alligator Gar, has been directly related to rising and falling river stages and access to floodplain areas, including Alligator Gar (Miyazono et al. 2010), Paddlefish (Zigler et al. 2003), Longnose Gar, and Spotted Gar *(Lepisosteus oculatus*; (Snedden et al. 1999). In Australia, Golden Perch *Macquaria ambigua*, spawn during river flooding, and their recruitment is tied to high food densities on the inundated floodplain. In the absence of seasonal floods, these riverine predators resorb their gonads and do not spawn (Humphries et al. 1999).

The St. Catherine Creek National Wildlife Refuge (SCCNWR) is unique to the LMR, in that it provdes a large expanse of floodplain habitat that is typically inundated for a period of several weeks each spring, sometimes lasting into the early summer. Numerous fishes move

onto the refuge during rising river stages, but the chronology of floodplain use by the migrating assemblage is largely unknown. Moreover, little information exists on the specificity (or lack thereof) of habitat use by obligate and facultative floodplain fishes along this reach of the river. Accordingly, the objectives of this part of my study were to identify floodplain habitat features associated with desired fish assemblage characteristics and determine if Alligator Gar play a role as a surrogate species for floodplain restoration efforts.

2.2 STUDY AREA

The study was conducted in the Lower Mississippi River Basin on the SCCNWR near the town of Natchez, in Adams County, Mississippi. (31° 25' 36.23" N, 91° 27' 2.47"W; Figure 2.1). The refuge currently consists of 8,499 hectares (21,442 acres) bordered by the Mississippi River to the west, bluffs to the east, and the Homochitto River to the south. The refuge is directly influenced by the Mississippi River, receiving floodwaters through St. Catherine Creek as river stages approach 10.7 m at gage 07290880 located in Natchez, Mississippi. Elevated river stage determines the extent and duration of flooding on the landscape, with residual water held in areas that remain permanently inundated even when disconnected from the main river. Butler Lake is a recreational fishing area that measures 2.2 km^2 and is connected to the river by St. Catherine Creek; a weir at the south end maintains year round water levels. The Bluehole is a 0.024-km^2 borrow pit lake located further inland on the floodplain connected by St. Catherine Creek to Butler Lake (Allen et al. 2014a). Cypress swamps and hardwood forests composed of oak *Quercas* spp., gum *Eucalyptus* spp., elm *Ulmus* spp., ash *Fraxinus* spp., cottonwood *Populus* spp., and pine *Pinus* spp., cover about 30% of the refuge, with 10% consisting of open water and the remainder comprised of cleared agricultural land and batture land created by the meanderings

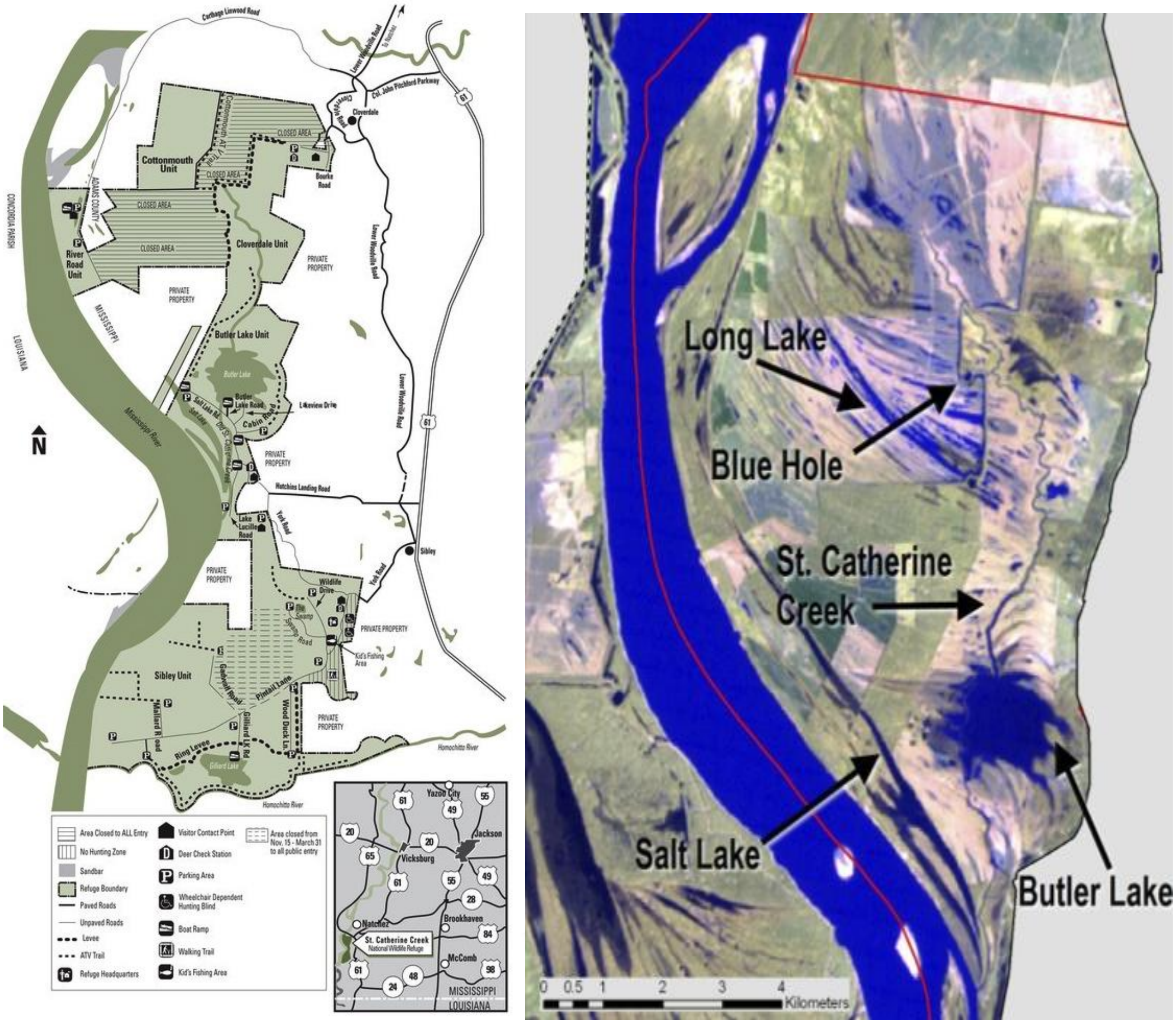

Figure 2.1. Maps of St. Catherine Creek National Wildlife Refuge near Natchez, Mississippi, as well as permanent water bodies on the refuge that provide aquatic habitat during post-flood periods.

of the Mississippi River. Bottomland hardwood stands, cypress-button bush swamp, and upland hardwoods on the bluffs and hills overlooking the alluvial floodplain cover three fourths of the refuge topography during high flooding. Within the refuge, over 4.45 hectares (11,000 acres) of agricultural lands have been reforested with native oaks *Quercas* spp., pecan *Carya* spp., green ash *Fraxinus pennsylvanica,* and southern bald cypress *Taxodium distichum*. Ownership of these reforested farmlands, which were once covered with mature bottomland hardwoods, was

obtained by the U.S. Fish and Wildlife Service (USFWS) in 1990. Lakes on the refuge during low-water periods average about 2 m in depth, whereas during inundation, floodplain depths can increase in some areas to 13 m (Allen et al. 2014b).

2.3 METHODS

2.3.1 Fish Assemblage Field Sampling

I used gill nets to sample fishes throughout the flood pulse, recording species and sizes as well as GPS location, water quality, depth, distance from river, and density and type of underwater structure. At each sampling site (n=62), two experimental monofilament gill nets (each 2.4 m deep X 30.5 m long with 6.3, 7.6, 8.9, and 10.2–cm mesh) and 1 braided polyfilament gill net (1 panel 3 m deep X 45.72 m long with 12.7-cm mesh; typically used to catch Alligator Gar), were set as strike nets for 1 hour, alternating the landward net orientation of the experimental nets for large and small mesh size. Locations changed as the flood pulse progressed and receded, and I used this type of mobile sampling scheme at locations near the floodplain channel access and along the flood edge, across the floodplain at flood peak, and along the receding waterline and residual waterways as the flood subsided. Fishes were removed from nets immediately and handled in accordance with a USFWS collection permit. All identifiable species were recorded and released in the field, and those that could not be reliably identified were placed in an ice slurry and transported to the lab for identification (LSU AgCenter IACUC A2011-16). I measured total length for all fish (TL; mm) as well as girth (G; mm) for Alligator Gar only. In addition, I scanned each Alligator Gar electronically for the presence of Passive Integrated Transponder (PIT) tags, and visually inspected the fish for T-bar, VEMCO Acoustic Transmitter and ATS Radio Tags and tag numbers, which were recorded if present. If no PIT tag was detected, I injected one BIOMARK HPT12 (12.5-mm, 134.2 kHz ISO

FDXB) or (12.5-mm, 125 kHz FDXA) tag in the soft tissue at the base of the dorsal fin, as well as T-bar tags in both the right and left pectoral fins (USFWS BR#### tag numbers).

Water quality data was collected daily across the floodplain as part of a concurrent study with the USFWS. At each site, we used stationary YSI multi-probe electronic meters (Yellow Spring Instruments Inc., Yellow Springs, OH) to measure depth (m), water temperature (°C), dissolved oxygen (mg/l), pH, specific conductance (ms), and turbidity (NTU). I recorded river stage (m) based on the USGS gage in Natchez (USGS gage 07290880). Connectivity of the floodplain was considered to have occurred when river stage was above 10.7 m as previously designated by Allen et al. (2014a). This is the typical river stage at which overland flooding occurs in the SCCNWR, allowing fish access to otherwise inaccessible habitats (Figure 2.2). During this process, I recorded GPS points, floodplain boundaries of the SCCNWR, and pictures of habitat conditions with a Garmin Montana 650.

Habitat type at each site was classified with GIS habitat classifications according to inundation frequency and aerial imagery and then verified visually on the water at each site. The mobile sampling scheme represented a variety of habitat types across the SCCNWR floodplain:

Residual water (REWA) - locations in channels that hold water longer when disconnected from the river and were persistently inundated.

Flooded vegetation (FLVG) - habitats with low vegetation, including patches of flooded vegetation intermixed with shrub/scrub woody vegetation, in intermittently inundated areas.

Flooded timber (FLTB) - forest stands that were intermittently inundated.

Open water (OPWA) - areas with little to no vegetation, such as flooded roads or mud banks, or open water below the weir.

Inundation frequency of each site was determined with GIS inundation layers by Allen et al. (2014b). All data was recorded on data sheets in the field.

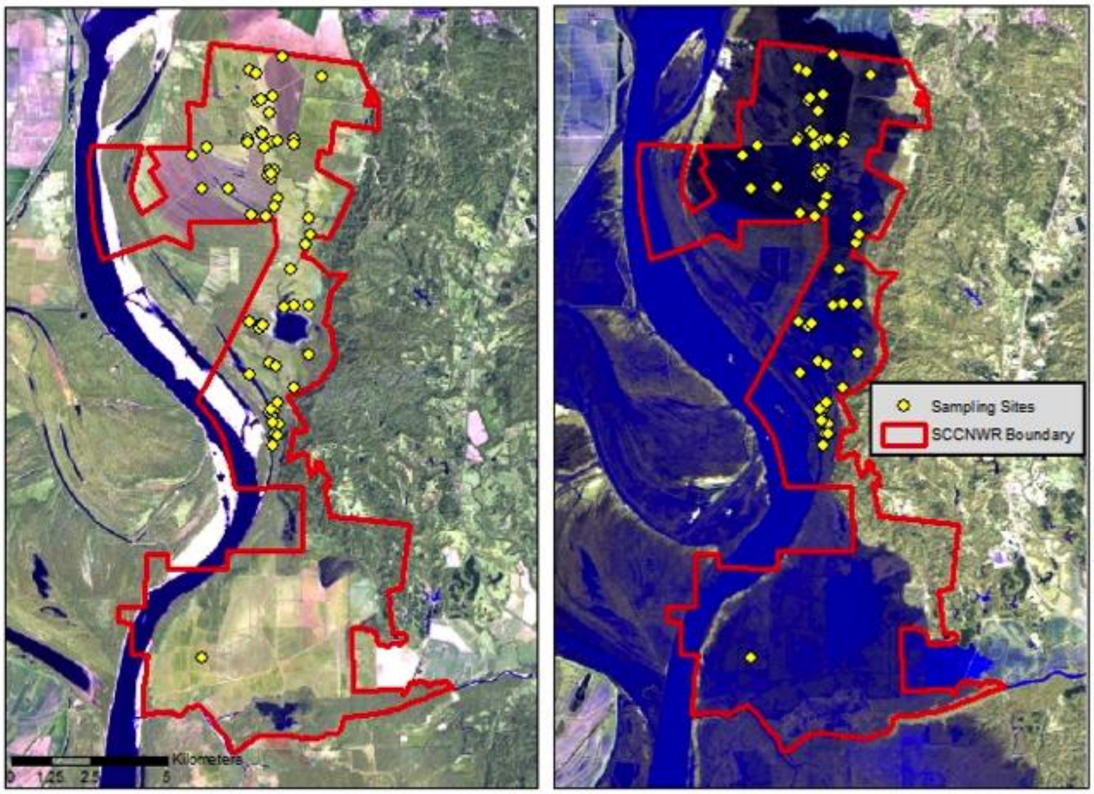

Figure 2.2. Comparison of St. Catherine Creek NWR inundation when disconnected during low (2.9 m) and high (14.9 m) Mississippi River stages.

2.3.2 Statistical Analysis

Data obtained by the mobile sampling scheme outlined above were used to describe fish assemblage composition and abundance across the floodplain and between habitats types on SCCNWR. I used a combination of multivariate and regression analysis to quantify linkages between fish assemblages and sampling site characteristics. Exploratory analysis of all variables collected (water quality data, depth, TL of fish, net size, date of sample, habitat structure, distance to river, inundation frequency, and river stage) was used to screen for ordinations present in the data. I evaluated the ordination by Principal Component Analysis (PCA), Detrended Correspondence Analysis (DCA), as well as Nonmetric Multidimensional Scaling (NMDS). The data was dominated by zones and showed that NMDS (program R, version 3.0.1,

package VEGAN) was the best choice according to published data (Van den Brink et al. 2003, Hirst and Jackson 2007) to examine fish assemblage composition and abundance in relation to date of sample, habitat structure, distance to river, inundation frequency, and river stage at each sampling site (all other variables were not used in this final analysis). NMDS is a robust ordination technique that models the relationships among assemblages across multiple dimensions, but unlike Principal Component Analysis (PCA) does not require assumptions of normality or linearity and generally fits a model in fewer dimensions (Kwak and Peterson 2007). Results of the NMDS ordination were mapped, with each sample's position plotted around correlated axes according to its relationship with all other samples in the analysis (Clarke 1993). Unfortunately, NMDS has no formal quantifiable means of interpretation, so I used regression and visual interpretation to further analyze the relationships that became evident from the NMDS analyses (Kwak and Peterson 2007). I also explored individual relationships between catch with these variables by generalized linear mixed models (PROC GLIMMIX; SAS Institute Inc. 2011) with log links and Poisson distributions. A generalized linear mixed model was used with fixed efforts of river stage, distance to river, and inundation directly related to the presence of Alligator Gar with a logit link and binomial probability distribution.

2.4 RESULTS

A total of 373 fishes representing 14 species (Table 2.1) were sampled across 62 sites during two sampling periods (April 25-August 20, 2013, and April 20-July 23, 2014). Samples were evenly distributed across the floodplain and were similar among the four habitat types (REWA=19, OPWA=16, FLVG=16, FLTB=11; Appendix A), with 22 samples taken from sites when the river was disconnected and 40 samples when the river was connected (Appendix B). From January through August of both years, the Mississippi River exceeded 10.7 m for 163 days

Table 2.1. List of native (N) and exotic € species collected in 2013 and 2014 from the St. Catherine's Creek National Wildlife Refuge floodplain along the Lower Mississippi River.

Common Name	Scientific Name	Origin	*N*	Occurrence Frequency (%)	FLTB (%)	FLVG (%)	OPWA (%)	REWA (%)
Smallmouth Buffalo	*Ictiobus bubalus*	N	177	47.5	22	27	22	29
Bigmouth Buffalo	*Ictiobus cyprinellus*	N	58	16.5	26	22	16	36
Alligator Gar	*Atractosteus spatula*	N	31	8.3	32	26	6	35
Common Carp	*Cyprinus carpio*	E	22	5.9	36	23	18	23
Blue Catfish	*Ictalurus furcatus*	N	19	5.1	21	37	16	26
Silver Carp	*Hypophthalmichthys molitrix*	E	17	4.6	47	6	47	0
Gizzard Shad	*Dorosoma cepedianum*	N	13	3.5	23	8	38	31
Freshwater Drum	*Aplodinotus grunniens*	N	12	3.2	25	25	50	0
Paddlefish	*Polyodon spathula*	N	8	2.1	13	13	75	0
Longnose Gar	*Lepisosteus osseus*	N	5	1.3	0	20	0	85
Channel Catfish	*Ictalurus punctatus*	N	4	1.1	0	25	50	25
Bighead Carp	*Hypophthalmichthys nobilis*	E	4	1.1	25	75	0	0
Threadfin Shad	*Dorosoma petenense*	N	2	0.5	0	0	100	0
Spotted Gar	*Lepisosteus oculatus*	N	1	0.2	0	0	100	0

in 2013 (maximum river stage 15.3 m) and 134 days in 2014 (maximum river stage 14.0 m), with both years above the long term (1983-2012) average of 116 days. Water quality data collected across both years indicated average temperatures of 22.2 (±6.6)°C (Table 2.2), with Butler Lake averaging 2.5 (±6.6)°C and Blue Hole averaging 4.4 (±6.6)°C warmer than main stem river (Allen et al. 2014a).

Table 2.2. Water quality data including ranges, means, and medians of parameters measured across the floodplain.

	Mean	SD	Range	Median
Temperature (°C)	22.2	6.6	5.6–44.3	22.7
Conductivity (µS/cm)	150.29	173.81	0.00–644.22	0.55
pH	7.60	0.49	4.27–9.46	7.55
Turbidity (NTU)	41.1	128.0	-12.8–1587.0	13.4
Dissolved Oxygen (%)	79.41	37.98	-1.10–500.00	82.18
Dissolved Oxygen (mg/L)	7.49	3.45	-0.03–26.65	7.55

The most frequently caught species was Smallmouth Buffalo (*Ictiobus bubalus)*, which made up approximately half of the total catch (47%), and was found in all habitat types (REWA 29%, FLTB=22%, FLVG=27%, OPWA=22%). Bigmouth buffalo (*Ictiobus cyprinellus)* was the second most abundant species (16%), and were slightly more common in REWA (38%) relative to the other habitat types (<26%; Figure 2.3).

Regarding the two species of conservation concern, Paddlefish were found strictly in OPWA and FLVG at sites located below the weir at Butler Lake, although only eight fish were captured. Conversely, I collected 31 Alligator Gar (Appendix C), with 29 found in REWA, FLTB, and FLVG and only two in OPWA (Figure 2.3). Alligator Gar were caught at 22 sites across the floodplain, with 6 sites producing multiple fish. These sites also produced substantial abundances of other fish species, including 53.8% (n=13) of the Gizzard Shad, 45.5% (n=22) of the Common Carp, and 60.0 % (n=5) of the Longnose Gar that I collected during my study.

Among the less common fishes, Silver Carp were found almost exclusively in OPWA and FLTB, whereas four of the five Longnose Gar were found in REWA. Threadfin Shad and Spotted Gar were rarely encountered, but were found strictly in OPWA (Table 2.1).

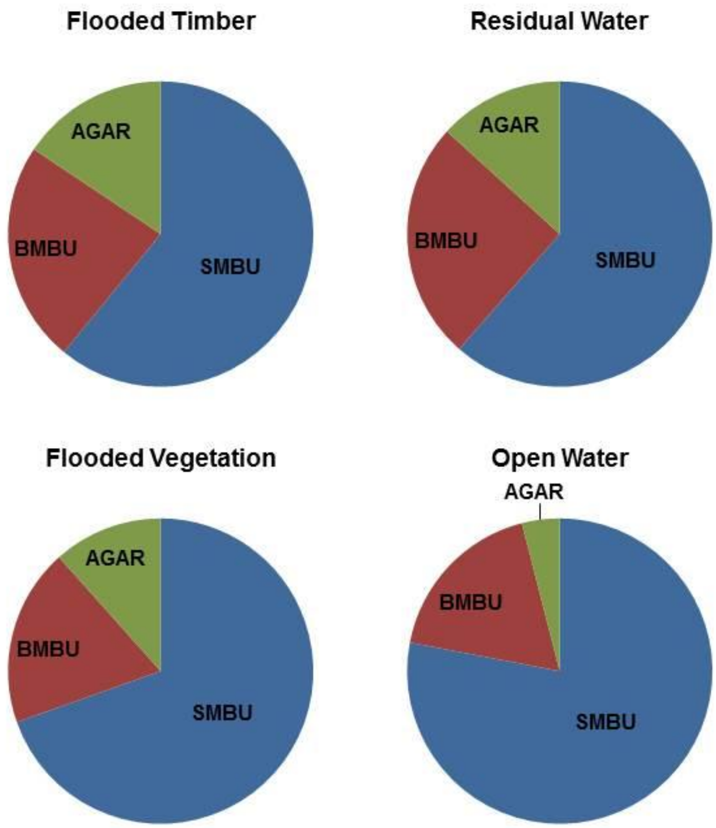

Figure 2.3. Proportion of top three fish species (SMBU=Smallmouth Buffalo, BMBU=Bigmouth Buffalo, and AGAR=Alligator Gar) caught by habitat.

NMDS analysis provided two axes with a stress of 0.17, which indicates a useful 2-dimensional picture for interpretation (Clarke 1993). Analyses revealed that fish assemblage structure was more strongly related to habitats in REWA and OPWA, distance to river, sample year, and river stage than to inundation frequency, and habitats FLVG and FLTB; Figure 2.4). Species located near the center of ordination (e.g., Gizzard Shad, Bighead Carp, Bigmouth

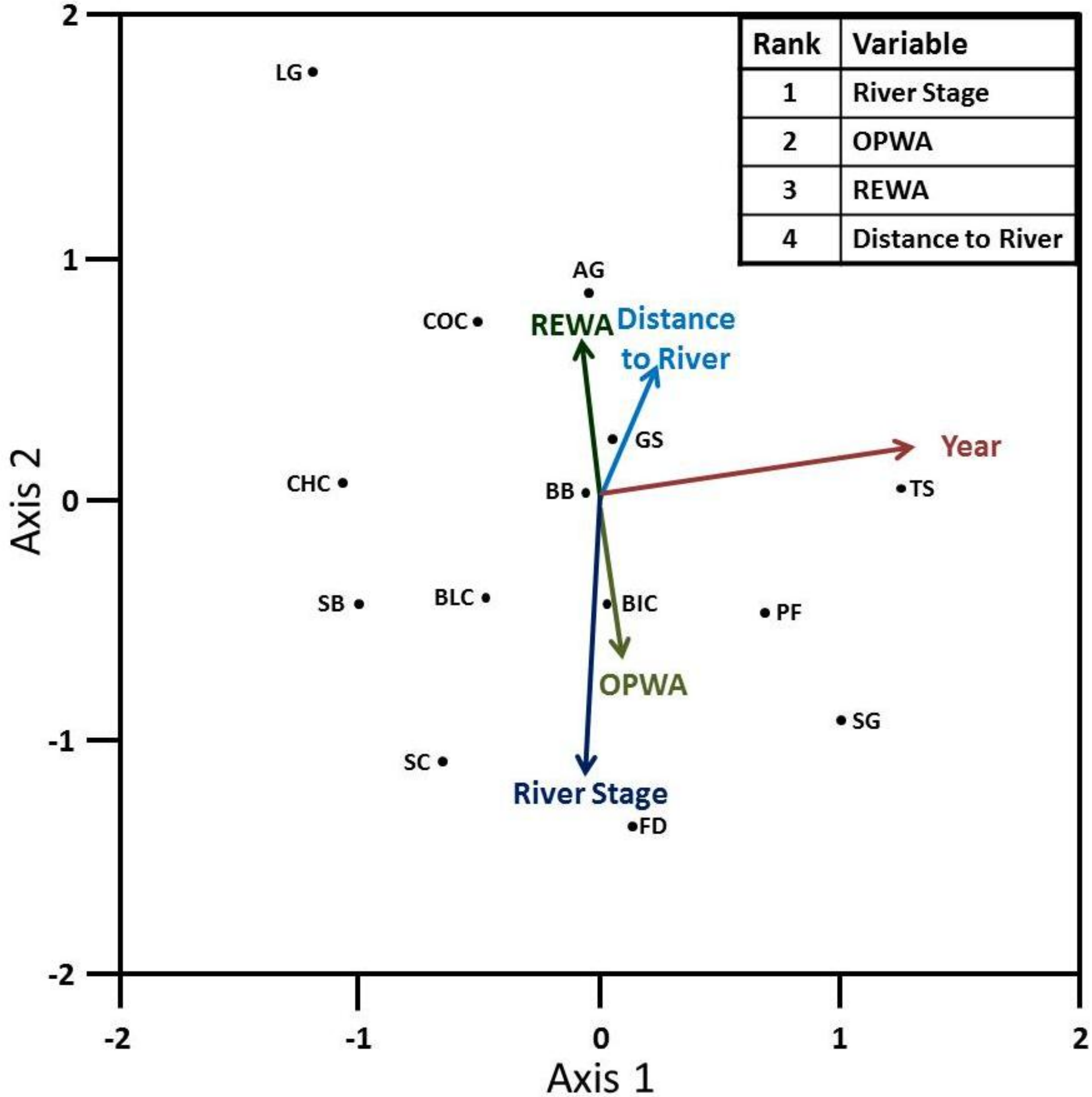

Figure 2.4. Non-metric multidimensional scaling ordination of species (AG=Alligator Gar, BIC=Bighead Carp, BLC=Blue Catfish, BB=Bigmouth Buffalo, CHC=Channel Catfish, COC=Common Carp, FD=Freshwater Drum, GS=Gizzard Shad, LG=Longnose Gar, PF=Paddlefish, SC=Silver Carp, SB=Smallmouth Buffalo, SG=Spotted Gar, and TS=Threadfin Shad) by residual water (REWA), open water (OPWA), distance to river, river stage, and year. Inset with variables listed by rank of importance.

Buffalo, Blue Catfish, Channel Catfish, and Smallmouth Buffalo) were collected at most sites, and were locally abundant; however, the latter three were captured with higher frequency in 2013, which strongly influenced their position on the bi-plot. In contrast, Threadfin Shad Paddlefish, and Spotted Gar were associated with higher abundances in 2014, with the latter two species also displaying positive relationships with OPWA habitat. Spotted Gar, Freshwater Drum and Silver Carp were associated with higher river stages. Longnose Gar, although rare, were captured only in 2013 in REWA and were positively associated with distance from the river. Alligator gar were closely associated with REWA habitat and lower river stages, as was Common Carp. Further analysis of the Alligator Gar data with a generalized linear mixed model substantiated results from the NMDS, and indicated that the probability of catching Alligator Gar increased at lower river stages ($F_{1,411} = 5.39$, $P = 0.02$). Log-linear models were performed on the abundance of fish per habitat however, other than Alligator gar, species models were not significant.

2.5 DISCUSSION

I designed this study to elucidate the temporal and spatial characteristics of fishes accessing floodplain habitats on the SCCNWR. However, sampling such a large, dynamic system in a spatially explicit way through time presented some obstacles regarding data collection. The sampling design was difficult due to the stochastic availability of different habitats at different times, as well as the changing nature of the sampling sites, i.e., a sample at the flood edge one week would be different in terms of depth and duration of inundation in succeeding weeks. In addition, some areas were difficult to access and sample because of dense stands of submerged timber, but were still accessible to fishes. I decided to use strike netting with gill nets instead of electrofishing to collect my samples, as I wanted the collections to

represent fishes in each of the habitat types, and did not want to “chase” fishes around the refuge. In addition, electrofishing in open water typically yielded no fishes, and this technique was no more effective in dense submerged structure as the flood front moved across the refuge. However, gill nets were selective for mobile species and active individuals (Kaller et al. 2013), which may account for the absence of some species that I observed during sampling but did not capture in the nets. Additionally, gill nets have biased capture probabilities related to mesh sizes, as well as species differences in the probability of retention (Murphy and Willis 1996). I used monofilament nets to minimize net visibility, and attempted to maximize capture success by setting multiple mesh sizes in opposing net orientations. In addition, I included the large-mesh braided polyfilament net in each set, as previous collections with this gear had yielded Alligator Gar and other larger fishes that were able to break through the monofilament nets.

Currently, SCCNWR management involving this area is passive and allows for uncontrolled flooding and fish passage as described by (Ickes et al. 2005) through the use of culverts and the weir. This permits the floodplain to be naturally inundated by the annual Mississippi River flood pulse, which produces a certain amount of variability in flooding magnitude, pulse duration, and river connectivity. During flood pulses, fishes are able to disperse throughout the floodplain at high water, and are then forced to either return to the river mainstem or stay in off-channel REWA habitats (Li and Gelwick 2005). The fish assemblage on SCCNWR that was susceptible to gill netting was dominated by large bodied, long lived, riverine fish species that were able to exploit the feeding, reproductive, and refuge benefits of this floodplain, although fish collections revealed differences in resource needs among species.

Spatiotemporal variability in catch success of the 14 species of fish I collected indicated the composition of the fish assemblage at any point in time on the SCCNWR during the flood pulse was influenced primarily by variation in flooding magnitude (year), distance to the river connecting the floodplain to the main river channel, habitat availability of residual water and open water, and height of river stages. Similar factors were influential in studies in the Upper Mississippi River as well, particularly river elevation, habitat, and year (Barko et al. 2004, Pyron et al. 2014). Miyazono et al. (2010) found that species with periodic life-history strategies such as Alligator Gar, tended to occur in floodplain lakes with higher connectivity-index scores than other species. Residual water was closely related to distance to the river, i.e., the more permanent waterbodies on SCCNWR that hold water throughout the year were further away from the mainstem river, but were flooded earlier as water entered the system through St. Catherine's Creek (negative association of river stage and REWA). Fishes that were collected more frequently in these areas such as Blue Hole may have responded to greater stability of water levels and temperatures, and these habitats may act as refuge areas for species associated with deeper waterbodies (Allen et al. 2014a). Similarly, higher river stages flooded more OPWA areas closer to the river as the pulse progressed, although most of the species did not seem to be abundant in unstructured habitats. Annual variation in duration of flooding and river stage were evident from the NMDS plot, with 2013 exhibiting higher river stages and a longer inundation period, which allowed access to more habitats for longer periods relative to 2014. Although Baker et al. (1991) reported low associations between fish assemblage types and physical habitats in the lower Mississippi River, these results were likely influenced by the large number of backwater areas that were sampled. The SCCNWR is one of the few areas of extensive low-relief floodplain that is still directly connected to the LMR, and fish collections indicate that

restoring river connections in other floodplain areas that would allow extended inundation of structurally complex habitats could significantly improve fish production throughout the lower river.

Several of the habitat generalists (Bighead Carp, Blue Catfish, Channel Catfish, and Smallmouth Buffalo) were more abundant in 2013 collections, which was likely related to the higher river stages and longer inundation of the floodplain during my first year of sampling. Fish production has been shown to increase (up to a 66% increase in Smallmouth Buffalo alone) with duration of inundation and warmer water temperatures (Schramm et al. 2009). Although Freshwater Drum, Spotted Gar, and Paddlefish were correlated with open water habitat and higher river stages, the majority of Spotted Gar and Paddlefish were caught during the lower-magnitude 2014 flood pulse. Smallmouth and Bigmouth Buffalos appeared to be ubiquitous members of the floodplain assemblage, being abundant across all habitat types during both years. This appears to be consistent with similar studies done in the Mississippi River, which found related fish assemblages (Cobb et al. 1984, Lowery and Authority 1987, Schramm et al. 2009) and dominance by habitat generalists (Barko and Herzog 2003, Barko et al. 2004). Buffalo are commercially important species in Mississippi/Louisiana, and their generalist life histories appear to be similar to those reported in other Mississippi Alluvial Valley studies (Madejczyk et al. 1998, Andrews 2013). This may indicate that the fish assemblage in these areas are moving toward a system dominated by more tolerant species, which may be increasingly true across the Mississippi River system (Kinsolving and Bain 1993, Barko et al. 2004). Connectivity and movement of fishes between waterbodies is thought to have a homogenizing affect on fish assemblage composition (Amoros and Bornette 2002). The relationship of river stage to variation in fish assemblage composition has been attributed to the lack of flood pulse connectivity

between mainstem river and floodplains (Amoros and Bornette 2002), which significantly affects the reproduction and recruitment of species such as Paddlefish, Freshwater Drum, (Baker et al. 1991, Bodensteiner and Lewis 1992) and Alligator Gar (Ferrara 2001, Mendoza et al. 2002, Miyazono et al. 2010, Allen et al. 2014b).

All paddlefish were captured at sites located below the weir at Butler Lake. Paddlefish are known to congregate in deeper (> 3 m), low-velocity areas (Jennings and Zigler 2009), often exhibiting fidelity to particular sites and tributaries, but make extensive movements within lentic and lotic systems, with spawning occurring in off-channel areas in deep waters. Paddlefish use backwater sloughs during periods of high discharge, but move to main channel border habitats as river stage declines (Rehwinkel 1978, Southall and Hubert 1984, Moen et al. 1992). These observations are consistent with the location of Paddlefish below the weir on St. Catherine's Creek in areas that were generally deeper and cooler than other areas of the floodplain.

In contrast to Paddlefish, Alligator Gar quickly moved onto the floodplain as waters rose and were often found in the REWA lakes. These movements were similar to Spotted Gar in the Atchafalaya Basin, which move onto the floodplain immediately upon inundation (Snedden et al. 1999). Other studies have shown that Alligator Gar prefer to remain in the deep water refuge of the Blue Hole when the floodplain is inaccessible (Allen et al. 2014a), and similar results have been shown with other gar species (Bonvillain 2006). Previous telemetry studies have found that large Alligator Gar are found in all habitat types throughout the SCCNWR during high river stages (Allen et al. 2014a), which was also reflected in their presence at 22 sites sampled in this study. Their association with REWA habitats is likely due to their use of these deeper waterways as natural corridors to move across the floodplain, and their concentration and vulnerability to netting in these channels when floodwaters recede. Connectivity and proximity to the mainstem

river directly influence temperature on the floodplain, and these deeper channel areas may provide more favorable temperature conditions (Tockner et al. 2000) including reduced variability during spring and winter months (Allen et al. 2014a). Additional studies have shown other fish populations may require winter thermal refuges provided by these types of backwater habitats, particularly those susceptible to winter mortality and fluctuations that can affect year class strength (McLean et al. 1985, Bodensteiner and Lewis 1992, Shoup and Wahl 2009, Sullivan and Watzin 2009). Furthermore, these areas offer refugia during periods of disturbance in the mainstem river (e.g., floods and droughts) that can supply recruits during recovery of the river-floodplain system (Poff and Ward 1990, Sedell et al. 1990). Considering that available spawning habitat may be a limiting factor for Alligator Gar populations in the LMRV, these thermal refuge areas located further away from river connections may be key to conservation efforts for Alligator Gar, specifically in restocking areas on the Mississippi River.

Open field habitats that support herbaceous vegetation may offer ideal spawning conditions for many riverine species, particularly Alligator Gar (Buckmeier 2008, Buckmeier et al. 2013). Life-history adaptations of riverine fishes often include recurring migrations in sequence with seasonal flood pulses to exploit off-channel habitats for reproduction, feeding, and refuge during intolerable river conditions (McLean et al. 1985, Bodensteiner and Lewis 1992, Humphries et al. 1999, Ickes et al. 2005). Alligator Gar have been observed spawning in open field habitats on the SCCCNWR, and these areas have been assigned a high ranking for spawning suitability (Allen et al. 2014b). It is not clear whether open canopy habitat is a necessary prerequisite for these conditions, and further research on spawning locations is needed. Currently, these habitats in the SCCNWR are maintained as agricultural fields through a farming cooperative program with the refuge. As such, these cultivated areas may be part of a habitat

mosaic on the SCCNWR floodplain that is providing ideal conditions for the various life stages of this species of concern. Amoros and Bornette (2002) discuss the importance of similar influences of habitat heterogeneity on fish recruitment and the diversity of floodplain fish assemblages.

Given the large population of Alligator Gar in, and apparent site fidelity of these fish to, the SCCNWR, this area offers a unique and important floodplain habitat that is unlike any other in the LMRV. This gives us information needed in examining these fish as a surrogate species for floodplains. A surrogate species should be one that is easily observed or captured, represents many other species in the floodplain, is cost effective to monitor, is supported by an existing biological knowledge base, and is responsive to a variety of conservation strategies (Campbell 2012). Given these guidelines, Alligator Gar appears to be an excellent candidate for a floodplain-dependent surrogate species in the LMRV, considering its extensive movements and potential interactions with other floodplain fishes. It appears that management of the SCCNWR as a fisheries resource should focus on maintaining connectivity to the river, allowing for uncontrolled flooding, and encouraging the mosaic of terrestrial habitats that contribute to the physicochemical diversity of flooded habitats on the refuge. These data on floodplain habitat associations of LMRV fishes during the flood pulse can be applied to LMRV floodplain restoration programs, particularly for re-stocking of Alligator Gar, as well as a guide to identifying priority areas for floodplain reconnection. Coupled with concurrent studies by the USFWS, results indicate that SCCNWR is a model to guide these floodplain restoration efforts in the LMRV. Preservation of current floodplain systems as well as floodplain restoration will

offer broad scale benefits, as increased areas of floodplains similar to St. Catherine Creek NWR could provide critical habitat for species of concern as well as benefit a of variety of fishes, wildlife, migratory birds and waterfowl.

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CHAPTER 3. USING SIDE SCAN SONAR TO ASSESS ALLIGATOR GAR

3.1 INTRODUCTION

A major consequence of managing riverine-floodplain systems is the loss of floodplain connectivity and reduction in overflow habitats available to riverine biota. The extensive levee systems in the lower Mississippi River (LMR; Tockner and Stanford 2002, Ickes et al. 2005) have eliminated vast areas of potential fish habitat and interrupted the natural exchange of water, sediment, nutrients, and organic debris that are vital resources for riverine and floodplain organisms (Kwak 1988, Bayley 1991, Poff et al. 1997, Humphries et al. 1999, Burgess et al. 2012). The ecological benefits associated with maintaining or restoring natural flow regimes in floodplain rivers are based on the idea that natural flow conditions maximize the ability of native species to fill available ecological niches (Ickes et al. 2005, Burgess et al. 2012, Pyron et al. 2014). Riverine floodplains are major spawning and nursery grounds for a variety of fishes, which is likely related to the availability of structurally complex backwaters, warmer water temperatures, and high densities of prey for larvae and juveniles (Ross and Baker 1983, Junk et al. 1989, Mendoza et al. 2002, Springer 2002, Robertson et al. 2008). Use of these habitats by the widespread presence of opportunistic fishes can be interpreted as evidence that floodplains are important refuges under stressful conditions, including droughts, floods, and unfavorable temperatures (Sullivan and Watzin 2009, Pyron et al. 2014). Shallow standing backwaters generally offer low current velocities, warmer water temperatures and submerged woody debris/vegetation for protection of eggs and larvae, contributing to their value as prime spawning grounds (Bayley 1991, Bodensteiner and Lewis 1992, Olden et al. 2001, Allen et al. 2014b). Availability of off-channel spawning habitat is believed to be the limiting factor for Alligator

Gar populations in the Mississippi Alluvial Valley (MAV), and the St. Catherine Creek National Wildlife Refuge (SCCNWR) in Natchez, MS, is one of the only refuges in the Lower Mississippi River (LMR) accessible to direct inundation from the river.

The family Lepisosteidae is an ancient group of fishes that has existed since the Cretaceous period approximately 180 million years ago (Rayner 1941, Wiley 1976). Gar possess several characteristics that have been advantageous to their survival, including rapid juvenile growth (Toole 1971, Mendoza et al. 2002), interlocking ganoid scales that reduce predatory mortality (Gilbert and Williams 2002), and a physostomous and highly vascularized swim bladder that allows them to breathe air and live in hypoxic water that can be fatal to other fish species (Potter 1927). Alligator Gar, which are long-lived and can reach 3 m in length and 150 kg in weight (U.S. Fish and Wildlife Service), require large home ranges and diverse riverine and floodplain habitats to complete all life stages (Indiana Division of Fish and Wildlife 2012, Buckmeier et al. 2013).

Alligator Gar historically ranged throughout most of the lower Mississippi drainage, including the Ohio and Missouri rivers, and even south to the Gulf of Mexico (Lee et al. 1980, de León et al. 2001), although they are now primarily restricted to coastal rivers with limited inland populations (Ferrara 2001, Robertson et al. 2008). Once considered abundant, many populations in the northern and western drainages of Mississippi River have been extirpated (Mendoza et al. 2002, O'Connell et al. 2007, DiBenedetto 2009). Currently the U.S. Fish and Wildlife Service and the Gulf Coastal Plain Ozarks Landscape Conservation Cooperative (GCPOLCC) have identified Alligator Gar as a species of concern in the MAV.

Despite their imperiled status throughout most of their range, Alligator Gar are still relatively abundant in Louisiana (U.S. Fish and Wildlife Service), and are of both commercial and recreational value (Buckmeier et al. 2013). Bowfishermen and sport anglers consider large alligator gar to be trophy fish, and it is believed that angling activity specifically targeting gar has increased (Ferrara 2001). The mean commercial harvest of Alligator Gar in Louisiana from 1999 to 2006 was 523,617 pounds/year, with the 2003 landings valued at greater than $515,000 (Southwick Associates 2008). With the exception of Louisiana, all other states in the Alligator Gar's historic range have implemented harvest regulations or issued declarations of extirpation (Buckmeier et al. 2013). Restoration and enhancement of Alligator Gar populations has been limited by inadequate knowledge of many basic life history characteristics and habitat needs (Buckmeier 2008, Inebnit 2009, Buckmeier et al. 2013), as well as limited data on current population numbers throughout most of their range. Brood stock collection, aquacultural production, and restocking by the USFWS have been ongoing for over 10 years. However, these are costly and time-consuming efforts, and benefits of these programs in terms of improving population status have yet to be demonstrated.

To date, collection efforts to determine Alligator Gar population status and habitat associations have relied on jug lines, gill netting, and electroshocking (DiBenedetto 2009). Electroshocking is not generally successful for capturing Alligator Gar, as their strong swimming ability and ganoid scales result in considerable resistance to electricity (personal observation). Gill netting typically has the highest success rate, but is also the most stressful technique, typically causing external and sometimes internal damage to the fish that can result in death (Murphy and Willis 1996). Moreover, fishes are usually captured during low water periods during the summer, with netted individuals already stressed from high water temperatures and

low dissolved oxygen levels. If feasible, side-scan sonar would be a non-invasive, less labor-intensive, and logistically simpler approach, relative to traditional mark-recapture, telemetry, and population estimation techniques, for monitoring Alligator Gar population status. Side scan sonar provides real time remote sensed data based on reflected sound that produces high quality images of underwater structure (Kaeser and Litts 2013a). This technique is conducive to analyses of fishes and habitat characteristics in inundated backwater floodplain areas that are characterized by low flow and shallow depths (Kaeser and Litts 2010). The target strength of individual fish depends on orientation (Boswell et al. 2008) morphological characteristics, such as length, weight, scales, fat content, gonad development, and swimbladder (Frouzova et al. 2005). This technique has been used to identify aquatic species such as Manatees (*Trichechus* spp.; Gonzalez-Socoloske and Olivera-Gomez 2012), Gulf Sturgeon (*A. oxyrinchus desotoi*; Flowers and Hightower 2013) and other fish species worldwide (Frouzova et al. 2005, Langkau et al. 2012). Although few fishes have the defining features suitable for detection by side scan sonar, the substantial size, reflective ganoid scales, and distinguishable shape of Alligator Gar make them high potential candidates for a sonar-based assessment.

Refuge managers on the SCCNWR have limited information to consider when evaluating Alligator Gar aquatic habitat suitability and options for floodplain conservation and restoration. Habitat availability has been assessed with remote sensing and water quality measurements coupled with telemetry observations of habitat use to identify potentially suitable Alligator Gar habitat (Allen et al. 2014b). However, GIS data typically do not include quality information about underwater habitat characteristics, and there is significant time and expense associated with ground verification of remote sensed data and telemetry studies, both of which ultimately produce limited fine-scale data of direct application to studies of Alligator Gar. Side-scan sonar

could be incorporated into GIS analyses to investigate the presence/absence and abundance of Alligator Gar up and down the LMRV in defined habitat types, and if successful could provide an easy-to-use method for assessing Alligator Gar population densities in different habitats in the inundated floodplain. Consequently, the objectives of this project were to develop a sampling protocol for surveying Alligator Gar with side-scan sonar, and identify those floodplain habitats most frequented by Alligator Gar during the 2014 flood pulse.

3.2 STUDY AREA

The study was conducted in Lower Mississippi River Basin on SCCNWR near the town of Natchez, in Adams County, Mississippi. (31° 25' 36.23" N, 91° 27' 2.47"W). The SCCNWR is directly influenced by the Mississippi River and presently covers 8,499 hectares (21,442 acres) bordered by the Mississippi River to the west, bluffs to the east, and the Homochitto River to the south. Cypress swamps and hardwood forests composed of oak *Quercas* spp., gum *Eucalyptus* spp., elm *Ulmus* spp., ash *Fraxinus* spp., cottonwood *Populus* spp., and pine *Pinus* spp., cover about 30% of the refuge. Ten percent of the acreage is open water, while the remaining property consists of cleared land and batture land created by the meanderings of the Mississippi River. Habitat includes bottomland hardwood, cypress-button bush swamp, and upland hardwoods on the bluffs and hills overlooking the alluvial flood plain of the Mississippi River, which covers three fourths of the refuge topography during high flooding. Since acquiring ownership in 1990, the USFWS has reforested over 4.45 hectares (11,000 acres) of former farmland with native oaks, pecan, green ash and southern bald cypress. This area comprises most of the 8,499 hectares (21,442 acres) of floodplain habitat where this study was focused. Water depth on the refuge ranges from dry farmable land in the summer to 13 m during the annual flood pulse that typically begins in March and usually persists for 3-5 months.

3.3 METHODS

3.3.1 Side-Scan Sonar Unit

The side scan sonar unit used for this survey was the Humminbird 1198C dual frequency unit featuring side imaging and DualBeam plus sonar. The unit operates at frequencies of 455 or 800 kHz, with maximum side-to-side scan ranges of 86 to 55 m, respectively, with 180^{o} degree coverage equivalent to 146 m (Kaeser and Litts 2013a). The side-scan sonar unit was towed by a 5-m aluminum work boat (or Hobie kayak when necessary) operating at optimal speeds between 6.4 and 9.6 km/h following Kaeser and Litts (2013b) workbook. Subsequently, DNR Garmin, ArcGIS, and IrfanView software were used to capture, process, and analyze the side-scan sonar data. These software packages link GPS coordinates, clip images, create real-time, geo-referenced mosaic displays of sonar imagery, allow delineation and measurement of potential sonar targets and maps, and can export data for further processing. The images were processed following Kaeser and Litts (2013b).

3.3.2 Side-Scan Sonar Surveys

Sonar surveys were performed over 3 d on 28, 29, and 30 of August 2014 in each of the sampling sites (Blue Hole, Butler Lake, and the connecting St. Catherine Creek), with sampling days selected to be as close as possible to reduce the chance of fish movement between sites. Surveys were completed during low-water conditions when Alligator Gar were concentrated into residual waterways off of the floodplain.

Prior to surveying, I established transects across each site using ArcGIS and aerial imagery. Concentric circular paths parallel to the bank were created by digitizing the shoreline of the lakes at a 1:20,000 km scale with an aerial image taken when water levels were close to the water level at the time of the survey, and creating three 52-m buffers (total width of survey

swath) around each water body that would be traversed during the survey. I also created short parallel transects across the waterbodies using the line tool, all of which were spaced evenly at 52 m to cover the center of the lake (Appendix D). These pre-established routes created in ArcGIS were converted to tracks and loaded, using DNR Garmin, onto a GPS unit used for navigation during the surveys. I began the survey in Butler Lake, then moved upstream through St. Catherine Creek to Blue Hole to a point where depths were too shallow to permit effective operation of side-scan sonar [approximately 0.6 m; (Kaeser and Litts 2013a)]. Total distance surveyed in the three waterbodies was 11 km.

The side-scan sonar unit was deployed at a depth of approximately 0.6 m below the surface, with depth remaining constant for all surveys except when shallow water required the transducer be temporarily raised to a shallower depth. I used the side-scan sonar in high frequency (455 kHz/800kHz) mode with a total swath width of 50 m, allowing adjustment to a depth of 10% of the range setting being used (Ex: 85 per side= 2.6 m (8.5ft) depth of water). These settings were found to provide optimal compromise between area swept and target detail (Flowers and Hightower 2013, Kaeser and Litts 2013a).

Side-scan sonar data was analyzed in the laboratory by reviewing each side-scan sonar file and identifying potential alligator gar targets (see Figure 3.1 for description of targets). When an alligator gar was observed, the target was marked by recording the sonar photograph number and GPS coordinates were taken. The target was described in terms of quality and shape and classified as an Alligator Gar (yes) or non-Alligator Gar (no). Classification was a subjective judgment of the observer based on target size and shape, with two independent observers processing the files and classifying targets.

I attempted to simultaneously detect telemetered Alligator Gar during side-scan surveys. These fish (n=62) have been tagged with VEMCO telemetry transmitters within the past three years as part of separate ongoing research by USFWS. To detect tagged fish, I submerged a VEMCO receiver at different locations during each survey site. When a fish was detected the receiver recorded the individual tag code and time. In addition, Alligator Gar exhibit behaviors of rolling on top of the water and surfacing to gulp air. Consequently, I also recorded these observations of surface activity, with fish positions estimated by time stamps to coordinate with the side-scan sonar file times and locations.

Figure 3.1. Characteristics of adult Alligator Gar that contribute to the success of side-scan sonar surveys.

3.3.3 Side-Scan Sonar Analysis

Side-scan sonar and telemetry detections were plotted in ArcGIS and recorded by site and day, which required substantial processing time given the large amount of data collected during the surveys. Analysis and processing followed Kaeser and Litts (2013b), with maps generated from the detection data and base map imagery.

3.4 RESULTS

A total area of 2.2 km^2 of Butler Lake was surveyed with the three circular paths parallel to the bank and 13 straight transects across the lake that averaged 1.2 km in length. Side-scan sonar images were collected along these transects at 455khz approximately every 21 seconds. A total of 721 images were collected in Butler Lake. After processing each image a total estimate of 407 Alligator Gar with approximate total lengths > 1 m were observed.

A total area of 0.016 km^2 of Blue Hole was surveyed on one day, with 0.008 km^2 unavailable due to shallow depths. I used a single circular path along the bank and two straight transects across the center to survey available habitat. Side-scan sonar images were collected along these transects at 800khz setting, scanning 12.2 m per side at approximately 12 second intervals. A total of 67 images were collected in Blue Hole. After processing each image a total estimate of 108 Alligator Gar with approximate total lengths > 1 m were observed.

Surveys were done with both 455khz and 800khz for comparison of quality and detection of fish. The 800khz produced better images with higher clarity and more detailed photos of Alligator Gar (see Figure 3.2). Comparison of blue versus amber color palettes revealed that amber provided more distinct shadows and clearer differences in light vs. dark. A total of 4 and 11 tagged Alligator Gar were detected in Butler Lake and Blue Hole, respectively. All fish were considered active tagged fish based on telemetry results from a concurrent study by USFWS.

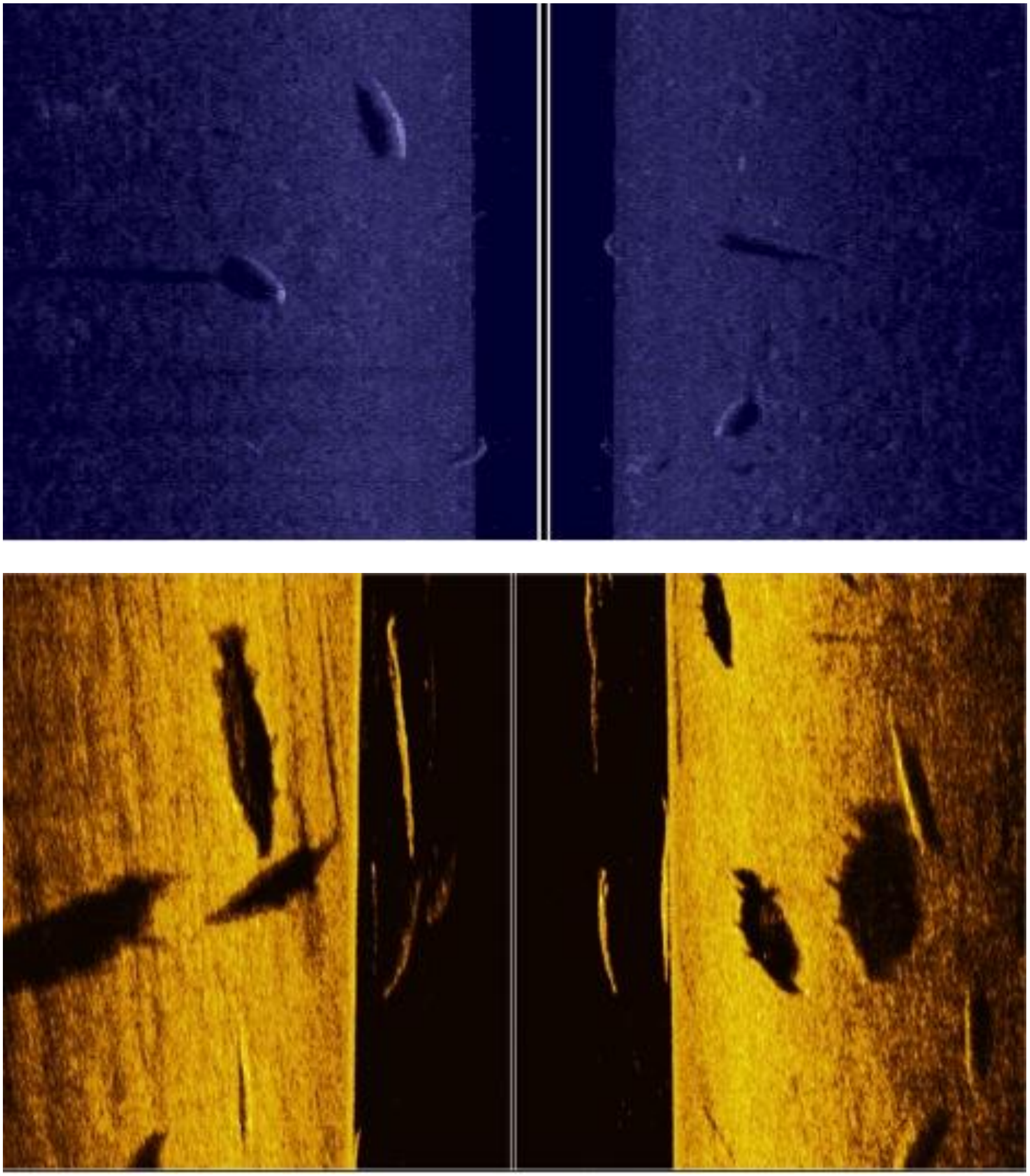

Figure 3.2. Side-scan sonar images of alligator gar in Butler Lake (top), with data collected at 455khz, with a blue filter, at 25.9 m per side, and Blue Hole (bottom), with data collected at 800khz, with an amber filter, at 12.19 m per side.

3.5 DISCUSSION

Results of this study showed that Alligator Gar could be detected in SCCNWR with side-scan sonar imaging, with fish locations that were consistent with historic observations based on gill netting and telemetry. Side-scan sonar results were corroborated by data obtained during brood stock collection (R. Campbell, pers. comm.), telemetry studies (Allen et al. 2014a), and my fish assemblage data collection (Chapter 2), all of which indicates a large, low-water resident Alligator Gar population on the St. Catherine Creek National Wildlife Refuge in Butler Lake and Blue Hole. Telemetry data indicate that these fish exhibit substantial site fidelity and consistent movement patterns among years (Allen et al. 2014a), suggesting that sonar data is capable of providing accurate assessments of the SCCCNWR Alligator Gar population.

There are several factors that likely influenced the accuracy of the sonar images for censusing Alligator Gar. First, many other fishes were concentrated in these permanent floodplain lakes after the retreat of the 2014 flood pulse. Based on the length parameters set in this study we could not positively confirm images of smaller gar, however, visual observations indicated that there were a large number of juvenile and sub-adult gar (which could have been Spotted Gar *Lepisosteus oculatus* or Longnose Gar *L. osseus*) in the lakes. Second, fishes that did not produce a clear image because of their position directly under the boat, or those that did not result in a large target or a shadow that could be measured could also not be confirmed as Alligator Gar. Third, some fishes may have appeared in more than one image due to movement during the survey, which was impossible to determine. Fourth, I could not always differentiate large Carp spp. (which were up to 177 cm total length in my collections) from Alligator Gar in some of the images. As a consequence, my designations of positive Alligator Gar images were

conservative and limited to adult fish, but were supported by historic collection records, telemetry data, field observations of surface activity of gar, and the large size of Alligator Gar in relation to other fishes present in the system.

As shown in other studies, acoustic image quality was dependent on fish orientation (Boswell et al. 2008, Frouzova et al. 2005, Gonzalez-Socoloske and Olivera-Gomez 2012, Langkau et al. 2012, Flowers and Hightower 2013), bottom features, including substrate/vegetation, water turbidity and turbulence, boat wake and fish motion (Draštík and Kubečka 2005, Nealson and Brundage 2007, Flowers and Hightower 2013). However, studies have shown that fish avoidance of side-scan sonar equipment in shallow waters does not appear to be a problem, and calculated abundances may be much more representative of true numbers compared to other sampling gear (Draštík and Kubečka 2005). Fish with periodic life-history stages (*Lepisosetus* spp.), such as Alligator gar require a broad range of habitat requirements to compete their life cycle like low current, warm water temperatures and flooded vegetation for spawning, tended to occur in floodplain lakes with higher connectivity-index scores than other species (Miyazono et al. 2010). Therefore surveying lakes may be beneficial for monitoring these species. Site-specific features that affected the quality of the survey in the present study included wind-generated turbulence and jumping Silver Carp *Hypothalmichthys molitrix*, both of which resulted in wavy distortion of some side-scan sonar images. Other factors such as bottom type/reflectivity and the presence of schools of small fishes have also been reported to affect image quality (Gonzalez-Socoloske and Olivera-Gomez 2012, Flowers and Hightower 2013), but these factors were not evident in SCCNWR. Of the two frequencies used, 800khz improved the clarity and detail of the fish images, resulting in a greater number of definitively identified Alligator Gar. Although this may be due to water depth and size of sonar swath, field tests

indicated that 800khz worked best with all swath sizes less than 21 m. There is a tradeoff with the swath size vs. number of transects, which needs to be evaluated based on the size of the study site and the time available for post-processing. The amber palette for survey images appeared to show more detail (relative to blue) and made the shadows more clearly defined based on better contrast of light and dark.

Most freshwater sonar research has focused on surveys of fishes, habitat, and mussels in rivers and streams (Frouzova et al. 2005, Mueller et al. 2008, Kaeser and Litts 2010, Gonzalez-Socoloske and Olivera-Gomez 2012, Flowers and Hightower 2013). The floodplain lakes on the SCCNWR presented several challenges to sonar techniques, including vegetated littoral areas and large stands of flooded trees and cypress knees that had to be avoided. When surveying large rivers or streams, passes are made parallel to the bank along the entire segment of the area to be mapped (Kaeser and Litts 2013a), which creates long transects with no overlap in points. Mapping the lake along pre-established circular paths parallel to the bank and along short transects across the lake based on aerial imagery may be problematic because of differences in water levels, as well as shallow areas, flooded trees, and other obstacles not visible in the aerial imagery that nonetheless affect the ability to follow pre-established paths. These path corrections can be accomplished during the survey, but often result in some overlap and gaps in images in the overall map (Appendix E). In addition, numerous transects were needed to cover the entirety of the lake, resulting in choppy transects with overlapping points that resulted in extended time for post-processing.

Based on my results, I would revise the surveying protocol by including more transects with smaller survey paths, perhaps 13 m per side, to improve clarity of fish images. This would also likely increase the clarity of habitat features for assessment of fish-habitat associations,

which will likely be the next step for SCCNWR Alligator Gar. In addition, I would increase the number of surveys at different times throughout the year, which would help increase detection rates and provide data on seasonal changes in fish locations/habitat use. This of course would result in substantially increased time spent in the field conducting surveys as well as on post-processing of the images. In this study area, recording a GPS location for each Alligator Gar was not feasible due to the large number of fish; having a second person in the boat with the responsibility of recording GPS locations would increase the data recorded during surveys.

The use of efficient and effective side-scan sonar surveys has several advantages for distinctive fish like Alligator Gar; reduced costs and labor, fewer days in the field, and elimination of risks to the fish and people associated with more traditional netting and electrofishing. The importance of hyrdoacoustics for the study of fish density, biomass, behaviors, and habitat preferences is widely recognized (Frouzova et al. 2005). Acoustic surveys could also be used to focus more intensive sampling, e.g., identifying areas where fish are located and minimizing collection efforts to known locations. Long-term surveys over the same areas could provide similar information gathered by traditional collection methods, i.e., abundance (and density, which is unknown when fish are collected by nets) and habitat use, spawning locations, and changes in population in restored habitats. This technology has significant potential to identify and prioritize areas for floodplain restoration and help guide management of floodplain habitats for Alligator Gar.

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CHAPTER 4. MANAGEMENT IMPLICATIONS

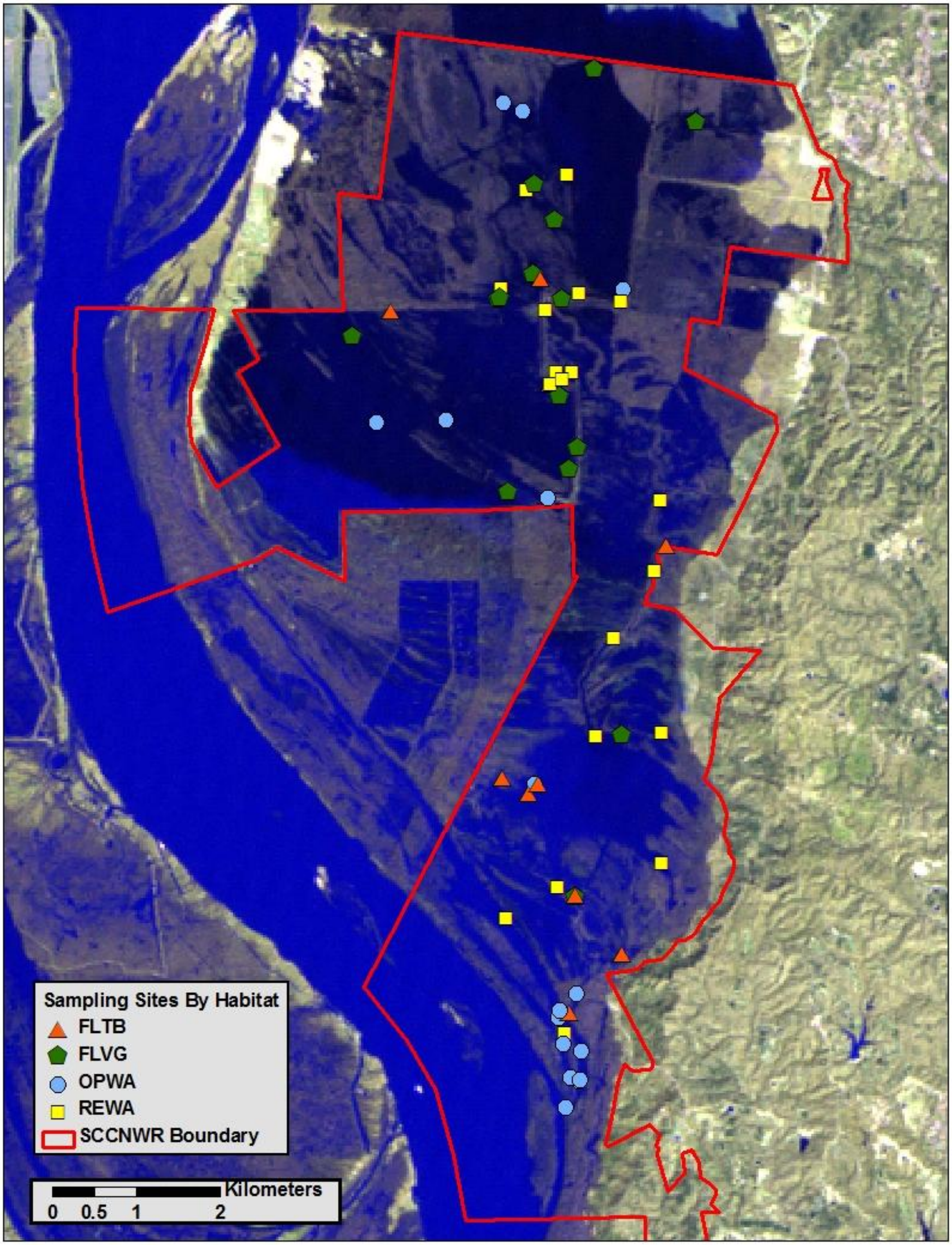
The fish assemblage on SCCNWR was dominated by large bodied, long lived, riverine fish species that exploit the feeding, reproductive, and refuge benefits of this floodplain. Given the abundance of floodplain fishes and the site fidelity of Alligator Gar at SCCNWR, this area offers an excellent model for restoration efforts in the in the LMRV. Alligator Gar appears to be an appropriate choice as a surrogate species for obligate and facultative floodplain fishes that were found on the SCCNWR floodplain. This long-lived apex predator exhibited wide dispersal in all floodplain areas, and habitat-use patterns were similar to those of several other fishes. Management of the SCCNWR Alligator Gar population should be primarily focused on maintaining connectivity to the river and promoting floodplain access during the annual flood pulse. Whether the weir on St. Catherine Creek should be sustained, depends on the ecology and physiology of Alligator Gar in this system. The weir does maintain a low-water refuge for fish during base river flow, and numerous Alligator Gar remain in these lakes during low water before accessing the floodplain during the next flood pulse. However, conditions in these lakes, particularly Blue Hole, would appear to deteriorate substantially as the low water season progresses, with high temperatures, low dissolved oxygen conditions, high gar densities, and minimal forage. Whether these fish would be in better condition for spawning if they returned to the river is unknown, but would be an interesting area of research.

Alligator gar were reliably detected in SCCNWR system with side-scan sonar, verified by independent visual evidence. The use of side-scan sonar surveys could reduce sampling time, personnel requirements, and equipment/logistic costs relative to traditional net sampling, while simultaneously reducing potential damage to fish associated with traditional netting methods. Long term surveys over the same areas could provide excellent temporal and spatial data on

Alligator Gar abundance, and combined with GIS information on floodplain habitat characteristics (perhaps obtained at low water prior to flooding), could be used to pinpoint specific habitat characteristics to be used as objectives for floodplain restoration efforts. I would suggest separate sonar surveys for fish presence (single pass around the perimeter of flooded habitats) and habitat (multiple passes with narrow band width to improve clarity of habitat characteristics) to reduce the possibilities of repeat observations for fish movement.

Floodplain habitat loss in most large river systems in the U.S. is substantial, with 90% of the historic floodplain of the LMRV lost in the last century. Although these habitats are recognized as important areas for a large diversity of fish and wildlife, they have not generally been monitored or managed in the same manner as terrestrial habitat. Beyond "maintaining" or "increasing," little information is available to managers to guide the conservation and restoration of large river floodplains and the dynamic aquatic habitats they provide. Floodplain restoration in the LMRV will offer broad scale benefits, as areas similar to St. Catherine Creek NWR provide critical habitat for species of concern such as Alligator Gar, as well as a variety of other fishes, mammals, herpetofauna, and migratory birds and waterfowl. The use of systematic netting programs and sonar surveys can produce a tremendous amount of data on aquatic species that use these floodplains and their responses to management activities. Continued inventories through time should be an integral part of floodplain management programs, improving and focusing restoration efforts to redevelop these systems as functioning floodplain rivers.

APPENDIX A. SAMPLING SITE BY HABITAT

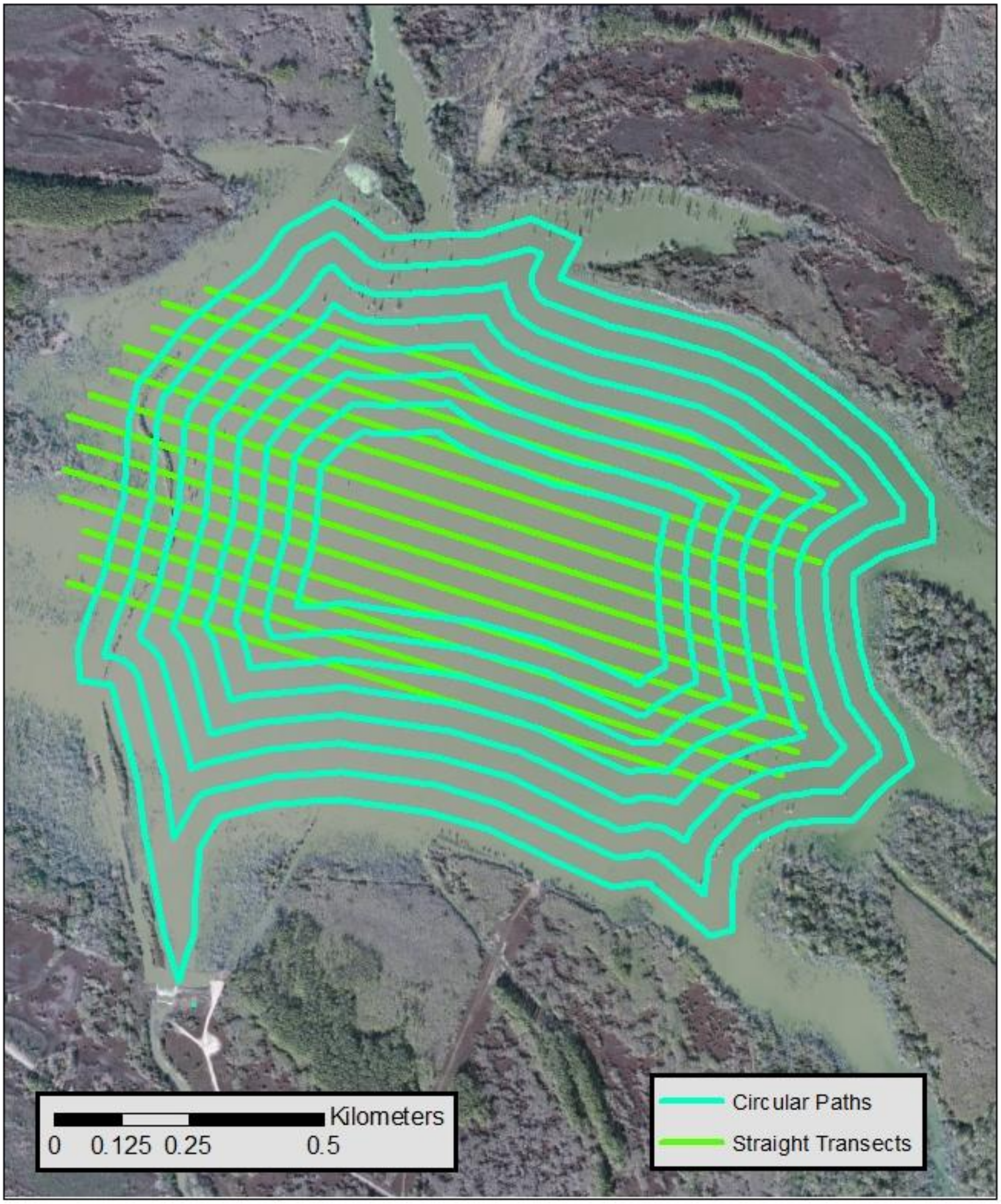


APPENDIX B. SAMPLING SITE AT HIGH WATER VS LOW WATER

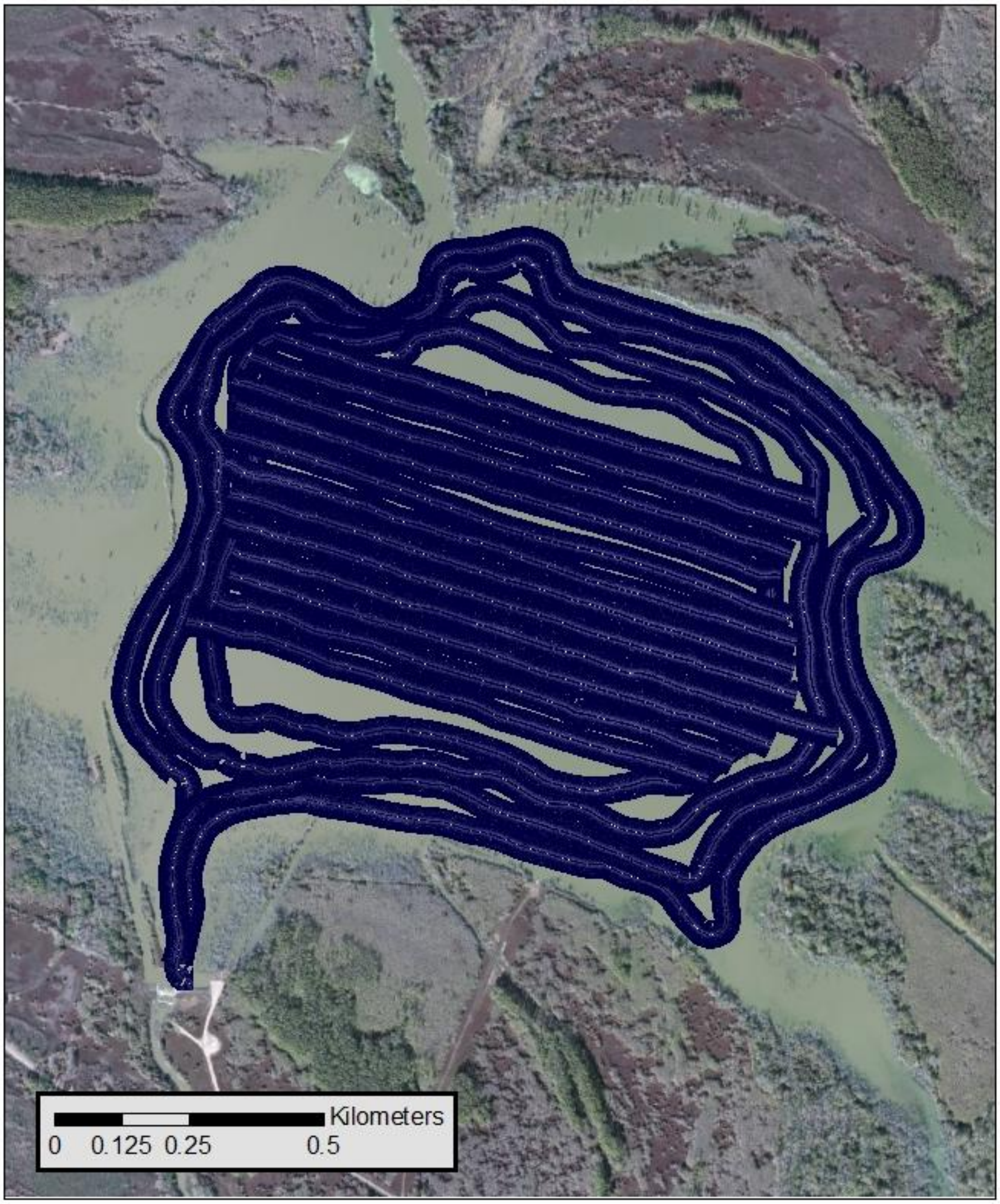
APPENDIX C. ALLIGATOR GAR CAPTURED

Alligator Gar			
Total Length (cm)	Girth (cm)	Habitat	River Stage (ft)
57	16	FLTB	32.49
61	18	OPWA	34.97
66	17	REWA	29.07
67	24	FLVG	35.87
71	22	FLVG	34.97
74	24	FLTB	32.49
76	18	FLVG	41.99
107	41	FLTB	43.70
114	43	FLTB	50.07
114	41	REWA	35.88
124	46	REWA	31.54
142	53	FLVG	41.99
163	69	FLTB	43.70
165	69	FLVG	42.98
168	69	REWA	32.49
182	76	FLVG	34.97
183	76	FLVG	42.98
183	79	FLTB	29.07
183	76	FLTB	27.02
188	71	FLTB	43.70
188	85	REWA	35.69
190	75	FLVG	34.97
191	77	OPWA	46.81
192	61	FLTB	43.70
195	76	REWA	39.94
198	84	REWA	28.03
198	84	REWA	35.87
201	74	FLTB	43.70
202	66	FLTB	50.07
203	89	REWA	35.87
218	82	REWA	34.53
219	89	REWA	35.13

APPENDIX D. MAP OF PRE-ESTABLISHED TRANSECTS ON BUTLER LAKE



APPENDIX E. SONAR MAP OF BUTLER LAKE



VITA

Alonda LaShawn McCarty, daughter of Regina Lockaby and Tim McCarty, raised in New Smyrna Beach, Florida and born April of 1986. She graduated from New Smyrna Beach High School in 2004, and went on to be Vice President for the Florida Association of the Future Farmers of America. She attended Eastern Kentucky University and graduated with a Bachelor of Science degree in Wildlife Management in 2011. Prior to enrolling in the graduate program at Louisiana State University in 2012, she worked continuously in the wildlife field through her undergraduate career with the National Park Service, at Canaveral National Seashore and then Big South Fork NRRA, then upon graduation with the U.S. Fish and Wildlife Service working with waterfowl conservation and alligator gar. Alonda is currently a candidate for the Master of Science degree in fisheries.