Mississippi Valley Division,
Regional Planning and Environment Division South

Yazoo Backwater Area Water Management Project

APPENDIX F-6 - Aquatic Resources and Fisheries

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2024 DEIS Yazoo Area Pump Project

AQUATIC RESOURCES APPENDIX

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AQUATIC EVALUATION

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ERDC-EL

Introduction

An aquatic evaluation of fishery resources impacted by the 2024DEIS Yazoo Area Pump Project (DEIS). The U.S. Army Corps of Engineers (USACE) is evaluating new information on ecological effects of project alternatives. This appendix is divided into five major parts each with their own objective, but together, describe the ecological status of the mussel and fish communities in the Yazoo Study Area as well as potential mitigation strategies to improve biotic diversity.

1. EnviroFish - A re-analysis of existing floodplain habitat was completed for spawning and rearing fishes that includes more recent hydrologic data (1978 - 2020) and improved elevation mapping data (10-meter versus 30-meter resolution). Average Daily Flooded Acres (ADFAs) were calculated using EnviroFish 1.0 for the No Action Baseline Alternative and two project alternatives. Reforestation requirements to offset impacts are presented.
2. Dissolved Oxygen –Statistical relationships are presented between hypoxia and fish species abundance, including larvae, juvenile, and adult life stages, using a long-term dataset collected in the Big Sunflower-Steele Bayou drainage over 30 years.
3. Fish Species Trend Analysis – The status and trends of the Big Sunflower fish assemblage over the past 50 years is described. Drainage-wide impairments to the aquatic environment are identified.
4. Alternative Mitigation – The aquatic benefits of alternative mitigation are discussed using supplemental groundwater wells from the Mississippi River alluvial aquifer to re-establish environmental flows enhancing survival of aquatic fauna.
5. Steele Bayou Structure and Pump – Potential risk of fish entrained or impinged during pumping operations is evaluated along with optimizing operation of the gates to increase bi-directional flow.

Part 1: EnviroFish

Background

Beginning in the late 1980’s, the USACE Vicksburg District and the US Fish and Wildlife Service (FWS) jointly worked to devise a method to assess the impact of flood control projects on the fishery resources of the Yazoo Basin. The two agencies agreed that the loss of spawning and rearing habitat during the spring floods was one of the likely causes of the decline of the basin’s fishery resources. The EnviroFish program was the result of the cooperative effort. The original program was written in FORTRAN and required several external text files to supply the required input data. The program was updated in the late 1990s. The updated program was written in “C++” and interfaced directly with the HEC Data Storage System (HEC-DSSVUE) hydrologic database. HEC-DSS stores the daily stages and the stage-area curves required by the EnviroFish program.

The output of EnviroFish is coupled to a spreadsheet that estimates acres of floodplain habitat suitable for fish reproduction under a given set of hydrologic conditions in the form of alternatives (Killgore et al. 2012). Utilizing the results of the hydrologic model (*i.e.,* daily elevations), EnviroFish integrates the daily flood elevations, floodplain land use, and Habitat Suitability Indices (HSI) to calculate a response variable. The response variable is in the form of a Habitat Unit annualized over the project life (AAHU) and the output was used by the Project Delivery Team to complete the impact and mitigation analysis of the alternatives on spawning and rearing fishes. The Model was certified by USACE National Ecosystem Restoration Planning Center of Expertise (ECO-PCX).

Objective

The objectives of this analysis were to calculate average daily flooded area (ADFA) for the No Action Alternative and two alternatives, calculate impacts, and determine floodplain reforestation acres necessary to offset impacts. The two alternatives evaluated are as follows:

ALTERNATIVE 2:

- 25,000 cfs pump; backwater managed at 90.0ft during crop season (25Mar-15Oct) and 93.0ft during non-crop season (16Oct-24Mar)

ALTERNATIVE 3:

- 25,000 cfs pump; backwater managed at 90.0ft during crop season (15Mar-15Oct) and 93.0ft during non-crop season (16Oct-14Mar)
- Nonstructural feature:
  - Modify operation of Steele Bayou water control structure to optimize fisheries exchange.
  - Acquisition or flood-proofing of primary residential properties between 90.0 - 93.0ft

Approach

Average Daily Flooded Acres (ADFA) are an area equivalent to one acre that is inundated on average every day of a defined season for a specified number of years. The ADFAs were calculated using the elevation data and hydrologically modeled water surface elevation. A new dataset was used to calculate Average Daily Flooded Acres that included hydrologic data up to 2020 (1978 - 2020) and improved digital elevation mapping data (10-meter DEM) compared to previous evaluations. The aerial measure of inundation (ADFAs) is multiplied by the appropriate Habitat Suitability Index (HSI) value in EnviroFish to output Habitat Units (HU) with which to compare alternatives and annualized over the 50-year project life.

Seasonally flooded habitat types were delineated from the National Agricultural Statistics Service (NASS) 2022 Crop Data Layer and verified with ground- truth to characterize floodplain land-use in the Yazoo Backwater Study Area. ADFAs of each habitat type by stage elevation (i.e., stage-area curves) were determined with EnviroFish. Habitat types are defined as follows:

1. Agriculture – all areas in which an agricultural product was grown including Pecan orchards and pasture lands.
2. Fallow – agricultural lands that have been abandoned where there is a prevalence of herbaceous, non-woody cover.
3. Bottomland hardwoods – Forested areas incorporates 5 NASS land-cover: evergreen forest, deciduous forest, mixed forest, forested wetlands, and herbaceous wetlands.

For this application, only agriculture and bottomland hardwood cover types within the 2- year flood frequency were considered. Fallow lands were not included in ADFA calculations because they represent less than 1% of all land-cover, but were used in calculation of reforestation mitigation acres during the growth transition period. EnviroFish calculates ADFAs by land-use (cleared or forested) for spawning and rearing separately. Spawning acres were restricted to a minimum depth of 1.0 foot and flooded for a minimum duration of 8 consecutive days. A minimum water depth of 1.0 foot allows adults to access shallow, flooded areas; a water depth less than 1.0 foot is not considered realistic due to physical limitations in the spawning process. Flood duration of at least 8 consecutive days ensures suitable time for nest construction and other spawning activities by the adults and recognizes that shorter durations may result in the eggs becoming stranded and desiccated if water recedes too quickly. Alternatively, if the water recedes too rapidly off the floodplain, organic matter, nutrients, and newly hatched aquatic organisms may be carried into the river instead of remaining in the floodplain and permanent backwaters. The minimum one foot, 8-day duration rule is considered a conservative value to delineate spawning requirements for warm water fish species found in the Mississippi River basin. This rule guarantees an effective spawning window, emphasizes longer development times, and provides a margin for temporal variation in spawning activities (i.e., adult movement onto the floodplain, nest construction, and guarding/dispersal of fry). The average duration of these activities is eight days, thus the minimum elevation in each 8-day period was used to calculate the spawning acreage. This calculation was accomplished with a moving window. The program determines the minimum elevation in an 8-day period, then the window is moved forward one day, and the calculation is repeated.

The rearing life stage includes yolk-sac and post yolk-sac larval phases, both having volitional behaviors to change locations within the floodplain. Two different types of rearing are calculated. Total rearing is unrestricted and provides the total area flooded for each day. Restricted rearing can establish minimum and/or maximum depths for rearing. For this project the rearing area had no minimum depth, but the maximum depth was restricted to 10 feet, due to low dissolved oxygen (DO) levels observed in deeper areas (see Section2).

The EnviroFish Program provides two output files, but the main goal is to determine the Average Daily Flooded Acres (ADFA) of flooded land for the period of record (POR). The two output files are a summary file of the ADFA by year and a file of the daily acres flooded. The daily file provides five columns of data. The data fields are stage, total rearing acres, restricted rearing acres and spawning acres. There are separate output files for cleared (agricultural) and forested areas. The second output file is the summary statistics file. This file has 13 output statistics, which are: year, mean-stage, total rearing, restricted rearing, and spawning area, maximum-stage, total rearing, restricted rearing, and spawning area, and minimum-stage, total rearing, restricted rearing, and spawning area (available upon request). Finally, the program calculates the POR values for the previously listed statistics. In all previous studies, the Corps used a spawning and rearing season from 1 March to 30 June of each year for the period or record from 1978-2020. For this study, the spawning and rearing season was subdivided into three sub-seasons accounting for 100-percent of the spawning and rearing for the entire year. The sub-seasons were: 1, March; 2, April and May; and 3, June. The three seasons account for fish species spawning early, middle, and late in the spawning season with the majority of species spawning in April and May. The EnviroFish program was not designed to have subseasons, so the program was run for the entire year, and SAS was used to calculate the statistics for each sub-seasons.

The majority of the species that spawn and rear in riverine floodplains are pre-adapted to structurally complex habitats such as bottomland hardwoods. Therefore, cleared lands have less value for spawning and rearing habitat and eggs and larvae have a higher risk of becoming stranded or preyed upon in cleared lands as floodwaters recede. The HSI values reflect this trend, with optimum conditions occurring for bottomland hardwoods (HSI = 1.0); intermediate values for fallow fields (HSI = 0.5); and the lowest value for cleared, agricultural lands (HSI = 0.2). These values represent a community-level perspective on the biological response (i.e., spawning and rearing) of the fishes of the Yazoo Study Area to flooding. Further information on HSI development and modeling spawning and rearing habitat in floodplains are provided in the EnviroFish 1.0 manual (Killgore et al. 2012), which was certified in October 2020 by the Ecosystem Restoration National Planning Center of Expertise for this project. Because the Proposed Plan would reduce flooding within the Yazoo Backwater, loss in Average Annual Habitat Units between the No Action Base Alternative and the two proposed alternatives were calculated and mitigation requirements determined to offset loss in aquatic habitat. This analysis made certain assumptions on the application of EnviroFish to calculate ADFAs:

1. Larval fish have the potential to utilize the same habitat as spawning sites. Larval fish have smaller physical dimensions that allow access to shallower (< 1.0 feet) water than physically available for spawning needs (typically ≥ 1.0 feet depth, 8 days duration). The EnviroFish software was used to define minimum and maximum allowable depths for spawning and/or rearing to accurately represent a specific situation. For rearing, a maximum depth was used, labelled "Restricted Rearing" to account for hypoxia in deeper waters.
2. Habitat acres were quantified for floodplain habitat only. This was done because the project would impact the extent of floodplain habitat with no/minimal effect on channel and other permanent aquatic habitat.
3. Many factors dictate the overall timing of the spawning and rearing period. Optimum conditions for spawning occur when the flood pulse and warmer temperatures are coupled. Although there are multiple variables that dictate when fishes will actually spawn, the model assumed that spawning takes place from 1 March to 30 June.
4. Flooded bottomland hardwoods in the 2-year flood frequency are the preferred spawning and rearing habitat.

Results and Discussion

The EnviroFish analyses were performed on six hydrologic reaches. There are four reaches in the Big Sunflower Basin and two in the Steele Bayou Basin. The four Big Sunflower reaches are Little Callao, Anguilla, Holly Bluff and Little Sunflower, from upstream to downstream. The two Steele Bayou reaches are: Grace and Steele Bayou, also from upstream to downstream. The average annual duration of flooding varies from upstream to downstream, with the downstream stations experiencing the greatest duration of flooding. A common misconception about the spawning and rearing season is that there is out-of-channel flooding every day during this season. This is not true, and for some of the upstream stations the average annual days with stages equal to or greater than the 1-year frequency flood elevation is less than 10 days. In contrast, for the most downstream station, the average annual days with flooding greater than or equal to the 1-year frequency event is 28 days. The spawning season lasts for 122 days each year, thus most days have less flooding than the 1-year frequency event.

Mean ADFA values for spawning and restricted rearing (max depth=10 ft) were used to determine impacts and mitigation requirements. Forested lands comprised approximately 80% of the total landuse in the 2-year floodplain, with Steele Bayou and Little Sunflower being the most heavily forested (Table 1). Reforestation efforts over the past 30 years in the 2-year floodplain have contributed to large conversions of crop lands to bottomland hardwoods. Overall percent loss of ADFA ranged from 7 to 12 percent depending on life stage and alternative (Table 1). Comparing Habitat Units between base and alternatives resulted in a loss of 2,264 for spawning and 1,862 for rearing under Alternative 2, and for Alternative 3, the HU loss was 2,184 and 1,747 for spawning and rearing respectively (Table 2).

For mitigation calculations, Average Annual Habitat Units (AAHUs) were calculated for the conversion of agricultural land to BLH over a 54-year project life. This calculation assumed four years of project construction, and ten years for the reforested areas to obtain full, functional value for spawning and rearing of fishes (Table 3). This analysis resulted in 0.71 AAHU gained per acre of reforested agriculture land. Reforestation acres to offset impacts were higher for spawning than rearing. Alternative 2 resulted in 3201 acres of reforested habitat to offset impacts, whereas Alternative 3 resulted in 3088 acres (Table 3). Selection of sites for reforestation should ensure that lands are flooded at depths of least 1-ft over an 8-day period during part of the spawning season.

Table 1. EnviroFish Summary of Average Daily Flooded Acres for each reach by land cover, alternative, and life stage during March-June based on the period of record from 1978 - 2020.

		Base				Alternative 2				Alternative 3		
Reach	Landcover	Elevation	Spawning	Rearing		Elevation	Spawning	Rearing		Elevation	Spawning	Rearing
Little Callao	Clear	92.2	26.8	68.4		91.9	23.9	63.3		91.9	24.0	63.4
Anguilla	Clear	90.1	498.1	1236.7		89.7	281.4	883.1		89.7	282.1	885.2
Holly Bluff	Clear	87.7	472.8	837.5		87.0	245.8	603.5		87.0	250.1	610.6
Little Sunflower	Clear	82.7	2998.9	4457.6		82.3	2641.0	4219.1		82.3	2653.6	4234.4
Grace	Clear	89.9	67.9	114.1		89.5	46.7	78.3		89.5	46.8	78.5
Steele Bayou	Clear	81.0	2425.9	3670.9		80.6	1120.6	2214.2		80.6	1150.2	2283.5
Average Totals			6490.5	10385.2			4359.5	8061.5			4406.9	8155.6
Little Callao	Forest	92.2	110.3	177.6		91.9	103.8	170.9		91.9	103.9	171.0
Anguilla	Forest	90.1	385.1	622.2		89.7	336.3	554.8		89.7	336.9	555.5
Holly Bluff	Forest	87.7	1676.3	2799.7		87.0	1246.2	2352.4		87.0	1246.2	2352.4
Little Sunflower	Forest	82.7	13322.0	19469.9		82.3	12548.9	19079.3		82.3	12594.1	19122.7
Grace	Forest	89.9	722.2	1042.1		89.5	630.5	908.0		89.5	632.2	909.6
Steele Bayou	Forest	81.0	9794.7	14027.4		80.6	9307.0	13676.6		80.6	9329.7	13725.9
Average total			26010.5	38138.8			24172.6	36741.9			24243.0	36837.2
Little Callao	Total	92.2	137.1	246.0		91.9	127.7	234.2		91.9	127.8	234.4
Anguilla	Total	90.1	883.2	1858.9		89.7	617.8	1437.9		89.7	619.0	1440.7
Holly Bluff	Total	87.7	2149.1	3637.2		87.0	1492.0	2955.9		87.0	1496.3	2963.0

Little Sunflower	Total	82.7	16320.9	23927.5		82.3	15189.9	23298.4		82.3	15247.8	23357.2
Grace	Total	89.9	790.1	1156.2		89.5	677.2	986.3		89.5	679.0	988.1
Steele Bayou	Total	81.0	12220.6	17698.3		80.6	10427.6	15890.7		80.6	10479.9	16009.4
Average total			32501.0	48524.0			28532.1	44803.4			28649.8	44992.8
Percent Change							-12.2	-7.7			-11.8	-7.3

Table 2. Average Daily Flooded Acres (ADFA) weighted by days in each month over the period of record from 1978 - 2020 during the spawning season (March-June) and Habitat Units (HU) for each life stage and land cover. Sample size is n=18 for each line corresponding to the average values of six hydraulic reaches over 3 seasons. Habitat Suitability Index for cleared and forested lands was 0.2 and 1.0, respectively.					
Alt	Land Cover	Spawning ADFA	Spawning HU	Rearing ADFA	Rearing HU
Base	Clear	6490.5	1298.1	10385.2	2077.0
	Forest	26010.5	26010.5	38138.8	38138.8
	Total	32501.0	27308.6	48524.0	40215.8
Alt1	Clear	4359.5	871.9	8061.5	1612.3
	Forest	24172.6	24172.6	36741.9	36741.9
	Total	28532.1	25044.5	44803.4	38354.2
Alt2	Clear	4406.9	881.4	8155.6	1631.1
	Forest	24243.0	24243.0	36837.2	36837.2
	Total	28649.8	25124.3	44992.8	38468.3

Table 3. Calculation of reforestation acres to offset impacts to spawning and rearing of fishes in the Yazoo Backwater Area.		
Alternative 2		
	Spawning	Rearing
HU loss	2264	1862
ADFA Loss	3969	3721
Average Annual Habitat Units Gained per Acre of Reforested Agricultural Land		
Without Reforestation (54 years @0.2)	10.8	10.8
Transition (10 Years @0.5)	5	5
Reforested HU's (44 years@1.0)	44	44
Net HU Value (with -without)	38.2	38.2
AAHU's gained per acre(38.2/54)	0.71	0.71
Reforestation acres (0.71 AAHU per acre credit)	**3201**	**2632**
Alternative 3		
	Spawning	Rearing
HU loss	2184	1748
ADFA Loss	3851	3531
Average Annual Habitat Units Gained per Acre of Reforested Agricultural Land		
Without Reforestation (54 years @0.2)	10.8	10.8
Transition (10 Years @0.5)	5	5
Reforested HU's (44 years@1.0)	44	44
Net HU Value (with-without)	38.2	38.2
AAHU's gained per acre(38.2/54)	0.71	0.71
Reforestation acres (0.71 AAHU per acre credit)	**3088**	**2470**

Part 2. Dissolved Oxygen

Background

Most backwaters in the Lower Mississippi River basin become hypoxic as water temperature warms. Backwaters include oxbow lakes and any deep waterbody that becomes ponded or stratified for long periods of time. Natural backwaters have an outlet (e.g., tie channel in oxbow lakes) that fish can escape thru during periods of low dissolved oxygen whereas the Yazoo backwater becomes an isolated system once the structure is closed. The hypolimnion of the thermally-stratified water in the Yazoo Backwater becomes hypoxic or anoxic. Oxygen replenishment by vertical mixing, oxygen demand, and residence time of bottom water jointly determine the oxygen budget and the temporal and spatial extent of bottom hypoxia (Kuo et al. 1991).

Hypoxia has been measured during Yazoo Study Area flooding events on numerous occasions (Figure 1). Hypoxia in general has negative impacts on fishes and other aquatic organisms. In the Big Sunflower River, fish species richness was shown to be directly related to dissolved oxygen concentration and ordination using nonmetric multidimensional scaling indicated strong association between fish community structure and dissolved oxygen (Shields and Knight 2011). Species adapted for aerial and surface film respiration often dominated the fish assemblage in hypoxic waters including the Big Sunflower, whereas less tolerant species such as bass, darters, and larger benthic fishes avoid hypoxic waters due to physiological limitations (Hoover and Killgore 1998, Killgore and Hoover 2001).

Objective

Fish and habitat data have been collected in the Big Sunflower-Steele Bayou drainage since the early 1990's. These data were collected for different reasons related to flood control or habitat restoration, but field techniques have been consistent. An analysis of this database was performed to evaluate biotic responses to a range of dissolved oxygen regimes in the Yazoo Study Area. In addition, the estimated volume of hypoxic water during a major hydrologic event was estimated for different stratification scenarios to evaluate the geographic scope of the issue. Recent dissolved oxygen measurements below the outlet of the Steele Bayou water control structure are also summarized. The information will be used to evaluate biological impairment identified in the Yazoo Basin, including low dissolved oxygen (303d listed by Mississippi Department of Environmental Quality) and U.S. Environmental Protection Agency (EPA), in addition to discussion of the potential problems with reforestation to address hypoxic waterbodies.

Approach

Volume

The volume of water that spreads out across the Yazoo Study Area was estimated for the 2019 flood for waters 1 – 5, 5 – 10 and > 10 feet deep. These depth intervals were based on different stratification depths of the water column measured at multiple locations (see Water Quality Appendix). On 23 May 2019, the water level on the landside of the Steele Bayou water control structure peaked at 98.23 feet

NGVD (USACE 2019). The assumption was made that water would back up across the Yazoo Study Area filling any area with an elevation lower than 98.2 feet NGVD. For this application, the Yazoo Study Area (area of interest) was defined as the area south of Highway 82 composed of the Steele, Sunflower, and Quiver watersheds, as defined by the National Hydrography Dataset (USGS 2016), extending to the Yazoo Backwater Connecting Channel and excluding the area protected by the Yazoo backwater levee. The elevation-area and elevation-volume by depth interval was calculated using the FESM model for elevations 60 to 108 feet NGVD.

Fish

Two databases were used to evaluate relationships between dissolved oxygen and biotic response variables. The light trap database consisted of larval and juvenile fish collected by slotted Plexiglas traps (1 square foot) baited with chemical light sticks set overnight. Traps were set in littoral areas throughout the Yazoo Study Area in river and floodplain habitats between 1990 and 2008. The electroshocking database consisted of mostly adult and juvenile fish collected by a boat-mounted electro-shocker in the Yazoo Study Area in 2003, 2009, 2015, and 2019. Each sample represented five minutes of pedal (electricity on) time. Dissolved oxygen was measured during each sampling event. Bivariate plots were created of dissolved oxygen and percent fish abundance for each database.

Probability density functions were fitted to the data using three methods: lognormal, Weibull, and Gamma distributions. These plots were visually inspected to evaluate effects of hypoxia on fish abundance. A box and whisker plot was created to show the weighted distribution of fish over the range of dissolved oxygen measured in the Yazoo Study Area. Fish were divided by family to evaluate tolerance taxonomically. Abundance was weighted according to the number of individuals as:

$$Xw_i = \frac{\sum_i W_i X_i}{\sum Wi}$$

where W_i is the number of individuals and X_i is the dissolved oxygen.

Results and Discussion

Volume

The volume of water during the 2019 flood was mapped (Figure 2) and calculated (Table 4) for three different depths to represent possible thermoclines below which water may become hypoxic (< 3.0 mg/l) or anoxic (< 1.0 mg/l) near the bottom. Stratification depths were based on monitoring data summarized in the Water Quality Appendix. At a thermocline depth of 5 feet, 58% of the total volume could be hypoxic compared to 29% at a thermocline depth of 10 feet (Table 4). Even with a shifting thermocline, hypoxia could be extensive during prolonged flooding events occurring in spring and summer. Dissolved oxygen was also monitored below the Steele Bayou Structure. Those measurements were compared to a natural backwater, Forest Home Chute, and the Yazoo River above the confluence of Steele Bayou. A total of six to seven measurements were taken in August 2019 and May – June 2020. The mean (± 1 standard deviation) dissolved oxygen below Steele Bayou was 2.0 ± 0.7 mg/l compared to Forest Home Chute (7.7 ± 1.0 mg/l) and the Yazoo River (5.1 ± 1.5 mg/l). In addition, Vicksburg

District collected dissolved oxygen profiles during backwater events noting low dissolved oxygen. These data further support the presence of hypoxia during and after a flooding event.

Fish

A total of 26,233 larval and juvenile fish representing at least 32 species were collected with light traps (n = 398) in the Big Sunflower-Steele Bayou drainage from 1990 through 2003 (Table 5). More species were collected, but taxonomic identification of larval fish is tenuous for some species and can only be identified to genus or family level. Five taxa represented over 90% of the total assemblage. Shad (Gizzard and Threadfin) were most abundant followed by Buffalo (likely Smallmouth and Bigmouth). Buffalo are obligate floodplain spawners. The sunfish genus *Lepomis* was the third most abundant taxa. Up to nine species in this genus have been documented in the Yazoo Study Area (see Table 7, Electroshocking data) and all are nest builders in shallow areas. Crappie were fourth in abundance represented by White and Black. Mosquitofish, which are live-bearing fish, are often attracted to light traps and were fifth in abundance. Other common taxa collected included Common Carp, Gar (Spotted, Longnose, and Shortnose) and various species of minnows and shiners.

Probability density functions fitted to a histogram of percent abundance of larval/juvenile fish over a range of dissolved oxygen indicates a slightly skewed normal distribution with the highest abundance at 6.0 to 7.0 mg/l of dissolved oxygen, then rapidly declining below 5.0 mg/l (Figure 3). The distribution is also skewed to the right where abundance rapidly declines above 8.0 mg/l. There are several possible reasons for this trend. Average 24-hr dissolved oxygen levels are rarely above 6.0 to 7.0 mg/l. Higher levels are typically associated with super saturation occurring late in the day. The same areas experiencing super saturation are often hypoxic in the mornings, resulting in lower fish abundance. To further illustrate impacts of hypoxia on larval fishes, a ratio to compare total abundance of larval and juvenile fish in hypoxic (dissolved oxygen < 3.0 milligrams per liter, mg/l)) and normoxic (> 3.0 mg/l) water collected with light traps between 1990 and 2008 in the Yazoo Study Area was calculated (Table 6). The mean number of individuals collected in hypoxic water was almost 40% less compared to the abundance in normoxic water. These data confirm that hypoxic conditions occurring during flood events can have negative impacts to spawning and rearing fishes. Even slight increases in dissolved oxygen, at least above 2.0 mg/l, may be adequate for longer survival and recruitment of fish in the Yazoo Study Area.

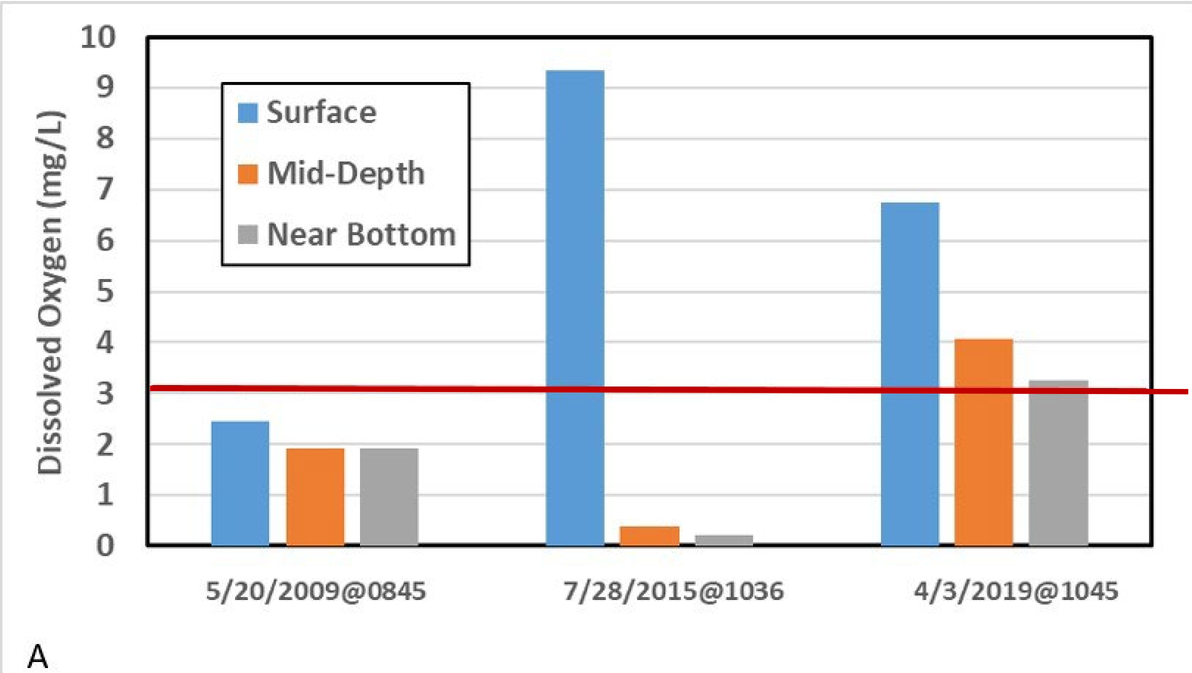
Both adult and older juveniles are included in the electroshocking data. A total of 2,126 individual fish were collected with the electroshocker in 83, 5-minute samples (total shocking time of 415 minutes) during 2003, 2009, 2015, and 2019 (Table 7). A total of 41 species were collected with Shad (mostly Gizzard), Buffalo (Smallmouth and Bigmouth), Spotted Gar, and Bluegill representing 70 percent of all species combined. Probability density functions fitted to the histogram of percent abundance over a range of dissolved oxygen were similar to the light trap data (Figure 4). Percent abundance of total individuals peaked around 6.0 mg/l and then rapidly declined below 3.0 mg/l. Percent abundance also declined above 7.0 mg/l probably for similar reasons described for light trap data.

The electroshocking data was evaluated by family using a box and whiskers plot (Figure 5). The weighted abundance confirmed that taxa with alternative modes or respiration (bowfin – Amiidae; gars –

Lepisosteidae) typically occurred at low dissolved oxygen levels and are often the top predators in hypoxic environments. Suckers (Catostomidae) including buffalo were usually found in normoxic (6.0 to 7.0 mg/l) waters, along with shad (Clupeidae) and catfish (Ictaluridae). These families are less tolerant to low dissolved oxygen and may experience higher mortality during hypoxic conditions or move out of the area if possible. The speciose families of sunfishes (Centrarchidae) and minnows/shiners (Cyprinidae) had a wide distribution across the dissolved oxygen range sampled, but mean values occur in the range of 4 to 6 mg/l.

Field collections in the Yazoo Study Area and upper reaches of the Big Sunflower-Steele Bayou drainage over the past 30 years occurred over a wide range of dissolved oxygen concentrations from extreme hypoxic (< 1.0 mg/l) to saturated (> 10.0 mg/l) waters. Correlation analysis indicate a statistically significant, positive relationship between fish abundance and dissolved oxygen for all life stages. Dissolved oxygen concentrations greater than 5.0 mg/l are widely accepted as a standard for the protection of fish, although this value varies among state and federal agencies (Doudoroff and Shumway 1970). Some warm water fishes are adapted to dissolved oxygen concentrations below 5.0 mg/l without effects on growth, development, and behavior (Ekau et al. 2010). One study reported that dissolved oxygen concentrations will have to decline below 2.0 mg/l to severely impact fish assemblage composition in vegetated areas (Killgore and Hoover 2001). Those species maladapted for aerial and surface film respiration are eliminated and may contribute to a decline in fish species richness and abundance in riverine backwaters, river channels, and lakes (Shields and Knight 2011). Low dissolved oxygen along with other major impairments to aquatic habitat in the Yazoo Study Area has resulted in a fish community dominated by habitat and water quality tolerant species. However, more sensitive species do occur in lower numbers indicating potential recolonization if habitat conditions improve.

Avoidance of hypoxic areas is one adaptive mechanism of fish. In shallow areas, only the surface layer can serve as a refuge, but in deep waters many organisms have developed vertical migration strategies to use, pass through, and cope with hypoxic zones (Ekau et al. 2010). Unobstructed backwaters also provide horizontal and lateral avenues of escape from hypoxic waters. Once Steele Bayou water control structure is closed, the only avenue of escape is to move upstream or laterally into shallower water or smaller tributaries. The extensive area of hypoxia during flooding in the Yazoo Study Area (see Water Quality Appendix) require fish to move upstream over 55 miles beyond the old Lock and Dam into the shallower, upper reaches of the drainage. The spatial extent of hypoxia such as in the Yazoo Study Area and the limited avenues of escape in regulated floodplains can lead to high mortality (Jones and Stuart 2008).



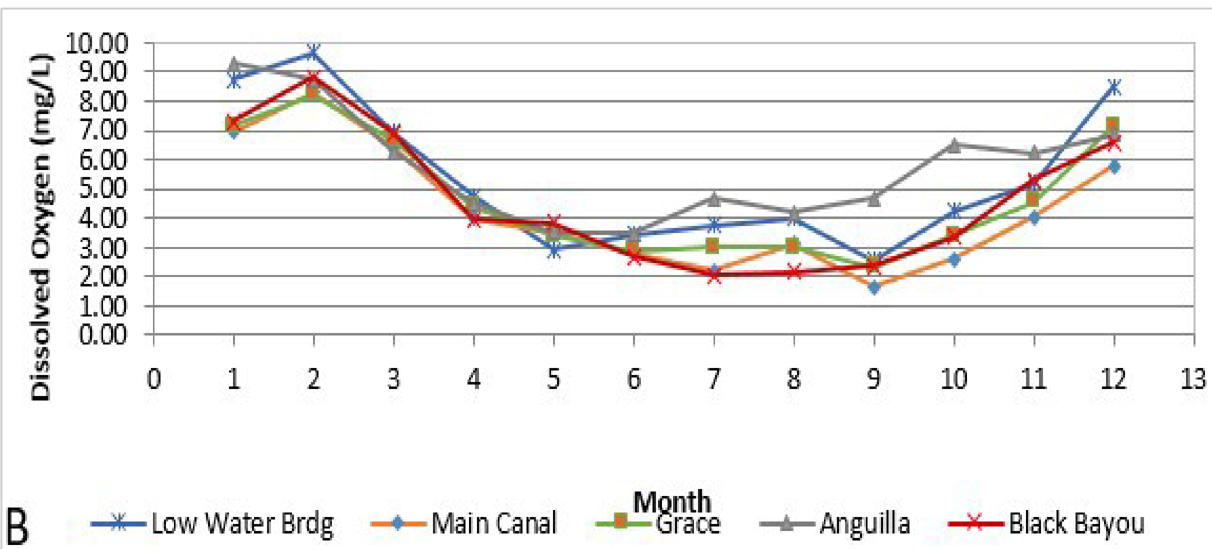


Figure 1. Mean dissolved oxygen at surface, mid, and near bottom depths above the Steele Bayou Structure during three sampling events (date/time) when the Steele Bayou Structure was closed (Panel A), and mean monthly surface dissolved oxygen measurements at five locations in the Yazoo Study Area combined from 2005-2015 (Panel B) (Figures obtained from MVK, B. Johnson and D. Johnson, unpublished data). Red horizontal line in Panel A indicates EPA's threshold of physiological impairment.

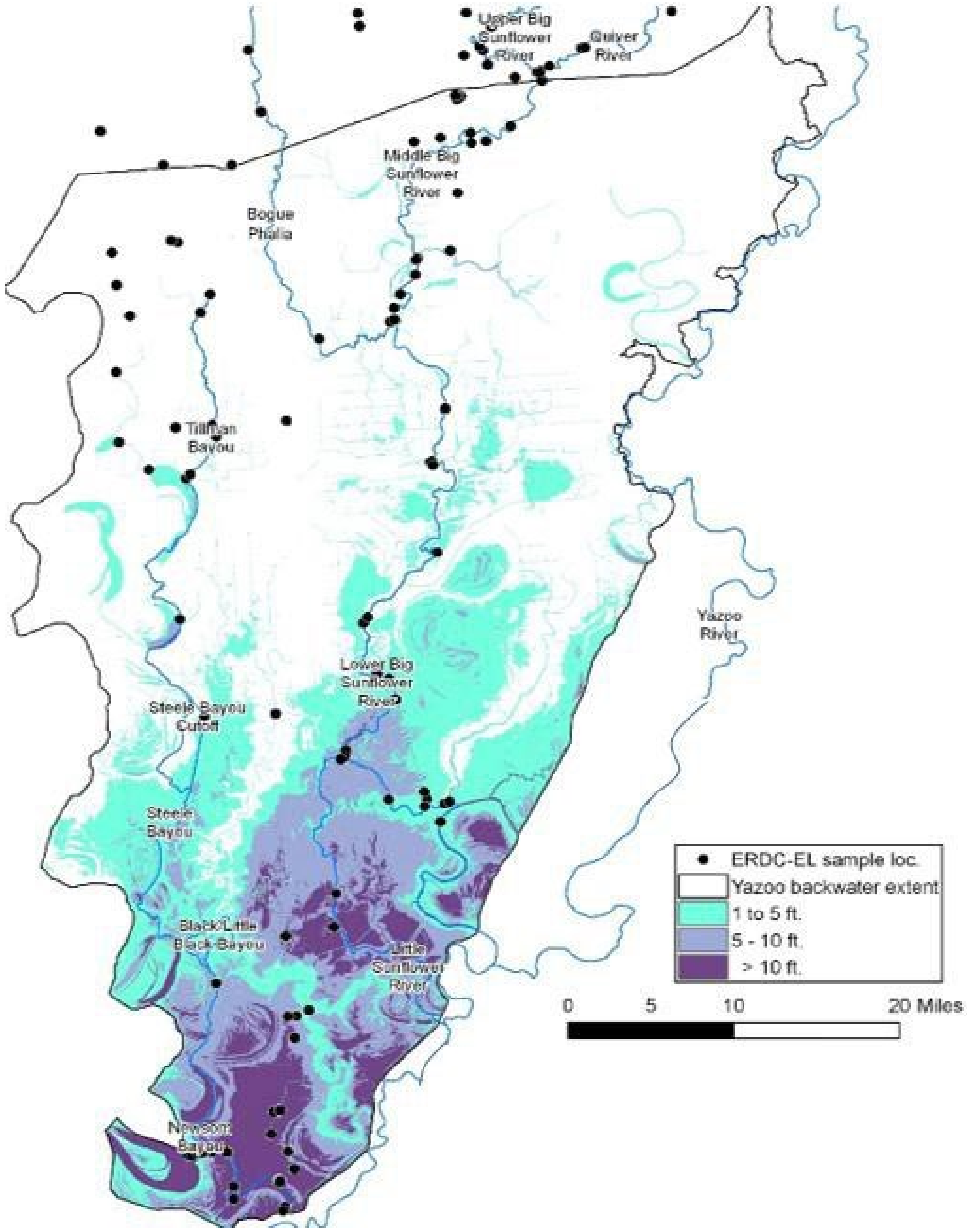


Figure 2. Map of water volume at different depths during a Yazoo Study Area flooding event at 98.2 feet, NGVD elevation. Volumes used to estimate area of hypoxia beginning at hypothesized depths of 5 or 10 feet.

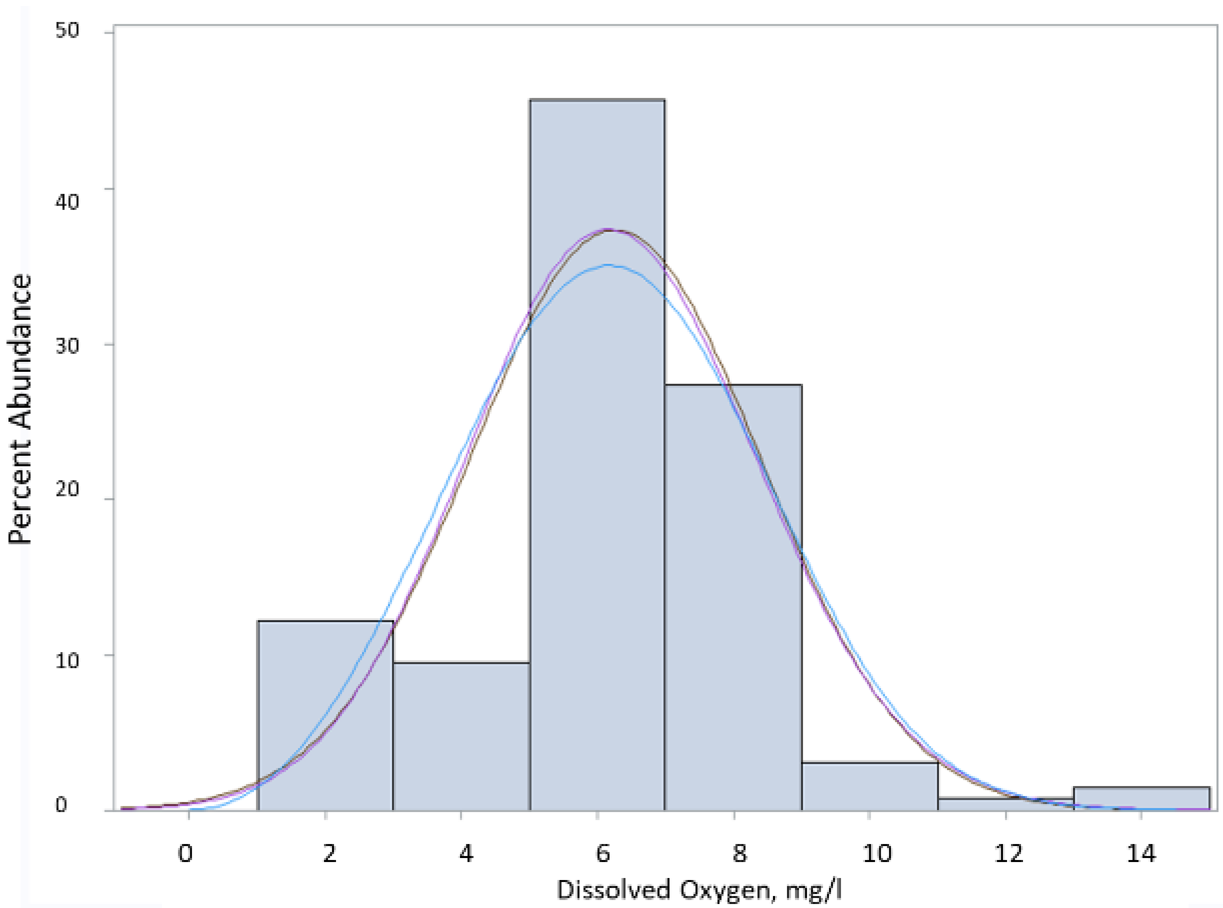


Figure 3. Percent abundance of all taxa (see Table 6) collected with light traps (n = 398) over a range of dissolved oxygen in the Big Sunflower-Steele Bayou drainage from 1990 through 2003. Lines represent probability density functions fitted to the data using three methods: lognormal, Weibull, and Gamma distributions.

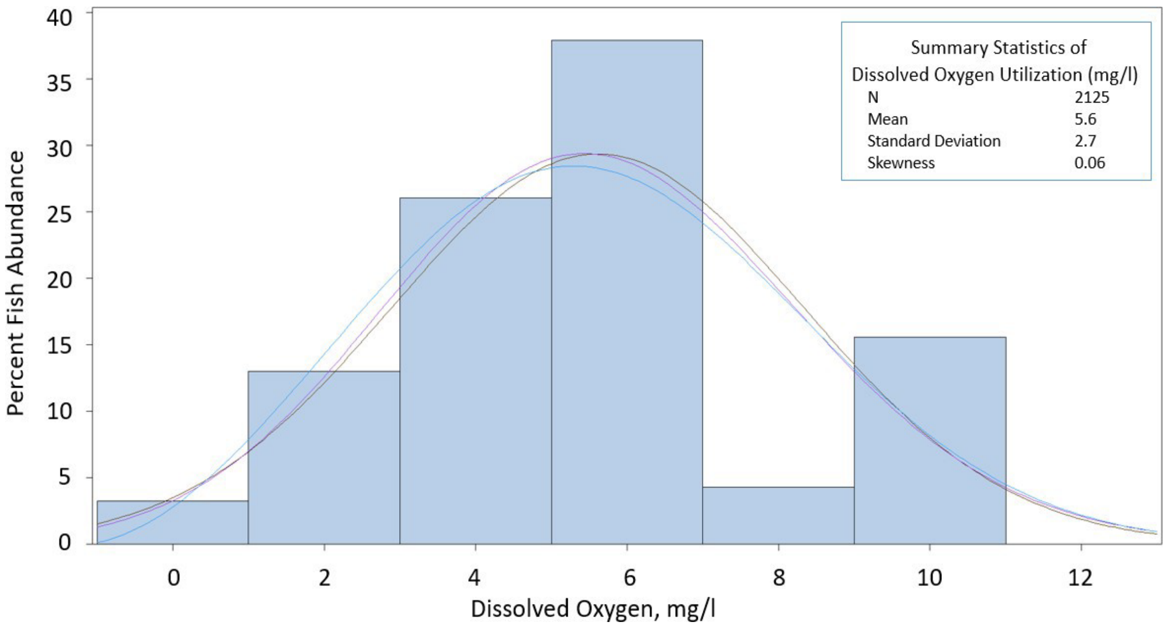


Figure 4. Percent abundance of total individuals (n = 2,126) of fish collected with a boat-mounted electroshocker (n = 83, 5-min samples) over a range of dissolved oxygen in the Yazoo Study Area. Data collected in 2003, 2009, 2015, and 2019. Probability density curves are shown for lognormal (blue), Weilbull (brown), and Gamma (purple) distributions.

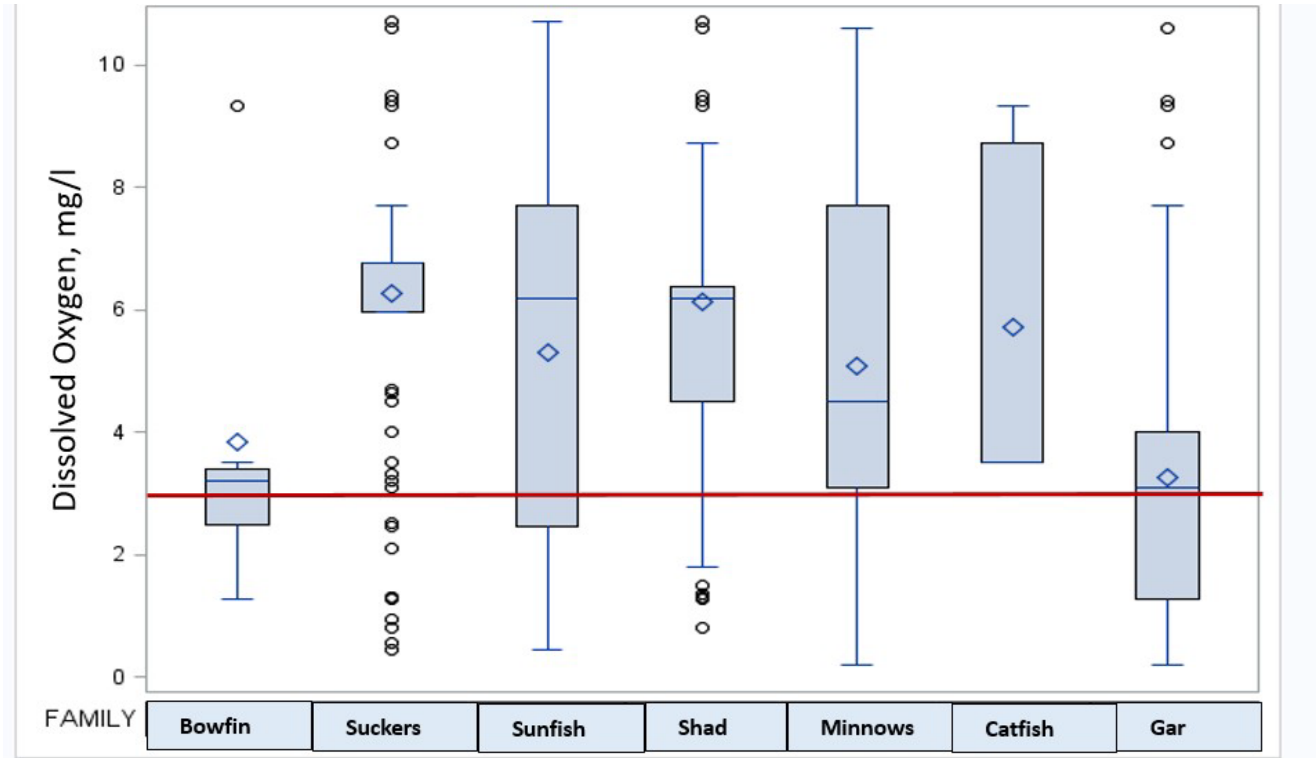


Figure 5. Box and whiskers plot of the weighted distribution of fish families over the range of dissolved oxygen measured in the Big Sunflower-Steele Bayou in 2003, 2009, 2015, and 2019, electroshocking data. Total sample size was 2,025 individuals. Each box includes mean weighted abundance (diamond), median (horizontal line inside box), first and third quartile (lower and upper edge of box, respectively) and minimum and maximum values (endpoint of lower and upper whisker, respectively). Circles represent extreme values outside of the normal distribution. Red line indicates EPA's threshold of physiological impairment.

Table 4. The estimated acre feet of water by depth interval within the Yazoo Study Area at the 23 May 2019 flood peak of 426,308 acres

Volume by Depth	Acre-Feet	Percent of Total
0 to 5 ft vol.	1,712,943.5	58
5 to 10 ft vol.	855,688.4	29
> 10 ft vol.	397,059.8	13
Total	2,965,691.6	100

Table 5. Number of individuals by taxa collected with light traps (n = 398) in the Big Sunflower-Steele Bayou drainage from 1990 - 2003. Taxa are arranged in order of abundance.

Taxa	Common Name	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Clupeidae	Shad	6,702	25.55	6,702	25.55
Ictiobus sp.	Buffalo	5,268	20.08	11,970	45.63
Lepomis sp.	Sunfish	4,586	17.48	16,556	63.11
Pomoxis sp.	Crappie	2,309	8.8	18,865	71.91
Gambusia affinis	Mosquitofish	2,132	8.13	20,997	80.04
Dorosoma cepedianum	Gizzard Shad	1,953	7.44	22,950	87.49
Cyprinus carpio	Common Carp	1,232	4.7	24,182	92.18
Aplodinotus grunniens	Freshwater Drum	425	1.62	24,607	93.8
Lepisosteus sp.	Gar	291	1.11	24,898	94.91
Cyprinidae	Minnows/Shiners	243	0.93	25,141	95.84
Catostomidae	Suckers	187	0.71	25,328	96.55
Pomoxis annularis	White Crappie	174	0.66	25,502	97.21
Dorosoma petenense	Threadfin Shad	95	0.36	25,597	97.58
Lepomis cyanellus	Green sunfish	86	0.33	25,683	97.9
Lepisosteus oculatus	Spotted Gar	83	0.32	25,766	98.22
Notemigonus crysoleucas	Golden Shiner	72	0.27	25,838	98.49
Percidae	Darters	59	0.22	25,897	98.72
Pomoxis nirgomaculata	Black Crappie	44	0.17	25,941	98.89
Centrarchus macropterus	Flier	35	0.13	25,976	99.02
Morone chrysops	White Bass	33	0.13	26,009	99.15
Labidesthes sicculus	Brook Silverside	30	0.11	26,039	99.26
Centrarchidae	Sunfish	27	0.1	26,066	99.36
Mendia beryllina	Inland Silverside	20	0.08	26,086	99.44

Notropis lutrensis	Red Shiner	20	0.08	26,106	99.52
Notropis.sp.	Minnows	19	0.07	26,125	99.59
Lepomis symmetricus	Bantam Sunfish	18	0.07	26,143	99.66
Hypophthalmichthys nobilis	Bighead Carp	15	0.06	26,158	99.71
Micropterus salmoides	Largemouth Bass	10	0.04	26,168	99.75
Etheostoma sp.	Darter	9	0.03	26,177	99.79
Lepisoteus osseus	Longnose Gar	9	0.03	26,186	99.82
Micropterus sp	Black Bass	6	0.02	26,192	99.84
Ctenopharyngodon idella	Grass Carp	6	0.02	26,197	99.86
Ellasoma zonatum	Banded Pygmy Sunfish	5	0.02	26,202	99.88
Atherinidae	Silverside	4	0.02	26,206	99.9
Lepomis gulosus	Warmouth	4	0.02	26,210	99.91
Lythrurus sp.	Shiner	3	0.01	26,213	99.92
Pimephales vigilax	Bullhead Minnow	3	0.01	26,216	99.94
Aphredoderus sayanus	Pirate Perch	2	0.01	26,218	99.94
Carpiodes sp.	Redhorse	2	0.01	26,220	99.95
Fundulus sp.	Topminnow	2	0.01	26,222	99.96
Lepisoteus platostomus	Shortnose Gar	2	0.01	26,224	99.97
Lepomis miniatus	Redspotted Sunfish	2	0.01	26,226	99.97
Esox americanus	Grass Pickerel	1	0	26,228	99.98
Fundulus notatus	Blackstripe Topminnow	1	0	26,229	99.98
Fundulus chrysotus	Golden Topminnow	1	0	26,230	99.99
Ameiurus natalis	Yellow Bullhead	1	0	26,231	99.99
Lepomis macrochirus	Bluegill	1	0	26,232	100
Minytrema melanops	Spotted Sucker	1	0	26,233	100

Table 6. Number of larval and juvenile fish caught in light traps (n=number of traps) set in hypoxic (dissolved oxygen < 3.0 mg/l) and normoxic (dissolved oxygen =>3.0 mg/l) waters, Yazoo Study Area, 1990-2008. The mean number of individuals collected in hypoxic water was divided by the mean number of individuals collected in normoxic water to obtain the percent difference in total abundance of larval and juvenile fishes (0.6).

TYPE	n	Mean	Standard Deviation	Minimum	Maximum
Hypoxic	173	74	487	1	6,387
Normoxic	186	121	827	1	11,225

Table 7. Number of individuals by taxa collected with an electroshocking boat (n = 83, 5-minute samples) in the Big Sunflower-Steele Bayou drainage during 2003, 2009, 2015, and 2019. Taxa are arranged in order of abundance.

Taxa	Common Name	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Ictiobus sp.	Ictiobus sp.	439	20.65	439	20.65
Dorosoma cepedianum	Gizzard Shad	401	18.86	840	39.51
Dorosoma petenense	Threadfin Shad	285	13.41	1,125	52.92
Lepisosteus oculatus	Spotted Gar	118	5.55	1,243	58.47
Lepomis macrochirus	Bluegill	88	4.14	1,331	62.61
Ictiobus cyprinellus	Bigmouth Buffalo	76	3.57	1,407	66.18
Ictiobus bubalus	Smallmouth Buffalo	68	3.2	1,475	69.38
Lepomis megalotis	Longear Sunfish	54	2.54	1,529	71.92
Micropterus salmoides	Largemouth Bass	46	2.16	1,575	74.08
Lepomis gulosus	Warmouth	45	2.12	1,620	76.2
Lepisosteus platostomus	Shortnose Gar	44	2.07	1,664	78.27
Hypophthalmichthys molitrix	Silver Carp	38	1.79	1,702	80.06
Lepomis humilis	Orangespotted Sunfish	37	1.74	1,739	81.8
Cyprinella lutrensis	Red Shiner	34	1.6	1,773	83.4
Pomoxis sp.	Pomoxis sp.	34	1.6	1,807	85
Cyprinus carpio	Common Carp	32	1.51	1,839	86.5
Micropterus sp.	Micropterus sp.	32	1.51	1,871	88.01
Gambusia affinis	Mosquitofish	31	1.46	1,902	89.46
Cyprinella venusta	Blacktail Shiner	28	1.32	1,930	90.78
Lepomis cyanellus	Green Sunfish	25	1.18	1,955	91.96
Lepomis miniatus	Redspotted Sunfish	19	0.89	1,974	92.85
Aplodinotus grunniens	Freshwater Drum	17	0.8	1,991	93.65

Lepisosteus osseus	Longnose Gar	17	0.8	2,008	94.45
Notemigonus crysoleucas	Golden Shiner	16	0.75	2,024	95.2
Ictiobus niger	Black Buffalo	14	0.66	2,038	95.86
Notropis atherinoides	Emerald Shiner	14	0.66	2,052	96.52
Amia calva	Bowfin	12	0.56	2,064	97.08
Pomoxis annularis	White Crappie	11	0.52	2,075	97.6
Carpiodes carpio	River Carpsucker	9	0.42	2,084	98.02
Lepomis symmetricus	Bantam Sunfish	8	0.38	2,092	98.4
Morone chrysops	White Bass	7	0.33	2,099	98.73
Pomoxis nigromaculatus	Black Crappie	5	0.24	2,104	98.97
Lepisosteus sp.	Lepisosteus sp.	4	0.19	2,108	99.15
Ictalurus furcatus	Blue Catfish	3	0.14	2,111	99.29
Micropterus punctulatus	Spotted Bass	3	0.14	2,114	99.44
Ameiurus natalis	Yellow Bullhead	1	0.05	2,115	99.48
C.venusta X lutrensis	C.venusta X lutrensis	1	0.05	2,116	99.53
Ctenopharyngodon idella	Grass Carp	1	0.05	2,117	99.58
Fundulus chrysotus	Golden Topminnow	1	0.05	2,118	99.62
Fundulus notatus	Blackstripe Topminnow	1	0.05	2,119	99.67
Fundulus sp.	Topminnow	1	0.05	2,120	99.72
Lepomis marginatus	Dollar Sunfish	1	0.05	2,121	99.76
Lepomis microlophus	Redear Sunfish	1	0.05	2,122	99.81
Menidia beryllina	Inland Silverside	1	0.05	2,123	99.86
Morone saxatilis	Striped Bass	1	0.05	2,124	99.91
Polyodon spathula	Paddlefish	1	0.05	2,125	99.95
Pylodictis olivaris	Flathead Catfish	1	0.05	2,126	100

Part 3. Fish Species Status and Trends

Background

Five families of fish taxonomically dominate the ichthyofauna of the Mississippi Alluvial Valley (MAV): Cyprinidae (83 spp.), Percidae (46 spp.), Centrarchidae (22 spp.), Catostomidae (21 spp.), and Ictaluridae (19 spp.) (Cross et al. 1986). The Mississippi River Basin is a principal center of diversity of the North American fish fauna (Burr and Page 1986, Conner and Suttkus 1986, Robison 1986). Fish species share a common distribution throughout the alluvial valley, with current variation in occurrence and abundance due to river engineering and subsequent environmental conditions (Baker et al. 1991, Schramm et al. 2016).

Prior to European settlement, 10 million hectares of bottomland hardwood forests occurred in the MAV from Illinois down to the mouth of the Mississippi River (Schoenholtz et al. 2001). In 1820, Audubon was traveling downstream on the Mississippi River and recorded the following as he stopped at the mouth of the Yazoo River (Rhodes 2004): "a beautiful stream of transparent water, covered with thousands of geese and ducks and filled with fish." Many of the tributaries of the Lower Mississippi River during the time of Audubon were likely tannin-stained, blackwater streams with sandy and gravel substrates, perennial flows, and bordered by almost an endless bottomland hardwood forest. However, by the mid-1980s, all that remained of the valley's forested land was roughly 6.6 million acres (Oswalt 2013).

Today, most low-gradient streams in the MAV, including the Yazoo Basin, have soft, unconsolidated substrates of silt and mud, depressed hydrographs due to groundwater depletion and other forms of irrigation, and minimal forested riparian zones (Schoenholtz et al. 2001, Clark et al. 2011). Consequently, flood control and agricultural practices in this ecoregion have impaired physical habitat, water quality, and fish communities (Chen et al. 2016). This section evaluates long-term trends in the fish assemblage of the Big Sunflower – Steele Bayou drainage that includes the Yazoo Study Area as agricultural development peaked and flood control projects were completed in the latter part of the 20th century. The intent is to provide supporting documentation on the status of the aquatic environment as part of the Proposed Plan.

Objective

1. Compare diversity indices between the Big Sunflower – Steele Bayou drainage and reference sites in the lower MAV.
2. Evaluate multi-decadal trends in species abundance in the Big Sunflower – Steele Bayou drainage.

Approach

<u>Comparison Among Drainages</u>

Existing seining data were used to describe and compare fish communities among different drainage basins in the Lower Mississippi River Valley. The drainages represent a gradient in habitat impairment ranging from highly impacted to least disturbed (Stoddard et al. 2006).

Sampling occurred within the MAV in Stahler Stream Orders 4 - 7 (Figure 6). Localities occur in two different USEPA Level III Ecoregions (Mississippi Alluvial Plain and South Central Plains) but in a single biotic province, the Austroriparian Zone (Blair 1950; Hubbs 1957).
Drainages sampled were Big Sunflower and tributaries (i.e., Big Sunflower River, Quiver River, Bogue Phalia, and Steele Bayou); White River in Arkansas (i.e., river kilometers, rkm 314-443); Cache River in Arkansas within the Rex Hancock-Black Swamp Wildlife Management Area (i.e., rkm 87.4 – 117.8); Cypress Bayou system in East Texas (i.e., Little Cypress Bayou, Black Cypress Bayou, Big Cypress Bayou, and 12-Mile Bayou that flows into the Red River); and the Red River (i.e., rkm 370.3 – 436.4, between Shreveport, Louisiana and Arkansas State Line).
Sampling years and frequency varied by drainage, but all samples used in this analysis were collected during the summer and autumn (Julian Day range = 173 - 341). The Big Sunflower drainage represents chronic agricultural impacts to aquatic habitat: minimal riparian zone, deep, soft substrates, and intermittent flows. An exception was the Big Sunflower gravel bar reach sampled in 2014 - 2015; this site experiences perennial flow and is considered least disturbed in the Yazoo River Basin. Other drainages served as reference sites. The White and Red River drainages are surrounded by agriculture but have perennial flows with more stable substrates. The Cache River sites in the White River drainage are also heavily forested, but due to clay substrates and upstream irrigation, can revert to intermittent flows during the summer and fall. Cypress Bayou drainage in East Texas lies within the West Gulf Coastal Plain ecoregion, is a tributary of the Red River, and was sampled below Lake O' the Pines including Big Cypress Bayou, Little Cypress Bayou, and Black Cypress Bayou. Cypress Bayou represents a less disturbed drainage similar to intact bottomland hardwood ecosystems in the MAV with a heavily forested riparian zone, stable to soft substrates, and flows ranging from intermittent due to seven upstream water supply dams to perennial.

Fish were collected using a 3.0 meter by 2.5 meter, 50 millimeter mesh seine. Seining was conducted in water < 1.5 meters and a sample consisted of 10 hauls. Catch per unit effort (CPUE) was quantified by species as number/10 seine hauls or percentage of the total number collected. Fish metrics were selected to represent attributes of the assemblage that could be correlated to the principal stressors. Informative metrics describing taxonomic composition, tolerance of poor habitat and water quality, and affinity for flowing water were calculated from the individual samples and applied across a broad zoogeographic range in the MAV, which encompasses multiple ecoregions but with similar fish faunas. Taxonomic metrics included:

1. Percent darters, benthic and sight-predators characteristic of firm substrates, clear water, and flowing water;
2. Percent minnows (Cyprinidae), many of which are facultative or obligate rheophilic species;
3. Percent black bass (*Micropterus* spp.) indicative of forage availability and/or food web complexity;
4. Percent *Lepomis* sunfishes, a group of tolerant species ubiquitous in impaired delta streams, characterized three ways - Orangespotted Sunfish (*Lepomis humilus)*, juvenile *Lepomis* sp., and juvenile White Crappie (*Pomoxis annularis*);
5. Percent Mosquitofish *Gambusia affinis,* often numerically dominant in impaired delta streams.

Functional fish metrics were based on qualitative classifications of each species as "intolerant" (I) or "tolerant" (T) of degraded structural habitat (e.g., reduced coarse substrates, instream cover, shading), water quality (e.g., increased turbidity and temperature, reduced dissolved oxygen), and flow (e.g., slack water, reduced depth, as well as reduced depth and hydraulic variability). Tolerance designations of most species were based on a published consensus of experts (Jester et al. 1992). Species not addressed in that study were assigned tolerances based on regional Index of Biotic Integrity studies (Paller et al. 1996, Emery et al. 2003, Bramblett et al. 2005). A binary designation (I vs T) was used rather than an ordinal scale (intolerant, moderately intolerant, moderately tolerant, tolerant) for parsimony and clarity. Functional metrics included: percent habitat intolerant fish (i.e., sensitive to reductions in clean surfaces, crevices for spawning and cover for hiding), percent water quality intolerant fish (i.e., sensitive to hyperthermia, hypoxia, and suspended solids), and percent flow intolerant fish (i.e., rheophilic, sensitive to diminished base flows).

Assemblages were ordinated among drainages using non-metric multidimensional scaling on BrayCurtis similarity matrices of fourth-root transformed CPUE (Clarke and Gorley 2015). Fourth-root transformation increases the contribution of rare species and reduces the effect of dominant species so that natural disparities in species abundance are made more equitable (Goodsell and Connell 2002). Means of biotic metric values by drainage were statistically compared using MANOVA and the test statistic Wilks' Lambda to evaluate multivariate differences among drainages (Proc GLM, SAS Institute 2015). For this test, the combined dependent variables were compared among the different drainages, and if the model was significant ($p < 0.05$), further testing was conducted using univariate ANOVA. If a significant difference in individual metrics among drainages was detected from the ANOVA, mean values were compared using the Student–Newman–Keuls multiple range test (SAS Institute 2015). All biotic metric percentages were arcsine transformed prior to analyses.

Temporal Trend Analysis

Changes in species richness over time were evaluated for 21 sites in the Big Sunflower – Steele Bayou drainage (Table 8). Samples were collected between 1993 and 2014. Most sites were sampled repeatedly on a seasonal basis but not necessarily annually. Fish were sampled the same as previously described for the inter-basin comparison where a unit of effort was species abundance per 10 seine hauls. Rarefaction was used to determine species richness, which is a measure of the number of species "expected" in a sample of 100 (Clarke and Gorley 2015). Rarefaction is not as sensitive to sample size as raw species richness. A box plot was created of the annual rarefaction values in the drainage during this time period. Mean values of the four reference streams previously described were provided as a comparison to the Big Sunflower-Steele Bayou fish assemblage structure.

Results and Discussion

Comparison Among Drainages

A total of 84,697 fish representing 101 species and 20 families were collected with seines in 175 samples from 1990 to 2015 (Table 9). Our species list is comparable to zoogeographic accounts by Conner and Suttkus (1986) and Cross et al. (1986) in the Lower Mississippi River Valley who report five families that dominate the taxonomic diversity of the ichthyofaunal. Number of species for these families in our study were: Cyprinidae (33 spp.), Centrarchidae (15 spp.), Percidae (13 spp), Catostomidae (8 spp.), and Ictaluridae (8 spp.).

Cyprinidae was the dominant family in the White-Cache drainage with 21 species collected and 8 unique to the drainage. Darters consisted mainly of the *Etheostoma* complex and were more diverse in the White-Cache and Cypress drainages where *Percina* and *Ammocrypta* were also represented. Shovelnose Sturgeon (*Scaphirhynchus platorynchus)* and Chub Shiner (*Notropis potteri)* were collected only in the Red River. Bowfin (*Amia calva)* and American Eel (*Anguilla rostrata)* were collected only in the Big Sunflower-Steele Bayou drainage, although both of these species are widespread throughout the MAV.

Biotic metrics further illustrated faunal differences among drainages (Table 10). The Big Sunflower-Steele Bayou drainage had lower species richness and lower abundance of intolerant species. The Big Sunflower gravel bars were similar to the overall drainage except species richness was higher, considerably more minnows were present, and the assemblage was comprised of more habitat intolerant species. Metrics for the three reference drainages (Cypress Bayou, Red, and White/Cache) were relatively comparable among each other, with some exceptions, but values were statistically higher compared to the Big Sunflower-Steele Bayou drainage.

The Non-metric Multidimensional Scaling (NMDS) showed clear separation of the resemblance matrix of transformed species abundance values between the Big Sunflower-Steele Bayou drainage and reference sites (Figure 7). Stress values for the NMDS ordinations were less than 0.2 (2-D stress = 0.19, 3-D stress = 0.13) indicating good representation of the sample patterns across drainages. Stress measures how well the reduced number of dimensions in the NMDS ordination represents the original position of samples (and assemblage structure) in the complete multidimensional space. Stress values greater than 3.0 indicate poor representation. Stress increases with number of samples, number of variables, and potential outliers.

Biotic metrics followed a similar pattern as previously described. Tolerant species such as Mosquitofish, juvenile *Lepomis*, and Orangespotted Sunfish were dominant in the Big SunflowerSteele Bayou drainage. As forested habitat increased along Axis 1, darters, *Micropterus* bass, and other habitat intolerant species were more common in the Cypress Bayou drainage where woody structure was present with stable substrates. The White and Red drainages with higher discharge were ordinated along Axis 2 associated with greater numbers of rheophilic minnows and shiners.

Long-term impacts to the aquatic environment are typified by the Big Sunflower-Steele Bayou drainage where fish communities are impaired. The assemblage is usually dominated numerically by a few species (i.e., Orangespotted Sunfish, juvenile *Lepomis*, and Mosquitofish) and most fishes are considered “moderately tolerant” or “tolerant” of degraded water quality and habitat (Jester et al. 1992). Homogenization of fish assemblages in the Yazoo Study Area reflects long periods of low water, excessive sedimentation, and land-use alterations over the past century. Possible solutions to restore and mitigate aquatic habitat conditions is discussed in the following section.

Temporal Trend Analysis

This analysis focused on temporal trends of the fish assemblage in the Big Sunflower-Steele Bayou drainage. It included 212 collections of fish at the 21 sites shown in Table 8 sampled during 10 different years spanning a 21-year time period. All seasons were included in this analysis, rather than summer-autumn only in the previous interbasin comparison, resulting in a higher sample size. The majority of collections were made in the Big Sunflower (n = 175), followed by Quiver (n = 27), and Steele Bayou (n = 10). Sample frequency ranged from 4 in 2006 to 81 in 1993. Years with small samples sizes were retained in graphical analyses of the annual trends.

Species richness derived from rarefaction ranged from 4.0 - 21.0 with a mean (± 1 standard deviation) value of 10.9 ± 3.1. There was considerable interannual variation, but mean values and the range of most observations each year in the Big Sunflower-Steele Bayou drainage were less than reference drainages with improved flow and forested riparian buffers (Figure 8). The Cache River had the highest mean richness value (19.2 ± 7.3, n = 4), followed by the Red River (18.5 ± 2.7, n = 10), White River (16.2 ± 5.0, n = 9) and Cypress Bayou (14.8 ± 4.0, n = 26). Low species richness in the Big Sunflower drainage further supports the findings of degraded habitat conditions and impairment of the fish assemblage.

Major changes have not been observed in the Big Sunflower-Steele Bayou drainage fish assemblage since 1993. Previously, a pollution control study by Mississippi Game and Fish Commission documented fish assemblages occurring in 1971 – 1972 (Mississippi Game and Fish Commission 1972). Fish were collected using rotenone, but despite different sampling methodologies from the current approach, only two species (Cypress Minnow (*Hybognathus hayi),* Chain Pickerel, which was probably Redfin Pickerel (*Esox americanus)*) collected in 1971-1972 were not collected in the 1990-2000's collections. However, the abundance of rheophilic minnows and madtoms were substantially higher in the 1970's including Emerald Shiner, Tadpole Madtom, and Freckled Madtom. As with other collections, fish were numerically dominated by Gizzard Shad, bullheads, and several species of sunfish.

Both of the studies referenced in the previous paragraph indicate that the fish assemblage in the Big Sunflower-Steele drainage was already impacted by anthropogenic impacts prior to the 1970's. The Mississippi Board of Water Commissioners (1966) reported that irrigation withdrawals in the Yazoo Study Area were not appreciable prior to 1951 but steadily increased after that time affecting low flows in the streams. Furthermore, low-flow indices for the Big Sunflower, Hushpuckena, and Bogue Phalia show reductions in low-flow indices of 27 – 36% resulting from withdrawals for irrigation since 1951. By the 1970's, rheophilic and benthicoriented species were in decline due to low flows and excessive sedimentation, and by the 1990's, the fish assemblage was highly altered consisting of habitat-tolerant species. The combined loss of perennial flows, loss of trees along the streambanks, and accretion of sediments in the channel are identified as the primary stressors that could be addressed in restoration programs.

Table 8. ERDC seining sampling sites in the Big Sunflower-Steele Bayou drainage between 1993 and 2014 used to calculate annual diversity indices over a 21-year time period.	
Location/Site	Comments
Big Sunflower at Choctaw Bayou 32.86401°N; 090.80994°W	Sampling began in early 90's. Represents lower reach of Big Sunflower (below Lock and Dam)
Big Sunflower at Auter above HWY 14 33.04308°N; 090.70070°W	Sampling began in early 90's. Represents lower reach of Big Sunflower (below Lock and Dam)
Big Sunflower at mouth of Bogue Phalia (BGPHA MTH2) 33.25412°N; 090.72991°W	Sampling began in early 90's. Represents middle reach of Big Sunflower between the Lock and Dam and mouth of Quiver River
Big Sunflower below Brumfield Landing (Kinlock 3) 33.27681°N; 090.72366°W	Sampling began in early 90's. Represents middle reach of Big Sunflower between Lock and Dam and mouth of Quiver River
Big Sunflower at Brumfield Landing (Kinlock 2) 33.30694°N; 090.70505°W	Sampling began in early 90's. Represents middle reach of Big Sunflower between Lock and Dam and mouth of Quiver River
Big Sunflower above mouth of Quiver River 33.46959°N; 090.526824°W	Sampling began in early 90's. Represents upper reach of Big Sunflower between mouth of Quiver and Clarksdale
Big Sunflower east of Merigold (UPPR and Winery Rushing) 33.83261°N; 090.67196°W	Sampling began in early 90's. Represents upper reach of Big Sunflower between mouth of Quiver and Clarksdale
Big Sunflower south of Hopson 34.15674°N; 090.55031°W	Sampling began in early 90's. Represents upper reach of Big Sunflower between mouth of Quiver and Clarksdale
Bogue Phalia at the mouth 33.2432°N; 090.73046°W	Sampling began in early 90's. Represents lower reach of Bogue Phalia
Bogue Phalia at HWY448 33.60297°N; 090.85279°W	Sampling began in early 90's. Represents middle reach of Bogue (below cut-off)
Bogue Phalia at HWY 61 33.44744°N; 090.85888°W	Sampling began in early 90's. Represents upper reach of Bogue Phalia (above cut-off)
Quiver River 1.0 mi above mouth 33.47467°N; 090.55401°W	Sampling began in early 90's. Represents lower reach of Quiver River
Quiver River at Hwy 3 (including weir) 33.48892°N; 90.51881°W	Lower Reach
Quiver River at HWY 442 33.9413°N; 90.4639°W	Middle Reach
Quiver River at Hwy 32 33.9132°N; 90.4683°W	Upper Reach

Steele Bayou at Control Structure 32.46214°N; 090.89490°W	Downstream confluence of Steele and Big Sunflower river systems. Steele Bayou Restoration Monitoring
Steele Bayou at Hwy 1 32.55023°N; 90.57430°W	Middle Reach
Steele Bayou at Hwy 14 Weir 32.9072°N; 90.9531°W	Long-term sampling site, Middle Reach
Steele Bayou near Grace 32.9959 °N ; 90.9734°W	Weir Site
Steele Bayou at Yazoo NWR 33.074540°N; 90.961094°W	Upper Reach
Black Bayou at HWY 12 weir 33.157642°N; 90.924679°W	Weir at Leroy Percy State Park

Table 9. Mean catch per unit effort (CPUE; number/10 seine hauls) and grand total of fish species collected in streams, rivers, and bayous in the Mississippi Alluvial Plain and South Central Plain USEPA Level III ecoregions between 1990 to 2015 during summer and autumn. Metric classifications are Intolerant(I) or Tolerant (T) for habitat (HAB), water quality (WQ), and flow (FLOW) with IFLOW = yes and TFLOW = no. [1] Introduced species

Scientific Name	Common Name	Big Sunflower, n=119	Big Sunflower Gravel Bars, n=7	White/Cache n=13	Red, n=10	Cypress, n=26	Grand Total, n=175	Metric Classification
Scaphirhynchus platorynchus	Shovelnose Sturgeon				0.50		5	IHAB, IWQ, IFLOW
Lepisosteus oculatus	Spotted Gar	0.20	0.14	0.08	0.10		27	THAB, TWQ, TFLOW
Lepisosteus osseus	Longnose Gar	0.13			0.60		22	THAB, TWQ, IFLOW
Lepisosteus platostomus	Shortnose Gar	0.24			0.20		31	THAB, TWQ, TFLOW
Amia calva	Bowfin	0.01					1	THAB, TWQ, TFLOW
Hiodon alosoides	Goldeye			0.08			1	THAB, IWQ, IFLOW
Anguilla rostrata	American Eel	0.01					1	IHAB, IWQ, IFLOW
Alosa chrysochloris	Skipjack Herring				0.10		1	IHAB, IWQ, IFLOW
Dorosoma cepedianum	Gizzard Shad	20.08		2.54	15.70	0.12	2,583	THAB, TWQ, TFLOW
Dorosoma petenense	Threadfin Shad	3.85		0.15	13.10	9.65	842	IHAB, TWQ, IFLOW
Esox americanus	Redfin Pickerel			0.15		0.27	9	IHAB, IWQ, TFLOW
Campostoma anomalum	Central Stoneroller			0.15			2	IHAB, IWQ, IFLOW
Cyprinella galactura	Whitetail Shiner			0.08			1	IHAB, IWQ, IFLOW

Cyprinella lutrensis	Red Shiner	14.87	16.14		307.00	0.62	4,969	THAB, TWQ, IFLOW
Cyprinella venusta	Blacktail Shiner	134.16	185.71	121.31	3.10	6.19	19,034	THAB, TWQ, IFLOW
Cyprinella whipplei	Steelcolor Shiner			0.08			1	IHAB, IWQ, IFLOW
Cyprinus carpio	Common Carp[I]	1.06		0.15	0.10	0.04	130	THAB, TWQ, TFLOW
Erimystax x-punctatus	Gravel Chub			0.62			8	IHAB, IWQ, IFLOW
Hybognathus hayi	Cypress Minnow					0.04	1	IHAB, IWQ, IFLOW
Hybognathus nuchalis	Mississippi Silvery Minnow			41.46	0.20	0.04	542	IHAB, IWQ, IFLOW
Hybopsis amblops	Bigeye Chub			5.54			72	IHAB, IWQ, IFLOW
Hybopsis amnis	Pallid Shiner			2.08		0.73	46	IHAB, IWQ, IFLOW
Luxilus chrysocephalus	Striped Shiner					0.12	3	IHAB, IWQ, IFLOW
Luxilus pilsbryi	Duskystripe Shiner			0.23			3	IHAB, IWQ, IFLOW
Lythrurus fumeus	Ribbon Shiner			8.38		11.19	400	IHAB, IWQ, IFLOW
Lythrurus umbratilis	Redfin Shiner		0.14			1.23	33	IHAB, IWQ, IFLOW
Macrhybopsis hyostoma	Shoal Chub	23.45	138.14	0.62	15.40		3,920	IHAB, IWQ, IFLOW
Macrhybopsis storeriana	Silver Chub	0.01			2.40		25	IHAB, IWQ, IFLOW
Notemigonus crysoleucas	Golden Shiner	0.77	0.14	0.62		0.12	104	THAB, TWQ, TFLOW
Notropis atherinoides	Emerald Shiner	5.03	10.43	6.62	137.60		2,134	THAB, TWQ, IFLOW
Notropis buchanani	Ghost Shiner	38.57	5.14		4.30		4,669	THAB, TWQ, IFLOW

Notropis chalybaeus	Ironcolor Shiner					3.54	92	IHAB, IWQ, TFLOW
Notropis maculatus	Taillight Shiner			0.46		0.08	8	IHAB, IWQ, TFLOW
Notropis nubilus	Ozark Minnow			0.08			1	IHAB, IWQ, IFLOW
Notropis potteri	Chub Shiner				77.30		773	IHAB, IWQ, IFLOW
Notropis rubellus	Rosyface Shiner			0.62			8	IHAB, IWQ, IFLOW
Notropis sabinae	Sabine Shiner			1.54			20	IHAB, IWQ, IFLOW
Notropis shumardi	Silverband Shiner				34.50		345	IHAB, IWQ, IFLOW
Notropis telescopus	Telescope Shiner			5.00			65	IHAB, IWQ, IFLOW
Notropis texanus	Weed Shiner			9.77		12.85	461	IHAB, IWQ, TFLOW
Notropis volucellus	Mimic Shiner	0.58		38.92			575	IHAB, IWQ, TFLOW
Opsopoeodus emiliae	Pugnose Minnow	0.07		11.62	0.40		163	IHAB, IWQ, TFLOW
Pimephales notatus	Bluntnose Minnow					2.19	57	THAB, TWQ, TFLOW
Pimephales vigilax	Bullhead Minnow	14.49	94.00		306.70	5.62	5,595	THAB, TWQ, TFLOW
Carpiodes carpio	River Carpsucker			0.08	2.50		26	IHAB, IWQ, IFLOW
Cycleptus elongatus	Blue Sucker				1.60		16	IHAB, IWQ, IFLOW
Hypentelium nigricans	Northern Hogsucker			0.15			2	IHAB, IWQ, IFLOW
Ictiobus bubalus	Smallmouth Buffalo	0.61		0.08			80	THAB, TWQ, IFLOW
Ictiobus cyprinellus	Bigmouth Buffalo	0.20		0.31	0.10		29	THAB, TWQ, IFLOW

Ictiobus niger	Black Buffalo	0.04		0.15			7	THAB, TWQ, IFLOW
Minytrema melanops	Spotted Sucker					0.50	13	IHAB, IWQ, IFLOW
Moxostoma erythrurum	Golden Redhorse			3.23			42	IHAB, IWQ, IFLOW
Ameiurus melas	Black Bullhead	0.03					3	THAB, TWQ, TFLOW
Ameiurus natalis	Yellow Bullhead	0.18				0.04	22	THAB, TWQ, TFLOW
Ictalurus furcatus	Blue Catfish	1.00		0.31	4.90		172	THAB, TWQ, IFLOW
Ictalurus punctatus	Channel Catfish	5.44	4.29	3.00	4.30	0.08	761	THAB, TWQ, IFLOW
Noturus eleutherus	Mountain Madtom			0.46			6	IHAB, IWQ, IFLOW
Noturus gyrinus	Tadpole Madtom	0.46		0.08		0.62	72	IHAB, IWQ, TFLOW
Noturus nocturnus	Freckled Madtom	0.22	6.71			0.08	75	IHAB, IWQ, TFLOW
Pylodictus olivaris	Flathead Catfish	0.28	0.57		0.30	0.08	42	THAB, TWQ, IFLOW
Aphredoderus sayanus	Pirate Perch	0.06		0.85		0.38	28	IHAB, IWQ, TFLOW
Fundulus blairae	Western Starhead Topminnow					1.15	30	THAB, IWQ, TFLOW
Fundulus chrysotus	Golden Topminnow	0.24				0.23	34	THAB, IWQ, TFLOW
Fundulus notatus	Blackstripe Topminnow			0.08		9.04	236	THAB, IWQ, TFLOW
Fundulus olivaceus	Blackspotted Topminnow			2.00			26	THAB, IWQ, IFLOW
Gambusia affinis	Mosquitofish	165.95	116.29	11.15	0.70	25.69	21,382	THAB, TWQ, TFLOW
Labidesthes sicculus	Brook Silverside	0.23		18.77	0.80	40.31	1,327	IHAB, IWQ, IFLOW

Menidia audens	Inland Silverside	1.63			13.90	5.58	478	IHAB, IWQ, IFLOW
Morone chrysops	White Bass	0.03			0.80		11	THAB, TWQ, IFLOW
Morone mississippiensis	Yellow Bass				0.10		1	IHAB, IWQ, IFLOW
Elassoma zonatum	Banded Pygmy Sunfish	0.07		0.15		0.15	14	IHAB, IWQ, TFLOW
Centrarchus macropterus	Flier	0.02		0.08			3	IHAB, IWQ, TFLOW
Lepomis cyanellus	Green Sunfish	3.18	1.86	0.38		0.04	397	IHAB, IWQ, IFLOW
Lepomis gulosus	Warmouth	3.61		0.46		0.54	450	THAB, TWQ, TFLOW
Lepomis humilis	Orangespotted Sunfish	39.17	0.43	0.69	6.20	0.04	4,736	THAB, TWQ, TFLOW
Lepomis macrochirus	Bluegill	29.20	0.43	4.92	3.80	9.96	3,839	THAB, TWQ, TFLOW
Lepomis marginatus	Dollar Sunfish	0.58		2.00	0.30	2.62	166	THAB, IWQ, TFLOW
Lepomis megalotis	Longear Sunfish	2.10		2.00	3.20	8.35	525	IHAB, IWQ, IFLOW
Lepomis microlophus	Redear Sunfish	0.02		0.15	0.30	3.73	104	THAB, TWQ, TFLOW
Lepomis miniatus	Redspotted Sunfish	0.40	2.14	1.15	0.30	2.23	139	THAB, IWQ, TFLOW
Lepomis symmetricus	Bantam Sunfish	0.50		0.23		0.31	71	IHAB, IWQ, TFLOW
Micropterus dolomieu	Smallmouth Bass			0.08			1	IHAB, IWQ, IFLOW
Micropterus punctulatus	Spotted Bass			1.38	0.10	0.58	34	IHAB, IWQ, IFLOW
Micropterus salmoides	Largemouth Bass	0.06		0.62	1.30	2.62	96	IHAB, TWQ, TFLOW
Pomoxis annularis	White Crappie	5.40	0.43	0.08	0.20	0.04	650	THAB, TWQ, TFLOW

Pomoxis nigromaculatus	Black Crappie	0.14			0.30	0.23	26	THAB, TWQ, TFLOW
Ammocrypto clara	Western Sand Darter			2.31			30	IHAB, IWQ, IFLOW
Ammocrypta vivax	Scaly Sand Darter			0.15		0.85	24	IHAB, IWQ, IFLOW
Crystallaria asprella	Crystal Darter			0.54			7	IHAB, IWQ, IFLOW
Etheostoma asprigene	Mud Darter			0.77		0.58	25	IHAB, IWQ, IFLOW
Etheostoma caeruleum	Rainbow Darter			0.15			2	IHAB, IWQ, IFLOW
Etheostoma chlorosoma	Bluntnose Darter	0.30		2.46		1.96	119	IHAB, IWQ, IFLOW
Etheostoma gracile	Slough Darter	0.03		0.23	0.10	0.23	13	IHAB, IWQ, IFLOW
Etheostoma histrio	Harlequin Darter	0.06		0.00		0.54	21	IHAB, IWQ, IFLOW
Etheostoma proeliare	Cypress Darter	0.30		0.00		2.92	112	IHAB, IWQ, IFLOW
Etheostoma stigmaeum	Speckled Darter	0.02		0.00			2	IHAB, IWQ, IFLOW
Percina caprodes	Logperch			0.00	0.10	1.58	42	IHAB, IWQ, IFLOW
Percina maculata	Blackside Darter			0.00		0.92	24	IHAB, IWQ, IFLOW
Percina sciera	Dusky Darter			0.00	0.10	0.31	9	IHAB, IWQ, IFLOW
Aplodinotus grunniens	Freshwater Drum	2.16		0.62	2.00		285	THAB, TWQ, IFLOW
Oreochromis niloticus	Nile Tilapia[I]		3.86	0.00			27	THAB, TWQ, TFLOW
Total number of species		54	19	65	45	54	101	
Total number of individuals		62,058	4,109	4,176	9,682	4,672	84,697	

Table 10. Un –transformed mean (standard deviation) and minimum-maximum values of biotic metrics by drainage basin. Mean metric values with different superscript letters along the row are significantly different ($p < 0.05$) among drainage basins according to the Student–Newman–Keuls multiple range test. Data was arcsine transformed prior to ANOVA.

Metric	Big Sunflower n=119	Big Sunflower Gravel Bars n=7	Cypress Bayou n=26	Red n=10	White n=13
Percent Minnows	0.33 (0.29)[a] 0-0.95	0.8 (0.21)[b] 0.35-0.95	0.32 (0.23)[a] 0-0.76	0.85 (0.14)[b] 0.5-0.98	0.71 (0.29)[b] 0.06-0.99
Percent *Lepomis*	0.23 (0.24)[a] 0-0.89	(0.01)[b] 0-0.02	0.19 (0.16)[a] 0.02-0.51	0.01 (0.02)[b] 0-0.05	(0.05)[b] 0-0.15
Percent *Micropterus*	0a 0-0.01	0a 0	(0.02)[b] 0-0.09	0 (0.01)[b] 0-0.04	(0.01)[b] 0-0.05
Percent Darters	0 (0.01)[a] 0-0.06	0 (0)[a]	0.06 (0.05)[b] 0-0.24	0 (0)[a]	0.06 (0.09)[b] 0-0.32
Percent Orangespotted Sunfish	0.11 (0.15)[a] 0-0.8	0 (0)[b] 0-0.01	0 (0)[b]	0 (0.01)[b] 0-0.03	0 (0)[b] 0-0.01
Percent Habitat Intolerant	0.01 (0.06)[a] 0-0.65	0.22 (0.09)[b] 0.1-0.36	0.17 (0.17)[b] 0-0.58	0.10 (0.08)[c] 0-0.28	0.2 (0.15)[b] 0-0.49
Percent Water Quality Intolerant	0 (0)[a]	0 (0)[a]	0.04 (0.08)[b] 0-0.26	0.09 (0.08)[c] 0-0.28	0.05 (0.06)[b] 0-0.24
Percent Rheophilic	0.35 (0.27)[a] 0-0.95	0.65 (0.2)[b] 0.32-0.93	0.44 (0.17)[a] 0.11-0.86	0.66 (0.21)[b] 0.38-0.91	0.57 (0.22)[b] 0.07-0.83

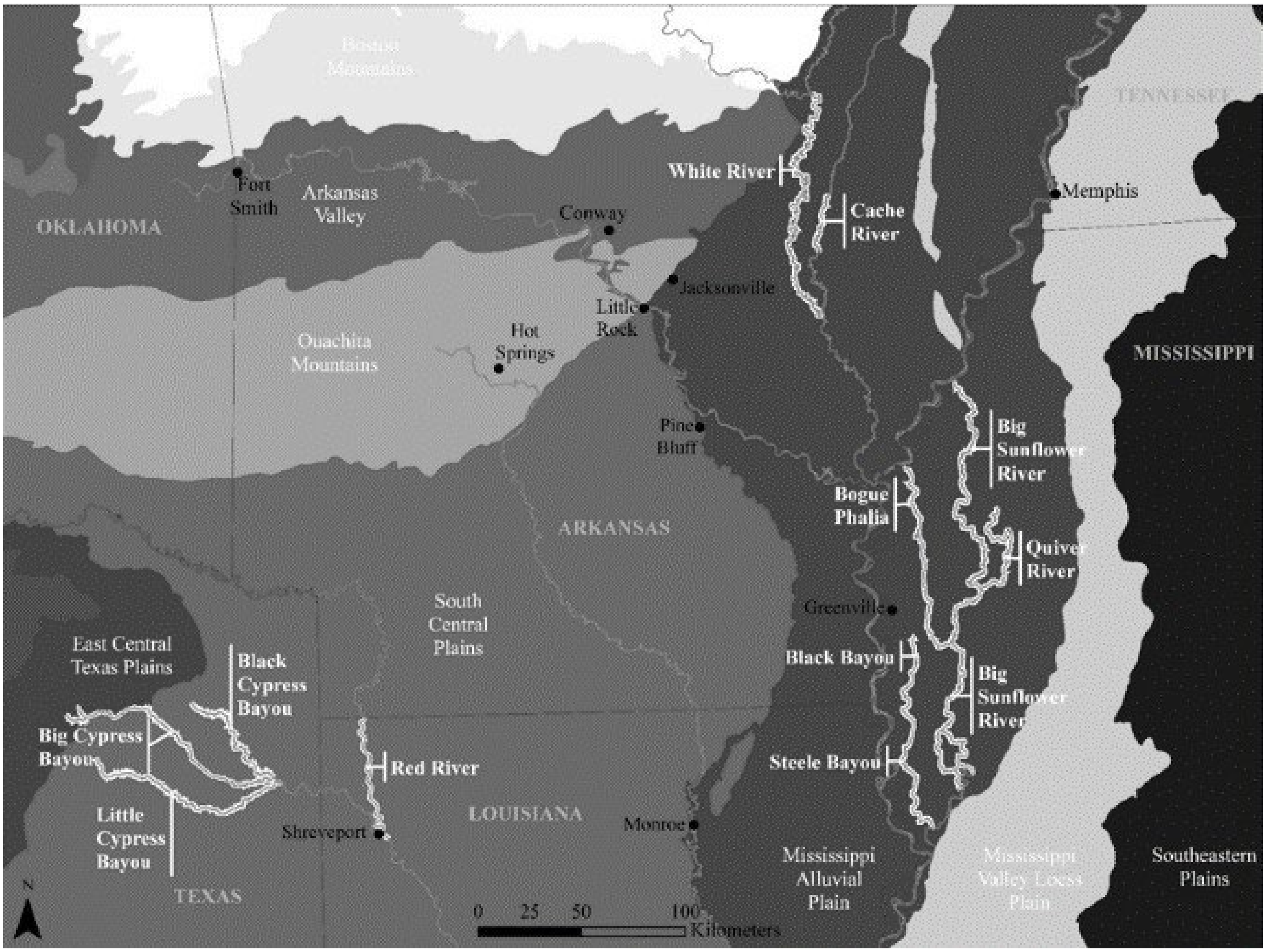


Figure 6. Sampling locations in the Mississippi River Alluvial Plain and South Central Plains USEPA Ecoregions.

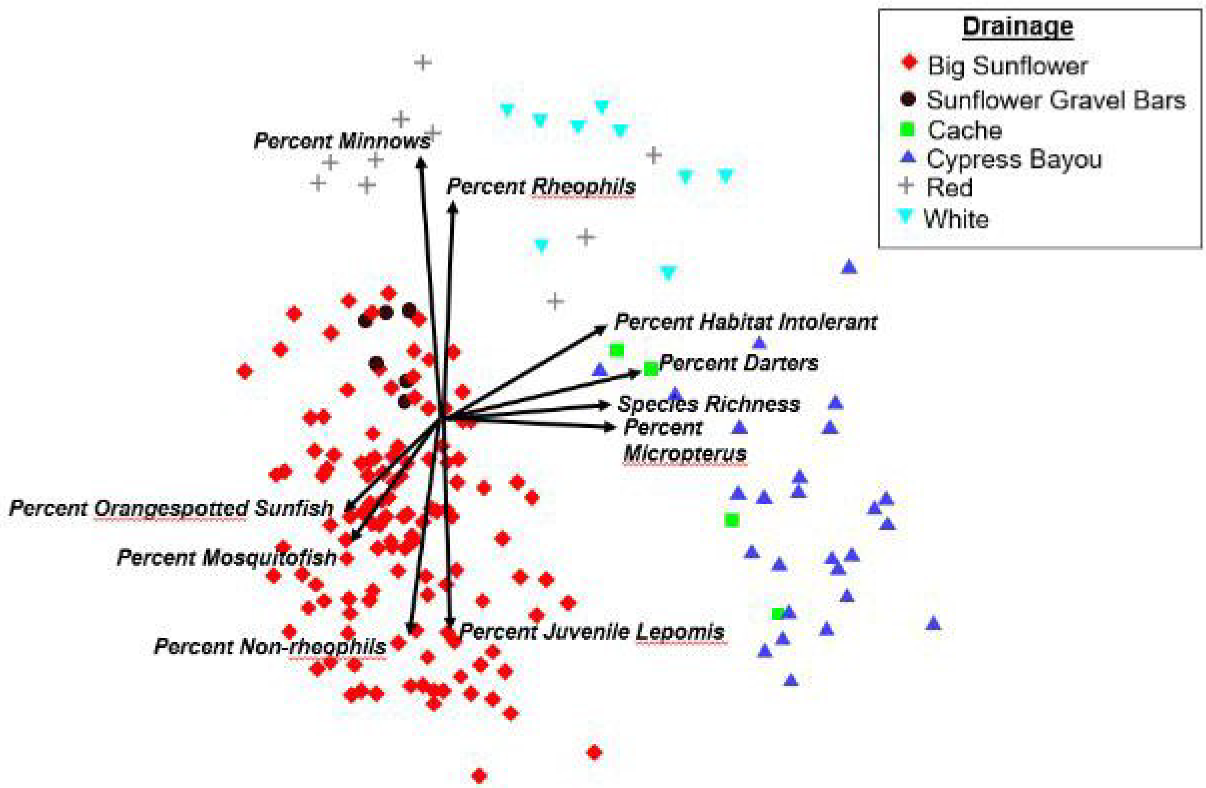


Figure 7. Nonmetric multidimensional scaling (NMDS) ordinations of species abundance for delta streams in the Mississippi Alluvial Prairie and South Central Plains Level III Ecoregions. Vectors on the NMDS plot identify the direction of correlation with biotic metrics, and vector length identifies the relative strength of the correlations; only variables with Spearman correlation ≥ 0.4 are shown.

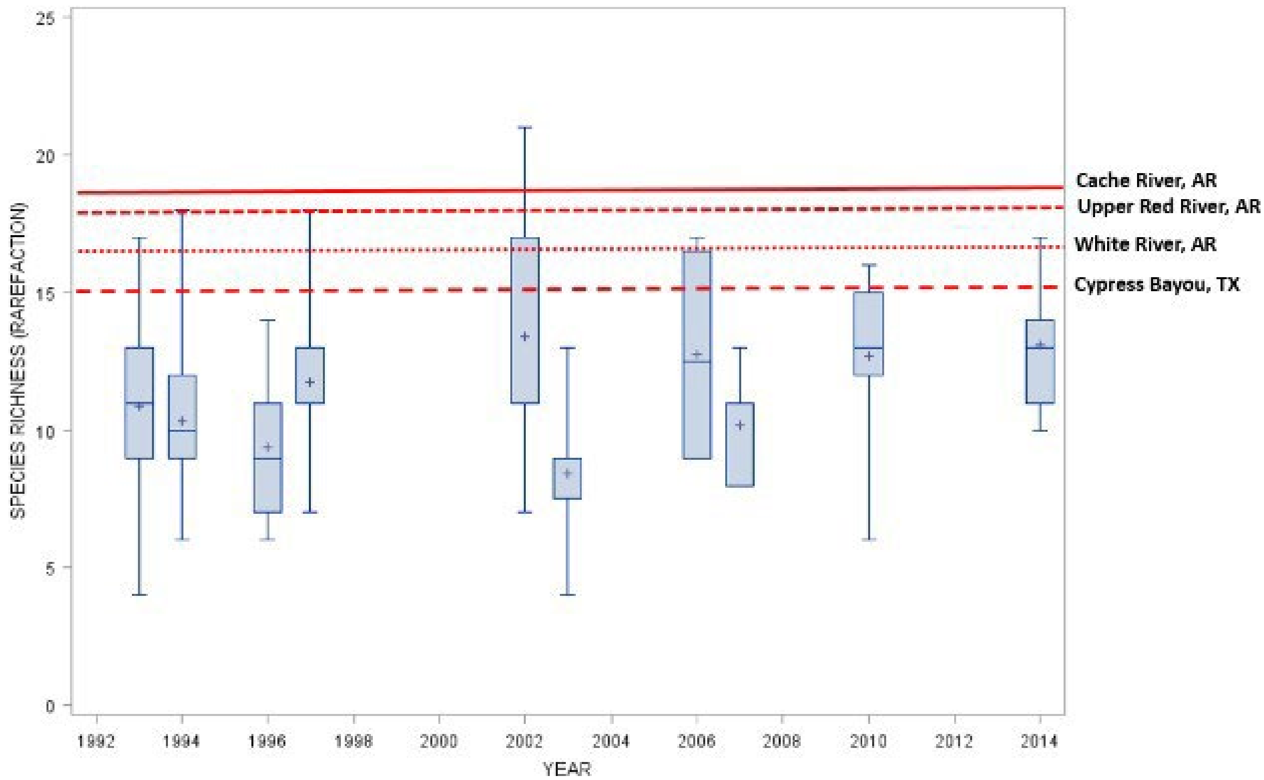


Figure 8. Box and whisker plot of species richness determined by rarefaction from 1992 to 2014 for the Big Sunflower – Steele Bayou drainage. Mean species richness by rarefaction for reference drainages are shown by red lines.

Part 4: Alternative Mitigation

Background

Cost-effective remediation of hypoxia in the Yazoo Study Area will require better understanding of autotrophic and heterotrophic processes that control dissolved oxygen and the relationship of these processes to discharge (Shields and Knight 2011). Considerations should be made to evaluate alternatives that reduce the magnitude and duration of hypoxia during floods. Recent data suggest that even slight increases in dissolved oxygen (> 2.0 mg/l) could lead to higher survival of many species after the flood recedes.

Reforestation of the 2-year floodplain in the Yazoo Study Area has been an ongoing conservations program and is the primary mitigation method to compensate for spawning and rearing impacts of the Proposed Plan. However, periodic hypoxia during spring and summer floods indicate that reforestation efforts may provide limited benefits to spawning and rearing fishes. Adult fishes spawning during a flood event must cope with the physiological stress of low dissolved oxygen; and once eggs hatch, larval fishes moving into deeper water encounter hypoxic conditions that likely lead to higher mortality. In addition, reforestation does not address all primary stressors to the Big Sunflower-Steele Bayou drainage including the Yazoo Study Area. Reduction of surface flows and abundance of fine sediments are not addressed. These stressors severely limit aquatic habitat and reduce spawning and foraging opportunities.

A conceptual model was developed for restoration opportunities in the Lower Mississippi Alluvial Valley that included data in the Yazoo River Basin (Killgore et al. 2024). The model distinguished three types of conservation actions relevant to large agricultural floodplains: reforestation of large parcels and riparian zone conservation, in-channel interventions and connectivity preservation, and flow augmentation (Figure 9). These types of conservation actions can bring improved water properties to impacted reaches, higher reach biodiversity, more intolerant species, and more rheophilic fishes. For the Yazoo Backwater Project, there is an opportunity to consider both in-kind mitigation by reforesting the floodplain, and alternative mitigation by establishment of environmental flows and other measures to offset impacts of the selected alternatives.

Objective

The objective of this section is to evaluate and discuss alternative methods of mitigation and describe the benefits of environmental flow establishment.

Approach

Land use alterations in the Big Sunflower-Steele Bayou drainage are pressed environmental disturbances culminating over a century resulting in stream degradation. The loss of forested riparian corridors, fine sediment accumulation in the channels, and reduction of surface flows are the principal or primary stressors to aquatic life in low-gradient warm water streams (Wang et al. 1997; Wood and Armitage 1997). These stressors influence other parameters (e.g., nutrients, dissolved oxygen) in a hierarchical organization of environmental influences that determine fish composition (Dembkowski and Miranda 2012). Management of land use disturbances, or the principal environmental variables impacting fish communities, can reverse or possibly restore stream habitat condition and recovery of the fish community.

Mitigation measures that could potentially benefit recovery of the fish community are discussed. The approach is to consider the life cycle of fishes and associated anthropogenic impairments to each life stage. Flood-induced hypoxia during the spring and early summer likely impacts successful spawning and rearing regardless of reforestation. The juvenile and adult life stages that do survive through the flood season are faced with extreme low flows during the fall. Therefore, improving low flows may compensate for impacts of hypoxia during the spring using both in-kind and out-of-kind mitigation.

Results and Discussion

Flow augmentation, or creation of environmental flows (E-flows), from the proposed 34 supplemental low flow groundwater wells in the tributaries of the Big Sunflower – Steele drainage will restore perennial flow and shall consider at least three criteria:

1. Provide adequate water to avoid desiccation of established mussel beds. Mussels are widespread and abundant in the Big Sunflower-Steele Bayou drainage and include regional and federally protected species (Jones et al. 2005). Empirical relationships between river stage and wetted perimeter of mussel beds can establish minimum discharge requirements. Additional analysis of E-flow benefits to mussels are discussed below under "Mussel Recruitment."
2. Ensure periodic fish passage flows over weirs for spawning movements and recolonization. The old Lock and Dam on the Big Sunflower River and other weirs in the drainage can be impediments to upstream/downstream movements of fish during low water. Environmental flows should consider the minimum water depth over the weir crest for passage of target species. Additional analysis of fish passage, including a telemetry study that monitored fish passage over a weir, is discussed below under "Fish Passage."
3. Manage hydraulic connectivity between the river channel and low-elevation backwaters or tributary mouths. Slight increases in discharge can potentially re-connect large areas of backwaters otherwise isolated during non-flowing conditions.

Abstraction of water has caused formerly perennial rivers to become intermittent, and this trend is expected to increase due to climatic drying and water appropriation (Thibault et al. 2014). The Big Sunflower River is a key example of a once perennial stream that now does not flow in the fall due to groundwater depletion. Prior to the 1980's, low flow discharge of the Big Sunflower River at Sunflower, Mississippi was approximately 100 cubic feet per second (cfs) (Figure 10, 10% frequency). By the 1990's into the 2000's, low flow fall discharge was less than 20 cfs and lower reaches of the Big Sunflower River usually cease flowing (see Engineering Appendix for more information on low flows).

Thirty-four supplemental low flow groundwater wells placed primarily along Highway 1 extending from near Clarksdale (Coahoma County) south to Arcola (Washington County) are proposed to augment stream flows in multiple systems within the Yazoo Study Area. Three reaches in the Big Sunflower were established to reflect benefits of low flows to endangered mussels (i.e., Rabbitsfoot and Sheepnose) that occur in the upper reach between Clarksdale and Indianola. Eleven wells in Harris Bayou and Hushpuckena River watersheds would supplement low flows in this upper reach. Eleven wells in the Bogue Phalia Basin watershed would augment flows in the middle Big Sunflower River from Indianola down to the Little Callao gage near the Old Lock and Dam. Established mussel beds occur in this reach, particularly below the Old Lock and Dam, although the two endangered species have not been collected in this reach. Five wells in the Deer Creek watershed would augment flows in the lower Big Sunflower reach between the Steele Bayou structure and the Old Lock and Dam through Rolling Fork Creek. In addition, five wells in Main Canal and two in upper Black Bayou (Fish Lake Bayou) will augment flows in the Steele Bayou watershed.

The wells would only be operated during the fall low flow period after irrigation return flows cease. However, considerations can be made to maintain environmental flows during the entire year. Irrigation return flows from the agricultural fields maintain summer low flows in most of the stream channels. Minimum flow targets will be established for downstream locations based on the number of wells operated will vary so that the target flows are met. The minimum flows will be established through the Monitoring and Adaptive Management Program for this project. The wells will be located in areas near the Mississippi River levee to minimize possible impacts to the alluvial aquifer. The groundwater elevation will be monitored at all sites to evaluate the impact of well usage to the aquifer. All wells will be located outside of the current cone of depression in the groundwater table. Three scenarios were developed as illustrative examples of benefits to aquatic systems gained by the implementation of supplemental flows.

Instream habitat - To assess the potential for improvements to instream aquatic habitats as the result of supplemental flows, stage and discharge data were evaluated at the USGS gage (7288280) on the Big Sunflower River near Merigold, Mississippi (Sunflower County). The gage is located within the upper reach between Indianola-Clarksdale that contain the only extant populations of federally listed Sheepnose and Rabbitsfoot mussels in the Yazoo Basin. Mean daily values for both water surface elevation (feet) and discharge (cfs) were compiled for the period of record for the gage (discharge: 1 October 1992 - 12 August 2020; stage: 5 March 1993 - 12 August 2020). Values for the two parameters were plotted against each other and using a best fit line approach, a 3rd order polynomial curve was fit to the data ($R^2 = 0.9936$) (Figure 11). Equation 1 was used to predict stage for a given discharge value.

Equation 1. $y = 2E\text{-}11x3 - 6E\text{-}07x2 + 0.0069x + 4.1112$

A predicted stage at Merigold was calculated for a range of discharge values (0 - 150 cfs) based on the estimated discharge proposed for the supplemental low flow groundwater wells (Table 11). Examination of the data indicates an increase of 25 cfs at the Merigold gage would correspond to an increase in 2.08 inches in stage height beyond the baseline conditions. Similarly, a 50 cfs supplemental flow would result in a 4.17 inch increase in stage. Supplemental flows during low flow conditions, particularly August – October (Figure 12), would improve stream conditions during this critical period, likely resulting in improved water quality in the affected streams. Even slight increases in stage would provide an increase in wetted perimeter resulting in an increase in available habitat for aquatic species such as fishes, mussels, and macroinvertebrates. Mussel species would experience reduced mortality associated with elevated water temperature during low water conditions. Improvement in water quality and macroinvertebrate production may improve the condition factor of fishes resulting in increases in survivorship during the following winter and spring periods. This improved health would transfer to the spring spawning period and positively benefit annual recruitment cycles. In addition, one would likely see increases in overall abundance and richness at most sites, particularly with the fishes.

Fish passage - Declining alluvial aquifer levels in the Mississippi Delta in combination with reduced base level stream flows have been the subject of much debate among agricultural, commercial, environmental, and residential interests (McKee 2011). These concerns have prompted discussions regarding interbasin transfer of water as a possible approach to supplement base level stream flows and improve aquifer recharge capabilities. There have also been discussions on the amount of water that is needed to maintain biotic sustainability of the associated stream fauna (i.e., environmental flows), the need for weirs to pool water at different locations within the watershed to accommodate flood risk management concerns (Bednarek 2001) and assuring sources for surface water withdrawal (Acreman and Dunbar 2004). Pooling water through construction of weirs or other features has the potential to impact fish movement within these systems, especially given the current number of weirs already in place, this impact could be offset by supplemental flows.

Slack et al. 2024 (in Press) conducted a telemetry-based project to evaluate fish passage over a weir in a Mississippi Delta stream. The target species for the study, buffalo fish (Catostomidae: *Ictiobus* sp.), is a large, migratory species well known for its migratory behavior within streams and rivers in the MAV for spawning, rearing and feeding purposes (Swingle 1957, Johnson 1963, Wrenn 1969, Moen 1974). These data evaluated the weir as a barrier to fish passage with respect to frequency and timing of passage events (movement windows) in relation to ambient environmental factors (e.g., temperature) and river conditions (e.g., stage). This work was critical given the pervasive nature of weir and instream structure placement in low gradient streams within the region for channel maintenance and water supply purposes (Shields et al. 1998, Killgore et al. 2008, Shields et al. 2013).

Fish passage in the study area was observed during periods of elevated stage and varied with upstream and downstream direction. In all cases but one, passage events occurred when stage exceed 97.24 feet. The crest elevation of the weir in the study area was 96 feet. The most extensive period for passage was during the spring when water temperature ranged 11.6 - 21.4 C (Mean = 16.6) and was likely an indication of pre-spawning migration behavior.

The probability of passage is increased during periods of elevated river stage. A compilation of historic stage data for the gage station located in the Yazoo Study Area (USACE gage at Highway 12) indicates a distinct seasonal pattern of probable fish passage events (Figure 13).
May - November is the period with the greatest percentage of days when water stage elevation ≤ weir crest height thus representing the period when passage probability is low (Mean = 18.1% of days, range = 10.7 - 30.0). In contrast, December - April represents the period when the probability of passage is higher given the lower percentage of days ≤ weir crest height (Mean = 2.0% of days, range = 0 - 2.7) thus providing a larger proportion of days where stage exceeds weir crest height.

Supplemental flows within this region during critical periods of low flow could improve the probability of fish passage events by increasing the number of days when weir crest height is exceeded (Figure 14). Incremental increases in stage causes a general shifting of the cumulative frequency curve to the right with the curve of each respective stage interval (e.g., 3, 6, 9, 12 inches) encompassing a larger percentage of days with weir crest exceedance.

Weirs will continue to be an important part of channel stabilization and maintenance in agricultural landscapes. They are also becoming an important element in restoration and water supply. Incorporating supplemental flows into these operations is beneficial to support fish passage, particularly in smaller streams, and can directly affect fisheries resources by improving dispersal capabilities for many species. In addition, improved fish passage benefits mussels. Infected mussel host fish could access new areas of suitable habitat for mussel colonization (population expansion) or provide additional fish hosts access to current mussel habitat during the glochidia release period thereby increasing probability of infestation.

Fish Habitat Units- Re-establishing perennial flows with the supplemental low flow groundwater wells may offset high mortality of larvae and juvenile fish in the spring from hypoxia with higher rates of survival of juveniles and adults during autumn. This approach addresses the overall aquatic community during all life stages.

Changes in fish biotic metrics were evaluated between seining samples collected with and without flow in seven different drainages (Table 12). Two metrics were significantly different (ANOVA, $p < 0.001$) between the two flow scenarios. Percent abundance of rheophlic (flow-oriented) fishes increased 40% with flow while percent abundance of minnows and shiners increased 60% (Table 12).

Wetted acres of streams and rivers were determined to quantify spatial extent of the environmental flows. Average width of the primary waterbodies was determined from cross sections taken during seining samples (Table 13). Stream length was provided by MVK and acres were calculated (Table 13). A total of 9,321 acres of streams would be influenced by supplementation of environmental flows. Mean percent abundance of minnows and shiners for non-flowing and flowing scenarios (Table 12) were applied as HSI scores and multiplied by acres to obtain AAHUs (Table 14). Average Annual Habitat Units increased 40% with flows, further justifying benefits of supplemental flows.

Mussel recruitment- The freshwater mussel fauna of Mississippi is quite diverse and includes 83 described species (Jones et al. 2019) ranking fifth within the nation in terms of total diversity (Jones et al. 2005). The Yazoo drainage ranks second in the state in terms of richness (n = 44) (Jones et al. 2019) and contains 18 Species of Greatest Conservation Need (MMNS 2015) including three federally listed species (Fat Pocketbook, Rabbitsfoot, and Sheepnose).

Suitable water conditions are critical to freshwater mussel survival and health, and the group is strongly reliant on natural flow regimes (Strayer 2008, Haag 2012). Habitat and stream flow alterations can have significant impacts on native species and have been the primary cause for decline in many species (Bogan 1993, Haag and Williams 2014). Freshwater mussels require a fish host to complete the reproductive process as glochidia are released from the female mussel and encyst on the host fish. This strategy evolved as a dispersal mechanism for sessile benthic organisms with limited mobility. Mussels also possess substantial life history diversity with the development of unique reproductive strategies to improve fish host infection rates. In addition, species differ in the timing of reproductive specific milestone, but can generally be considered either short or long-term brooders. For short-term brooders, the activities associated with spawning, glochidia brooding and release occur within a single season compared to long-term brooders in which glochidia are typically brooded over winter following the spawning event and released the following year (Cummings and Graf 2015, Landis and Stoeckel 2016; Figure 15).

Thus, sufficient flow conditions during these critical phases is extremely important to promote mussel recruitment.

Within the Yazoo drainage, 67% (n = 31) of mussels exhibit a long-term reproductive strategy (bradytictic) which includes the Fat Pocketbook mussel. Short-term brooders (tachytictic) comprise 33% (n = 15) of species including both the Sheepnose and Rabbitsfoot mussel. For the Big Sunflower River upper reach between Indianola and Clarksdale, low flow conditions occur August - October and generally coincide with the spawning and brood period for long-term brooders, and the brooding and glochidia release period for short-term brooders. Providing supplemental flows during this period would improve mussel fish host interaction due to increased instream habitat and enhance survivorship of newly recruited mussel as they release from their respective fish hosts and transition to riverine habitats.

Summary of Alternative Mitigation

A watershed approach for compensatory mitigation of adverse impacts of the project on fishery resources was considered during the planning process. A watershed approach recognizes the overall resource needs of the entire riverine system during all seasons rather than on-site mitigation that considers only locally important functions and values. Reforestation of agricultural lands has been the primary in-kind mitigation feature of the project area. However, despite over 30 years of reforesting lands in the project area, increases in fish diversity and/or richness has not been evident since monitoring began in the 1990's. Fish diversity metrics measured in the Big Sunflower-Steele Bayou drainage are typically 20-50% lower than reference watersheds in the same ecoregion. Hypoxia within the floodplain during prolonged inundation periods has been identified as a primary deterrent to mitigating adverse impacts in the project area using reforestation. Therefore, reforesting agricultural lands in the project area does not fully compensate adverse impacts justifying consideration of out-of-kind mitigation that provides greater ecological importance to the overall aquatic resources in the watershed.

Low flows during late summer and autumn has been identified as a major contributor to depressed fishery resources in the watershed. Beginning in the 1950's and continuing today, the Big Sunflower-Steele Bayou drainage has been transformed from a perennial to an intermittent stream during seasonal low flow periods due to water abstraction. Fish spawning and rearing during the spring must cope with low dissolved oxygen during prolonged flooding that reduces the ecological value of reforestation in the floodplain, and those individuals that do survive are further impacted by prolonged periods of low flows during the summer-fall thereby affecting annual fishery recruitment strength. Meaningful mitigation must consider the entire life cycle of fishes and the associated anthropogenic impairments to each life stage. These ecological issues can more effectively be addressed through both in-kind and out-of-kind mitigation.

Recognizing that low flows during the summer-autumn season provides greater ecological lift than simply more reforestation, 34 supplemental low flow groundwater wells are proposed to augment stream flows in multiple stream systems within the Big Sunflower-Steele Bayou drainage (i.e., environmental flows). Well field operation will occur on an annual basis regardless of flooding conditions in the lower reach of the Yazoo Project Area. Re-establishing perennial flow with supplemental low flow groundwater wells is considered part of potential project features that will benefit all reaches from the headwaters to the mouth at Steele Bayou structure. This approach offsets the high mortality of larvae and juvenile fishes occurring in the spring during hypoxic events with increased survival rates of juvenile and adult fishes during autumn. Environmental flows also benefit mussels, including federally endangered species, as reproductive success in freshwater mussels is dependent on diverse and functional fish assemblages. Environmental flows benefit a total of 9,321 acres of streams, and based on a statistical habitat model, yields 1,678 AAHU's, which is a 40% increase compared to existing conditions. This analysis demonstrates that using both in- kind and out-of-kind or alternative mitigation fully compensates for adverse impacts of the project, takes a watershed approach rather than localized, and addresses all life stages of fishes during the year.

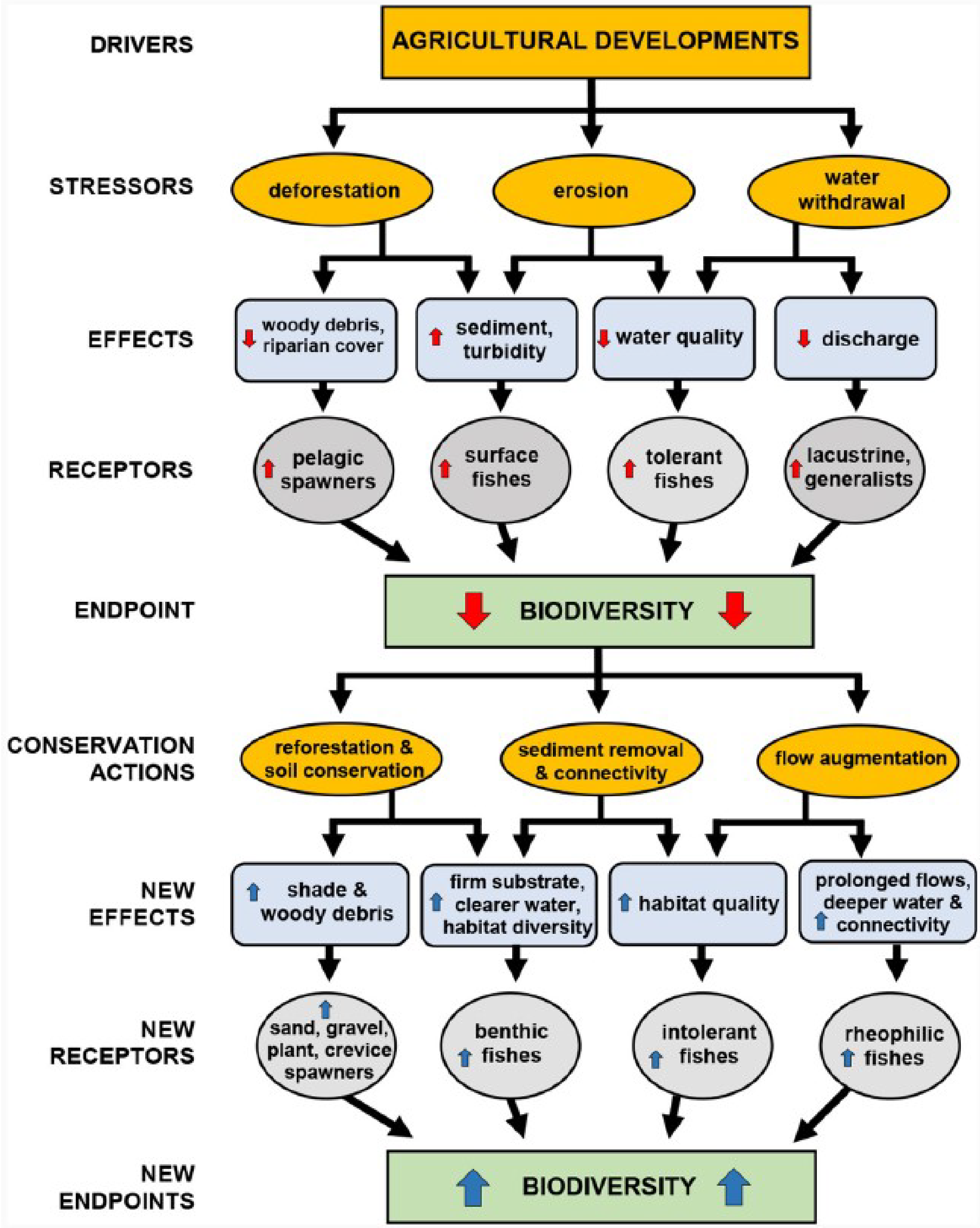


Figure 9. Conceptual model for fish conservation in streams of the Lower Mississippi River historic floodplain, identifying drivers, stressors, effects, receptors, endpoints and conservation actions. Upward arrows in red and blue indicate increase; downward indicate decrease. From Killgore et al. 2024.

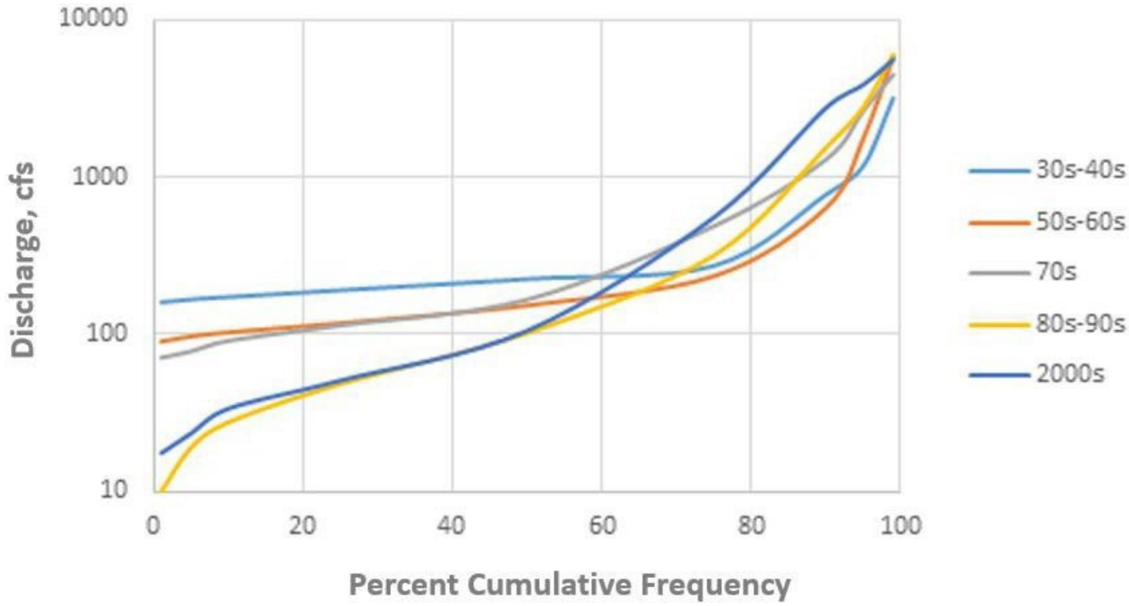


Figure 10. Big Sunflower discharge (cfs) at Sunflower, Mississippi during autumn.
Graph provided by D. Johnson, MVK.

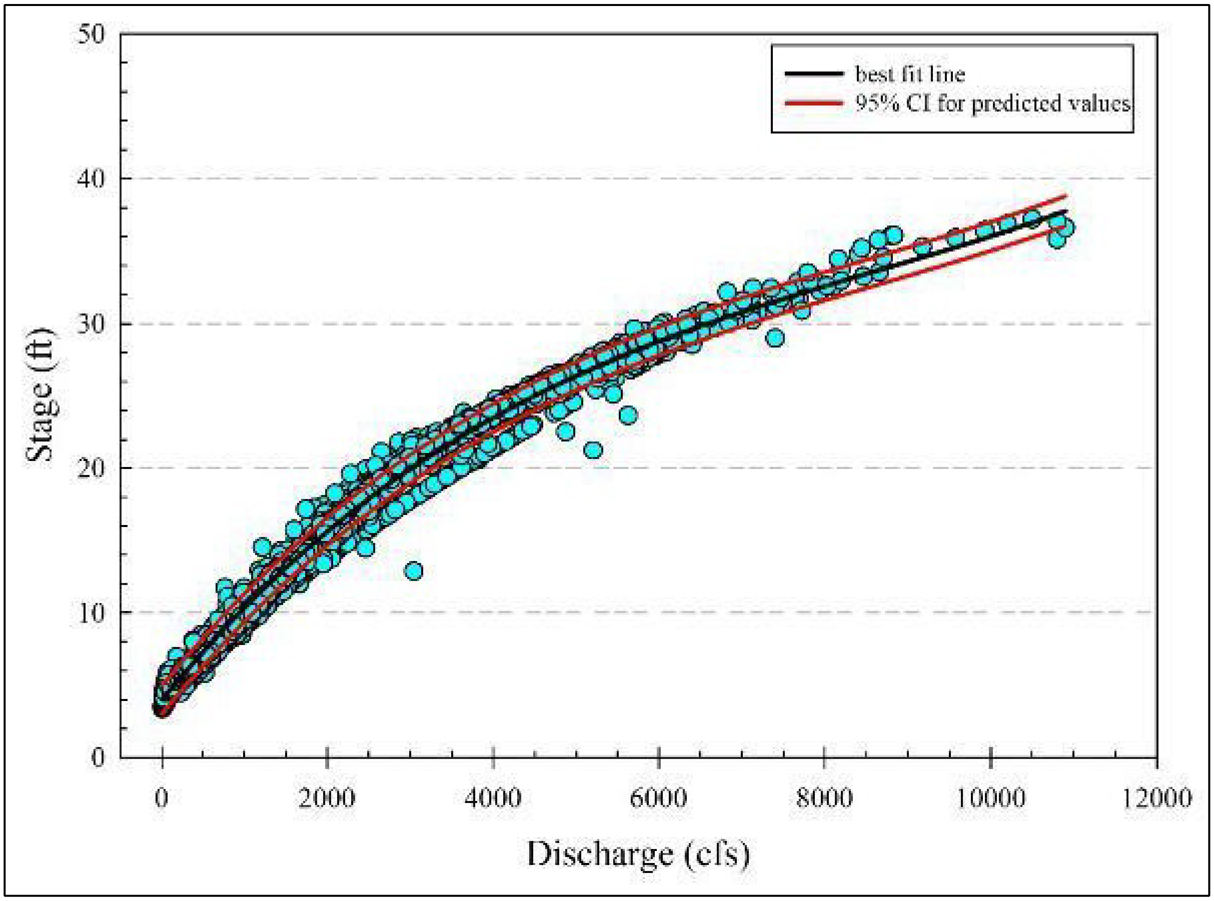


Figure 11. Compiled water surface elevation (stage, ft) and discharge data for Merigold gage (USGS 7288280) including best fit line and 95% confidence intervals for predicted stage values.

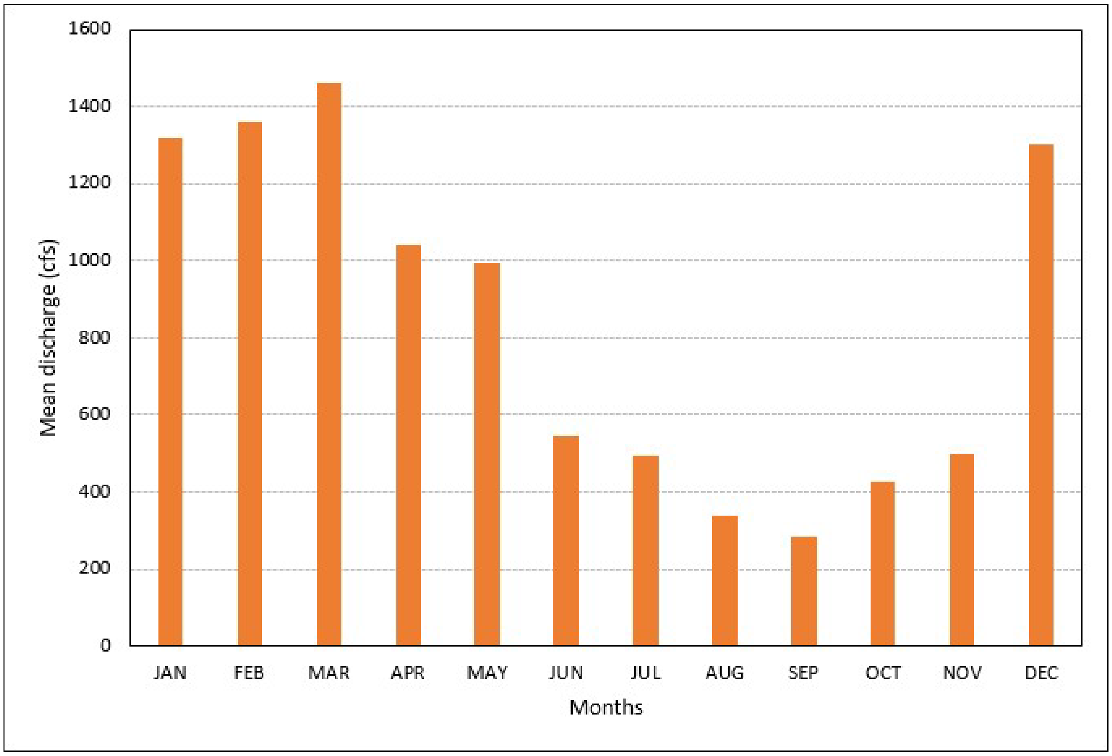


Figure 12. Mean monthly discharge for Big Sunflower River at Merigold (USGS 7288280). Data represent period of record for the gage (1993-2020).

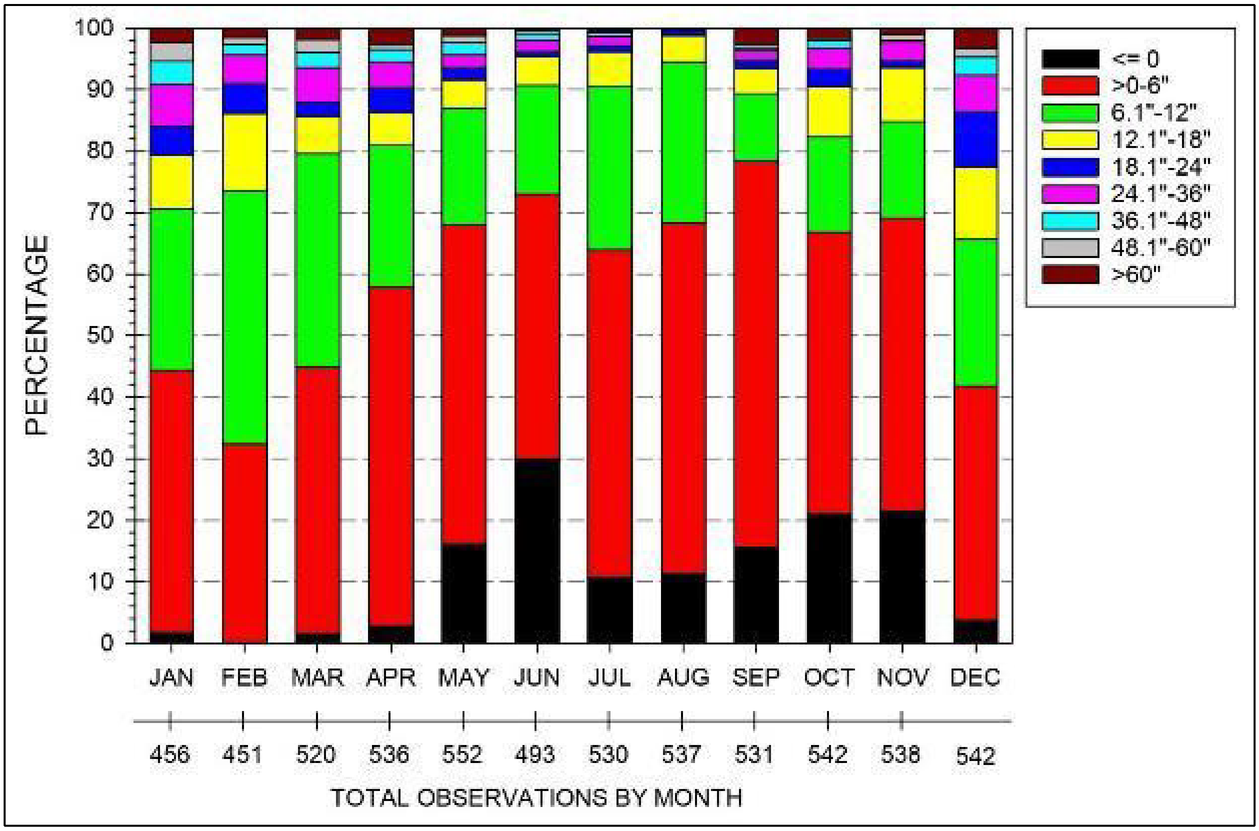


Figure 13. Cumulative percentage of difference between stage height and weir crest by month (1997 - 2014) based on USACE gage station maintained at Highway 12, Leroy Percy State Park and Wildlife Management Area (WMA) approximately 5 miles west of Hollandale, Mississippi (Washington County). Data used to evaluate fish passage opportunities over a weir.

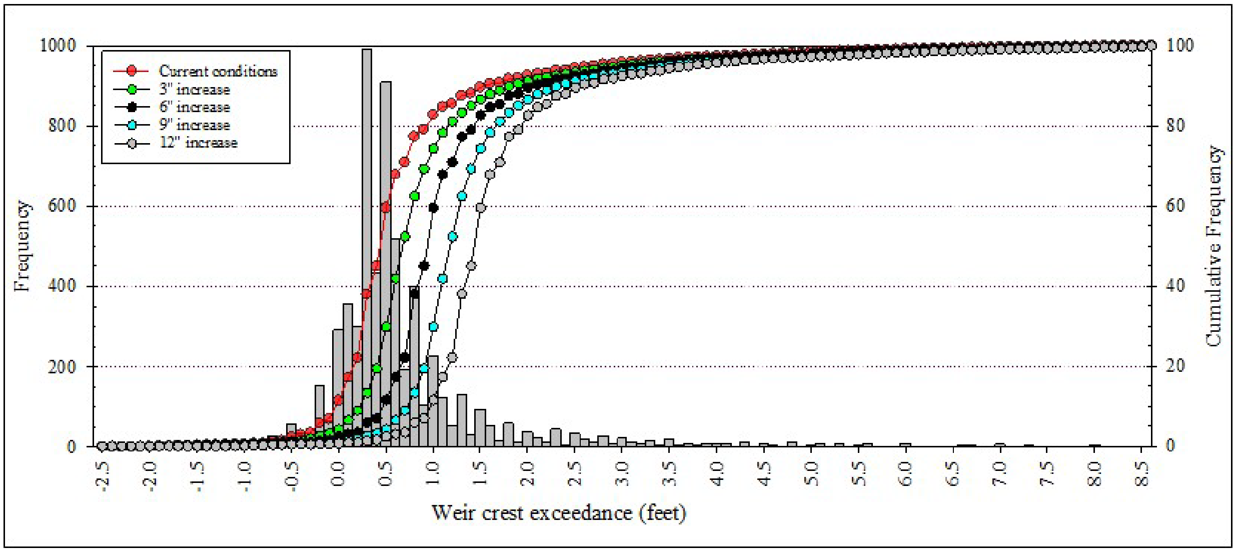


Figure 14. Plot of frequency of stage conditions for USACE gage at Highway 12 for 1997 - 2014. Gray histogram represents compiled stage records for differing intervals of weir crest elevation exceedance. Colored lines reflect cumulative frequency of all stage events including current status and conditions reflected with increased stage levels (3, 6, 9, and 12 inches) related to supplemental flows.

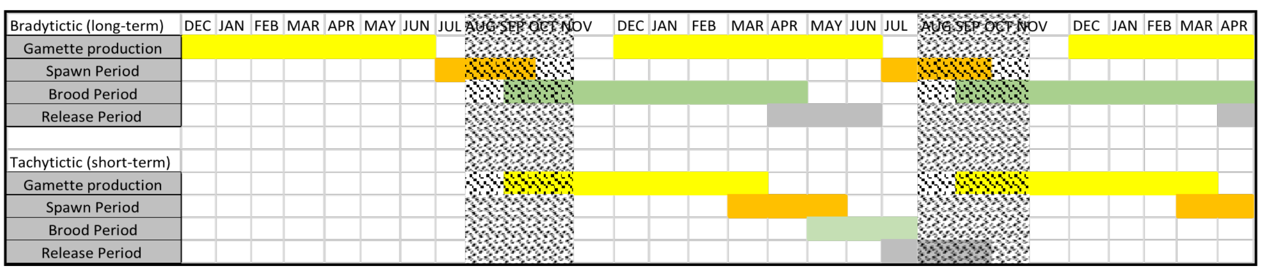


Figure 15. General schematic depicting relative timing of reproductive stages for long-term and short-term brooding strategies in freshwater mussels. Months with diagonal hatch represent low flow months at Merigold gage (Figure 13). Recent studies provide support that gametogenisis in long-term brooders likely occurs throughout the entire year.

Table 11. Predicted stage output values for specified discharge input values based on historic data at USGS gage (7288280) on the Big Sunflower River. Incremental change presents the increase in stage between a specific discharge and the initial baseline discharge rate (0).

Discharge input (cfs)	Stage output (feet)	Incremental change (inches)
0	4.11	0.00
5	4.15	0.42
10	4.18	0.83
15	4.22	1.25
20	4.25	1.66
25	4.28	2.08
30	4.32	2.50
35	4.35	2.92
40	4.39	3.33
45	4.42	3.75
50	4.46	4.17
55	4.49	4.59
60	4.53	5.01
65	4.56	5.43
70	4.60	5.85
75	4.63	6.27
80	4.67	6.69
85	4.70	7.11
90	4.74	7.54
95	4.77	7.96
100	4.81	8.38
105	4.84	8.80
110	4.88	9.23
115	4.92	9.65
120	4.95	10.08
125	4.99	10.50
130	5.02	10.92

135	5.06	11.35
140	5.09	11.77
145	5.13	12.20
150	5.16	12.63

Table 12. Percent difference in the abundance of minnows, shiners, and other rheophilic fishes with and without flow. Data derived from seining collections from the following drainages: Bayou Bartholomew, Big Sunflower, Cache River, Quiver River, Cypress Bayou, Middle White River, and Red River above Shreveport, Louisiana. Flowing water classified as surface water velocity greater than 5 centimeters per second (cm/s), N = number of samples

Flowtype	Variable	N	Mean cm/s	Std Dev	Minimum cm/s	Maximum cm/s
Non-flowing	Percent Rheophilic	28	0.3	0.2	0.0	0.8
	Percent Minnows and Shiners	28	0.2	0.2	0.0	1.0
Flowing	Percent Rheophilic	80	0.5	0.3	0.0	1.0
	Percent Minnows and Shiners	80	0.5	0.3	0.0	1.0

Table 13. Wetted width (feet) of stream reaches during summer and fall in the Big Sunflower-Steele drainage used to calculate acres benefitting from environmental flows. N = number of measurements.

Stream Reach	N	Mean	Standard Deviation	Minimum	Maximum
Big Sunflower	54	167	116	23	510
Black Bayou	17	87	40	19	141
Bogue Phalia	15	87	27	43	130
Deer Creek	15	99	39	19.8	156
Main Canal	9	95	45	32	168
Steele Bayou	9	168	80	51	273
Stream Order 1-2 (Harris, Huschpukena, Richies)	3	33	21	17	57

Table 14. Calculation of wetted acres of receiving streams and rivers from 34 supplemental low flow groundwater wells and Average Annual Habitat Units (AAHU) with and without flow. The Habitat Suitability Index weighting factors in parenthesis were mean values of the percent abundance of minnows and shiners collected in flowing water compared to non-flowing samples (Table 13).							
Stream	Km	Miles	Width, feet	Length, feet	Acres	Without Flow AAHU (0.28)	With Flow AAHU (0.46)
Big Sunflower	355	208	167	1,096,128	4,202.3	1,177	1,933
Harris	30	17	33	91,344	69.2	19	32
Richies	15	9	33	46,464	35.2	10	16
Hushpuckena	93	54	33	286,176	216.8	61	100
Bogue Phalia	137	80	87	422,400	843.6	236	388
Little Sunflower	48	27	95	144,672	315.5	88	145
Steele Bayou	116	68	168	359,568	1386.8	388	638
Main Canal	21	13	95	66,000	143.9	40	66
Black Bayou	38	22	87	116,160	232.0	65	107
Deer Creek	267	156	99	825,264	1875.6	525	863
Total	1,118	654		3,974,256	9,321	2,610	4,288
Percent Difference in Habitat Units	0.39						

Part 5: Steele Bayou Structure and Pump

Entrainment and Impingement

The proposed project would install and operate twelve pumps with an overall capacity of approximately 25,000 cubic feet per second with at least 20 pumps in the Yazoo Basin to reduce seasonal flood elevations above 90 feet National Geodetic Vertical Datum (NGVD). Fish approaching the intakes are susceptible to entrainment by the pumps, which have axial flow impellers operating at 145 to 151 RPM's creating intake velocities of 1.7 ft/sec increasing to 2.3 ft/sec at the trash rack, and 5.8 ft/sec at the formed suction intake. The trash racks are spaced approximately 5.5 inches apart preventing larger fish from entering the intakes, although adult fish could become trapped against the racks (i.e., impingement). Small-bodied fish could be entrained and are susceptible to physical strike of the impeller and can be subjected to rapid changes in shear stress, pressure, acceleration, and turbulence.

To evaluate species composition of potentially entrained fish, the outlet below Steele Bayou Structure was sampled with paired "bongo" nets (0.75-m diameter, 4.5-m long, 505-µm mesh) during August 2019 and May-June 2020 after the Steele Bayou gates were open following impoundment. Net samples were taken below the water surface and each sample was of 5-min duration fished from a stationary boat. A General Oceanics Model 2035-B flow meter was mounted in the mouth of each net to measure velocity of water passing through the net. Meter readings and duration of sampling were converted to an estimate of water volume filtered for each sample. Samples were fixed and preserved in 5% buffered formalin. In the laboratory, fishes were identified to the lowest practical taxon and enumerated. Catch was expressed as density (e.g., number of larval fishes/100 m3 of water filtered) and used to describe temporal patterns in occurrence and relative abundance.

USACE acknowledges that entrainment may occur during operation of the pumps but does not anticipate significant impacts to fish populations in the study area based on the reasons listed below. However, fish passing though the pumps will be monitored with bongo nets as part of the Monitoring and Adaptive Management Plan. Fish will be examined either in the field or laboratory for injury associated with impingement or propeller strikes. If significant mortality is observed, population models will be developed to evaluate long-term impacts on fish recruitment and potential mitigation strategies recommended to offset pump-induced mortality.

a. Over 98 percent of the fishes collected with bongo nets were either Gizzard or Threadfin Shad, and of these individuals, 99 percent were larvae or juveniles (Table 15). Gizzard and Threadfin Shad are ubiquitous throughout the lower Mississippi Valley and are often the most abundant fish species in lakes and rivers. No protected or rare species were collected.
b. The pump station will draw water near the bottom of the inlet channel, which is approximately 27 feet in total depth. Based on the Water Quality and Aquatic Appendix, deeper water during impoundment is hypoxic (less than three milligrams per liter of dissolved oxygen) and avoided by fish.

c. Most adult fish, including minnows, have burst speeds of three feet per second or greater that can be maintained for at least 30 seconds, which exceeds the water velocity at the trash intake but not the formed intake. Most fish avoid moving backwards in a current (at the point of entrainment) and will exhibit burst swimming speeds to move out of the intake area if possible. Fish entrained and not injured would move through the outlet into the Yazoo River where access to floodplain and riverine habitat is widely available.
d. Studies of fish entrainment through power plant turbines concluded that overall mortality is less than five percent (Cada 1990). However, entrainment and impingement will be monitored during pumping operations to determine potential injury of fish as they pass through the pumps.

Optimizing Gate Operation

There are over 100 species of fish that live in the Yazoo and Mississippi Rivers, while after 30 years of sampling the Yazoo Backwater Area (YBA), only 65 species have been documented. Many of the fish absent in the YBA are minnows, darters, and certain suckers that could be recruited from the Yazoo-Mississippi Rivers if gate operations would be slightly modified during optimum hydraulic conditions. Presently, the Yazoo Backwater levees isolate the entire Big Sunflower-Steele Bayou watershed from adjacent Mississippi River drainages. Typical operation of the Steele Bayou gate is to only allow water to flow out of the sump preventing any type of bi-directional flow. However, evaluation of historic water level data indicates there are more opportunities to create inflows than previously assumed.

Table 15. Abundance of fish species collected in bongo nets directly below the outlet of Steele Bayou during summer 2019 and spring-summer 2020 after the Steele Bayou structure was opened following impoundment. Abundance is expressed as number of fish/100 m^3 of water filtered.

Scientific Name	Common Name	Frequency	Percent	Cumulative Frequency	Cumulative Percent
Clupeidae	Shad	1643.0	47.4	1643.0	47.4
Dorosoma sp.	Shad (either Gizzard or Threadfin)	1101.6	31.8	2744.6	79.1
Dorosoma cepedianum	Gizzard Shad	673.6	19.4	3418.2	98.6
Pomoxis nigromaculatus	Black Crappie	19.0	0.6	3437.2	99.1
Lepisosteus oculatus	Spotted Gar	10.8	0.3	3448.0	99.4
Hypophthalmichthys molitrix	Silver Carp	4.7	0.1	3452.7	99.6
Pomoxis annularis	White Crappie	3.8	0.1	3456.4	99.7
Ictiobus sp.	Buffalo	3.7	0.1	3460.2	99.8
Micropterus salmoides	Largemouth Bass	2.2	0.1	3462.4	99.8
Centrarchus macropterus	Flier	1.7	0.1	3464.1	99.9
Morone chrysops	White Bass	1.4	0.0	3465.5	99.9
Gambusia affinis	Mosquitofish	1.2	0.0	3466.7	100.0
Aphredoderus sayanus	Pirate Perch	0.7	0.0	3467.5	100.0
Lepomis sp.	Sunfish	0.7	0.0	3468.2	100.0

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