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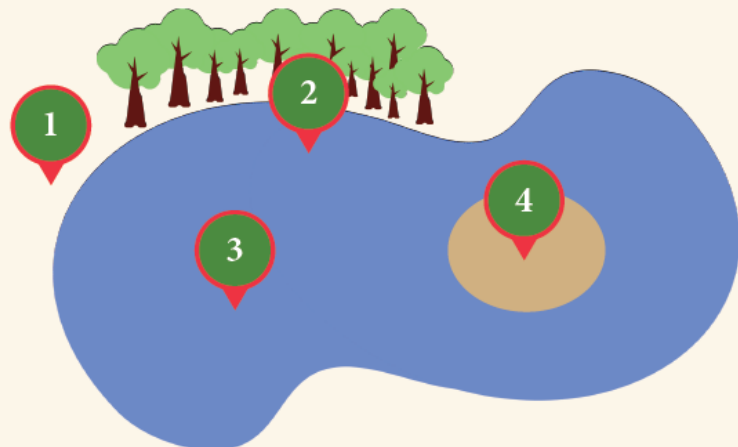
Ecological Model to Evaluate Borrow Areas in the Lower Mississippi River

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ENVIRONMENTAL DESIGN OF BORROW AREAS

1 Borrow areas can be constructed on the river side or land side of the levee. They can cover up to 20 acres or more.

2 Riparian buffers of native trees should border 50-75% of the periphery.



3 Should be bowl-shaped. Deep water (up to 10 feet, 1:3 slope) should cover up to 75%; shallow water (less than 5 feet, 1:10 slope) should cover 25%.

4 Islands and sinuous shorelines create varying depths and promote higher fish diversity.

MRG&P

Mississippi River
Geomorphology &
Potamology Program



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Ecological Model to Evaluate Borrow Areas in the Lower Mississippi River

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Final Report

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Abstract

An aquatic analysis of constructing borrow areas adjacent to the main line levees in the Lower Mississippi River was conducted as part of an Environmental Impact Statement for upgrading the levee system. A Habitat Suitability Index (HSI) regression model based on field collections was developed to predict fish species richness as a function of the morphometry and water quality of borrow areas. The HSI score was multiplied by acres of borrow areas created during construction to obtain habitat units (HUs) for each alternative indicating a substantial gain of fishery habitat in the floodplain. Environmental features identified by the model to increase fish species richness and overall habitat heterogeneity include the shape of the pit (e.g., bowl-shaped with deep water rather than long rectangular with shallower water), the availability of littoral areas for fish spawning and rearing, using best management practices such as tree screens and bank stabilization to lower turbidity, adding islands, and creating sinuous shorelines. The project results in an overall gain in aquatic habitat by creating permanent or semi-permanent water bodies on the floodplain that our research indicates may be occupied by at least 75 species of fish contributing to the overall biodiversity of the lower Mississippi River.

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Preface

This study was conducted for the Mississippi River Geomorphology and Potamology Program under Mississippi Valley Division, Mississippi River and Tributaries project, “Ecological Model to Evaluate Borrow Areas in the Lower Mississippi River.” Additional support was provided by the US Army Engineer Districts, Memphis, Vicksburg, and New Orleans, Kent Parrish, senior program manager, Vicksburg District. The technical monitors were Dr. James W. Lewis, Dr. David May, and Mr. Andrew (Andy) J. Ashley, Director, Mississippi River Science and Technology Office, US Army Corps of Engineers (USACE), Mississippi Valley Division.

The work was performed by the Aquatic Ecology and Invasive Species Branch of the Ecosystem Evaluation and Engineering Division, US Army Engineer Research and Development Center–Environmental Laboratory (ERDC-EL). At the time of publication, Mr. Alan W. Katzenmeyer was branch chief; and Mr. Mark D. Farr was division chief. The deputy director of ERDC-EL was Dr. Brandon J. Lafferty, and the director was Dr. Edmond J. Russo Jr.

The following individuals at ERDC during this multidecadal study assisted with field work: Dr. Reid Adams, Mr. Jay Collins, Mr. Steven George, Dr. Sherry Lynn Harrel, Dr. James P. Kirk, Mr. Bradley Lewis, Dr. James Morrow, Jr., Dr. Catherine Murphy, Ms. Tracy Robinson, and Mr. Larry Sanders. Assistance in the field and identification of juvenile and adult fishes were provided by Dr. Neil H. Douglas, University of Louisiana at Monroe.

Independent technical reviews were provided by Mr. Mike Thron (Memphis District) and Dr. Bruce Pruitt (ERDC-EL), the final report was edited by Ms. Sarah Deuell, ERDC-Information Technology Laboratory. The Model was certified by USACE National Ecosystem Restoration Planning Center of Expertise (ECO-PCX), Dr. Gregory Miller, supervisor.

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COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was the director.

1 Introduction

1.1 Background

Borrow areas provide fill material to raise the elevation of levees or during construction of other flood control structures. Commonly referred to as *pits*, fill material is excavated using backhoes and transported to the construction site. Borrow areas are usually formed as elongated trenches parallel with the levee, with average sizes ranging from 20–40 acres and average depths of 3–4 ft.* However, considerable variation in size, depth, and morphology of borrow areas occur along the 1,200 mi of the Lower Mississippi River (LMR) from Cape Girardeau, Missouri, to the mouth. Most borrow areas in the LMR are riverside of the levee to avoid affecting agricultural lands or other infrastructure landside of the levees. Borrow areas usually retain water year-around from a combination of overbank flow, groundwater discharge, and precipitation providing habitat for aquatic invertebrates, fish, and many other vertebrates. There are approximately 39,000 acres of borrow areas in the LMR that essentially function as floodplain waterbodies and are recognized as important ecological features of the riverine system (Baker et al. 1991; Miranda et al. 2013).

Borrow areas in the LMR were sampled in the early 1980s (Cobb et al 1984) and again in the mid-1990s (Miranda et al. 2013). Rotenone was used to estimate standing stock (i.e., pounds per acre) of representative fish species during both decades as part of an evaluation of raising the elevation of the mainline levees along the LMR. Gillnets and seines were also used to sample shoreline and pelagic fishes in the mid-1990s in addition to rotenone. Comparison of the fish assemblage between borrow areas and natural floodplain lakes indicated that man-made borrow areas riverside of the levee function similarly as floodplain lakes and tended to include a greater representation of fish species that require access to diverse environments, including lentic, lotic, and palustrine habitats.

* For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

1.2 Objectives

This technical report describes the methods used to develop and apply Habitat Suitability Index (HSI) models using the borrow area fish database to document changes in aquatic habitat as part of levee construction. This information was included in the Supplemental Environmental Impact Statement (SEIS II) to address the impacts associated with the construction of remaining authorized work on the Mississippi River mainline levees (MRL) feature of the Mississippi River and Tributaries (MR&T) project. The project extends from Cape Girardeau, Missouri to Head of Passes, Louisiana for a total distance of 1,008 river miles (RMs). Features includes raising and widening deficient portions of the levee to its authorized design grade and cross-section using material from borrow areas, and installing measures to manage seepage during periods of high water in those areas at risk of losing levee foundation materials (Mike Thron, Memphis District, pers. comm., May 2018). The report is divided into three parts: development of the HSI model, applying the ecological model for impact assessment, and recommendations for environmental design concepts.

1.3 Approach

This technical report is divided into three primary sections. The first section is a detailed description of developing the HSI model to estimate fishery and other aquatic benefits of constructing borrow areas while raising the elevation of the mainline levee system in the LMR. This information includes habitat characterization of borrow areas, sampling and quantifying fish abundance and diversity using various collecting gears, and the statistical methods of creating a multiple regression equation as the ecological model. Additional methods were developed and discussed to compare the relative value between riverside and landside borrow areas. The second section is a summary of the impact analysis using the ecological model. Habitat Units are calculated to quantify the benefits of constructing borrow areas as functional waterbodies in the floodplain. The third section provides recommendations on environmental design of borrow areas with details on the morphometry, water quality, and riparian characteristics that enhance the overall ecological value of borrow areas in the floodplain of the LMR.

2 Part I: Habitat Suitability Index (HSI) Model

2.1 Purpose and Objective

The Habitat Evaluation Procedure (HEP) was used to evaluate alternatives (i.e., number, size, and morphology of borrow areas), including environmental design features, to optimize aquatic habitat of borrow areas. The output of HEP is referred to as Habitat Units (HUs), which are calculated by multiplying a HSI value ranging from 0 (no habitat value) to 1.0 (optimum habitat value), by area (e.g., acres) of work item locations (USFWS 1980). Comparison of HUs before and after construction provides a measure of impacts or benefits to the aquatic ecosystem.

Regression models were developed to predict changes in fish diversity as a function of morphological and water quality attributes of borrow areas. The model with the best fit was standardized to a HSI to evaluate environmental consequences of constructing these permanent or semipermanent water bodies in the LMR batture (i.e., floodplain). Converting a statistical model to a HSI value conforms to the application of the HEP to analyze an array of alternatives and conduct incremental analysis of project benefits.

Data used in model development were derived from 1-acre rotenone samples in 25 borrow pits collected in 1981 for the Lower Mississippi River Environmental Program, and 8 borrow areas in the mid-1990s for the first Supplemental Environmental Impact Statement on the MRL feature of the MR&T project SEIS I. All of these data were collected riverside of the levee (i.e., batture). In addition, riverside and landside borrow areas were sampled in 1997 and 2019 using seines and gillnets for a total of 15 sampling events to compare differences in fish assemblages on both sides of the levee. These data were used to develop a Relative Value Index (RVI) for landside borrow areas not connected to the Mississippi River. A RVI is used to document value judgements made during resource planning (USFWS 1980), and in this case, the difference in species diversity measures between riverside borrow areas periodically connected to the Mississippi River and landside borrow areas isolated from the river. The final HSI models were certified by the US Army Corps of Engineers (USACE) National Ecosystem Restoration Planning Center of Expertise (ECO-PCX) and were used in Section 3 of this report to

quantify changes in fishery habitat as borrow areas are being created, enlarged, or deepened to raise the elevation of the MRL. Models were also used to provide guidance on environmental design of borrow areas to maximize fish diversity.

2.2 Methods

2.2.1 Geographic Location

Ecological surveys of 25 MRL borrow areas along the LMR were conducted in the early 1980s using rotenone to collect fishes. Results were published in a series of four reports, one of which summarized fishery investigations (Cobb et al. 1984) and another provided environmental design considerations for borrow areas (Aggus and Plosky 1986). In 1996–1997, 8 riverside borrow areas, 7 of which were previously sampled by Cobb et al. (1984), were sampled with rotenone (Killgore et al. 1998). These databases were combined for a total of 33 sampling events in the batture bordering Missouri, Tennessee, Arkansas, Mississippi, and Louisiana (Table 1). We assumed that each sampling event in the same borrow area represented an independent observation since at least a decade had passed between events. In addition, 5 riverside and 4 landside borrow areas were sampled with seines and gillnets in 1997 to compare fish diversity among the two locations and develop an RVI (USFWS 1980). The same five riverside borrow areas were sampled in 2019 using seines and gillnets, and an additional borrow area was added in 2019 at Modoc, Arkansas, for a total sample size of 15 (Table 1).

Table 1. Location of 31 borrow areas sampled in 1981, 1996–1997, and 2019. Borrow areas bordered Missouri, Tennessee, Arkansas, Mississippi, and Louisiana. The four Lake Providence sites in Louisiana were the landside borrow areas.

Borrow Area	Location	River Mile (RM)	Descending Bank	Distance to River (Miles)	Year Sampled Rotenone		Year Sampled Gillnet/Seine		USACE District
					1981	1996–1997	1997	2019	
1 ^a	Madison Parish, Louisiana	431	Right (R)	0.3	X ^a	—	—	—	Vicksburg
2	Tensas Parish, Louisiana	407	R	2.4	X	X	—	—	Vicksburg
3	East Carroll Parish, Louisiana	469	R	0.4	X	—	—	—	Vicksburg
4 ^a	East Carroll Parish, Louisiana	482	R	0.4	X ^a	—	—	—	Vicksburg
5	East Carroll Parish, Louisiana	462	R	0.6	X	—	—	—	Vicksburg
6	Madison Parish, Louisiana	433	R	1.3	X	X	—	—	Vicksburg
7	Warren County, Mississippi	460	Left (L)	0.9	X	—	—	—	Vicksburg
8	Bolivar County, Mississippi	593	L	0.3	X	—	—	—	Vicksburg
9	Bolivar County, Mississippi	595	L	1.1	X	X	—	—	Vicksburg
10	Madison Parish, Louisiana	456	R	0.1	X	—	—	—	Vicksburg
11 ^a	Bolivar County, Mississippi	602	L	2.1	X ^a	—	—	—	Vicksburg
12	Concordia & Tensas Parish, Louisiana	377	R	0.7	X	—	—	—	Vicksburg
13 ^a	Phillips County, Arkansas	656	R	0.3	X	X ^a	X	X	Memphis
14	Desha County, Arkansas	584	R	4.3	X	—	—	—	Memphis
15	Coahoma County, Mississippi	659	L	1.8	X	X	X	X	Memphis
16	Concord Parish, Louisiana	355	R	0.2	X	—	—	—	Vicksburg
17 ^a	Mississippi County, Arkansas	773	R	2.3	X ^a	X	X	X	Memphis
18	Concord Parish, Louisiana	323	R	1.8	X	—	—	—	New Orleans

Table 1 (cont.). Location of 31 borrow areas sampled in 1981, 1996–1997, and 2019. Borrow areas bordered Missouri, Tennessee, Arkansas, Mississippi, and Louisiana. The four Lake Providence sites in Louisiana were the landside borrow areas.

Borrow Area	Location	RM	Descending Bank	Distance to River (Miles)	Year Sampled Rotenone		Year Sampled Gillnet/Seine		USACE District
					1981	1996–1997	1997	2019	
19	New Madrid County, Missouri	877	R	0.8	X	—	—	—	Memphis
20	Concord Parish, Louisiana	305	R	0.3	X	—	—	—	New Orleans
21	New Madrid County, Missouri	881	R	2.5	X	—	—	—	Memphis
22	Concord Parish, Louisiana	315	R	0.4	X	—	—	—	New Orleans
23	Shelby County, Tennessee	720	L	1	X	—	—	—	Memphis
24	St. James Parish, Louisiana	151	L	0.1	X	—	—	—	New Orleans
25 ^a	Ascension Parish, Louisiana	180	L	0.1	X ^a	X	X	X	New Orleans
Bayou Goula	Iberville Parish, Louisiana	194	R	0.1	—	X	X	X	New Orleans
Lake Providence–1	East Carroll Parish, Louisiana	497	R	3.6	—	—	X	—	Vicksburg
Lake Providence–2	East Carroll Parish, Louisiana	494	R	3.5	—	—	X	—	Vicksburg
Lake Providence–3	East Carroll Parish, Louisiana	493	R	2.3	—	—	X	—	Vicksburg
Lake Providence–4	East Carroll Parish, Louisiana	492	R	1.8	—	—	X	—	Vicksburg
Modoc	Phillips County, Arkansas	634	R	1.0	—	—	—	X	Memphis

^a Borrow areas designated as outliers for the standardized species richness model (see Table 6).

2.2.2 Habitat Variables

Borrow areas were sampled in mid to late summer during the three decades when isolated from the Mississippi River. The same water quality, hydrologic, and morphometric variables measured by Cobb et al. (1984) were obtained during the 1996–1997 and 2019 sampling periods. Water quality was measured at the water's surface with calibrated multiparameter meters. Variables included water temperature, dissolved oxygen, pH, specific conductivity, and turbidity. In 1981 and 1996–1997, bathymetric and ground surface elevations were measured by survey teams to calculate mean depth, maximum depth, area, volume, percent area with depth greater than 5 ft, and percent area with depth greater than 10 ft. In 2019 bathymetric data were collected using a YSI i3XO EcoMapper® autonomous underwater vehicle supplemented by stadia rod readings with GPS coordinates in shallow water (<2 ft) and paired with bare ground lidar data downloaded from the National Map (<https://www.usgs.gov/faqs/what-lidar-data-and-where-can-i-download-it>, accessed May 2019). The controlling elevation for each borrow area was used as the water surface elevation in calculating surface area and volume. The controlling elevation is the National Geodetic Vertical Datum (NGVD in feet) representing the low point of the borrow area basin rim and is the elevation below which water cannot drain out by gravity, or conversely, the elevation of the river above which water must rise to enter the area. Borrow area flooding, or days flooded, was assumed to occur when river stage exceeded the controlling elevation, considering major topographic features that could influence stages in the borrow area vicinity (Cobb et al. 1984).

Borrow area morphometry was expressed as a volume development index (VDI) and shoreline development index (SDI). The VDI is the ratio of the calculated volume of the borrow area to the volume of a cone with basal area and height equal to the surface area and maximum depth. Thus, if the $VDI = 1$, the borrow area basin resembles a cone; if the $VDI < 1$, the borrow area basin is very slender or rectangular; if the $VDI > 1$, it is more bowl-shaped. The SDI is the ratio of the actual borrow area shoreline length to the circumference of a circle with the same area. Circular borrow areas have an SDI near 1.0, and SDI increases as it becomes more elongated. The degree of shoreline irregularity and amount of littoral zone increase with increasing values of SDI (Cobb et al. 1984).

To calculate the Cobb et al. (1984) and Killgore et al. (1998) variables for the borrow pits sampled in 2019, a terrain surface model was created from

the lidar data, borrow pit bed elevation, and a polygon of the lidar water's edge (Esri 2016). The polygon of the water's edge was designated as a soft line to separating the lidar and bathymetric data with no change in slope. To calculate the borrow pit bed elevation for the model, the EcoMapper and stadia rod depth readings were subtracted from the water surface elevation. Water surface elevation was determined by intersecting GPS points collected at the water's edge with the lidar data and from a surveyor's level set up on the nearby levee slope. The levee point elevation was determined from the lidar data. If multiple water surface elevations were calculated for one borrow pit, the values were averaged.

To calculate the variables, one-foot contours were created from the terrain using the Cobb et al. (1984) controlling elevation as the index contour so area and volume would be comparable between the 1984, 1996–1997, and 2019 data sets. Because the Cobb et al. (1984) contours relied on widely spaced transect data, small features were not included, thus for the 2019 data, the minimum contour length was 65 ft. The other morphometric variables were calculated as per Cobb et al. (1984), with the following changes:

- The Add Surface Information tool in ArcGIS (Esri 2019) was used to calculate the mean depth below the controlling elevation.
- The maximum depth was the deepest elevation recorded by the EcoMapper subtracted from the controlling elevation.
- The SDI was calculated per the Cobb et al. (1984) method, which is the ratio of the shoreline length to the circumference of a circle with an equivalent area.

All other variables were calculated with no modifications.

2.2.3 Connection Frequency

Floodplain water bodies provide critical habitat for riverine fishes, and thus the frequency and timing of connection (connection frequency) between the river and the water body is an important factor in determining the fish community. The connection frequency of the riverside borrow areas was defined as the number of days that the river's water surface exceeded the borrow pit's controlling elevation over a defined time period. Connection frequency was determined using gage data, RMs, controlling elevation and sampling date (Oliver et al. 2016). For each borrow pit, the nearest upstream and downstream gages with

data from 1970 to 2019 were used. For Borrow pits 16, 18, 20, 22, 24, 25 and Bayou Goula, gage data began in March 1987 for Baton Rouge gage and December 1997 for Reserve gage. The average slope between Natchez and Baton Rouge and Baton Rouge and Reserve was calculated from the available data. The average slope was then used to calculate earlier data for Baton Rouge and Reserve from the Natchez gage data. The RM location of the gages was retrieved from USACE's Rivergages.com (<https://rivergages.mvr.usace.army.mil/WaterControl/new/layout.cfm>) and for borrow areas with published RMs from Cobb et al. (1984) and Killgore et al. (1998). For Bayou Goula and Modoc, the RM was determined from the point where the connecting channel reached the river. For 1981 and 1996–1997 data, Cobb et al. (1984) controlling elevations were used. Controlling elevations for borrow areas sampled in 2019 were determined from lidar data by locating the low areas (i.e., invert elevation) connecting the borrow area to the river, and when exceeded, incipient flooding occurs. Once low areas were located, the lidar point data were used to find the lowest point elevation (controlling elevation) or the water surface elevation (if the low area was submerged during lidar acquisition) (Oliver et al. 2016). The borrow pits and connection areas were evaluated by field crews during the summer of 2019 including low areas to determine submerged controlling elevations.

To calculate connection frequency, the river stage at the borrow area was calculated for each day from 1 January 1970 to 31 December 2019 using the upstream and downstream gage RM and stage and the RM of the borrow pit. Once the river stage at each borrow area was calculated, the connection frequencies for 1 month, 6 months, overwintering 6 months, 1 year, 5 years, and 10 years prior to the sampling date were calculated. These time periods were chosen because they capture short-term movements, spawning, overwintering (6 month period prior to spawning 6 months), overwintering and spawning, and longer-term changes reflecting water year variability. To evaluate the relationship between changes in area and volume and connection frequency, the connection frequency between the 1981 sampling date and the 1996–1997 or 2019 sampling date was also calculated.

2.2.4 Fish Sampling

All borrow areas were sampled from June to mid-September. In 1996–1997, riverside borrow areas were sampled with rotenone. Two 1-acre plots were blocked off by nets with 0.5 in. mesh in each borrow area and

rotenone applied to achieve a minimum of 1–2 mg/l concentration. Potassium permanganate was applied around the periphery of the plot to detoxify rotenone drifting outside the target area. Surfacing fish were collected, identified to species, measured (total length to the nearest mm), and weighed (Bettoli and Maceina 1983). Fish pickup occurred for two consecutive days after rotenone was applied. Fish assemblage of each borrow area was expressed on a per acre basis, which is the traditional method of reporting fish standing crop. However, number of fish per acre-foot can be calculated if volumetric estimates are required. These data were used to develop the HSI model for riverside borrow areas.

In 1997 and 2019, seines and gillnets were used in both riverside and landside borrow areas (Table 1). These data were used to compare fish assemblages between riverside borrow areas seasonally contiguous with the river and landside borrow areas permanently isolated from the river to develop the RVI. Shoreline fishes were collected using a 20 ft × 8 ft seine with 3/16 in. mesh; standard effort was 10 hauls stratified among all apparent macrohabitats. Pelagic (offshore) fishes were collected with gillnets (90 ft × 6 ft with 0.75, 1.5, 2.0, 2.5, 3.0, and 3.5 in. stretch mesh); standard effort was overnight sets of 5 to 6 gillnets set perpendicular to shore. Shoreline fishes were preserved in 10% formalin. Larger fishes were identified in the field and released. In the laboratory, fishes were washed, identified, and counted. Specimens were catalogued and deposited as holdings in the Mississippi Museum of Natural Science, Jackson, Mississippi.

2.2.5 Model Development

Fish diversity of borrow areas was calculated from all fish collections using Primer 7.0 (Clarke and Gorley 2015). Diversity is a collective property of fish communities and reflects species-abundance relationships of the collection. It is responsive to both species richness (the number of species) and species evenness (the distribution of individuals among those species). Diversity can be measured in various ways, but is typically expressed as *heterogeneity indices* that incorporate species richness and evenness into a single value, showing varying sensitivity to either richness or evenness components (Magurran 1988).

Diversity measures used in this evaluation are standardized species richness (S), Pielou's evenness index (J'), and Simpson's dominance index (D) (Magurran 1988; Ludwig and Reynolds 1988). Standardized species

richness is a probability-based method that addresses disparate numbers of individuals in a series of collections by quantifying the number of species expected in a random subsample of individuals taken from each collection. It is calculated by a process called rarefaction, is expressed as the number of species expected for a subsample of given size, and can range from one to the total number of species in the community (S^*) that is assumed to be the number observed in each collection. Mean abundance (i.e., number per acre) was used in calculating standardized species richness.

Evenness quantifies how individuals in a collection are distributed among species, specifically how they diverge from an equitable distribution among all the species. Pielou's evenness index (J') is a ratio of an observed logarithmic function (Shannon's H') to a hypothetical community in which all species are equally common (H'_{max}),

$$J' = \frac{H'}{\log_e S}, \quad (1)$$

where S is total number of species. It ranges from values near 0.00 (numerical domination by one or a few species to values near 1.00 (comparable abundance of all species).

Dominance (D) is similar in concept to evenness but is an exponential function rather than a logarithmic function. This index quantifies the probability that two individuals drawn at random from a collection will be members of the same species. Dominance used in this analysis is designated as $1 - \lambda'$ in Primer 7.0. It ranges from values near 0.00 (almost inevitable that two sequential draws will be from the same species) to values near one (unlikely that two sequential draws will be from the same species). Dominance (λ) is calculated as

$$1 - \lambda' = \frac{1 - ((\sum_i N_i(N_i - 1))}{(N(N - 1))}, \quad (2)$$

where the abundance of the i th species is denoted by N , ($i = 1, 2, \dots, S$) and divided by their sum (N).

Multiple regression models were developed to predict diversity (dependent or response variable) as a function of habitat parameters (the independent or predictor) that describe the morphology and water quality of riverside borrow areas (Table 2). Multiple regression equations are empirical, do

not entail *a priori* decisions regarding relationships between habitat parameters and fishes, and thus reduce institutional bias. Instead, habitat value is assessed directly from baseline relationships between fish abundance (density or biomass) and physical habitat (area morphometry, connection frequency, and water quality). Multiple regression eliminates irrelevant variables from the final predictive model and quantifies correlation between habitat variables and fish abundance.

Multiple regression equations were generated with the REG Procedure in SAS v. 9.4 (SAS 2015). A two-tailed entry level selection value of the independent variables was set at $\alpha = 0.05$, and any independent variable entered would remain in the model at a significance level of $\alpha < 0.05$. The final model is achieved when no variables outside the model meet these criteria. These criteria aid in retaining independent variables that may be important in the final model. Not all model intercepts were statistically different from zero. Adjusted R^2 that was based on Pearson product-moment correlation coefficients and includes a penalty for over-fitting was used to assess model fit after stepwise selection. Multicollinearity among independent variables was assessed by examining variance inflation factor, which estimates how much the variance of a regression coefficient is inflated due to multicollinearity in the model. Influence of outliers was determined objectively using a combination of two statistical tests, (1) studentized residual values greater than three (which are calculated by dividing the residual by an estimate of its standard deviation) and (2) Cook's distance (D) depending on the point spread in each data set. For Cook's D -value, a possible outlier is generally more than three times the mean (Cook 1977). Residual plots on predicted values were used to evaluate suitability of the final model. The model was determined suitable based on the symmetrical pattern and constant spread observed in the range of the residuals indicating that the variables used in the model adequately predict the response in fish diversity. A HSI value was determined by dividing the calculated diversity value from the regression equation by the maximum value observed from the field data to normalize the output between 0.0 (no value) to 1.0 (maximum value).

Table 2. Comparison of morphometric and water quality variables for riverside borrow areas in the Mississippi River measured during summer of 1981 (Cobb et al. 1984), 1996–1997, and 2019. Overall, the typical borrow area in the Lower Mississippi River (LMR) batture was less than 20 acres and averaged 3 ft in depth, had a Shoreline Development Index ranging from 2.1 to 2.7, and was rectangular or bowl-shaped (i.e., VDI > 1.0).

Variable	1981, <i>n</i> = 25					1996–1997, <i>n</i> = 8					2019, <i>n</i> = 6				
	Mean	Median	Std Dev ^a	Min	Max	Mean	Median	Std Dev	Min	Max	Mean	Median	Std Dev	Min	Max
Water Temperature (°C)	31.7	31.8	2	27	35.5	31.4	31.7	4.4	24.2	37.9	32.0	32	1.7	29.7	34.4
Conductivity (µmhos/cm)	310.7	315	89.3	75	505	281	283	49	205	344	409.0	408	81.8	277.0	536.0
Dissolved Oxygen (mg/l)	6.8	6.5	2.5	0.6	11	6.8	7.3	1.7	3.6	8.6	11.2	10	4.3	7.2	19.9
pH	8.1	8.2	0.6	7	9.4	8	8	0.4	7.5	8.4	9.6	10	0.5	8.9	10.5
Turbidity (NTU) ^a	26.6	18	21	8	85	26	26.6	14	7	50	20.8	20	12.1	8.3	43.2
Surface Area (acres)	19.2	12.7	16.5	3.3	53.4	17	17.2	13.3	3.3	41	38.5	43.9	18.5	6.1	55.6
Average Depth (ft)	3.1	2.8	1.8	0.5	7.2	3.3	3.4	1.5	1.3	5.8	3.5	3.3	0.6	2.8	4.5
Maximum Depth (ft)	6.5	5.5	4.2	1.1	17.7	6.5	5.7	3.5	2.6	12.4	9.6	10.0	2.7	6.3	12.8
Percent Area (>5 ft)	27.5	17.1	27.6	0	71.7	15.9	10.9	19.6	0	53.8	26.2	21.5	11.6	14.8	41.6
Percent Area (>10 ft)	3.2	0	7.9	0	33	2.9	0	6.4	0	18	1.5	0.0	3.1	0.0	7.7
Shoreline Length (ft)	6,471	4,839	3,941	1,916	15,224	8,456	7,677	6,491	1,751	20,297	16,716	17,120	8,193	2,676	27,851
SDI	2.1	2	0.7	1.2	3.7	2.7	2.4	1.5	1.3	5.8	3.5	3.9	1.2	1.5	5.1
Volume (yd ³)	102,687	61,516	106,288	4,056	348,228	88,249	77,550	77,519	7,075	175,935	208,717	235,002	92,135	39,037	294,576
VDI	1.5	1.6	0.3	0.7	1.9	1.6	1.6	0.3	0.9	2	1.2	1.3	0.5	0.6	1.9
Basin Slope	0.04	0.03	0.03	0.01	0.14	0.03	0.01	0.04	0.00	0.10	0.05	0.05	0.01	0.04	0.07

^a Standard deviation (Std Dev), nephelometric turbidity units (NTU).

An RVI was calculated to determine the difference in fish habitat benefits between landside and riverside borrow pits. Standardized species richness was calculated for the seine and gillnet data collected in 1997 and 2019. Mean values were compared between riverside and landside borrow areas. An RVI (USFWS 1980) was calculated as follows:

$$\frac{((\sum x_i) \div n)}{((\sum y_i) \div n)} \quad (3)$$

where

- x = richness value of landside borrow areas,
- y = richness value of riverside borrow areas, and
- n = the number of observations for each category.

The RVI was used to weight the difference in HSI values between riverside and landside borrow areas.

2.2.6 Model Assumptions

The following model assumptions and limitations were identified:

1. The model provides guidance on the construction of environmentally enhanced borrow areas by identifying and quantifying correlations between physical habitat variables and species diversity.
2. The model only accounts for a portion of the variability in fish diversity and is sensitive to outliers.
3. The model does not imply causality.
4. Sampling methods must be similar for two samples to be compared by these indices and the communities to be compared should be taxonomically similar (Ludwig and Reynolds 1988). Since rotenone was used to collect fish to develop regression equations for HSI development, seines and gillnets were used to develop the RVI, and all sampling was conducted in the LMR either riverside or landside of the levee, these two requirements were met.
5. The model is not predictive for individual borrow areas over time because it does not address successional changes in physical habitat or hydrologic regime due to extremities in wet and dry periods. However, if successional changes can be identified, then short-term and long-term habitat-based shifts in fish diversity can be forecast by adjusting habitat inputs in the model.

2.3 Results and Discussion

2.3.1 Habitat

Borrow areas sampled in the batture represented a wide range of morphometric and water quality characteristics. They ranged in size from 3 to 53 acres, with mean depths of approximately 3 ft during all three sampling periods (Table 2). Maximum depth measured in any one borrow area was 17.7 ft, but mean percent area greater than 10 ft was only 3%. Overall, the typical borrow area in the LMR batture was less than 20 acres and averaged 3 ft in depth. The mean SDI ranged from 2.1 to 2.7 depending on sampling years with a maximum value measured of 5.8. Most borrow areas are bowl-shaped (i.e., VDI > 1.0) and shorelines often become more irregular over time, increasing the SDI above 2.0. Water quality was typical for summer conditions in relatively shallow, permanent water bodies in the batture. The mean water temperature was high (>31°C), with no observable flow, and some borrow areas were hypoxic (<3 mg/l dissolved oxygen) and turbid (>50 NTUs).

The mean (± 1 standard deviation) connection frequency per year was 90 ± 101 days including all sampling periods (Table 3). The variation of connection frequencies among the three sampling periods contributed to the high standard deviation. The mean annual connection frequency for the 1981 data were just 23 days, increased to 91 days for the 1996–1997 period, and rose to 254 days for the 2019 period illustrating changes in flood frequency over the last few decades. Other connection frequencies follow the same trend (Table 3). Based on recent flood frequency data, most borrow areas will be connected to the river annually as floodwaters approach the levees mixing both riverine and wetland fish species creating a more diverse assemblage. Consequently, overbank flood events from the river are considered the predominant water source.

Table 3. Riverside borrow areas sampled in 1981, 1996, 1997, and 2019 with the controlling elevation (National Geodetic Vertical Datum [NGVD], ft) and river mile (RM). The upstream and downstream gages were used to calculate the river stage at the borrow pit. The connection frequency represents the number of days that the borrow pit river stage exceeded the connection threshold elevation on a monthly and annual basis prior to sampling. The mean annual connection frequency for the 1981 data were just 23 days, increased to 91 days for the 1996–1997 period, and rose to 254 days for the 2019 period, illustrating changes in flood frequency over the last few decades.

Pit	Sample Date	Control		Gage		Connection Frequency (month)			Connection Frequency (years)			After 1981
		RM	Elev. (ft)	Upstream	Downstream	1	6	6–12	1	5	10	
1	6/10/1981	431	73.0	Vicksburg	Natchez	14	14	0	14	359	1,053	—
2	6/16/1981	400	68.8	Vicksburg	Natchez	0	0	0	0	195	679	—
2	7/24/1996	400	68.8	Vicksburg	Natchez	10	60	0	60	473	849	1,212
3	6/6/1981	469	89.0	Arkansas City	Vicksburg	10	10	0	10	293	911	—
4	6/19/1981	482	90.5	Arkansas City	Vicksburg	25	25	0	25	418	1,182	—
5	6/17/1981	462	84.0	Arkansas City	Vicksburg	22	22	0	22	386	1,104	—
6	9/23/1981	432.6	79.8	Vicksburg	Natchez	0	0	0	0	177	634	—
6	7/22/1996	432.6	79.8	Vicksburg	Natchez	10	57	0	57	400	707	1,031
7	6/23/1981	460	79.8	Arkansas City	Vicksburg	30	30	0	30	493	1,319	—
8	6/29/1981	593	139.8	Helena	Arkansas City	23	27	0	27	278	862	—
9	6/29/1981	595.1	137.2	Helena	Arkansas City	31	37	0	37	414	1,150	—
9	7/29/1996	595.1	137.2	Helena	Arkansas City	4	103	3	106	657	1,185	1,761
10	7/6/1981	456	81.6	Arkansas City	Vicksburg	25	35	0	35	401	1,125	—
11	7/6/1981	609	143.7	Helena	Arkansas City	25	38	0	38	405	1,124	—
12	7/10/1981	377	55.0	Vicksburg	Natchez	26	39	0	39	429	1,157	—
13	7/10/1981	652.4	171.0	Helena	Arkansas City	0	0	0	0	148	513	—
13	7/21/1997	652.4	171.0	Helena	Arkansas City	0	40	0	40	322	479	747
13	8/21/2019	652.4	170.8	Helena	Arkansas City	0	149	46	195	413	646	1,738
14	7/15/1981	584	137.0	Helena	Arkansas City	8	18	0	18	219	747	—

Table 3 (cont.). Riverside borrow areas sampled in 1981, 1996, 1997, and 2019 with the controlling elevation (National Geodetic Vertical Datum [NGVD], ft) and river mile (RM). The upstream and downstream gages were used to calculate the river stage at the borrow pit. The connection frequency represents the number of days that the borrow pit river stage exceeded the connection threshold elevation on a monthly and annual basis prior to sampling. The mean annual connection frequency for the 1981 data were just 23 days, increased to 91 days for the 1996–1997 period, and rose to 254 days for the 2019 period, illustrating changes in flood frequency over the last few decades.

Pit	Sample Date	Control		Gage		Connection Frequency (month)			Connection Frequency (years)			After 1981
		RM	Elev. (ft)	Upstream	Downstream	1	6	6–12	1	5	10	
15	7/13/1981	656.8	173.0	Helena	Arkansas City	0	0	0	0	150	516	—
15	7/29/1997	656.8	173.0	Helena	Arkansas City	0	40	0	40	319	476	743
15	8/19/2019	656.8	167.5	Helena	Arkansas City	12	162	122	284	620	1,090	3,258
16	7/20/1981	355	49.1	Natchez	Baton Rouge	17	40	0	40	431	1,154	—
17	7/20/1981	767.6	235.0	Mississippi HW ^a 152	Memphis	0	0	0	0	43	155	—
17	8/6/1997	767.6	235.0	Mississippi HW 152	Memphis	0	27	0	27	78	97	170
17	9/11/2019	767.6	232.8	Mississippi HW 152	Memphis	0	71	32	103	181	264	690
18	7/23/1981	323	41.8	Natchez	Baton Rouge	15	42	0	42	451	1,204	—
19	7/26/1981	877	279.1	New Madrid	Mississippi HW 152	0	7	0	7	200	632	—
20	7/27/1981	305	40.0	Natchez	Baton Rouge	8	38	0	38	397	1,076	—
21	7/28/1981	881	287.0	New Madrid	Mississippi HW 152	0	0	0	0	92	254	—
22	7/29/1981	315	47.0	Natchez	Baton Rouge	0	8	0	8	218	709	—
23	7/31/1981	720	195.0	Memphis	Helena	0	39	0	39	417	1,146	—
24	8/5/1981	151	14.0	Baton Rouge	Reserve	1	40	0	40	431	1,158	—
25	8/4/1981	178.6	21.0	Baton Rouge	Reserve	0	28	0	28	301	880	—
25	8/18/1997	178.6	21.0	Baton Rouge	Reserve	0	130	53	183	773	1,289	1,863
25	9/24/2019	180	18.3	Baton Rouge	Reserve	0	142	181	323	890	1,580	5,137
Goula	8/12/1997	196.6	25.0	Baton Rouge	Reserve	0	127	35	162	641	1,048	—
Goula	9/25/2019	197.4	18.2	Baton Rouge	Reserve	0	144	184	328	965	1,820	—
Modoc	8/20/2019	633.8	156.9	Helena	Arkansas City	12	162	128	290	648	1,141	—

^a HW (highway).

Long-term changes in habitat were evaluated by multivariate comparisons of those borrow areas sampled more than once (Table 4). Borrow areas 2, 6, and 9 were sampled in 1981 and 1996–1997, and borrow areas 13, 15, 17, and 25 were sampled during all three time periods. Comparing the four borrow areas sampled in 1981 and 2019 (38 years) showed moderate differences in average depth, decreasing 17% overall indicating patterns of sedimentation. However, surface acres were similar during the evaluation period. The mean percent area greater than 5 ft and the VDI showed substantial decreases of 33% and 40%, respectively. The mean shoreline length and SDI increased 38% and 39%, respectively. Number of days flooded annually increased during this same time period. Multivariate comparison of these morphological, bathymetric, and water quality variables over the 38-year period indicate that the shorelines of most borrow areas became more sinuous over time. Principal component analysis (PCA) demonstrates that water depth and overall volume decreases, probably from vertical accretion of sediments during flood events (Figure 1). More frequent floods may exacerbate this long-term trend. Despite these changes, relative positions of borrow areas along the first PCA axis—which is the axis that accounts for most data set variance—were approximately the same and did not change appreciably over time, suggesting that successional changes in physical habitat were comparable in all borrow areas studied.

Table 4. Comparison of morphometric, water quality, and species diversity variables for the same riverside borrow areas in the Mississippi River measured during summer of 1981 (Cobb et al. 1984), 1996–1997, and 2019. Only borrow areas 13, 15, 17, and 25 were sampled during all three years. Species diversity variables are only reported for the 1981 and 1996–1997 sampling periods when rotenone was used to collect fish.

Variable	Number 25			Number 2		Number 6		Number 9		Number 13			Number 15			Number 17		
Year	1981	1997	2019	1981	1996	1981	1996	1981	1996	1981	1997	2019	1981	1997	2019	1981	1997	2019
Surface Area (acres)	36.9	26.5	32.3	18.6	18.76	4.5	4.5	3.3	3.26	53.4	22.7	54.7	53.4	41	54.7	38.1	15.6	43.9
Mean Depth (ft)	5.6	3.7	4.5	5.7	5.8	3.8	2.7	1.7	1.3	3.8	3.8	3.1	3.9	4.2	3.3	3	1.5	2.8
Maximum Depth (ft)	10.3	7.1	10	10.4	10.7	6	5.3	3.5	2.6	16.9	12.4	12.1	7.5	6.1	6.7	5.7	2.6	12.8
Percent Area (>5 ft)	66.9	26.7	41.5	71	53.8	55.5	0	1.6	0	30.9	21.7	14.8	44.6	25	14.9	21.9	0	21.5
Percent Area (>10 ft)	7.6	0	0	21.4	5.1	0	0	0	0	8.3	18	7.7	0	0	0	0	0	0
Shoreline Length (ft)	15,224	12,196	16,771	4,839	5336	5,737	3,135	1,916	1,751	14,008	20,297	27,965	8,881	12,626	17,365	10,498	10,015	19,445
Shoreline Development	3.4	3.2	4	1.5	1.7	1.5	2	1.4	1.3	2.6	5.8	5.1	1.6	2.7	3.1	2.3	3.5	4
Volume (yd ³)	325,348	160,000	269,410	178,733	176,080	6,241	19,708	9,780	7,075	309,178	131,476	275,393	348,228	170,985	294,576	183,100	123,624	199,576
VDI	1.6	1.6	1.3	1.6	1.6	1.9	1.6	1.5	1.6	0.7	0.9	0.8	1.6	2	1.5	1.6	1.8	0.6
Mean Basin Slope	0.07	0.1	0.07	0.05	0.048	0.02	0.001	0.03	0.012	0.05	0.012	0.04	0.02	0.0028	0.04	0.03	0.0025	0.05
Number of Days Flooded Annually	81	130	180	71	60	89	80	84	62	56	82	195	56	82	284	25	46	109
Dissolved Oxygen (mg/l)	5.2	4.1	10.5	5.6	5.3	4.2	5.6	10.2	11.6	8.9	7.3	12.2	5.6	8.2	7.2	9.5	3.6	7.2
pH	7.9	7.4	9.5	8.1	7.7	7.6	8.1	8.2	8.9	8.4	7.5	8.9	7.7	8.4	9.3	8.1	7.5	7.2
Conductivity (µmhos/cm)	336	282	536	205	344	341	342	432	287	318	269	440	368	228	455	234	205	367

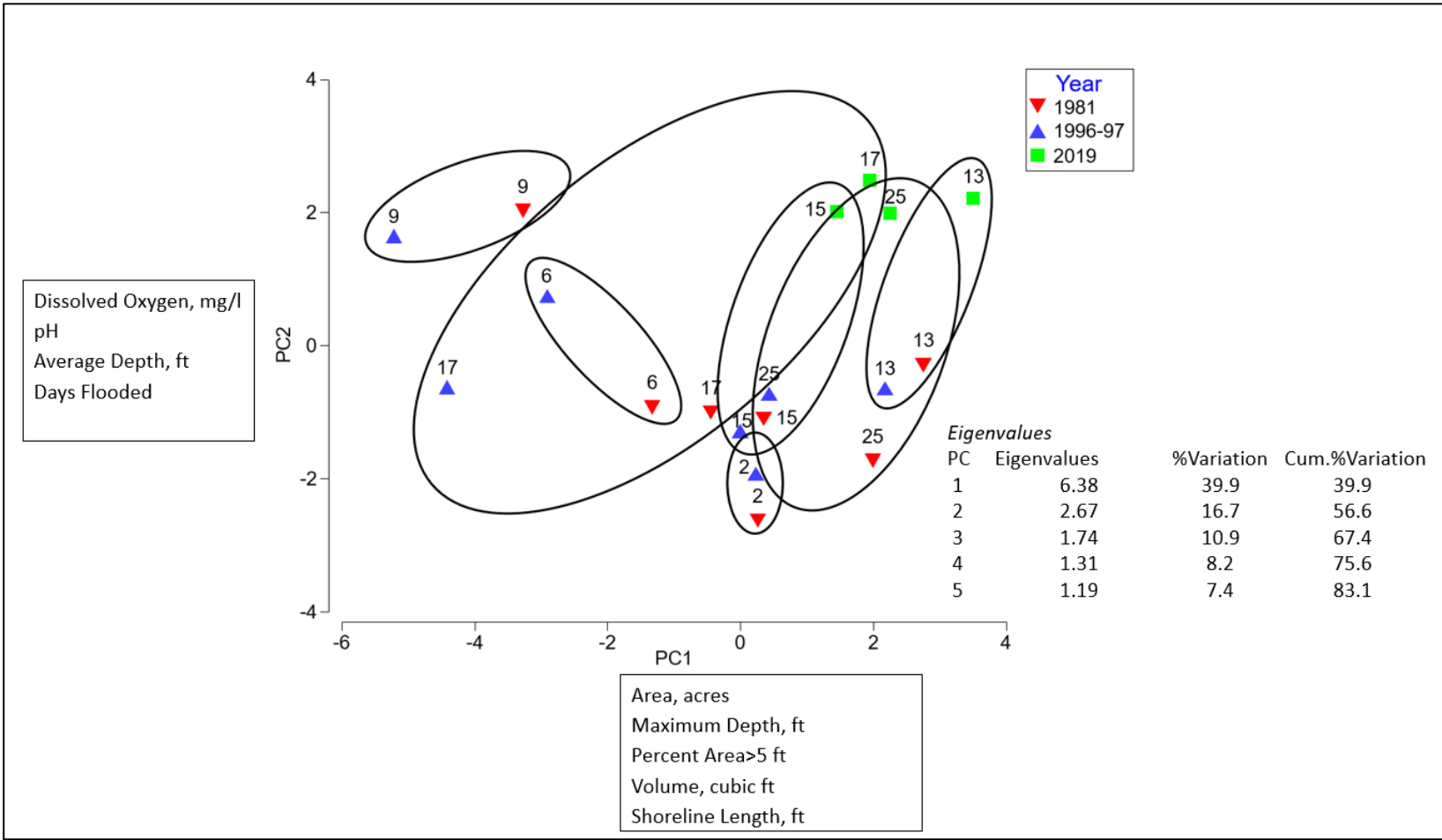
Table 4 (cont.). Comparison of morphometric, water quality, and species diversity variables for the same riverside borrow areas in the Mississippi River measured during summer of 1981 (Cobb et al. 1984), 1996–1997, and 2019. Only borrow areas 13, 15, 17, and 25 were sampled during all three years.

Species diversity variables are only reported for the 1981 and 1996–1997 sampling periods when rotenone was used to collect fish.

Variable	Number 25			Number 2		Number 6		Number 9		Number 13			Number 15			Number 17		
	1981	1997	2019	1981	1996	1981	1996	1981	1996	1981	1997	2019	1981	1997	2019	1981	1997	2019
Water Temperature (°C)	32	31.6	31.8	32	31	32	32	31	29	34	35	34	33	36	32	33	24	29
Turbidity (NTU)	10	35	24	42	22	18	15	13	44	8	7	8	10	33	9	16	27	25
Standardized Species Richness (S) ^a	26	40	–	28	40	33	38	27	26	29	44	–	32	43	–	20	33	–
Pielou's Evenness (<i>J'</i>)	0.21	0.23	–	0.58	0.36	0.52	0.32	0.6	0.54	0.47	0.44	–	0.52	0.5	–	0.42	0.52	–
Simpson's Dominance (<i>D</i>)	0.29	0.64	–	0.73	0.49	0.74	0.43	0.8	0.76	0.71	0.69	–	0.72	0.69	–	0.65	0.74	–

^a Number of species predicted for a random sample of 11,500 individuals based on rarefaction.

Figure 1. Principal component analysis (PCA) of morphometric and water quality variables measured in seven borrow areas sampled in 1981, 1996–1997, and 2019. Ellipses illustrate the relative position of the same borrow areas sampled in the three sampling periods. Boxes next to the principal component (PC) axis indicate high loading variables. Cumulative variation accounted for by each PC axis is shown in the inset table.



2.3.2 Fish Community—Rotenone Samples

Overall, 75 species of fishes were collected with rotenone from riverside borrow areas in 1981 and 1996–1997 (Table 5). The number of species collected per borrow area ranged from 18 to 50, with a mean (± 1 standard deviation) of 31 ± 8 species. The number of fish per acre ranged from 829 to 62,160, with a mean of $11,320 \pm 11,579$ fish. Taxonomically dominant groups were minnows (16 taxa) and sunfishes (13 taxa). Catfishes, suckers, and darters were moderately speciose (7–8 spp.). Invasive carps (minnow family) were only collected in 1996–1997; Grass Carp, Silver Carp, and Bighead Carp. Numerically abundant species were forage fishes, including Gizzard Shad, Threadfin Shad, and juvenile sunfishes. None of the species collected are federally listed as threatened or endangered (Anonymous 1997), but several species are regionally imperiled (Robison and Buchanan 1988; Jelks et al. 2008). Borrow areas with riverine connections function similarly to oxbow lakes and may provide alternate habitat and refugia during high water events for riverine and wetland species declining elsewhere in their range (Miranda et al. 2013).

Table 5. Species abundance (number per acre) for fishes collected with rotenone in borrow areas during 1981 ($n = 25$) and 1996–1997 ($n = 8$).

Family	Genus, Species	Common Names	1981	1996–1997	Totals
Polyodontidae (paddlefish)	<i>Polyodon spathula</i>	Paddlefish	44	41	85
Lepisosteidae (gars)	<i>Atractosteus spatula</i>	Alligator Gar	—	1	1
	<i>Lepisosteus oculatus</i>	Spotted Gar	587	407	994
	<i>Lepisosteus osseus</i>	Longnose Gar	7	7	14
	<i>Lepisosteus platostomus</i>	Shortnose Gar	289	11	300
	<i>Lepisosteus</i> sp.	Juvenile gar	20	3	23
Amiidae (bowfin)	<i>Amia calva</i>	Bowfin	42	49	91
Hiodontidae (mooneyes)	<i>Hiodon alosoides</i>	Goldeye	15	6	21
	<i>Hiodon</i> sp.	Juvenile Hiodontidae	—	24	24
Anguillidae (freshwater eels)	<i>Anguilla rostrata</i>	American Eel	9	—	9
Clupeidae (herrings)	<i>Alosa chrysochloris</i>	Skipjack Herring	1	10	11
	<i>Dorosoma cepedianum</i>	Gizzard Shad	135,590	25,021	160,611
	<i>Dorosoma petenense</i>	Threadfin Shad	50,285	7,573	57,858
	<i>Dorosoma</i> sp.	Juvenile shad	10	3,529	3,539
Cyprinidae (minnows)	<i>Ctenopharyngodon idella</i>	Grass Carp	—	2	2
	<i>Cyprinella lutrensis</i>	Red Shiner	20	—	20

Table 5 (cont.). Species abundance (number per acre) for fishes collected with rotenone in borrow areas during 1981 ($n = 25$) and 1996–1997 ($n = 8$).

Family	Genus, Species	Common Names	1981	1996–1997	Totals
Cyprinidae (minnows) (cont.)	<i>Cyprinella venusta</i>	Blacktail Shiner	—	2	2
	<i>Cyprinus carpio</i>	Common Carp	6,942	75	7,017
	<i>Hybognathus nuchalis</i>	Mississippi Silvery Minnow	—	1	1
	<i>Hypophthalmichthys molitrix</i>	Silver Carp	—	1	1
	<i>Hypophthalmichthys nobilis</i>	Bighead Carp	—	2	2
	<i>Lythrurus fumeus</i>	Ribbon Shiner	160		160
	<i>Macrhybopsis storeriana</i>	Silver Chub	—	20	20
	<i>Notropis atherinoides</i>	Emerald Shiner	100	1	101
	<i>Notemigonus crysoleucas</i>	Golden Shiner	212	196	408
	<i>Notropis blennioides</i>	River Shiner	10	—	10
	<i>Notropis maculatus</i>	Taillight Shiner	186	873	1,059
	<i>Notropis shumardi</i>	Silverband Shiner	67	8	75
	<i>Opsopoeodus emiliae</i>	Pugnose Minnow	191	1,151	1,342
	<i>Pimephales vigilax</i>	Bullhead Minnow	140	16	156
	<i>Notropis</i> sp.	Juvenile minnow/shiner	30	1	31
Catostomidae (suckers)	<i>Carpionodes carpio</i>	River Carpsucker	357	11	368
	<i>Carpionodes cyprinus</i>	Quillback	3	—	3
	<i>Carpionodes velifer</i>	Highfin Carpsucker	11	—	11
	<i>Ictiobus bubalus</i>	Smallmouth Buffalo	775	192	967
	<i>Ictiobus cyprinellus</i>	Bigmouth Buffalo	1,355	216	1,571
	<i>Ictiobus niger</i>	Black Buffalo	138	72	210
	<i>Minytrema melanops</i>	Spotted Sucker	7	4	11
	<i>Catostomidae</i>	Juvenile suckers	90	—	90
	<i>Ictiobus</i> sp.	Juvenile buffalo	—	2	2
Ictaluridae (catfishes)	<i>Ameiurus natalis</i>	Yellow Bullhead	335	66	401
	<i>Ameiurus melas</i>	Black Bullhead	1,304	14	1,318
	<i>Ameiurus nebulosus</i>	Brown Bullhead	2	—	2
	<i>Ictalurus furcatus</i>	Blue Catfish	17	1	18
	<i>Ictalurus punctatus</i>	Channel Catfish	2,344	703	3,047
	<i>Noturus gyrinus</i>	Tadpole Madtom	158	66	224
	<i>Noturus miurus</i>	Brindled Madtom ¹	10	—	10
	<i>Pygodictis olivaris</i>	Flathead Catfish	15	5	20
Esocidae (pikes)	<i>Esox americanus</i>	Grass or Redfin Pickerel	—	6	6
	<i>Esox niger</i>	Chain Pickerel	1	—	1
Aphredoderidae (pirate perch)	<i>Aphredoderus sayanus</i>	Pirate Perch	—	22	22
Mugilidae (mulletts)	<i>Mugil cephalus</i>	Striped Mullet	2	2	4

Table 5 (cont.). Species abundance (number per acre) for fishes collected with rotenone in borrow areas during 1981 ($n = 25$) and 1996–1997 ($n = 8$).

Family	Genus, Species	Common Names	1981	1996–1997	Totals
Atherinopsidae (silversides)	<i>Labidesthes sicculus</i>	Brook Silverside	1,379	37	1,416
	<i>Menidia audens</i>	Mississippi Silverside	3,035	260	3,295
	<i>Atherinopsidae</i>	Juvenile silversides	—	11	11
Fundulidae (topminnows)	<i>Fundulus chrysotus</i>	Golden Topminnow	11	17	28
	<i>Fundulus dispar</i>	Starhead Topminnow	—	16	16
	<i>Fundulus notatus</i>	Blackstripe Topminnow	31	140	171
	<i>Fundulus olivaceus</i>	Blackspotted Topminnow	283	—	283
Poeciliidae (livebearers)	<i>Gambusia affinis</i>	Western Mosquitofish	4,561	77	4,638
Moronidae (temperate basses)	<i>Morone chrysops</i>	White Bass	49	99	148
	<i>Morone mississippiensis</i>	Yellow Bass	728	245	973
Centrarchidae (sunfishes)	<i>Centrarchus macropterus</i>	Flier	—	9	9
	<i>Lepomis cyanellus</i>	Green Sunfish	36	83	119
	<i>Lepomis humilis</i>	Orangespotted Sunfish	13,035	2,397	15,432
	<i>Lepomis gulosus</i>	Warmouth	2,907	1,280	4,187
	<i>Lepomis macrochirus</i>	Bluegill	14,515	6,562	21,077
	<i>Lepomis marginatus</i>	Dollar Sunfish	—	131	131
	<i>Lepomis megalotis</i>	Longear Sunfish	4,226	206	4,432
	<i>Lepomis microlophus</i>	Redear Sunfish	97	682	779
	<i>Lepomis miniatus</i>	Redspotted Sunfish	32	47	79
	<i>Lepomis symmetricus</i>	Bantam Sunfish	—	213	213
	<i>Micropterus salmoides</i>	Largemouth Bass	647	983	1,632
	<i>Pomoxis annularis</i>	White Crappie	8,320	1,016	9,336
	<i>Pomoxis nigromaculatus</i>	Black Crappie	852	901	1,753
	<i>Lepomis</i> sp.	Juvenile sunfish	44,702	12,951	57,653
	<i>Pomoxis</i> sp.	Juvenile crappie	—	50	50
Percidae (perches)	<i>Etheostoma asprigene</i>	Mud Darter	—	9	9
	<i>Etheostoma chlorosoma</i>	Bluntnose Darter	—	3	3
	<i>Etheostoma proeliare</i>	Cypress Darter	—	3	3
	<i>Percina caprodes</i>	Logperch	1	11	12
	<i>Percina shumardi</i>	River Darter	—	2	2
	<i>Sander canadense</i>	Sauger	4	11	15
Sciaenidae (drums)	<i>Aplodinotus grunniens</i>	Freshwater Drum	1,943	1372	3,315
Totals	75 Species	75 Species	303,275	70,237	373,512

Borrow area fish communities were described using three different measures of species diversity. Standardized species richness ranged from 18 to 44 species per 11,500 individuals (i.e., approximates mean number of fish per acre), similar to total observed number of species that ranged from 18 to 50 (Table 6). However, rarefaction is less biased to sample size than raw species richness. Pielou's evenness index ranged from 0.2, indicating the presence of a few dominant species, to 0.7 indicating similarity in abundances among the species. Simpson dominance index ranged from 0.2 to 0.9 corresponding to the evenness metric that some borrow areas are dominated by only a few species. Gizzard Shad, Threadfin Shad, and juvenile sunfishes comprised almost 75% of the total individuals in borrow areas, contributing to low evenness and high dominance. Other species represented 5% or less of the total individuals.

Table 6. Statistical properties of fish species diversity measures for 33 rotenone sampling events in 1981 and 1996–1997.

Variable	Mean	Std Dev	Minimum	Maximum
Total species observed, S^*	31	8	18	50
Standardized species richness, $S/11,500$ individuals	29.1	6.8	18.0	44
Evenness, J'	0.5	0.1	0.2	0.7
Dominance, D	0.6	0.2	0.2	0.9
Number of fish per acre	11,330	11,575	829	62,160

Comparison of the diversity measures between decades showed species richness increasing from 1981 to 1996–1997, evenness remaining steady, but dominance shifting either up or down (Table 4). In addition to the three dominant species mentioned previously, Bluegill Sunfish, Channel Catfish, Orangespotted Sunfish, and White Crappie were common in the collections and further contributed to low evenness and high dominance of riverside borrow area fish communities. These species are widespread throughout the LMR and most are considered generalists in their tolerance to habitat and water quality fluctuations. Reductions in the depth of borrow areas are more than compensated by increases in shoreline complexity (e.g., shoreline length and SDI) so that habitat suitability, along with species richness, increases over time.

2.3.3 HSI Model—Rotenone Samples

The calculated values from the multiple regression equations for the three measures of diversity were investigated to select the most robust HSI model. Models for species evenness and dominance had low to moderate

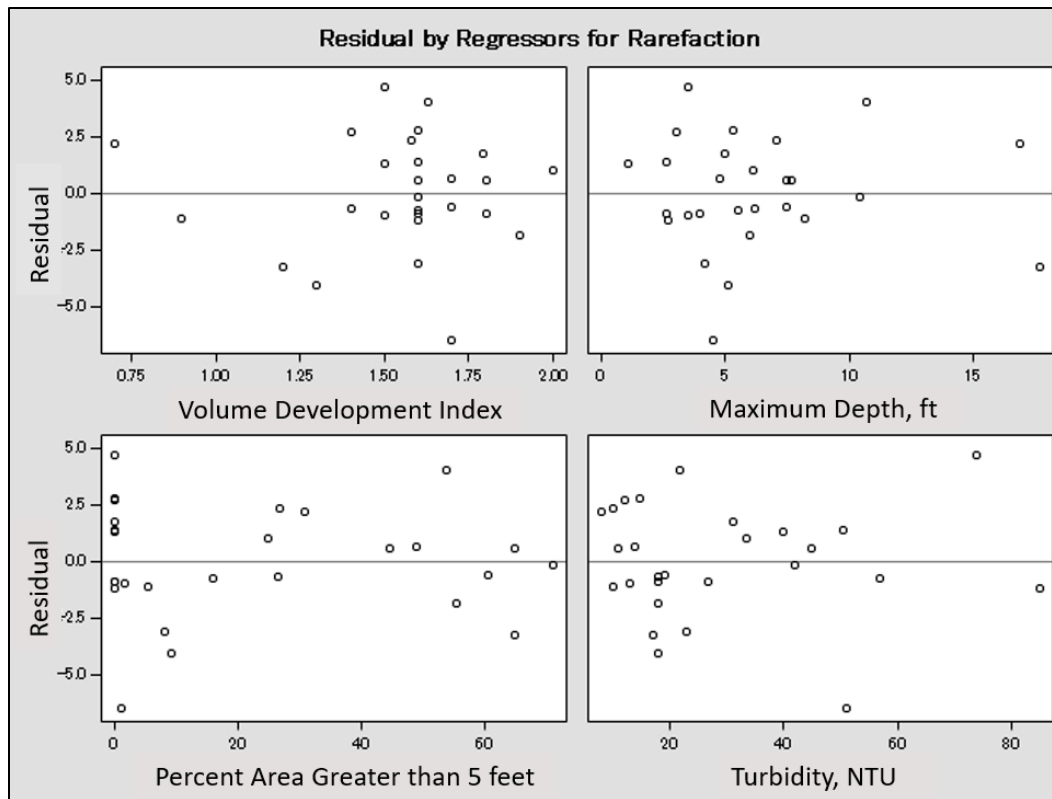
predictive capability with adjusted R^2 values less than 0.45 even with outliers removed (Table 7). Significant variables used in the model required an entry level of $\alpha = 0.05$ and retention selection value of $\alpha = 0.05$, thus weighting their importance in predicting species richness. Turbidity was the only independent variable that met these criteria for evenness and dominance. Low predictive capability and selection of only one independent variable may be due to the restricted range of possible values (as compared to species richness) and inherent bias of ratio-based measures.

Table 7. Multiple regression equations and statistical properties of diversity measures for riverside borrow areas in the LMR sampled in 1981 and 1996–1997 with rotenone. Standardized species richness had the highest correlation coefficient (R^2) with six outliers removed were used as the normalized habitat suitability index (HSI) to evaluate project alternatives.

Diversity Index	n	Model-Parameter Estimates	Adjusted R^2	F	Probability $> F$	Outliers Removed (Borrow Area Number/Year)
Pielou's Evenness	29	0.004 ($Turbidity_{NTU}$) + 0.41	0.43	22.17	0.0001	3/'81; 21/'81; 25/'81; 23/'81
Simpson Dominance	30	0.003 ($Turbidity_{NTU}$) + 0.60	0.17	7.09	0.0127	3/'81; 21/'81; 23/'81
Standardized Richness (Rarefaction)	27	31.2 (VDI) + 2.2 (Maximum Depth) - 0.2(Percent Area > 5ft) - 0.1($Turbidity_{NTU}$) - 24.3	0.83	31.74	0.0001	1/'81; 4/'81; 11/'81; 13/'97; 17/'81; 25/'81

The multiple regression with standardized species richness as the response variable was highly significant, and with outliers removed, the adjusted R^2 increased from 0.14 to 0.83. Six outliers were removed, decreasing the sample size from 33 to 27, to increase R^2 while retaining significant independent habitat variables influencing species richness. Outliers removed either had high dominance of one or two species (i.e., Threadfin Shad, Gizzard Shad, and small sunfish), or spurious correlations to the independent habitat variables. A final set of observations highly influential to the coefficient values were removed if they had a high predictive residual (>7), high studentized residual (>3), or high Cook's D value (>0.3) (Zuur et al. 2010). These measures were used to maximize the coefficient of determination resulting in the objective removal of the six borrow areas to achieve an R^2 of 0.83. Residuals did not show an obvious pattern, indicating that errors have constant variance, and there was no indication of correlated or missing variables (Figure 2). Therefore, the model met the assumption of independence for parametric analysis and errors were normally distributed.

Figure 2. Plot of (predictive or studentized) residuals between predicted standardized species richness and each independent variable for rotenone samples collected from riverside borrow areas in 1981 and 1996–1997.



The species richness multiple regression analysis retained the following four independent variables: VDI, maximum depth, percent area greater than 5 ft, and turbidity. VDI and maximum depth were positively correlated to species richness, while percent area greater than 5 ft and turbidity were negatively correlated, possibly due to low dissolved oxygen near the bottom. This combination of variables indicates that high species richness is associated with borrow areas more bowl-shaped than rectangular, areas with deep water (>6 to 7 ft), and lower turbidity. The negative correlation of percent area greater than 5 ft suggests that borrow areas with a combination of deep water and some areas less than 5 ft optimize species richness.

The model was highly significant ($F = 31.74$, $p < 0.0001$) with parameter estimates indicating that borrow area morphometry (i.e., VDI) has the greatest influence on HSI scores followed by maximum depth (Table 8). The presence of some shallow areas and reduced turbidity were statistically significant but were less influential on overall HSI scores. The variance inflation estimates, which indicate how much the variance

of regression coefficients are inflated due to multicollinearity in the model, was low (1) to moderate (4), suggesting a moderate to high reliability in predicting species richness from a combination of these habitat variables (Table 8).

Table 8. Statistical output of the multivariate regression analysis for the dependent variable species richness (determined by rarefaction), including parameter estimates and variance inflation scores for riverside borrow areas sampled with rotenone in 1981 and 1996–1997.

Analysis of Variance, $n = 27$					
Source	Degrees of Freedom (DF)	Sum of Squares	Mean Square	FValue	Probability > F
Model	4	934.89	233.72	31.74	<0.0001
Error	22	161.99	7.36	—	—
Corrected Total	26	1,096.88	—	—	—
—	Root-mean-square-error	2.71	R^2	0.85	—
—	Dependent Mean	29.16	Adjusted R^2	0.83	—
—	Coeff. Var.	9.30	—	—	—
Parameter Estimates, DF = 1					
Variable	Parameter Estimate	Standard Error	t Value	Probability > t	Variance Inflation
Intercept	-24.35	5.48	-4.45	0.0002	0.00
VDI (ft)	31.25	3.04	10.29	<0.0001	2.49
MAX_DEP (ft)	2.17	0.28	7.82	<0.0001	4.19
Arkansas_5FT (ft)	-0.20	0.04	-5.46	<0.0001	3.19
TURB_S (NTU)	-0.13	0.03	-4.67	0.0001	1.18

Maximum depth (MAX_DEP), percent area greater than 5 ft (Arkansas_5FT), and surface turbidity (TURB_S).

The predicted standardized species richness was divided by the maximum richness value to normalize the HSI score between 0 and 1. There were 43 species observed in the 27 borrow areas that were retained in the analysis. Thus, the species richness multiple regression equation was divided by 43 (Equation [4]).

$$HSI = \frac{31.2(VDI)+2.2(max. \text{ depth ft})-0.2(percent \text{ area } > 5ft)-0.1(turbidity \text{ NTU})-24.3}{43} \quad (4)$$

The calculated HSI may occasionally exceed 1.0 or fall below zero when using habitat values outside the range of those measured in the borrow areas; these values will be rescaled to 0.1 or 1.0. For application to the

MRL project, HSI values were multiplied by area (acres of borrow areas) to express alternatives as HUs.

2.3.4 Relative Value Index (RVI) for Landside Borrow Areas

Rotenone sampling was not conducted in landside borrow areas. Riverside and landside borrow were similar in morphometry. However, hydrology differs in that precipitation maintains water levels in most landside pits along with drainage ditches and relief wells that may provide some level of hyporheic flows. Most landside borrow areas were surrounded by agricultural fields. Conversely, periodic connection to the river and hyporheic flow from the Mississippi alluvial aquifer maintains water levels in riverside areas and most are surrounded by trees.

Seining and gillnet data were used to compare species assemblage differences between riverside and landside borrow areas. Overall, fishes were more abundant and diverse in riverside borrow areas than landside. A total of 18 species were collected with gillnets in landside borrow areas during 1997 compared to 31 and 30 species in riverside borrow areas during 1997 and 2019, respectively (Table 9). Gizzard Shad was the most abundant species in all borrow areas. Species associated with riverine environments were not unusual, and sometimes frequent, in riverside borrow areas, but were absent, and almost always in low abundance in landside borrow areas. These include Mooneye, Alligator Gar, White Bass, River Carpsucker, and Sauger. Seining had similar results. A total of 17 species were collected landside, compared to 38 and 44 species riverside during the 1997 and 2019 collections, respectively (Table 10). Four species comprised over 80% of the total individuals in landside borrow areas, Orangespotted Sunfish, Largemouth Bass, Mississippi Silverside, and Bluegill. With the exception of Mississippi Silverside, the three remaining species are habitat generalists and often found in isolated ponds and lakes. Invasive carp (i.e., primarily Silver Carp) were not collected in the 1980s, were present in relatively low numbers in the 1990s, but were prevalent in the 2019 collections based on observations of jumping adults.

Table 9. Number of fishes collected by species with gillnets in landside (1997) and riverside (1997 and 2019) borrow areas. Species are arranged in order of abundance. Columns for each respective sampling period are highlighted for frequency of occurrence (*F*) and relative percent occurrence (*P*).

Landside 1997, <i>n</i> = 23			Riverside 1997, <i>n</i> = 29			Riverside 2019, <i>n</i> = 36		
Common Name	<i>F</i>	<i>P</i>	Common Name	<i>F</i>	<i>P</i>	Common Name	<i>F</i>	<i>P</i>
Gizzard Shad	68	37.36	Gizzard Shad	98	21.03	Gizzard Shad	74	18.78
Bigmouth Buffalo	21	11.54	Spotted Gar	78	16.74	Spotted Gar	71	18.02
Common Carp	21	11.54	Common Carp	59	12.66	Smallmouth Buffalo	46	11.68
Spotted Gar	15	8.24	Bigmouth Buffalo	32	6.87	Shortnose Gar	41	10.41
White Crappie	9	4.95	Smallmouth Buffalo	30	6.44	Channel Catfish	31	7.87
Channel Catfish	7	3.85	Bowfin	27	5.79	Black Buffalo	25	6.35
Bowfin	6	3.3	Channel Catfish	27	5.79	River Carpsucker	14	3.55
Freshwater Drum	6	3.3	Black Buffalo	16	3.43	Bigmouth Buffalo	12	3.05
Black Bullhead	5	2.75	Freshwater Drum	14	3	Bowfin	10	2.54
Largemouth Bass	5	2.75	Largemouth Bass	14	3	Common Carp	10	2.54
Threadfin Shad	4	2.2	White Crappie	9	1.93	Silver Carp	10	2.54
Warmouth	4	2.2	Warmouth	8	1.72	Black Crappie	8	2.03
Black Crappie	3	1.65	Black Crappie	6	1.29	Longnose Gar	7	1.78
Bluegill	3	1.65	Bluegill	6	1.29	Threadfin Shad	6	1.52
Black Buffalo	1	0.55	Mooneye	6	1.29	Freshwater Drum	5	1.27
Blue Catfish	1	0.55	Black Bullhead	4	0.86	Striped Mullet	4	1.02
Paddlefish	1	0.55	Dollar Sunfish	4	0.86	Blue Catfish	3	0.76
Smallmouth Buffalo	1	0.55	Paddlefish	4	0.86	Orangespotted Sunfish	3	0.76
Yellow Bass	1	0.55	Shortnose Gar	4	0.86	Bluegill	2	0.51
—	—	—	Yellow Bass	4	0.86	Flathead Catfish	2	0.51
—	—	—	Flathead Catfish	2	0.43	White Crappie	2	0.51
—	—	—	Spotted Sucker	2	0.43	Lepomis sp.	1	0.25
—	—	—	Threadfin Shad	2	0.43	Morone sp.	1	0.25
—	—	—	Yellow Bullhead	2	0.43	Paddlefish	1	0.25
—	—	—	Alligator Gar	1	0.21	Quillback	1	0.25
—	—	—	Blue Catfish	1	0.21	Skipjack Herring	1	0.25
—	—	—	Redear Sunfish	1	0.21	Spotted Sucker	1	0.25
—	—	—	River Carpsucker	1	0.21	Warmouth	1	0.25
—	—	—	Sauger	1	0.21	White Bass	1	0.25
—	—	—	White Bass	1	0.21	—	—	—

Table 10. Number of fish collected by species with seines in landside and riverside borrow areas. Species are arranged in order of abundance.

Landside 1997, <i>n</i> = 4			Riverside 1997, <i>n</i> = 5			Riverside 2019, <i>n</i> = 6		
Common Name	<i>F</i>	<i>P</i>	Common Name	<i>F</i>	<i>P</i>	Common Name	<i>F</i>	<i>P</i>
Orangespotted Sunfish	713	36.3	Threadfin Shad	2,632	31.79	<i>Lepomis</i> sp.	2,453	34.39
Largemouth Bass	404	20.57	Orangespotted Sunfish	1,267	15.3	Orangespotted Sunfish	2,375	33.3
Mississippi Silverside	282	14.36	Bluegill	935	11.29	Mississippi Silverside	369	5.17
Bluegill	235	11.97	Pugnose Minnow	804	9.71	Western Mosquitofish	284	3.98
Golden Shiner	112	5.7	Western Mosquitofish	776	9.37	Threadfin Shad	281	3.94
White Crappie	61	3.11	<i>Lepomis</i> sp.	471	5.69	Bullhead Minnow	277	3.88
Golden Topminnow	37	1.88	Mississippi Silverside	415	5.01	Bluegill	189	2.65
Gizzard Shad	34	1.73	Gizzard Shad	152	1.84	Longear Sunfish	176	2.47
Threadfin Shad	33	1.68	Warmouth	96	1.16	Channel Catfish	149	2.09
Western Mosquitofish	28	1.43	Largemouth Bass	90	1.09	Shoal Chub	70	0.98
Channel Catfish	9	0.46	Longear Sunfish	89	1.08	Channel Shiner	64	0.9
Black Bullhead	5	0.25	Taillight Shiner	88	1.06	Freshwater Drum	58	0.81
Freshwater Drum	5	0.25	Bantam Sunfish	69	0.83	Blacktail Shiner	51	0.71
Bigmouth Buffalo	2	0.1	Blackstripe Topminnow	60	0.72	Silver Chub	40	0.56
Green Sunfish	2	0.1	Redear Sunfish	45	0.54	Mississippi Silvery Minnow	37	0.52
Bantam Sunfish	1	0.05	White Crappie	43	0.52	Gizzard Shad	27	0.38
White Bass	1	0.05	Bullhead Minnow	39	0.47	Warmouth	25	0.35
—	—	—	Silver Chub	34	0.41	Silverband Shiner	24	0.34
—	—	—	Channel Catfish	28	0.34	Black Crappie	22	0.31
—	—	—	Golden Shiner	23	0.28	Redspotted Sunfish	21	0.29
—	—	—	Golden Topminnow	21	0.25	Taillight Shiner	21	0.29
—	—	—	Green Sunfish	18	0.22	Blackstripe Topminnow	20	0.28
—	—	—	Black Crappie	17	0.21	Smallmouth Buffalo	19	0.27

Table 10 (cont.). Number of fish collected by species with seines in landside and riverside borrow areas. Species are arranged in order of abundance.

Landside 1997, <i>n</i> = 4			Riverside 1997, <i>n</i> = 5			Riverside 2019, <i>n</i> = 6		
Common Name	<i>F</i>	<i>P</i>	Common Name	<i>F</i>	<i>P</i>	Common Name	<i>F</i>	<i>P</i>
—	—	—	Blackbanded Darter	8	0.1	White Crappie	12	0.17
—	—	—	Smallmouth Buffalo	8	0.1	Blackspotted Topminnow	10	0.14
—	—	—	Sailfin Molly	7	0.08	Brook Silverside	10	0.14
—	—	—	Pirate Perch	6	0.07	Pugnose Minnow	9	0.13
—	—	—	Freshwater Drum	5	0.06	Bluntnose Darter	7	0.1
—	—	—	Yellow Bass	5	0.06	Blue Catfish	5	0.07
—	—	—	Bluntnose Darter	4	0.05	Green Sunfish	4	0.06
—	—	—	Redspotted Sunfish	4	0.05	Pirate Perch	3	0.04
—	—	—	Tadpole Madtom	4	0.05	Spotted Gar	3	0.04
—	—	—	Mud Darter	3	0.04	Flathead Catfish	2	0.03
—	—	—	Silverband Shiner	3	0.04	River Carpsucker	2	0.03
—	—	—	Starhead Topminnow	3	0.04	Spotted Bass	2	0.03
—	—	—	Bowfin	2	0.02	Tadpole Madtom	2	0.03
—	—	—	Gulf Pipefish	2	0.02	White Bass	2	0.03
—	—	—	Longnose Gar	2	0.02	Bantam Sunfish	1	0.01
—	—	—	Common Carp	1	0.01	Emerald Shiner	1	0.01
—	—	—	—	1	0.01	Longnose Gar	1	0.01
—	—	—	—	1	0.01	Mud Darter	1	0.01
—	—	—	—	1	0.01	Sauger	1	0.01
—	—	—	—	1	0.01	Shortnose Gar	1	0.01
—	—	—	—	1	0.01	Walleye	1	0.01
—	—	—	—	1	0.01	Yellow Bass	1	0.01

Species composition between riverside and landside borrow areas was similar to that described by Miranda et al. (2013) in that riverside borrow areas tended to have fish assemblages with a higher representation of rheophilic species that depend on flow, or simply the flooding, afforded by large tributaries to complete their life cycle in lacustrine systems. In contrast, landside oxbow lakes with reduced or no connectivity tended to have a higher representation of lacustrine species, partly because of the loss of rheophilic species and partly because of a more stable lacustrine environment that was less influenced by periodic floods.

Species diversity measures showed the same trends (Tables 11 and 12). For gillnets, species richness was 25% to 33% higher and catch-per-unit-effort

(i.e., number per 5 or 6 nets) was more than twice as high in riverside borrow areas. However, landside borrow areas were more likely to be dominated (i.e., lower D score) by one species, usually Gizzard Shad (Table 9). Seining data were even more pronounced. Species richness was twice as high in riverside borrow areas for both sampling periods. Evenness was higher in riverside borrow areas characterized by a more equitable abundance among a more diverse assemblage. Mean catch-per-unit-effort was three times higher in riverside borrow areas. Similar to gillnet data, landside pits were more likely to be dominated by only a few tolerant species (Table 10).

Table 11. Summary of fish species diversity measures for gillnets set in landside and riverside borrow areas sampled in 1997 and 2019.

Variable	Mean	Std Dev	Minimum	Maximum
	Landside 1997, $n = 23$			
Total species observed (S^*)	4.0	2.6	0.0	8.0
Standardized species richness ($S/12$ individuals)	3.8	2.4	0.0	8.0
Evenness (J')	0.9	0.2	0.5	1.0
Dominance, (D)	0.7	0.3	0.0	1.0
Number of fish per gillnet	7.9	6.1	0.0	22.0
—	Riverside 1997, $n = 30$			
Total species observed (S^*)	7.1	3.1	2.0	12.0
Standardized species richness ($S/12$ individuals)	5.7	2.0	2.0	9.0
Evenness, (J')	0.9	0.1	0.7	1.0
Dominance, (D)	0.8	0.1	0.6	1.0
Number of fish per gillnet	16.4	9.3	2.0	34.0
—	Riverside 2019, $n = 36$			
Total species observed (S^*)	5.5	2.4	1.0	13.0
Standardized species richness ($S/12$ individuals)	5.1	1.8	1.0	8.6
Evenness (J')	0.9	0.1	0.7	1.0
Dominance (D)	0.8	0.1	0.5	1.0
Number of fish per gillnet	10.4	6.0	1.0	27.0

Table 12. Summary of fish species diversity measures for seining in landside and riverside borrow areas sampled in 1997 and 2019.

Variable	Mean	Std Dev	Minimum	Maximum
	Landside 1997, <i>n</i> = 4			
Total species observed (<i>S</i> *)	9.5	2.4	8.0	13.0
Standardized species richness (<i>S</i> /12 individuals)	9.5	2.4	8.0	13.0
Evenness (<i>J'</i>)	0.5	0.1	0.4	0.6
Dominance (<i>D</i>)	0.6	0.1	0.5	0.6
Number of fish per 10 hauls	491	222	199	724
—	Riverside 1997, <i>n</i> = 5			
Total species observed (<i>S</i> *)	19.4	3.8	14.0	24.0
Standardized species richness (<i>S</i> /12 individuals)	18.5	3.3	14.0	22.0
Evenness (<i>J'</i>)	0.7	0.1	0.6	0.7
Dominance (<i>D</i>)	0.8	0.0	0.8	0.9
Number of fish per 10 hauls	1,656	1,716	298	3,991
—	Riverside 2019, <i>n</i> = 6			
Total species observed (<i>S</i> *)	19.8	7.2	9.0	29.0
Standardized species richness (<i>S</i> /12 individuals)	18.4	5.9	9.0	26.0
Evenness (<i>J'</i>)	0.6	0.1	0.3	0.7
Dominance (<i>D</i>)	0.7	0.1	0.5	0.8
Number of fish per 10 hauls	1,189	1,431	66	3,237

The average percent difference in standardized species richness between landside and riverside borrow areas was calculated separately by gear type, and the mean value was designated as the RVI. The two gears sample a different component of the fish assemblage and taking the mean value provides a more complete description of both small, littoral fish (seining) and larger pelagic fish (gillnets).

The RVI was calculated as follows:

- Percent difference using gillnets: $3.8 / 5.4 = 0.70$
- Percent difference using seines: $9.5 / 18.5 = 0.51$
- RVI, Mean of gillnets and seines: 0.6

For landside borrow areas, the HSI value calculated from Equation (4) should be multiplied by 0.6 prior to calculating HUs. The resulting value considers lower species richness in landside borrow areas based on seining and gillnet data collected in each type. These statistical models were used in the next section on impact analysis.

3 Part II: Impact Analysis

3.1 Purpose and Objective

Part II analyzes changes in fish habitat using the HEP for the MRL SEIS II. Alternative 1 was “no action” and was not considered in this analysis. Two alternatives were analyzed, Alternative 2—traditional construction and Alternative 3—avoid and minimize. Acres of borrow areas created, enlarged, or deepened for each alternative was provided by Mississippi Valley Division—Memphis, Vicksburg, and New Orleans Districts. The HSI for fish diversity described in Part I (Section 2) was multiplied by acres to calculate HUs gained as result of borrow area construction. Other than filling in existing borrow areas from road construction or enlargement of levees, impacts of construction on other resources (terrestrial, wetlands, and waterfowl) were considered in the other appendices to the SEIS II.

3.2 Methods

The proposed levee work will create new open water habitat mostly due to the construction of borrow areas and, in a few areas, deepen or fill existing open water within the active floodplain (riverside) and on land protected by the levee (landside). For the aquatic fisheries analysis, effects greater than 0.09 acres were analyzed. The existence of open water habitat and its acreage were determined using a land cover classification developed from false color infrared aerial photography with a 5 m resolution collected in 2014. The minimum mapping unit was 20 acres though smaller areas of land cover were often classified. Land cover classified as open water includes all aquatic features (borrow pits, scour holes, lakes, and channels) thus 2016 and 2017 National Agriculture Imagery Program images (NAIP, n.d.) were investigated to determine the type of aquatic feature affected by the project. Open water was assumed to be a borrow area if the feature was generally rectangular, near the levee, and had occasional peninsulas or traverses (narrow strips of land separating adjacent open water); any questionable open water was classified as borrow area.

Acreages were determined for Alternative 2 and 3. Alternative 2 (traditional construction) will consist of traditional construction methods to raise and stabilize the deficient sections of the levees and floodwalls and to control seepage. Borrow areas would normally be located riverside of the levee at the nearest sites with suitable soils. This plan would require no

special criteria for siting the location of borrow areas other than for engineering provisions. No provisions would be made for environmental enhancement features for the borrow areas. Alternative 3 (Avoid and Minimize) differs in the placement of some haul roads and borrow areas. During scoping, the major issues identified were location of borrow sites, loss of bottomland hardwood forest and associated wetlands, and landowner input (John Mike Thron, Memphis District, personnel communication 2020). This alternative seeks to avoid and minimize these impacts by placing borrow areas in less environmentally sensitive areas when practicable. In addition, environmental features (e.g., irregular shorelines, islands, variable depths, etc.) that could be incorporated into borrow area designs to increase habitat value would be explored with willing landowners and non-Federal sponsors during project design. The addition of these environmental features were analyzed separately since there would be no long term site protection instruments on these private lands and due to uncertainties related to the willingness and extent of these features.

3.3 Results and Discussion

3.3.1 Acres

Overall gains in borrow area acreage were the same for both alternatives. A grand total of 1,403.9 acres of borrow area will be constructed under Alternative 2—traditional construction (Table 13). Of this total, 525.6 acres and 877.7 acres will be gained for landside and riverside borrow areas, respectively. The Avoid and Minimize alternative without environmental aquatic features, will construct 1,404.5 acres of borrow area with 414.3 of those acres occurring landside and 987.7 acres riverside (Table 13). The grand totals in Table 13 include gains and losses of borrow area due to other proposed work. Fill for levee enlargements and haul roads results in a loss of borrow area ranging from 3.3 to 4.2 acres, depending on alternative and whether it is landside or riverside of the levee (Table 13). Excavation from relief wells and deepening of existing borrow areas will result in a gain of 4.8 acres for both alternatives.

Table 13. A summary of the borrow area acres that will be created on the landside or riverside of the levee under Alternative 2 (traditional construction) and Alternative 3 (Avoid and Minimize) without environmental features. Habitat Suitability Index values were calculated from Equation (1), Part I. Habitat values used in this analysis were VDI = 1.4, maximum depth = 7.5 ft, percent area > 5 ft = 23, and average turbidity = 24 NTUs (nephelometric turbidity units), resulting in a HSI = 0.7. Relative Value Index (RVI) indicating reduced species diversity was applied to all landside borrow areas by multiplying Habitat Units by 0.6. For the Alternative 2, a total of 525.6 acres and 877.7 acres will be gained for landside and riverside borrow areas, respectively. For Avoid and Minimize alternative, a total of 1,404.5 acres of borrow area will be constructed with 414.3 of those acres occurring landside and 987.7 acres riverside.

District	Location (Proposed Work)	Alternative 2 (Traditional Construction) without Environmental Features				Alternative 3 (Avoid and Minimize) without Environmental Features			
		Acres	HSI	RVI	Habitat Units	Acres	HSI	RVI	Habitat Units
Gains (+) of Open Water due to Land Cover Conversions with New Borrow Areas									
MVM ^a	Landside (borrow)	+349.5	0.7	0.6	+147	+43.5	0.7	0.6	+18
MVM	Riverside (borrow)	+207.9	0.7	—	+146	+513.1	0.7	—	+359
MVK	Landside (borrow)	+77.9	0.7	0.6	+33	+147.6	0.7	0.6	+62
MVK ^a	Riverside (borrow)	+479.7	0.7	—	+336	+409.6	0.7	—	+287
MVN	Landside (borrow)	+98.2	0.7	0.6	+41	+223.2	0.7	0.6	+94
MVN	Riverside (borrow)	+190.1	0.7	—	+133	+65	0.7	—	+46
TOTAL	Landside (borrow)	+525.6	—	—	+221	+414.3	—	—	+174
TOTAL	Riverside (borrow)	+877.7	—	—	+614	+987.7	—	—	+691
NET TOTAL		+1403.3	—	—	+835	+1402	—	—	+865
Gains (+) or Losses (-) of Existing Open Water due to Other Proposed Work									
MVM	Riverside: (fill of open water from levee enlargement)	-0.4	0.7	—	-0.3	-0.4	0.7	—	-0.3
MVM	Landside: (excavation from relief wells)	+5.7	0.7	0.6	+2.4	+5.7	0.7	0.6	+2.4
MVK	Riverside: (deepening of existing borrow area)	+0.2	0.7	—	+0.1	+0.2	0.7	—	+0.1
MVK	Riverside: (fill of open water from haul roads)	-3.8	0.7	—	-2.6	-2.9	0.7	—	-2.0
MVN	Riverside: (fill of open water from levee enlargement)	-0.2	0.7	—	-0.1	-0.2	0.7	—	-0.1
MVN	Landside: (fill of open water from levee enlargement)	-0.9	0.7	0.6	-0.4	-0.9	0.7	0.6	-0.4

Table 13 (cont.). A summary of the borrow area acres that will be created on the landside or riverside of the levee under Alternative 2 (traditional construction) and Alternative 3 (Avoid and Minimize) without environmental features. Habitat Suitability Index values were calculated from Equation (1), Part I. Habitat values used in this analysis were VDI = 1.4, maximum depth = 7.5 ft, percent area > 5 ft = 23, and average turbidity = 24 NTUs (nephelometric turbidity units), resulting in a HSI = 0.7. Relative Value Index (RVI) indicating reduced species diversity was applied to all landside borrow areas by multiplying Habitat Units by 0.6. For the Alternative 2, a total of 525.6 acres and 877.7 acres will be gained for landside and riverside borrow areas, respectively. For Avoid and Minimize alternative, a total of 1,404.5 acres of borrow area will be constructed with 414.3 of those acres occurring landside and 987.7 acres riverside.

District	Location (Proposed Work)	Alternative 2 (Traditional Construction) without Environmental Features				Alternative 3 (Avoid and Minimize) without Environmental Features			
		Acres	HSI	RVI	Habitat Units	Acres	HSI	RVI	Habitat Units
TOTAL	Landside	+4.8	—	—	+2.0	+4.8	—	—	+2.0
TOTAL	Riverside	-4.2	—	—	-2.9	-3.3	—	—	-2.3
NET TOTAL		+0.6	—	—	-0.9	+1.5	—	—	-0.3
<hr/>									
TOTAL	Landside	+530.4	—	—	+223	+419.1	—	—	+176
TOTAL	Riverside	+873.5	—	—	+611.1	+984.4	—	—	+688.7
GRAND TOTAL		+1,403.9	—	—	+834.1	+1403.5	—	—	+864.7

^a MVN (Mississippi Valley Division, New Orleans District) and MVK (Mississippi Valley Division, Vicksburg District).

3.3.2 HSI Values

HSI values were calculated for each alternative. The four habitat variables in the HSI model (VDI, maximum depth, percent area less than 5 ft, and turbidity) were estimated from borrow areas previously sampled and a HSI value calculated using Equation (5) (Table 14):

$$HSI = \frac{31.2(VDI) + 2.2(Max.Depth_{ft}) - 0.2(\% Area > 5ft) - 0.1(Turbidity_{NTU}) - 24.3}{43} \quad (5)$$

Table 14. Habitat variable estimates, based on the range of values in Table 2, for Alternatives 2 and 3 used in Equation (5) to calculate a HSI.

Alternative (2 versus 3)	VDI	Maximum Depth (ft)	Percent Area > 5 (ft)	Turbidity (NTU)	HSI
2. Traditional and Avoid and Minimize without Environmental Features	1.4	7.5	23	24	0.7
3. Avoid and Minimize with Environmental Features	1.7	10	25	10	1.0


A HSI of 0.7 was calculated for both alternatives without environmental features. The independent variables used in the model were the grand mean values for the three sampling periods (Table 15) and represented the basic design criteria of borrow areas for both alternatives without environmental features incorporated. Alternative 3—Avoid and Minimize will reduce placement of borrow areas in wetlands or bottomland hardwood forests, but does not necessarily consider the design of the borrow area itself for aquatic benefits. However, these additional environmental features would be considered when working with willing landowners and non-federal sponsors during project design (see Section 4 and Figure 3).

Table 15. Avoid and Minimize Alternative 3 with Environmental Features. HSI values were calculated from Equation (4), Part I. Habitat variables used in this analysis were VDI = 1.7, maximum depth = 10 ft, percent area > 5 ft = 25, and average turbidity = 10 NTU, resulting in an HSI of 1.0. RVI indicating reduced species diversity was applied to all landside borrow areas by multiplying HUs by 0.6.

District	Location	Acres	HSI	RVI	HUs
MVM	Landside	43.5	1	0.6	26
MVM	Riverside	513.1	1	—	513
MVK	Landside	147.6	1	0.6	89
MVK	Riverside	409.6	1	—	410
MVN	Landside	223.2	1	0.6	134
MVN	Riverside	65	1	—	65
TOTAL	Landside	414.3	—	—	249
TOTAL	Riverside	987.7	—	—	988
GRAND TOTAL		1,402	—	—	1,236

Figure 3. Brochure summarizing environmental design concepts for borrow area construction that can be handed out to willing landowners. (Brochure developed by Bruce Reid, Lower Mississippi River Conservation Committee. Public domain.)

LEVEES ANCHOR FLOOD CONTROL




More than 100 levee construction projects are planned.


Foremost among the flood-control works along the Lower Mississippi River is the 3,500-mile-long Mississippi River and Tributaries (MR&T) levee system. MR&T levees, which are constructed of compacted soil and clay, protect more than 4 million residents, 1.5 million homes, 33,000 farms, and vital transportation routes from destructive floods. The levees are designed to protect the Mississippi River valley against the maximum probable flood by confining flow to the channel and the river's 2-million-acre, leveed floodplain, except where it enters the natural backwater areas or is diverted purposely into floodway areas. The main stem levee system — is 2,203 miles long. Some 1,607 miles lie along the Mississippi River and 596 miles lie along the south banks of the Arkansas and Red rivers and in the Atchafalaya Basin. The levees are built by the federal government and are maintained by local interests, except when federal assistance is provided during major floods. Periodic inspections of levees and other flood-control works are made by personnel from the Corps and local levee and drainage districts.

PROJECT AREA

- Extends from Cape Girardeau, Missouri to the Gulf of Mexico.
- More than 100 levee construction and seepage-control projects planned.






ENVIRONMENTAL DESIGN OF MISSISSIPPI RIVER LEVEE BORROW AREAS




RECOMMENDATIONS FOR PRIVATE LANDOWNERS

This document was produced by the U.S. Army Corps of Engineers, Memphis, Vicksburg and New Orleans districts; the Engineer Research and Development Center; and the Lower Mississippi River Conservation Committee.

LEVEE WORK IMPACT STUDY

The U.S. Army Corps of Engineers has prepared a supplemental environmental impact statement to address the impacts associated with the construction of remaining authorized work on the Mississippi River mainline levees between Cape Girardeau, Missouri, and Head of Passes in Louisiana, where the river meets the Gulf of Mexico. Remaining work includes raising and widening portions of the levee using material from borrow areas and managing seepage to protect levee foundations. More than 100 new borrow areas are planned. The Corps is studying ways to minimize the environmental impacts of borrow area construction, as well as ways of designing new borrow areas so they harbor more fish and wildlife.



Raising a levee with new fill.

BUILDING A BORROW AREA


The U.S. Army Corps of Engineers receives funding for a levee construction project, and project-specific planning and design work begins.

The Corps requests right-of-entry from a private landowner — through a non-federal sponsor such as a local levee district — where a borrow area and associated features are planned. Soil surveys and other preliminary work begins to determine soil suitability and embankment quantities required. During project design efforts, the Corps and non-federal sponsors will work with landowners to facilitate property goals and incorporate environmental features, where appropriate.


Upon design completion, the Corps requests that the non-federal sponsor acquire the necessary right-of-way for the project. The Corps will incorporate environmental features into the construction contract. Levee construction projects, including borrow area excavation, usually take two to three years to complete, but final acceptance of the project is not granted by the Corps until all project features are constructed and turf has been established on newly constructed levee features.

ENVIRONMENTAL DESIGN OF BORROW AREAS


- Borrow areas can be constructed on the river side or land side of the levee. They can cover up to 20 acres or more.
- Riparian buffers of native trees should border 50-75% of the periphery.
- Should be bowl-shaped. Deep water (up to 10 feet, 1:3 slope) should cover up to 75%; shallow water (less than 5 feet, 1:10 slope) should cover 25%.
- Islands and sinuous shorelines create varying depths and promote higher fish diversity.




FISH AND WILDLIFE INHABITING BORROW AREAS




Up to 75 species of fish occur in borrow areas. Riverside borrow areas typically harbor more species.




Wading birds such as Roseate Spoonbills, Wood Storks, and Great Egrets regularly feed in borrow areas.



Waterfowl such as Black-bellied Whistling Ducks, Wood Ducks, and Mallards feed and rest in borrow areas.



Forest and wetland birds such as Prothonotary Wabblers frequent borrow areas with wooded shorelines.



Reptiles and amphibians such as the Red-eared Slider prefer still waters and woody debris for sunning.

3.3.3 Habitat Units (HUs)

Alternative 2 results in a grand total HU gain of 223 and 611.1 for landside and riverside borrow areas, respectively (Table 15). Lower proportional gains in HUs for landside borrow areas were due to application of the RVI of 0.6, indicating reduced species diversity in borrow areas landside of the levee (see Part I). Alternative 3 without environmental features will result in a HU gain of 176 and 688.7 for landside and riverside borrow areas, respectively (Table 15). The grand total includes other construction activity resulting in losses (i.e., fill from haul roads and levee enlargement) and gains (i.e., deepening existing borrow areas). Considering both gains and losses overall, approximately 1,400 acres of borrow area will be created during the project for each alternative, and up to 865 HUs gained for the Avoid and Minimize alternative without environmental features. However, if environmental features were incorporated in each borrow area, the gain in HUs would be 1,236 (Table 15).

4 Part III: Environmental Design Features

Based on field collections since the early 1980s, we now understand that borrow areas can provide excellent habitat for both floodplain and riverine fish species. Borrow areas can have similar fish species composition as natural lakes (Miranda et al. 2013) further justifying their construction in the LMR floodplain. Borrow areas are good candidates as restoration or mitigation measures since past studies have confirmed that fish rapidly colonize constructed pits supporting the notion of “build it and they will come” (Hilderbrand et al. 2005). However, high species diversity is dependent on environmental design concepts that improve the bathymetric, morphometric, and water quality attributes of borrow areas during construction.

Field collections in borrow areas since 1981 confirm that incorporation of environmental design features will increase fish diversity, increase HUs gained, and benefit multiple ecological resources in the LMR. These features would include consideration of the model variables thus increasing the HSI to 1.0 (i.e., avoid and minimize with environmental features). Design parameters would include higher VDI, making the borrow area more cone shaped with deeper water; increasing percent area less than 5 ft—suggesting moderate sloping banks rather than steep sides—and reducing turbidity by creating riparian buffers around the borrow area to filter sediment runoff, provide additional windbreaks to reduce wave action, or implement some level of bank stabilization.

These design features have multiple benefits. Deeper water is occupied by large-bodied individuals, overwintering fishes, and can moderate water temperatures during warmer months. Moderate sloping shorelines benefit nest-building fishes, such as sunfish, promote growth of aquatic vegetation used by smaller-bodied fishes, including larvae, juveniles, and many species of minnow and shiners, and vegetation is a preferred substrate to deposit eggs by larger fishes such as buffalo. Other features not included in the model can also benefit the aquatic community by increasing the heterogeneity of the borrow area including irregular shorelines and islands. Shields and Knight (2013) reported that larger-bodied fishes and some piscivores were more common in larger, more elongated pits with more sinuous shorelines and lower turbidity supporting the addition of these features in borrow area design.

A brochure was developed describing these environmental design features that could be included in the construction of borrow areas (Figure 3). The brochure is easy to distribute to willing landowners, helps build trust between USACE field engineers and landowners, succinctly summarizes the design and benefits of environmental features, and demonstrates USACE's commitment to environmental stewardship. Overall, multiple studies have confirmed that diversity in engineering of borrow areas can contribute to diversity in fish assemblages (Miranda et al. 2013).

5 Conclusion

The ecological value of borrow areas have been studied by USACE for almost 40 years. These studies have come to a similar conclusion that borrow areas provide habitat for a wide range of fish species, including recreational, commercial, and other species of conservation interest. Fish assemblages in borrow areas are similar to those in natural lakes, further corroborating the ecological importance of these habitats in sustaining biodiversity in the LMR. However, our research has shown that the fish assemblage of borrow areas located landside of levees are considerably less diverse than those that are riverside. Since borrow areas are constructed rather than naturally formed, they can be strategically located and environmentally enhanced to support a broader range of species. The recommendations developed from this research are intended to help guide future construction of borrow areas as levees are raised and modified.

Bibliography

- Aggus, L. R., and G. R. Ploskey. 1986. *Environmental Design Considerations for Main Stem Borrow Areas Along the Lower Mississippi River*. Lower Mississippi River Environmental Program, Report 4. Vicksburg, MS: US Army Corps of Engineers–Mississippi River Commission. <https://apps.dtic.mil/sti/citations/ADA172576>.
- Baker, J. A., K. J. Killgore, and R. L. Kasul. 1991. “Aquatic Habitats and Fish Communities in the Lower Mississippi River.” *CRC Reviews in Aquatic Sciences* 3 (4): 313–414. https://www.researchgate.net/publication/263751519_Aquatic_Habitats_and_Fish_Communities_in_the_Lower_Mississippi_River.
- Bettoli, P. W., and M. J. Maceina. 1983. “Sampling with Toxicants,” chap. 10 in L. A. Nielsen and D. L. Johnson (eds.), *Fisheries Techniques*, Second Edition, Bethesda, MD: American Fisheries Society. https://www.researchgate.net/profile/Michael-Maceina-2/publication/268077073_Sampling_with_toxicants/links/5461022b0cf27487b452690f/Sampling-with-toxicants.pdf
- Clarke, K. R., and R. N. Gorley. 2015. *PRIMER v7: User Manual/Tutorial*. 7th ed. Plymouth, UK: PRIMER-E. https://www.researchgate.net/publication/307447596_PRIMER_version_7_User_manualtutorial.
- Cobb, S. P., C. H. Pennington, J. A. Baker, and J. E. Scott. 1984. *Fishery and Ecological Investigations of Main Stem Levee Borrow Pits Along the Lower Mississippi River*. Lower Mississippi River Environmental Program, Report 1. Vicksburg, MS: US Army Corps of Engineers–Mississippi River Commission. <https://apps.dtic.mil/sti/citations/ADA157377>.
- Cook, R. D. 1977. “Detection of Influential Observations in Linear Regression.” *Technometrics* 19 (1), 15–18. <https://doi.org/10.2307/1268249>.
- Esri. 2016. “An Overview of Terrain Design.” ArcGIS 10.3. Accessed March 2016. <https://desktop.arcgis.com/en/arcmap/10.3/manage-data/terrains/an-overview-of-terrain-design.htm>.
- Esri. 2019. ArcGIS Desktop: Release 10.7.1. Redlands, California.
- Hilderbrand, R. H., A. C. Watts, and A. M. Randle 2005. The myths of restoration ecology. *Ecology and Society* 10(1): 19. <http://www.ecologyandsociety.org/vol10/iss1/art19/>.
- Jelks, H. L., S. J. Walsh, N. M. Burkhead, S. C-B. E. Diaz-Pardo, D. A. Hendrickson, J. Lyons, N. E. Mandrak, et al. 2008. “Conservation Status of Imperiled North American Freshwater and Diadromous Fishes.” *Fisheries* 33 (8), 372–407. <https://doi.org/10.1577/1548-8446-33.8.372>.

- Killgore, K. J., J. J. Hoover, and J. P. Kirk. 1998. "Evaluation of Aquatic Impacts of Mississippi River Mainline Levees Project," Appendix 8 in *Mississippi River Mainline Levees Enlargement and Seepage Control*. Supplement No. 1, Vol. III. Vicksburg, MS: US Army Corps of Engineers–New Orleans, Vicksburg, and Memphis Districts. https://www.mvk.usace.army.mil/Portals/58/docs/PP/MRL_SEIS/1998_MRL_SEIS_Volume3.pdf.
- Ludwig, J. A., and J. F. Reynolds. 1988. *Statistical Ecology: A Primer on Methods and Computing*. New York: John Wiley and Sons.
- Magurran, A. E. 1988. *Ecological Diversity and its Measurement*. Princeton, NJ: Princeton University Press. <https://doi.org/10.1007/978-94-015-7358-0>.
- Miranda, L. E., K. J. Killgore, and J. J. Hoover. 2013. "Fish Assemblages in Borrow-Pit Lakes of the Lower Mississippi River." *Transactions of the American Fisheries Society* 142 (3), 596–605. <https://doi.org/10.1080/00028487.2012.760486>.
- NAIP (National Agriculture Imagery Program Imagery). n.d. USDA-FSA-APFO, 2016–2017, Salt Lake City, Utah. <https://gis.apfo.usda.gov/arcgis/rest/services/NAIP>.
- Oliver, A. J., C. E. Murphy, C. D. Little, and K. Jack Killgore. 2016. *Measuring Connectivity of Floodplain Waterbodies to the Lower Mississippi River*. MRG&P Tech Note 1. Vicksburg, MS: US Army Engineer Research and Development Center–Mississippi River Geomorphology and Potamology Program. <https://hdl.handle.net/11681/20368>.
- Robison, H. W., and T. M. Buchanan. 1988. *Fishes of Arkansas*. Fayetteville, AR: University of Arkansas Press.
- SAS. 2015. Version 9.4, SAS Institute Inc., Cary, North Carolina, USA.
- Shields, F. D., and S. S. Knight. 2013. "Floodplain Restoration with Flood Control: Fish Habitat Value of Levee Borrow Pits." *Ecological Engineering* 53: 217–227. <https://doi.org/10.1016/j.ecoleng.2012.12.046>.
- USFWS (US Fish and Wildlife Service). 1980. *Habitat Evaluation Procedures (HEP)*. ESM 102. Washington, DC: US Fish and Wildlife Service. <https://digitalmedia.fws.gov/digital/collection/document/id/100>.
- Zuur, A. F., E. N. Ieno¹, and C. S. Elphick. 2010. "A Protocol for Data Exploration to Avoid Common Statistical Problems." *Methods in Ecology and Evolution* 1 (1): 3–14. <https://doi.org/10.1111/j.2041-210X.2009.00001.x>.

Abbreviations

DF	Degrees of freedom
ECO-PCX	National Ecosystem Restoration Planning Center of Expertise
HEP	Habitat Evaluation Procedure
HSI	Habitat Suitability Index
HU	Habitat unit
HW	Highway
L	Left
LMR	Lower Mississippi River
MR&T	Mississippi River and Tributaries
MRL	Mississippi River Levees
MVK	Mississippi Valley Division, Vicksburg District
MVM	Mississippi Valley Division, Memphis District
NAIP	National Agriculture Imagery Program
NGVD	National Geodetic Vertical Datum
NTU	Nephelometric turbidity units
PC	Principal component
PCA	Principal component analysis
R	Right
RM	River mile
RVI	Relative Value Index
SDI	Shoreline development index

SEIS II	Supplemental Environmental Impact Statement II
Std Dev	Standard Deviation
USACE	US Army Corps of Engineers
USFWS	US Fish and Wildlife Service
VDI	Volume development index

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14. ABSTRACT <p>An aquatic analysis of constructing borrow areas adjacent to the main line levees in the lower Mississippi River was conducted as part of an Environmental Impact Statement for upgrading the levee system. A Habitat Suitability Index (HSI) regression model based on field collections was developed to predict fish species richness as a function of the morphometry and water quality of borrow areas. The HSI score was multiplied by acres of borrow areas created during construction to obtain habitat units (HU) for each alternative indicating a substantial gain of fishery habitat in the floodplain. Environmental features identified by the model to increase fish species richness and overall habitat heterogeneity include the shape of the pit (e.g., bowl-shaped with deep water rather than long rectangular with shallower water), the availability of littoral areas for fish spawning and rearing, using best management practices such as tree screens and bank stabilization to lower turbidity, adding islands, and creating sinuous shorelines. The project results in an overall gain in aquatic habitat by creating permanent or semi-permanent water bodies on the floodplain that our research indicates may be occupied by at least 75 species of fish contributing to the overall biodiversity of the lower Mississippi River.</p>					
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