Appendix G

Fisheries

U.S. Army Corps of Engineers
Memphis District

Appendix G

St. Johns Bayou and New Madrid Floodway Project
Fisheries

Background

Flood risk damage measures are being evaluated for the St. Johns Bayou and New Madrid Floodway (SJNM) basins, an agricultural landscape located in southeast Missouri. Measures include closing the gap and building a water control structure in the levee near the outlet of the New Madrid Floodway to prevent Mississippi River backwater flooding. Two pumping stations will also be built in both basins to help drain interior water when outlet structures are closed during high Mississippi River stages. The St. Johns Bayou basin encompasses 450 square miles in southeast Missouri. The basin is protected by levees forming a sump that is drained by a gravity outlet when the Mississippi River elevation is lower than the interior elevation. Closure of the gates protects the interior from high Mississippi River stages. The New Madrid Floodway, which is 207 square miles, lies between the Birds Point-New Madrid setback levee and the Mississippi River mainline levee. The Floodway can divert Mississippi River flow during extreme floods, thereby reducing stages at Cairo, Illinois. It has been opened twice, during the floods of 1937 and 2011. Unlike St. Johns Bayou, the New Madrid Floodway is frequently flooded from Mississippi River backwater through a 1,500 ft. wide opening of the levee at New Madrid that is designed to serve as an outlet during Floodway operation.

Beginning in the late 1990’s, field surveys of fishes were conducted in the SJNM Basins by Southern Illinois University to establish a baseline condition for the Environmental Impact Statement of the project. Missouri Dept. of Conservation Open River Field Station was concurrently sampling fishes in the Mississippi River near the outlet of SJNM Basins, and in the late 2000’s, the Corps (ERDC-EL) began bio-assessment and telemetry studies. This information was compiled to help parameterize EnviroFish, a hydraulic model used to estimate acres of floodplain habitat suitable for fish reproduction under a given set of project alternatives.

Objectives

This document evaluates and summarizes project impacts on Mississippi River fishes utilizing the SJNM Basins as spawning and rearing habitat. The objectives are:

1. Describe existing conditions of aquatic habitat and fish community in the project area.
2. Evaluate fish movement through the existing culverts in St. Johns Basin and use this information to develop a fish passage “weighting” factor for the proposed structure in the New Madrid Floodway.
3. Calculate impacts of the project on fish spawning and rearing habitat.

Scope

This document is written in five parts to address each objective and provide documentation of all aspects of the analysis:

Part I: Description of Existing Conditions
Part II: Fish Movements through the St. Johns Water Control Structure
Part III: Evaluation of Project Impacts
Part IV: Acknowledgments
Part V: Literature Cited

Part 1: Description of Existing Conditions

Introduction

The St. Johns and New Madrid Basins (SJNM) cover over 650 square miles in southeast Missouri. The alluvial floodplain deposits are typically rich in organic material, and consequently, intense agricultural activities and subsequent flood control measures now characterize these areas: over 80% of the lands are agriculture. Flooding from the Mississippi River typically occurs during winter and spring. Approximately 1,000 acres flood each year in both basins, with a 2-year flood frequency of 12,000 and 45,000 in the St. Johns and New Madrid Basins, respectively (Figure I-1). In the New Madrid Basin, floodwaters back through the levee gap into Mud Ditch and follow the network of drainage ditches and bayous. In St. Johns Basin, backwater flooding from the Mississippi River is minimized by closing the gravity outlet structure. Managing flood pulses, which drive ecological process in floodplain rivers (Junk et al. 1989), has resulted in agricultural intensification (i.e., cleared, leveled, drained, farmland) in both basins creating a homogenous landscape.

Delta streams, bayous, and ditches that occur in SJNM Basins are typical throughout the alluvial floodplain of the lower Mississippi River. Delta streams are most prevalent in the Mississippi Embayment, a 4748 square mile area of the lower Mississippi River valley, which is comprised of 62 percent agricultural land (Kleiss et al. 2000). Low water (from instream and groundwater withdrawals; drainage control), excessive sedimentation (from deforestation-induced erosion), and the accumulation of historically used organo-chlorine pesticides such as DDT have degraded these streams and bayous resulting in dominance of tolerant fish species (Killgore et al. 2007; Miranda and Lucas 2004; Sullivan et al. 2004; Wang et al. 1997).

Objectives

1. Characterize fish assemblages in the project area based on field collections and data from other sources.
2. Compare fish assemblages between the St. Johns and New Madrid Basins

Methods

Fishery data from the project area, which includes the Mississippi River and St. Johns-New Madrid basins, were obtained from Missouri Department of Conservation (Cape Girardeau Open River Field Station) and Southern Illinois University (Sheehan et al. 1998). Gears included gill nets, seines, and electroshocking in the SJNM Basins and also trawling in the Mississippi River. More recently, ERDC-Environmental Laboratory sampled bayous and ditches in both basins during summer 2007.

Field Collections

ERDC-EL sampled fishes with an 8’ x 10’ or 8’ x 20’ seine constructed of 3/16” mesh, and consisted of 10 or 5 hauls, respectively, stratified among all apparent microhabitats. The smaller seine was generally utilized in upper reaches of the sampled rivers where the water body was typically narrower. The larger seine was utilized in lower reaches. Sampling efforts taken at each station were pooled into a single composite sample.

Water quality parameters were determined for each river section sampled. Dissolved oxygen, pH, conductivity, and water temperature were measured with a Quanta Hydrolab®. Turbidity was measured with a Hach 2100P® turbidimeter. River width and sampling distance were measured using a Bushnell® laser rangefinder. Water depth (stadia rod) and velocity (Marsh-McBirney Flo-Mate) were taken at 10 equidistant points along a cross sectional transect within the sampled reach. Stations were georeferenced using a hand-held Magellan® or Delorme PN40 GPS unit.

Analyses

Analytical assessments of assemblage structure and similarity were computed with the procedures in the PRIMER (Plymouth Routines in Multivariate Ecological Research) version 6 statistical package (Clarke and Warwick 2001; Clarke and Gorley 2006). Abundance values in the final species matrix were square root transformed to reduce the influence of the most common species (Clarke and Gorley 2006). No species were excluded due to rarity. Resemblance matrices were created by computing Bray-Curtis similarity indices for each assemblage comparison.

Non-metric multi-dimensional scaling (MDS) was conducted to provide a graphical presentation of the similarity among samples in a low-dimensional space with those samples (i.e., points on the figure) occurring close together representing samples that are very similar in community composition. The reduction of the original dataset to a low-dimensional space is measured as "stress" and represents the effectiveness of the data reduction technique in depicting the similarity among samples in the original high-dimensional space. Values < 0.05 represent excellent representation of the low-dimensional solution with a value of 0.01 representing a perfect fit; < 0.1 represents a good solution; < 0.2 represents useful 2-dimensional solutions but signals need for additional analyses to evaluate internal structure within the dataset; and stress values > 0.3 represent solutions that differ little from randomized points (Clarke and Warwick 2001).

An analysis of similarity (ANOSIM) was conducted to assess differences in species assemblages between systems (New Madrid, St. Johns Bayou). This analytical approach is analogous to a 1-way ANOVA and assesses the degree of variability in similarity values within treatments in order to establish the strength of differences that may be found between treatments. The test statistic for ANOSIM, R, ranges from 0 to 1. Values close to 0 indicate little difference between groups and values approaching 1 represent complete separation of the groups (Clarke and Warwick 2001). We calculated similarity percentages (SIMPER) on the raw abundance values to determine which species contribute to the similarity pattern depicted within groups (i.e., typifying species) as well as those species that contribute to the dissimilarity between groups (i.e., discriminating species). We conducted a hierarchical clustering technique (CLUSTER) on the resemblance matrix and incorporated the SIMPROF option to test for significance (alpha = 0.05) of internal structure.

The matrix for the comparison of environmental conditions consisted of 10 variables (water temperature, dissolved oxygen, conductivity, pH, turbidity, sediment depth, water depth, water velocity, stream width and discharge). Data were square-root-transformed, normalized and a Euclidean distance matrix was produced before conducting further analyses. A MDS was generated to provide a graphical presentation of the similarity among stations along with an ANOSIM to evaluate the difference between systems based on measured environmental conditions. A BEST (Bio-Env + STepwise) routine (Clarke and Gorley 2006) was conducted to assess differences in environmental condition factors between the respective groups of samples. The BEST routine provides a measure of agreement between structure in the biotic assemblage and any multivariate environmental pattern depicted for the same sampled stations.

Results and Discussion

Eighteen stations were sampled within the basin (St. Johns = 9; New Madrid = 9) with three stations located below the confluence of the two systems (St. Johns = 1; New Madrid = 2) (Figure I-2). These 3 stations were not included in any of the faunal or environmental analyses. Final resulting matrix included 15 stations (St. Johns = 8; New Madrid = 7).

Comparison of Fish Fauna

The results of the MDS provided a good solution for a 3-dimensional portrayal of the data (stress = 0.09). The 2-D solution had a slight reduction in fit (stress = 0.16) but is presented instead due to ease of interpretation (Figure I-3). Graphically, the MDS depicted a fairly clean separation between samples from the respective systems while also illustrating similarity among geographically proximal stations (e.g., St. Johns 1, 2, 3 and 4). Results of the SIMPROF indicated there was internal structure in terms of faunal similarity among the sampled stations (Global Pi = 2.239, p = 0.009) with the CLUSTER analysis (Figure I-4) depicting 4 major clusters among all sampled stations. For example, stations 15, 12, 11 and 14 were faunistically the most similar (group average = 47.07%) and the inclusive cluster was significantly different from remaining clusters.

The one-way ANOSIM indicated significant fish assemblage differences between the two systems (Global R = 0.329, p = 0.001). Average similarity among New Madrid stations based on raw abundance values was 30.37% with Western mosquitofish, Blacktail shiner and Bullhead minnow contributed the most to similarity within sites (i.e., typifying species) (68.5%) with 5 additional species contributing the remaining balance Table I-1). Average similarity among St. Johns stations was 26.27% with Western mosquitofish, Blacktail shiner and Ribbon shiner contributing 78.96% of that within group similarity. Four additional species contributed to the remaining balance.

The average dissimilarity between systems was 73.81% with most of these differences due to differences in relative abundance for commonly occurring species (i.e., Western mosquitofish, Bullhead minnow, Emerald shiner Bluntnose minnow) and species occurrence within only a single system (Table I-2). For example, of the 73.81% dissimilarity between systems, 21 species contributed 90% to that dissimilarity with 11 species occurring in both systems. Four species were found only within the New Madrid system; 6 only within the St. John system. Of those species found only within the New Madrid system, all are noted for being tolerant of poor water conditions (Orange spotted sunfish, Gizzard shad, Pugnose minnow).

Environmental Conditions

As with the comparisons of the fish fauna among stations, the results of the MDS for the environmental conditions provided a good solution for a 3-dimensional portrayal of the data (stress = 0.09). The 2-D solution had a slight reduction in fit (stress = 0.17) (Figure I-5) but illustrated a distinct separation between stations representing the respective systems and a grouping of stations similar to that depicted with the fish fauna MDS. The similarity in environmental conditions is depicted well with the results of the CLUSTER analysis (Figure I-6) although there was no internal structure indicated by the SIMPROF analysis (Global Pi = 0.108, p = 0.329). Results of the ANOSIM indicated that there were significant differences between systems in terms of measured environmental conditions (Global R = 0.282, p = 0.011)

Following the inclusion of all 10 environmental variables (Table I-3), the results of the BEST procedure indicated the best solution included 7 variables (Global Rho = 0.554, p = 0.02). Stepwise inclusion of each variable (BVSTEP) illustrated a substantial increase in correlated values with the addition of each explanatory variable. The best explanatory variables, in descending order of contribution, include dissolved oxygen, conductivity, pH, turbidity, depth, stream width and flow. Variables deemed non-significant in discriminating between stations were water temperature, sediment depth and water velocity. This suggests that sediment depth is relatively high throughout both basins and sluggish water persists, homogenizing the fish assemblage. Variation in some of the water quality and hydraulic variables may influence localized species richness, but overall, the summer fish assemblage in both basins are dominated by tolerant, ubiquitous species.

Summary

Ninety species of fish have been documented in the project area excluding the invasive Asian carp (silver, bighead, and grass carp) (Table I-4). Sampled fishes were characteristic of the lower Mississippi River and tributaries, and were dominated taxonomically by minnows (20 species), sunfishes (14 species), suckers (13 species), and darters (13 species).

There are two groups or guilds of fish species that that utilize the two basins for reproductive purposes: riverine (or transient) and permanent (Table I-4). Riverine species are those that occur primarily in the Mississippi River and will move onto flooded areas to spawn or rear during spring floods (e.g., buffalo). Collectively, the peak reproductive period of most Mississippi River fishes extends from March through June when water temperature ranges from 60-80 °F. Mississippi River fishes exhibit characteristic spawning chronologies: early-season spawners (March), mid-season spawners (April-May 15), and late-season spawners (May 16-June). Permanent species reside in the canals and bayous year-around (e.g., sunfishes). Although riverine species depend on Mississippi River flooding to complete critical life stages, permanent species are more dependent on habitat conditions in summer and fall (flow, sediments, and water quality). Therefore, Habitat Suitability Indices (HSI's) were developed specifically for the riverine species guild that spawn or rear in the two basins since spring flooding will be directly affected by the project.

In terms of the two basins, the St. Johns Bayou Basin is more diverse compared to the New Madrid Floodway. Sheehan et al (1998) documented 46 species in the floodway while 71 species were found in St. Johns Basin using multiple types of collecting gears. In 2007, ERDC-EL documented 42 species in St. Johns compared to 33 species in the floodway using seines to collect fish. Of the 42 species collected in St. Johns basin in 2007, 20 species were not found in New Madrid floodway. The fish assemblages in both basins are numerically dominated by widespread, tolerant species (e.g., mosquitofish, certain sunfishes and shiners). Characteristics of tolerant fish assemblages include adaptations to low dissolved oxygen and high pulses of suspended solids, no direct requirements for clean, firm substrates for spawning, and ability to live in shallow, slackwater pools for extended periods (Hoover and Killgore 1998; Scott and Hall 1997; Jester et al. 1992). However, St. Johns basin harbors more darters and minnows compared to the floodway. Darters and minnows, as well as a few other taxonomic groups typically occur in streams and bayous of higher habitat value, and differences in species richness between the two basins can be attributed to several factors:

1) St. Johns Basin is protected from unregulated Mississippi River flooding, which has resulted in reduced sedimentation in the streams. Typically, soft sediment depth in the streams is less than 1.0 ft in St. Johns compared to greater than 1 ft in New Madrid floodway. Turbidity is also higher in New Madrid Floodway, averaging 56 NTU’s in summer 2008 but only 27 NTU’s in St. Johns.
2) Flooding from the Mississippi River resets species composition in the New Madrid Floodway every 1-2 years reducing stability and persistence of fish species residing in the streams year around.
3) Channel degradation is accelerated in the New Madrid Floodway due to fluctuating water levels from Mississippi River floods. The ditches and bayous become incised and more homogeneous compared to St. Johns where the bayous are more sinuous.

Table I-1. Similarity percentages (SIMPER) on the raw abundance values by basin.

Group New Madrid
Average similarity: 30.37

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
WESTERN MOSQUITOFISH	47.71	10.36	0.92	34.11	34.11
BLACKTAIL SHINER	32.43	7.11	0.68	23.41	57.52
BULLHEAD MINNOW	15.29	3.33	0.68	10.98	68.50
ORANGESPOTTED SUNFISH	12.86	2.03	0.46	6.68	75.17
RIBBON SHINER	13.71	2.01	0.46	6.61	81.79
BROOK SILVERSIDE	6.86	1.20	0.58	3.96	85.75
GIZZARD SHAD	3.71	1.11	0.79	3.66	89.41
EMERALDSHINER	6.86	0.88	0.39	2.90	92.31

Group St. John
Average similarity: 26.97

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
WESTERN MOSQUITOFISH	88.63	13.56	1.33	50.27	50.27
BLACKTAIL SHINER	23.00	4.56	0.80	16.91	67.18
RIBBON SHINER	12.00	3.18	0.55	11.78	78.96
BLUNTNOSE MINNOW	9.88	0.96	0.79	3.54	82.50
BLUEGILL	5.50	0.79	0.34	2.91	85.41
BLACKSTRIPED TOPMINNOW	4.00	0.73	0.45	2.69	88.10
GREEN SUNFISH	4.88	0.64	0.50	2.39	90.49

Table I-2. Similarity percentages (SIMPER) on the raw abundance values showing dissimilarity among species and basins. Blue highlight indicates species not present in St. Johns system. Yellow highlight signifies those species not present in New Madrid system.

Groups New Madrid & St. John
Average dissimilarity = 73.81

Species	Group New Madrid Av.Abund	Group St. John Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
WESTERN MOSQUITOFISH	47.71	88.63	16.99	1.24	23.01	23.01
BLACKTAIL SHINER	32.43	23.00	10.13	0.99	13.73	36.74
BULLHEAD MINNOW	15.29	8.00	5.58	1.00	7.55	44.30
RIBBON SHINER	13.71	12.00	5.05	1.15	6.83	51.13
ORANGESPOTTED SUNFISH	12.86	0.00	4.21	0.64	5.71	56.84
BROOK SILVERSIDE	6.86	15.38	3.35	0.86	4.54	61.38
IRONCOLOR SHINER	0.00	24.38	3.04	0.51	4.12	65.50
EMERALD SHINER	6.86	0.38	2.17	0.71	2.94	68.44
BLUEGILL	2.00	5.50	2.02	0.80	2.73	71.17
BLUNTNOSE MINNOW	2.14	9.88	1.88	1.10	2.55	73.72
GOLDEN TOPMINNOW	0.00	6.75	1.76	0.37	2.38	76.11
BANDED PYGMY SUNFISH	0.00	6.00	1.61	0.44	2.18	78.29
GREEN SUNFISH	1.00	4.88	1.40	0.79	1.90	80.19
BLACKSTRIPED TOPMINNOW	0.57	4.00	1.24	0.83	1.68	81.87
GIZZARD SHAD	3.71	0.00	1.20	0.97	1.63	83.50
REDSPOTTED SUNFISH	0.00	3.38	0.89	0.85	1.21	84.71
PUGNOSE MINNOW	2.29	0.00	0.88	0.66	1.20	85.90
PIRATE PERCH	0.00	3.75	0.88	0.73	1.20	87.10
LEPOMIS SP	2.29	0.00	0.86	0.36	1.16	88.26
CYPRESS DARTER	0.00	3.88	0.84	0.47	1.14	89.40
BLACKSPOTTED TOPMINNOW	0.00	2.88	0.82	0.39	1.10	90.50

Table I-3. Water quality and hydraulic variables measured in the St. Johns Bayou (n=9)and New Madrid Floodway (n=9) Basins during summer 2007.

Variable	Mean	Std Dev	Minimum	Maximum
	New Madrid Floodway			
Water Temperature, C	30.3	2.0	26.3	32.2
Dissolved Oxygen, mg/l	6.7	2.0	3.1	9.3
Conductivity, umhos/cm	362.1	33.0	313.0	419.0
pH	7.7	0.2	7.4	7.8
Turbidity, NTU	56.7	9.1	45.4	67.9
Sediment Depth, ft	1.2	0.4	0.6	1.8
Water Depth, ft	2.4	2.0	0.3	6.3
Water Velocity, cm/s	0.4	0.4	0.0	1.1
Channel Width, ft	57.4	23.9	24.0	90.0
Discharge, cfs	32.5	42.6	0.0	137.8
	St. Johns Bayou			
Water Temperature, C	29.5	3.0	24.3	33.9
Dissolved Oxygen, mg/l	7.1	3.0	0.8	12.7
Conductivity, umhos/cm	300.4	26.2	265.0	335.0
pH	7.8	0.4	7.1	8.7
Turbidity, NTU	26.8	12.9	8.9	46.0
Sediment Depth, ft	1.0	0.4	0.3	1.6
Water Depth, ft	1.2	0.5	0.3	1.9
Water Velocity, cm/s	0.6	0.5	0.0	1.5
Channel Width, ft	50.4	30.2	20.0	93.0
Discharge, cfs	47.1	54.8	0.0	143.9

Table I-4. Guilds of fish species that occur in the St. Johns/New Madrid Project area based on substrate preferences for spawning (Balon 1984) and primary rearing location.

Pelagophils	Lithophils	Phytophils	Litho-Psammophils	Speleophils
Rear Primarily River Channel				
Skipjack herring Gizzard shad Threadfin shad Goldeye Mooneye Plains minnow Silver chub Speckled chub Emerald shiner River shiner Freshwater drum*	Shovelnose sturgeon Paddlefish Quillback Blue sucker Northern hog sucker Spotted sucker River redhorse Golden redhorse Shorthead redhorse White bass* Yellow bass Striped bass Smallmouth bass Sauger Walleye Chestnut lamprey		Silverband shiner River carpsucker Harlequin darter Logperch Blackside darter Saddleback darter Dusky darter River darter	Red shiner Spotfin shiner Blacktail shiner* Bullhead minnow Bluntnose minnow Blue catfish Flathead catfish Channel catfish* Freckled madtom Tadpole madtom Johnny darter
Rear Primarily in Floodplain				
Mimic shiner* Channel shiner		Spotted gar Longnose gar Shortnose gar Bowfin Grass pickerel Chain pickerel Smallmouth buffalo* Bigmouth buffalo Black buffalo Golden topminnow* Blackstripe topminnow Blackspotted topminnow Banded pygmy sunfish Mud darter Bluntnose darter Slough darter Cypress darter* Brook silverside Inland silverside	MS silvery minnow Ribbon shiner Golden shiner Ironcolor shiner Weed shiner Pugnose minnow Creek chubsucker Shadow bass Flier Green sunfish Warmouth Orangespotted sunfish Bluegill Longear sunfish* Redear sunfish Redspotted sunfish Spotted bass Largemouth bass* White crappie* Black crappie	Black bullhead Yellow bullhead Pirate perch*

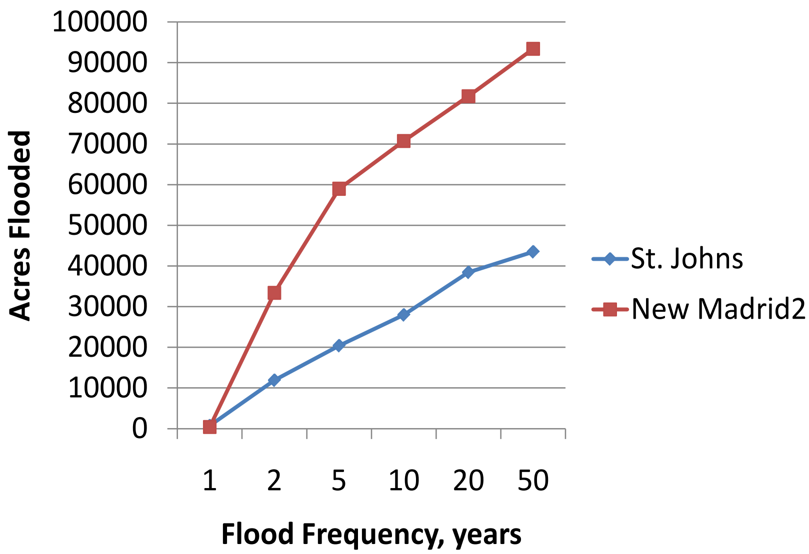

Figure 1-1. Acres flooded by flood frequency in St. Johns and New Madrid Basins.

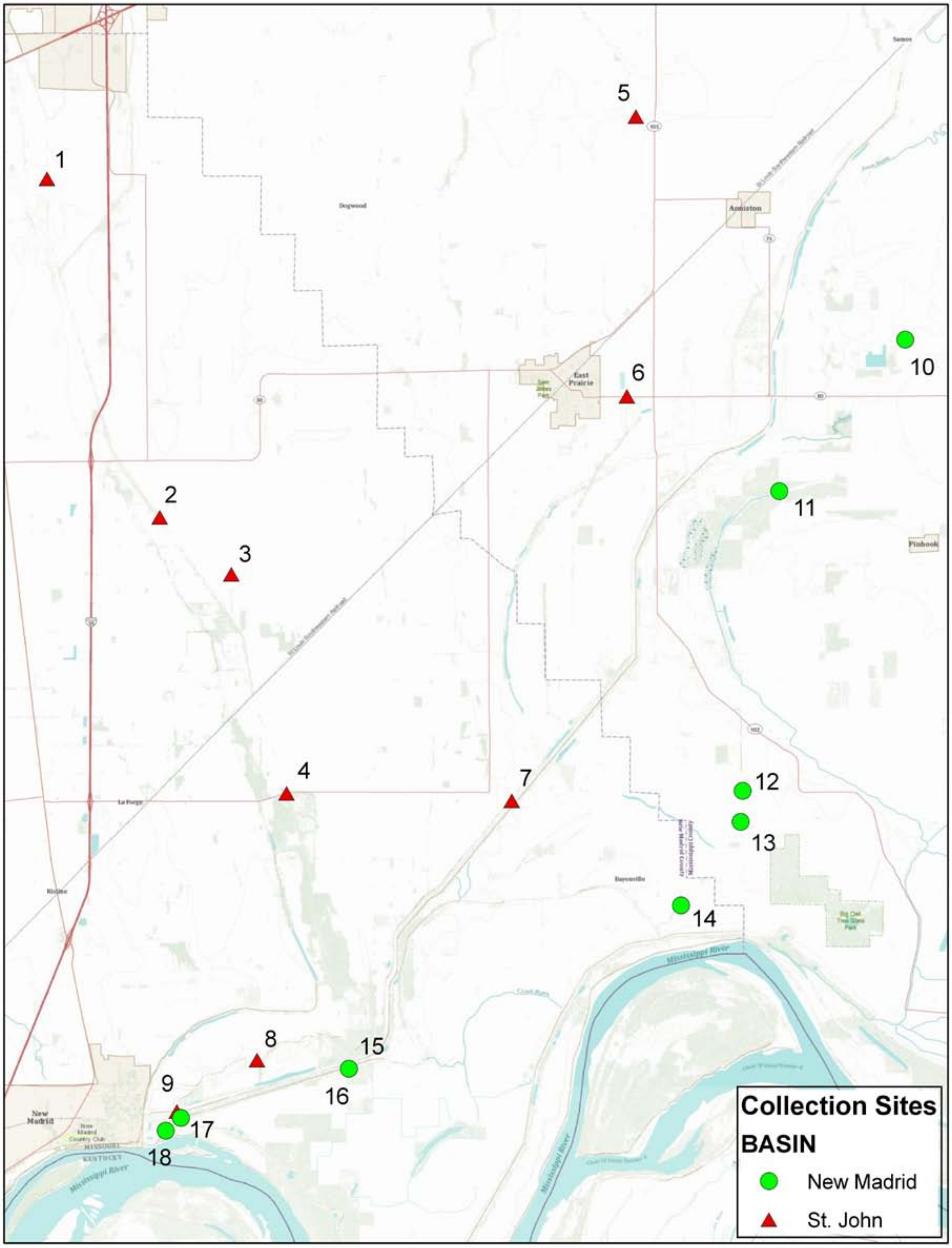

Figure I-2. Sampling sites during summer 2008.

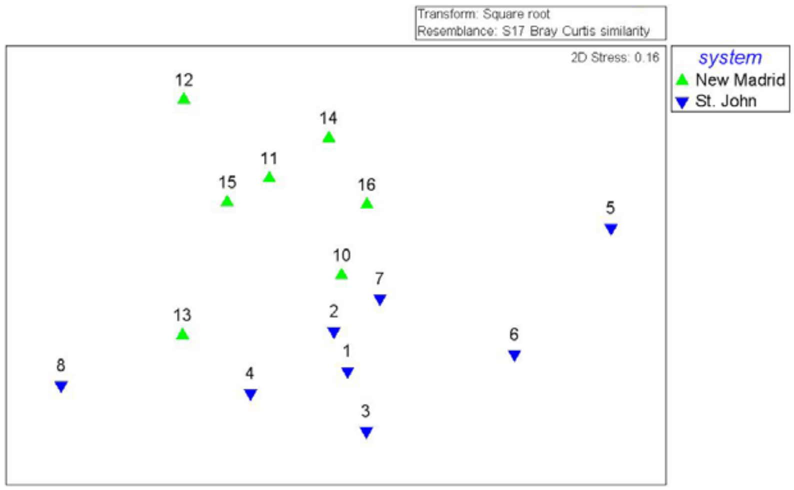

Figure I-3. Non-metric multi-dimensional scaling (MDS) of fish abundance for St. Johns and New Madrid Basins.

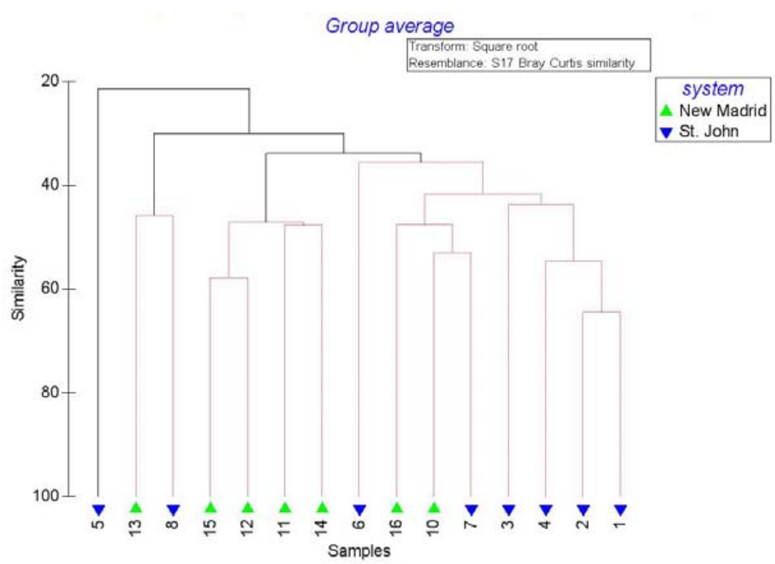

Figure I-4. Hierarchical clustering of sites based on the similarity of fish species abundance.

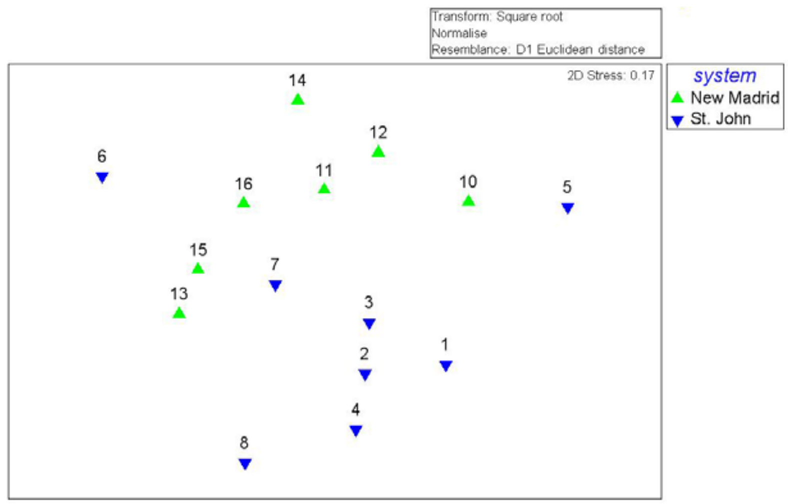

Figure I-5. Non-metric multi-dimensional scaling (MDS) of environmental variables for St. Johns and New Madrid Basins.

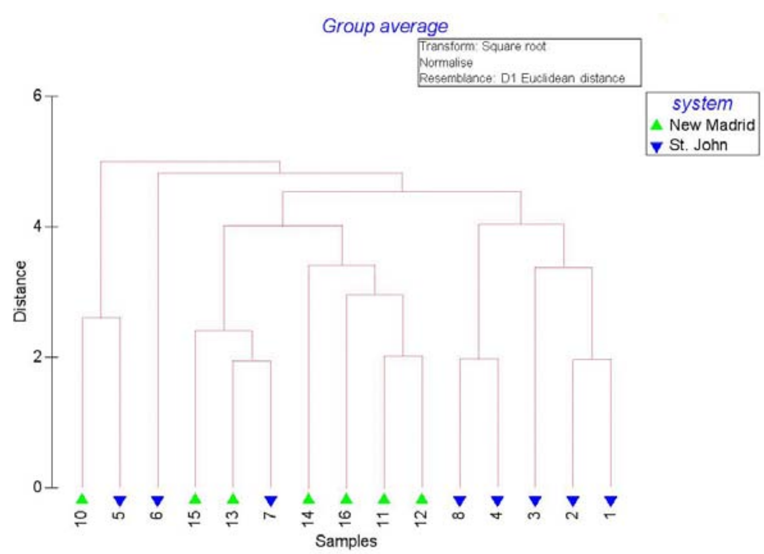

Figure I-6. Hierarchical clustering of sites based on the similarity of environmental conditions.

Part II: Fish Movements Through the St. Johns Water Control Structure

Introduction

Seasonal connectivity between rivers and floodplains created by flood pulses are considered critical for healthy riverine ecosystems (Junk et al. 1989; Winemiller 1996; Bowen et al. 2003; Sommer et al. 2004). Few riverine organisms can survive or develop without exploiting these seasonal floodplain habitats at some stage in their life (Feyrer et al. 2006; Flinn et al. 2008). Many riverine fish species rely upon seasonally predictable flood pulses, which provide access to floodplain areas that can be utilized for reproduction (i.e. spawning and rearing), foraging, overwintering, or as refuge from intolerable conditions (Knights et al 1995; Winemiller and Jepsen 1998; Barko and Herzog 2003, Bowen et al. 2003, Ickes et al. 2005). While the connection of a river to its floodplain is crucial for many riverine organisms, anthropogenic river modifications (e.g. navigation enhancements, water storage, and flood control) have impaired natural floodplain inundation, and as a result have reduced floodplain connectivity.

While there are still areas with direct connection to the river, most floodplains are separated from the river by levees for flood control measures. The long-term effects of reduced floodplain connectivity has yet to be understood, however the need to understand these effects has lead to the development of many floodplain management strategies. Often these management strategies have differing objectives (e.g. flood control, conserve floodplain connectivity); however, one of the most common options is to install a water control structure through levees which can aid in water level management but still provide connectivity (Henning 2004; Ickes et al 2005; Schultz et al. 2007). Although these water control structures can maintain floodplain connectivity, their effect on fish movement and passage is not yet certain (Ickes et al. 2005; Schultz et al. 2007).

Objectives

The main objective of this study was to evaluate fish movement through the St. Johns Bayou water control structure. The St. Johns Bayou basin extends from Commerce and Benton, Missouri to New Madrid, Missouri covering 450 square miles. It is separated from the Mississippi River by mainline and setback levees forming a sump that is drained by a gravity outlet when the Mississippi River is lower than the Bayou. The gravity outlet consists of six 10-foot by 10-foot gated concrete box culverts. During periods of high water on the Mississippi River (approximate elevation of 279 feet NAVD), the floodgates are closed, thus preventing Mississippi River backwater flooding. Closing the gates impounds interior runoff until the Mississippi River recedes to an elevation lower than the impounded landside water elevation. Structure remains open during the rest of the year. A similar structure is proposed for the New Madrid basin if a closure levee is constructed at the lower end of the Floodway. In order to determine fish passage through the existing structure, we conducted a telemetry study to evaluate fish movement and frequency of passage during spring 2010.

Methods

Fish were collected using a combination of gears including gill nets, electrofishing, trot lines, hoop nets, and trammel nets. All fish collected were marked with a floy to maintain a mark/recapture study increasing the chances of determining whether fish are passing through the water control structure. To further monitor fish passage and movement a subsample of 100 fish were implanted with ultrasonic transmitters. The majority of fish were collected downstream of the water control structure to increase our power to detect upstream movement into the potential spawning areas. Two groups of fish were implanted with tags; each group included a combination of species, representing mid-season spawners (April – May: largemouth bass, spotted bass, white bass, hybrid striped bass, freshwater drum, bowfin, river carpsucker, smallmouth buffalo, black buffalo, and bigmouth buffalo), and late season spawners (June – July: flathead catfish, blue catfish, channel catfish, and shortnose gar). The majority of tagging occurred in April 2010 when the study was initiated, so that all fish would be tagged before the mid-season spawning season commences; however remaining transmitters were implanted in early June when a second flood pulse occurred.

Ultrasonic transmitters implanted in fish were sized such that they did not exceed fish weight in water by 2-3%. Fish were anesthetized using a carbon dioxide and oxygen mixture; river water was circulated over fish gills during surgery. All surgical utensils were sanitized in 70% ethanol. Incisions were made ventrally, anterior to the anal openings. The incision areas were disinfected with betadine. A scalpel and curved hemostats were used to insert the tag and avoid damage to organs. The transmitter was pushed down and away from the incision site to alleviate any added stress on the wound. Incisions were closed with monofilament sutures attached to a curved cutting needle using simple interrupted sutures, as documented by Summerfelt and Smith (1990). The incision and sutures also were sealed with cyanoacrylate resin to prevent infection and to hold the wound and suture knots together securely. Immediately following the surgical procedure, tagged fish were placed in a recovery tank supplemented with oxygen and released after normal swimming occurred.

In order to monitor fish movement and passage through the water control structure, stationary receivers (Vemco VR2W) were placed at five locations within St. John's Bayou. Receivers were place immediately above and below the water control structure in St. Johns Bayou to constantly monitor fish movement around the structure. Other VR2W's were deployed downstream of the structure in Mud Ditch and near the Mississippi River to monitor fish movement out of the system into the Mississippi river, and in Mud Ditch above the St. Johns structure to monitor movement into or out of the New Madrid Floodway (Figure II-1). Stationary receivers were submerged on rebar stands with concrete anchors with the hydrophone oriented up (Figure II-2). These stands are retrieved with a boat mounted grappling hook rig on a monthly basis to download all data collected (Figure II- 3). The grappling hook rig is lowered to the riverbed near the stand and is dragged until it snags a retrieval cable between the stand and an anchor. In attempts to monitor long-range movements and movement out of the study area, we also incorporated data collected from our (SIUC and MDC cooperative) existing stationary receiver array in the Mississippi, Missouri, Illinois, and Ohio Rivers (Figure II-4).

All floy tag recaptures were documented to determine passage by marked fish. Detections by the stationary receivers were used to quantify fish movement and passage. For fish implanted with ultrasonic transmitters we summarized mean lengths and weights, number of detections, and passages. Passage occurred when a fish released on one side of the structure is detected on a receiver on the opposite side. Since stationary receivers directly above and below the water control structure were within close vicinity, fish were sometimes detected on both stationary receivers simultaneously. When this event occurred, passages were not recorded, until the fish was detected by receivers on one side of the structure. We also investigated the effects of river stage and water levels on number of detections within the bayou and passage through the water control structure.

Results and Discussion

Since 2008, over 2000 fish encompassing 38 different species have been floy tagged jointly by ERDC and SIU. While ten fish have been recaptured either by ERDC or SIU while sampling or by fisherman, no fish have been found on the opposite side of the water control structure in which they were tagged. Since recaptures were so limited, in April of 2010 we implanted 89 fish with ultrasonic transmitters (78 downstream of the water control structure and 11 upstream. Then in early June the remaining 11 fish were tagged downstream of the water control structure to increase our chances of detecting fish moving into St. John’s Bayou to access the floodplain (Table II-1). Mean lengths and weights of the fish implanted with ultrasonic transmitters are summarized in Table II-2.

Since the first day of tagging (April 12) until the last day VR2W’s were downloaded (Dec 9), 1,264,717 detections have been made by the stationary receiver array in the bayou and in the Mississippi and Ohio Rivers. All 100 fish were detected multiple times by multiple VR2W’s. While the majority (99%) of the detections where collected by the St. John’s –New Madrid array, fifteen fish were detected moving out of St. John’s Bayou into the Mississippi and Ohio Rivers. There were 2894 detections collected in the Ohio River, 38 detections in the Middle Mississippi River at River Mile 1.3, and 88 detections in the Lower Mississippi River at Caruthersville, MO.

The stationary receiver array allows us to document movement by summing the distance moved from one receiver to the next. While movements made in between VR2W’s cannot be determined, we can at least quantify the scale and directionality of movement. The fifteen fish detected moving out of the bayou and into the Mississippi and Ohio Rivers, included five different species moving up the Mississippi River into the Ohio or Middle Mississippi River, or fish were detected moving downriver to Caruthersville, Missouri on the Lower Mississippi River. Seven of these fifteen fish that moved out of the bayou were later detected moving back into the Bayou. Total movement by these fish with maximum movement upriver and downriver is summarized in Table II-3. Even though most fish (85) remained within the bayou, theses fish still moved among receivers within the bayou array (Table II-3).

In order to determine the effects of water level on number of fish that remained in the bayou, we used Mississippi River stage at New Madrid, Missouri as a surrogate for water entering or leaving the bayou (e.g. if the river stage was falling we assume water was leaving the bayou). Correlation showed that there was a positive relationship between increasing river stages and the number of fish detected by VR2W's in St. John's Bayou ($r = 0.73$, $P < 0.0001$; Figure II-5). This suggests that as river stages increase and water drains into the bayou making the floodplain connected and more accessible, more fish are found in the bayou. The St. Johns Bayou gravity outlet is closed at a river elevation at the New Madrid gage of approximately 29 feet. During 2010, the gate was open 34% when fish tagging began (April 14) to the end of the pre-defined spawning season (June 30) in 2010, assuming that the structure was closed when New Madrid elevation reaches 29 feet. Therefore, fish passage opportunities were limited particularly in May.

Thirteen of the 14 species tagged moved upstream through the structure (93%). Flathead catfish was the only species not detected moving through the structure, although only one individual was tagged during the study. Of the 85 fish tagged below St. Johns structure, all accessed the New Madrid Floodway at some point during the study. Forty-seven of those passages being made by fish moving downstream from the bayou toward the Mississippi River and 45 passages were made by fish moving upstream through the structure to access the floodplain (Table II-4). All 11 fish tagged above the St. Johns structure traveled through the culvert and exited the basin. Overall, 29 of the 85 (34%) fish passed through the structure one or more times for a total of 92 passage events. Correcting for the time the structure was closed during the spawning and rearing season (66%), fish passage was (52%).

Passage occurred most frequently during spring and summer months in which the tagged species typically spawn (Table II-5). However fish passed through the water control structure at least once each month (Table II-5). To evaluate how water flow through the structure may affect fish passage, we used the change in the Mississippi River stage at New Madrid, Missouri as an indicator of water draining from the bayou or entering the bayou. When we plotted the number of passages per day against the change in river stage, it was clear that passage occurred under all conditions (Figure II-6).

Although the main purpose of the water control structure is to prevent backwater flooding, it also retains connectivity to the floodplain protected by levees. Our study confirms fish movement through large water control structures. While it is unlikely that study fish were completely unaffected by the presence of the water control structure in St. John's Bayou, our data indicates that individuals of each study species; except flathead catfish passed through the structure.

The stationary receiver array was successful at documenting fish passage through the water control structure. From this data we were able to determine that the number of fish utilizing the bayou increased with rising water levels. With the majority of passages occurring during the spring and summer we assume that fish are accessing the floodplain through the water control structure to find suitable spawning habitat. Another peak in river stage during December 2010, followed by increased numbers of fish detected in the bayou shows that fish may also be using the floodplain for overwinter habitat as well. Not only has the receiver array within the bayou allowed us to quantify passage through the water control structure, but in addition we have also documented some long range movements by study species into the Mississippi and Ohio Rivers. While fifteen fish moved out of the bayou into these major rivers, seven of those fish moved back down into the bayou, showing that some species have a degree of site fidelity.

We recommend continued monitoring of fish passage and movements around the water control structure across multiple years to more fully understand how water-levels affect the connectivity to the floodplain and species ability to navigate the structure and access the floodplain. To improve the resolution of our data and expand our knowledge of passage and movement, we recommend increasing the number of transmitters implanted each year and attempt to tag more species in equal proportions. By continuing telemetry efforts we will be able to fully understand how the nuances in river stage and fish behavior interact to predict fish passage through water control structures along the Mississippi River.

Summary

Fish passage through the St. Johns water control structure near New Madrid, MO was evaluated in 2008 using telemetry. Stationary receivers were placed strategically at 5 locations below and above the structure in St. Johns Bayou, in New Madrid Floodway, and the outlet to the Mississippi River. A total of 100 individuals comprising 14 species were tagged. Total number of detections between April - Dec 2010 were 1,264,717. Fifteen individuals comprised of five species moved into the Mississippi and Ohio Rivers; 7 individuals returned to St. Johns Bayou. Thirteen of the 14 species moved upstream through the structure. Of the 85 individuals that stayed in the bayou, 29 fish passed through the structure for a total of 92 passage events. The downstream: upstream passage was roughly 50:50. Passage was correlated with river rise with frequency of passage higher in spring, but passage occurred each month through December 2008 when the study ended.

Table II-1. Species and number of fish surgically implanted with sonic transmitters during 2010 upstream and downstream of the water control structure in St. John's Bayou.

Location Tagged	Species	Date Tagged						Total
Upstream	Mid-Season Spawners	4/12/2010	4/13/2010	4/14/2010	4/29/2010	4/30/2010	6/11/2010	
	Bowfin			1				1
	Freshwater Drum			3				3
	Largemouth Bass			1				1
	River Carpsucker			1				1
	Black Buffalo			1				1
	Smallmouth Buffalo			4				4
Downstream	Mid-Season Spawners							
	Freshwater Drum		2			2	1	5
	Hybrid Striped Bass						1	1
	Largemouth Bass					1	1	2
	River Carpsucker	1	1				1	3
	Bigmouth Buffalo	1	7		5	1		14
	Black Buffalo					6	1	7
	Smallmouth Buffalo	3	22		2	3	2	32
	Spotted Bass	2	1		1			4
	White Bass	2				7	3	12
	Late-Season Spawners							
	Blue Catfish		2					2
	Channel Catfish		1				1	2
	Flathead Catfish		1					1
	Shortnose Gar	2			2			4
	Total	11	37	11	10	20	11	100

Table II-2. Mean lengths and weights of species implanted with ultrasonic transmitters in 2010.

Species	N	Mean TL (mm)	StdDev	Mean Wt (g)	StdDev
Bigmouth Buffalo	14	565.79	68.25	3135.93	1123.78
Black Buffalo	8	567.00	91.34	3093.25	1427.60
Blue Catfish	2	712.00	322.44	5875.00	6965.00
Bowfin	1	581.00	N/A	1892.00	N/A
Channel Catfish	2	562.00	189.50	2871.00	3010.86
Flathead Catfish	1	670.00	N/A	3750.00	N/A
Freshwater Drum	8	541.38	62.73	2782.50	980.24
Hybrid Stripped Bass	1	430.00	N/A	1010.00	N/A
Largemouth Bass	3	357.67	105.94	829.67	752.03
River Carpsucker	4	454.25	74.70	1458.25	697.85
Shortnose Gar	4	690.33	55.50	1212.25	203.55
Smallmouth Buffalo	36	586.67	100.54	3713.14	1900.81
Spotted Bass	4	367.75	42.15	772.00	220.31
White Bass	12	330.00	29.47	480.75	109.28

Table II-3. Total distance moved by indiviual fish within each species with maximum upriver and downriver movement shown for those speices which moved outside St. John's Bayou.

Movement Outside the Bayou		Total Distance	Maximum Distance Upriver	Maximum Distance Downriver
Species	Bigmouth Buffalo	64.2	64.1	0.1
	Black Buffalo	130.8	65.6	65.2
	Freshwater Drum	52.1	1	51.1
	Smallmouth Buffalo	134.3	67.1	67.2
	White Bass	85.8	74.9	51.4
Movement Within the Bayou				
Species	Bigmouth Buffalo	29.1		
	Black Buffalo	21.7		
	Blue Catfish	23.5		
	Bowfin	3		
	Channel Catfish	2.6		
	Flathead Catfish	11.8		
	Freshwater Drum	2.6		
	Hybrid Striped Bass	2.3		
	Largemouth Bass	12.8		
	River Carpsucker	16.8		
	Shortnose Gar	15.1		
	Smallmouth Buffalo	38.5		
	Spotted Bass	10.7		
	White Bass	43.2		

Table II-4. Fish passage through the water control structure in St. John's Bayou. Passsage was detected by stationary receivers placed above and below the structure. N represents the number of fish within each species that passed through the structure. The numbers depict the total number of passages.

Spawning Group	Species	N	Passage Downstream	Passage Upstream	Total
Mid-Season Spawners	Bigmouth Buffalo	3	2	4	6
	Black Buffalo	2	3	3	6
	Bowfin	1	1		1
	Freshwater Drum	3	3		3
	Hybrid Striped Bass	1		1	1
	Largemouth Bass	1	1		1
	River Carpsucker	1	1		1
	Smallmouth Buffalo	9	20	19	39
	Spotted Bass	1	3	3	6
	White Bass	3	9	9	18
Late Season Spawners	Blue Catfish	1	1	1	2
	Channel Catfish	1		1	1
	Shortnose Gar	2	3	4	7
	Total	29	47	45	92

Table II-5. Fish passage through the water control structure in St. John's Bayou. Passsage was detected by stationary receivers placed above and below the structure. The numbers depict the total number of passages per month.

		Passage Downstream									
Spawning Group	Species	April	May	June	July	August	September	October	November	December	Total
Mid-Season Spawners	Bigmouth Buffalo			1	1						2
	Black Buffalo		1	1						1	3
	Bowfin								1		1
	Freshwater Drum	2	1								3
	Largemouth Bass			1							1
	River Carpsucker	1									1
	Smallmouth Buffalo	3	2	8	3	3			1		20
	Spotted Bass							3			3
	White Bass		1				6	2			9
Late Season Spawners	Blue Catfish			1							1
	Shortnose Gar		1	1		1					3
	Total	6	6	13	4	4	6	5	2	1	47

		Passage Upstream									
Spawning Group	Species	April	May	June	July	August	September	October	November	December	Total
Mid-Season Spawners	Bigmouth Buffalo	2		1					1		4
	Black Buffalo			1	1			1			3
	Hybrid Striped Bass					1					1
	Smallmouth Buffalo	1	3	8	2	3				2	19
	Spotted Bass							3			3
	White Bass		1	1			6	1			9
Late Season Spawners	Blue Catfish	1									1
	Channel Catfish				1						1
	Shortnose Gar	1	1	1		1					4
	Total	5	5	12	4	5	6	5	1	2	45

Figure II-1. Locations of VR2W's in St. John's Bayou around the water control structure near New Madrid, Missouri. VR2W locations are shown in the white rectangles.

Figure II-2. Boat mounted winch system with grappling contraption of bow of boat that is used to retereive stationary recievers.

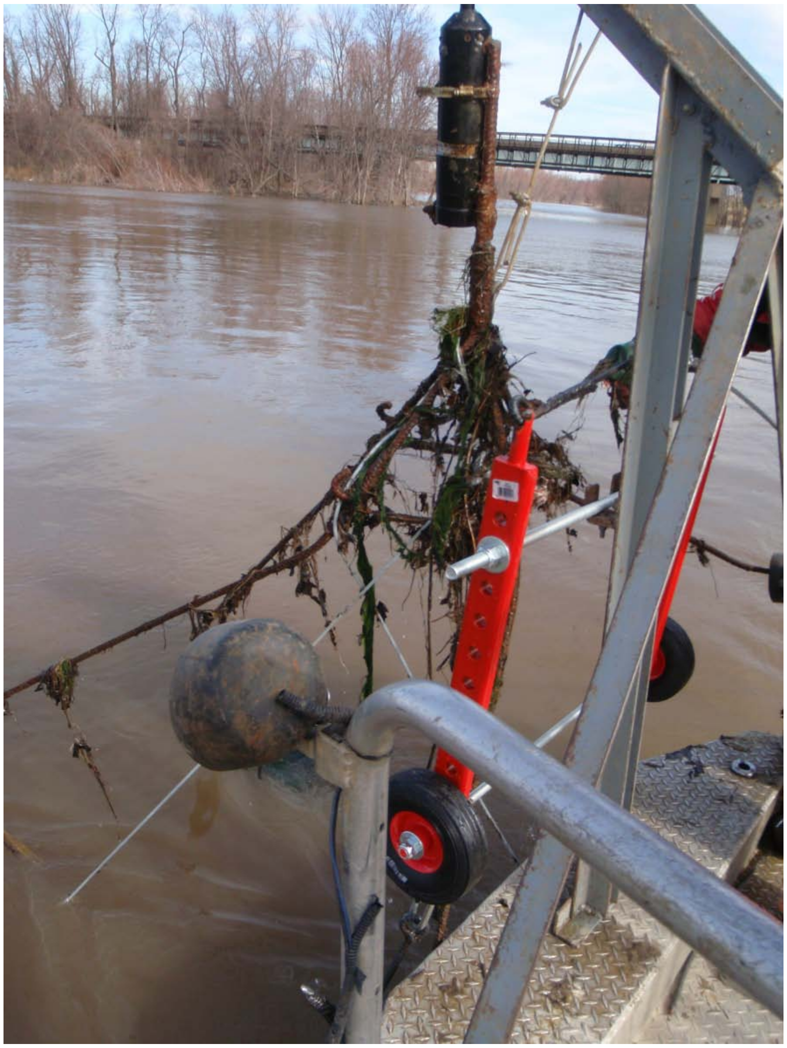

Figure II-3. VR2W on the rebar stand being winched up from the bottom, so that the data can be downloaded.

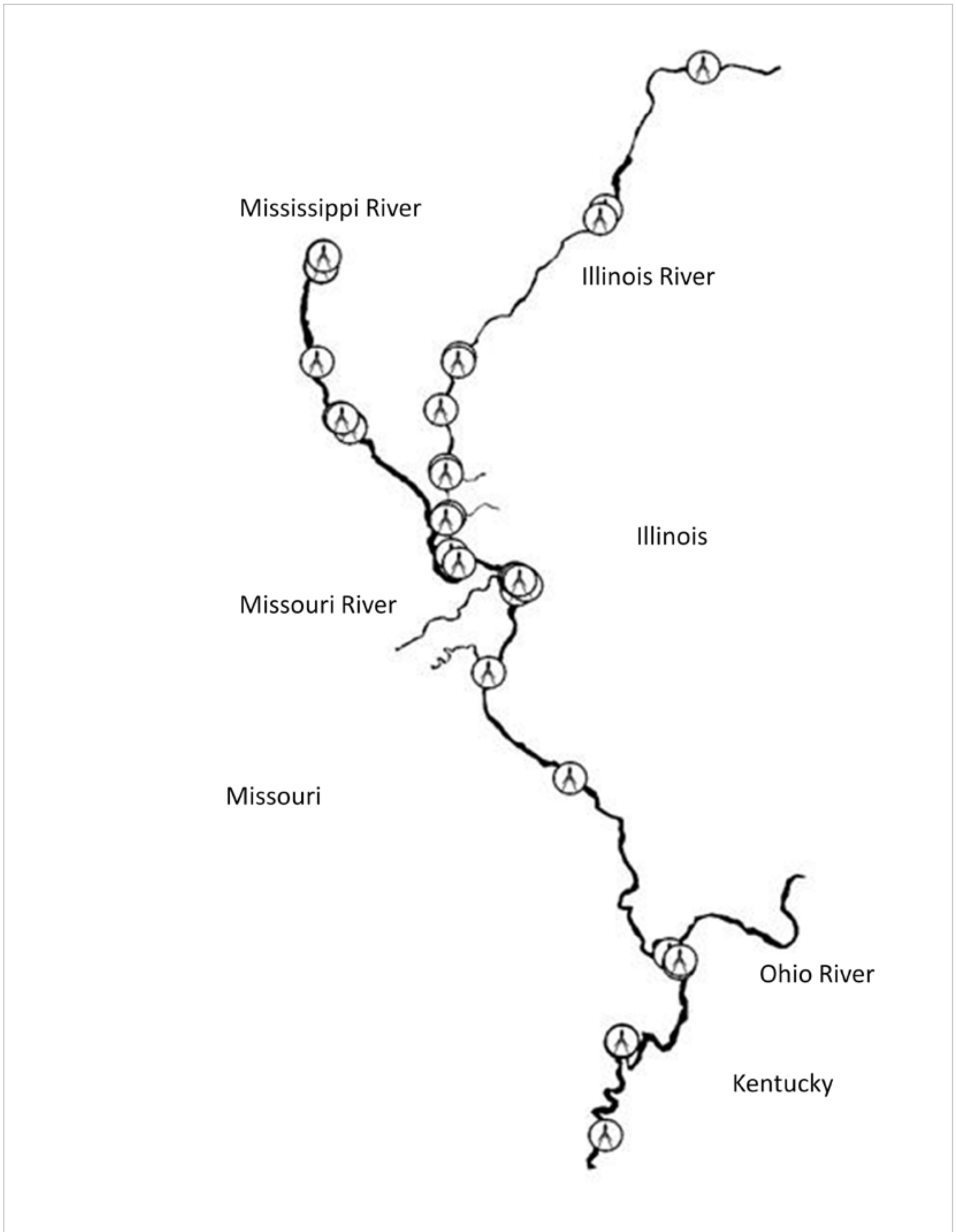

Figure II- 4. Locations of all VR2W's in our cooperative stationary receiver array covering the Mississippi, Illinois, Missouri, and Ohio Rivers. VR2W locations are shown with in the circles.

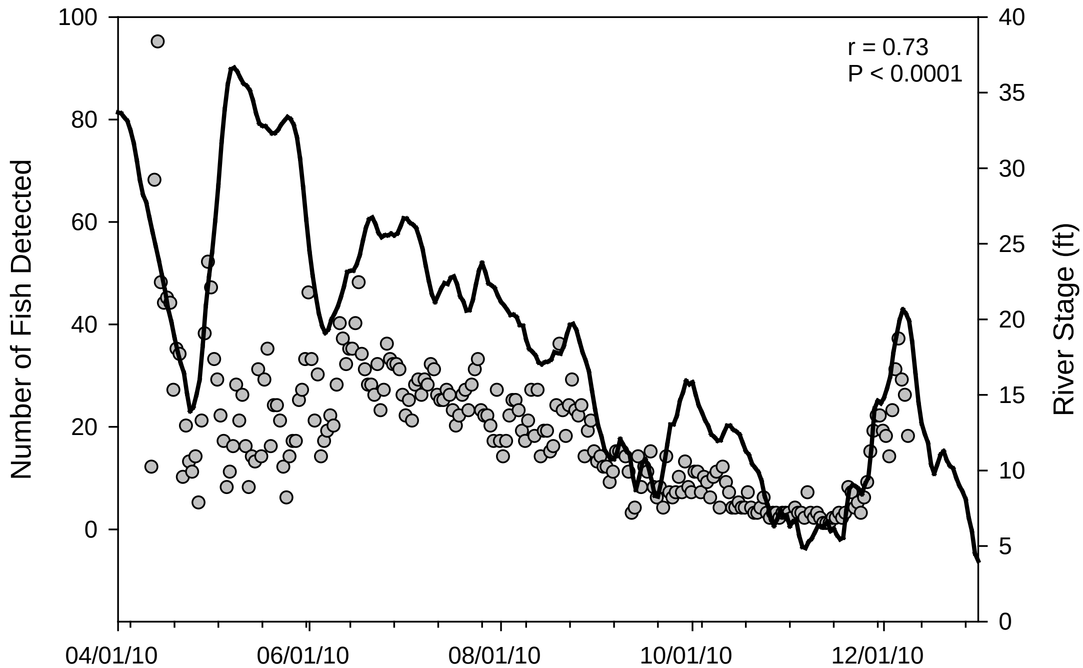

Figure II-5. Grey circles represent number of fish detected with the bayou each day plotted against Mississippi River stage at New Madrid, Missouri.

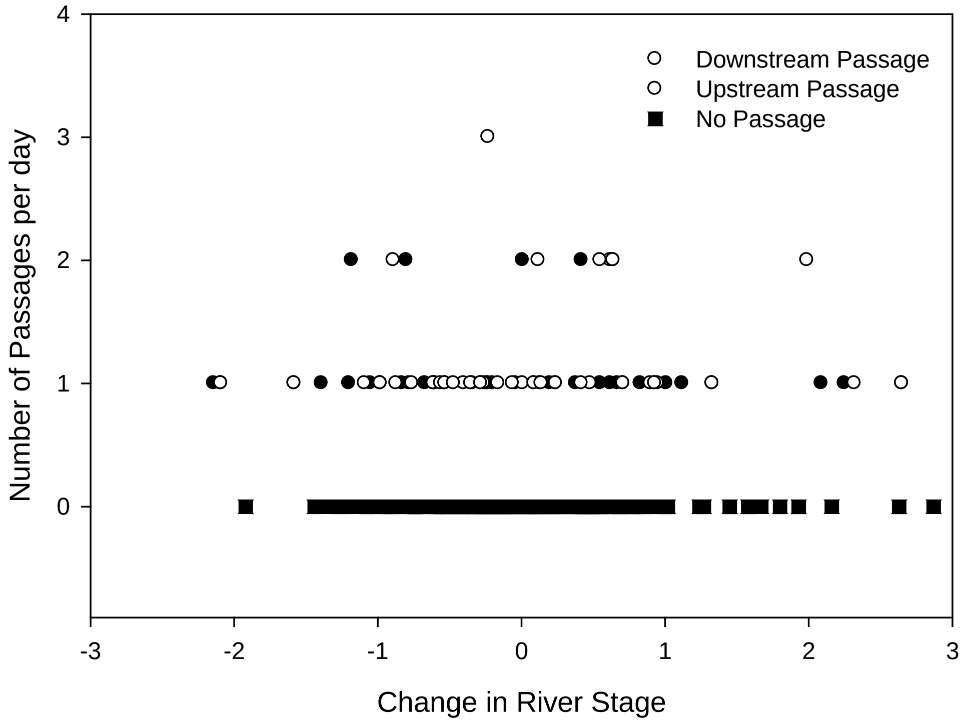

Figure II-6. The number of passages per day were plotted in relation to if the water levels at New Madrid, Missouri were falling (negative numbers) or rising (positive numbers), showing that passage occurs under all conditions.

Part III: Evaluation of Project Impacts

Introduction

Evaluation of project impacts on fisheries focused on spawning and rearing in the SJNM basins. Reproductive cycles of most floodplain fishes are closely related to timing, spatial extent, and duration of flooding, commonly referred to as the flood pulse (Junk et al 1989). Numerous fish species undergo regular migrations to use inundated floodplains for a variety of reproductive purposes such as spawning, short-term incubation of eggs, and eventually as nursery habitat for yolk-sac (non-feeding) larvae (Guillory 1979; Ross and Baker 1983; Finger and Stewart 1987; Copp 1989; Scott and Nielson 1989). Once the yolk-sac is gone, larval fish join adults in using temporarily inundated floodplains and waterbodies as foraging habitat, especially for the small insects and zooplankton that are often the initial food items (Lietman *et al* 1991). These early life history stages are often the limiting factor in population growth, and interannual variations in flooding regimes of rivers affect reproductive success and year-class strength of many species (Starrett 1951; Guillory 1979; Killgore et al. 1996) . Thus, any changes to the flood pulse will have both direct and indirect impacts to fishes that utilize the SJNM for spawning and rearing.

Objectives

The Habitat Evaluation Procedure (HEP) was used to quantify impacts of the project on fish habitat (USFWS 1980). The objectives of this part of the study were to:

1. Document methodology and assumptions used to calculate impacts
2. Evaluate fisheries impacts for each project alternative

Methods

The ecological model EnviroFish (Killgore *et al.*, 2011) was used to quantify the amount of fish spawning and rearing habitat in the project area under future without project conditions and each respective alternative. EnviroFish is a hydraulic model coupled to a spreadsheet that estimates acres of floodplain habitat suitable for fish reproduction under a given set of hydrologic conditions. Utilizing the results of the hydrologic model (*i.e.*, daily elevations), EnviroFish integrates the daily flood elevations, floodplain land use, and Habitat Suitability Indices (HSI) to calculate a response variable. The response variable is in the form of a Habitat Unit so the Habitat Evaluation Procedure (U.S. Fish and Wildlife Service 1980) can be used to complete the analysis of project alternatives. Like any ecological model, it is important to note that EnviroFish does not quantify actual spawning and rearing habitat. EnviroFish compares changes in potential spawning and rearing habitat among alternative scenarios (Battelle, 2010 – EnviroFish). Specific components of EnviroFish are described below.

Delineation of Floodplain Habitats

Five habitat types delineated from satellite imagery and ground-truthing characterized the majority of floodplain landuse in the SJNM Basins. The actual acres of each habitat type by stage elevation (i.e., stage-area curves) were entered into the EnviroFish software to calculate Average Daily Flooded Acres. Habitat Types are defined as follows:

a. Agriculture – all areas in which an agricultural product was grown including developed and pasture lands.
b. Fallow – agricultural lands that have been abandoned where there is a prevalence of herbaceous, non-woody cover.
c. Bottomland Hardwoods – All forested areas.
d. Marsh – areas that remain inundated/saturated for long periods of time during the growing season that do not support woody vegetation. These areas usually go dry during late summer/early fall. These areas include herbaceous wetland complexes that are managed for waterfowl and scrub-shrub.
e. Waterbodies – areas that retain water for the majority of the year or at least during the reproductive season. These areas include borrow pits, crevasse lakes/blue holes, floodplain lakes (*i.e.*, Riley Lake), oxbow lakes (*i.e.*, Hubbard Lake), artificial lakes (*i.e.*, Big Oak Tree Lake), scatters, breaks, and sloughs. It is important to note that some of these areas have been observed as dry during dry conditions. However, for the purpose of the model, they are classified as waterbodies.

Habitat Suitability Index Values

The majority of species that spawn and rear in riverine floodplains are pre-adapted to structurally complex habitats such as bottomland hardwoods. Therefore, cleared lands have less value for spawning and rearing habitat. The HSI values reflect this trend, with optimum conditions occurring for bottomland hardwoods, waterbodies, and marshes (HSI = 1.0); intermediate values for fallow fields (HSI = 0.5); and the lowest value for cleared, agricultural lands (HSI = 0.2). The final HSI values used in EnviroFish to weight acres were agreed upon by consensus of an interagency team of biologists (Delphi technique), independent peer review, supplemented by field data from tributaries of the lower Mississippi River (Table III-1).

HSI values are for combined life stages of spawning and rearing. They represent a community-level perspective on the biological response of warmwater fishes to flooding in riverine systems. In most large floodplain river systems, this would encompass a very large assemblage of fish species. Species within a guild are assumed to share similar reproductive requirements. In this particular case, fish species in the Lower Mississippi River Valley (including the St. Johns Bayou and New Madrid Floodway project area) are grouped on substrate used by spawning adults and characteristic habitat (*e.g.*, channel vs. floodplain) used by larvae (Table I-3). For species that spawn and rear in floodplains, different substrates or structural conditions are preferred to deposit eggs or construct nests: vegetation, sand, and/or crevices. For these reasons, bottomland hardwoods, marshes, and waterbodies have optimum HSI values because of their habitat heterogeneity.

In summary, at least three assumptions were made using these values:

1) Larval fish have the potential of utilizing the same habitat as spawning sites, with one exception. Larval fish have smaller physical dimensions and motility that allow access to more shallow (<1.0 ft) water than physically available for spawning needs (typically ≥ 1.0 ft depth, 8 days duration). The EnviroFish software can be used to define minimum and maximum allowable depths for spawning and/or rearing to accurately represent a specific situation.
2) The majority of species that spawn and rear in riverine floodplains are pre-adapted to structurally complex habitats such as bottomland hardwood wetlands (BLH). Therefore, cleared lands have less value for spawning and rearing. HSI values reflect this trend, with optimum conditions occurring for BLH and marshes (i.e., HSI = 1.0), intermediate values for fallow fields (HSI = 0.5), and the lowest value for cleared, agricultural lands (HSI = 0.2).
3) Similar to BLH, waterbodies are optimum (HSI=1.0) for spawning and rearing if the waterbody is periodically connected to the mainstem river during the reproductive season. This assumes that waterbodies provide adequate spawning substrates for egg deposition, and larval fish have high growth rates for survival in waterbodies that retain water during periods of early development.

Impact Assessment

HSI values were multiplied by area (acres of floodplain or riverbank habitats) to express project alternatives as Habitat Units (HU) according to the following equation:

$$HU = HSI \times AREA$$

The “AREA” used to calculate HU’s were Average Daily Flooded Acres (ADFA) quantified for each of the seasonally inundated floodplain habitats (*i.e.,* waterbodies were excluded, see below) for specific seasons (*i.e.,* early, mid, and late season). ADFA is a unit of measure of inundation. An ADFA is an area equivalent to one acre that is inundated on average every day of a defined season of a year for a specified number of years. For example, if that acre and an adjoining acre (two real-on the ground acres) were flooded for every day but in only half the specified number of years, the result would still be one ADFA. Similarly, if one acre was flooded every day but in only half the specified number of years, the result would be 0.5 ADFA.

Habitat Units were quantified for Year 0 for each respective basin and each respective season by multiplying ADFA by the HSI value for seasonally inundated floodplain habitat and surface acres by the HSI value for floodplain waterbodies. This process was repeated for Year 50 to account for future WRP enrollment. An Average Annual Habitat Unit (AAHU) was calculated by the following formula:

$$AAHU = \frac{HU_{Year\ 0} + HU_{Year\ 50}}{2}$$

Project impacts were calculated by the following formula:

Project Impacts = (AAHU Future Without Project x Fish Access Reduction)
– (AAHU Future With Project x Fish Access Reduction)

To facilitate calculations, EnviroFish output was transferred to an Excel spreadsheet which automatically averages 'Average Daily Flooded Acres' by alternative, season, and habitat. For Habitat Units, ADFA is multiplied by the appropriate Habitat Suitability Index. Summary statistics were calculated with VBA code (macro). Three temporary matrices (one per season) were constructed with the total of the five habitats' ADFA or HU from each year (67 values per matrix). These matrices were then randomly sampled from, with replacement, to populate a bootstrapped matrix of 67 values (years) for each season. This process is repeated 1000 times and the mean of each bootstrapped matrix is taken to produce 1000 bootstrapped means, from which summary statistics are calculated. To calculate confidence intervals, the 1000 bootstrapped means are sorted from smallest to largest and the 26th and 976th values are selected as this interval contains 95% of the calculated means. Bootstrapping is recommended when data are not normally distributed, such as hydrographic data, and thus, assumptions of parametric tests are violated (Sokal and Rohlf, 1995).

Alternatives were evaluated using the Habitat Evaluation Procedure. The analyses and reporting of results were separated by basin: St. Johns Bayou and New Madrid Floodway. The season with the maximum loss in HU's would be selected as the impact target. Specific assumptions and parameters used in EnviroFish are as follows:

1) Habitat was quantified for floodplain habitat. This is defined as species and individuals who spawn and rear on the floodplain and not necessarily reside in the network of drainage ditches or isolated waterbodies found in the project area.

2) Spawning and rearing habitat are combined into one life stage. Therefore, there is no separate spawning habitat and separate rearing habitat.

3) Many factors dictate the overall timing of the spawning and rearing period. Optimum conditions for spawning occur when the flood pulse and temperature are coupled (Junk *et al.*, 1989. Although there are multiple variable that dictate when fishes will actually spawn, the model assumed that spawning and rearing takes place from 1 March to 30 June (Pflieger 1997). To account for seasonality, the spawning and rearing season was further refined during the following periods:

    a. Early Season = 1 to 30 March
    b. Mid-Season = 1 April to 15 May
    c. Late Season = 16 May to 30 June

4) Depending on land use, the upper boundary of the functional floodplain will be confined to the two-year flood frequency for sub-optimal habitat (*i.e.* agriculture and fallow areas) and the five-year flood frequency for optimal habitat (*i.e.*, bottomland hardwoods, marsh, and waterbodies).

5) Specific hydrologic requirements of optimal and sub-optimal floodplains are as follows:

a. Optimal Habitat – minimum depth = 0.1 feet and minimum duration = one day. Once hatched, rearing fishes (including yolk-sac and post yolk-sac larval phases) can potentially use any area of the inundated floodplain regardless of flood depth and duration (Killgore *et al*, 2012).

b. Sub-optimal habitat – minimum depth = 1.0 feet and minimum duration = 8 consecutive days. Killgore *et al.* (2012) stated, a minimum water depth of one foot allows adults to access shallow, flooded areas, although a water depth less than one foot is not considered realistic due to physical limitations in the spawning process. Flood duration of at least eight consecutive days ensures that suitable time is allowed for nest construction and other spawning activities by the adults and recognizes that shorter durations may result on the eggs becoming stranded and desiccated if water recedes too quickly. The minimum one foot, eight-day duration rule is considered a conservative value to delineate spawning and rearing requirements for warmwater fish species found in the Mississippi River basin (Breder and Rosen, 1966; Carlander, 1969; Carlander, 1977; Becker, 1983; Robison and Buchanan 1988). If the water recedes too rapidly off the floodplain, organic matter, nutrients, and newly hatched aquatic organisms may be carried into the river instead of remaining in the floodplain and permanent backwaters (Sparks 1995). This rule guarantees an effective spawning window, emphasizes longer development times, and provides a margin for temporal variation in spawning activities (*i.e.,* adult movement onto the floodplain, nest construction, and guarding/dispersal of fry) [Killgore *et al* 2012].

   Based on the Phase 2 IEPR discussions, the justification for different hydrologic criteria according to land cover types is due to mortality and stranding factors on agricultural areas. Agricultural areas provide sub-optimal habitat and quickly drain as Mississippi River stages fall due to the vast network of drainage ditches and structures. Therefore, agricultural areas need to be inundated for 8-day duration to be suitable spawning and rearing habitat.

6) Based on the Phase 2 IEPR recommendations, fishery analysis will be split into two different zones regarding flood frequencies. Zone 1 will be within the two-year flood frequency. Analysis will be conducted on all habitat types (optimal and sub-optimal) utilizing the hydrologic criteria outlined above. Zone 2 (*i.e.,* areas that fall between the two-year and five-year frequencies) analysis will only be confined to "optimal habitat" (*i.e.,* waterbodies, marsh, and bottomland hardwoods). Sub-optimum habitat (*i.e.,* fallow and agricultural areas) will be excluded from the analysis.

   The justification for the different zones is based on the following:

   a. The floodplain closest to the river provides immediate access to reproductive fishes undergoing spawning migrations. Fish may have to travel miles from the mainstem river to reach lands corresponding to a 3-year or greater flood frequency. Therefore, fish are less likely to use the sub-optimal areas at greater distances from the river due to the long distance required

b. Even if adults do move great distances to spawn, eggs deposited in cleared lands far removed from the main stem river have a greater risk of becoming trapped and or desiccated. Rapid declines in water level increase the proportion of young fish stranded on the floodplain (Sparks 1995).
c. The independent review conducted for the EnviroFish model recommended weighting between optimal and sub-optimal habitat. Battelle (2010) stated the following:

   i. In reality, a small area of high-quality habitat is likely to outperform a large number of low-quality habitat areas, even if they both have equal HU values. This assumption allows the potential for rationally choosing a project alternative that provides a lot of corn field stubble and not bottomland hardwood forest over one where bottomland hardwood forest is present in moderate amounts. This assumption precludes the model from an organizing the output to maximize the highest quality habitat type.

   ii. …EnviroFish should not allow the opportunity to increase lots of acreage of really poor habitat for an alternative or future situation without regard for the absolute acreage of very high quality habitat. It might be more appropriate to calculate total Hus using only habitats with HSIs greater than some minimum value, for example 0.4. The planning decisions would be based on changes from what is known to be fair/good habitat to other fair/good habitat because the value of Hus would be much more comparable. Other avenues to correct for very poor or very good habitat (e.g., weighting) should also be considered.

7) The modified stage area curve will be used to account for Mississippi River connectivity within the New Madrid Floodway.

8) The H+H period of record will be used to describe future without project hydrologic conditions as well as alternatives. The period of record is highly variable from year to year (*e.g.,* there are some drought years, flood years, and average years). This hydrologic variability is expected to continue under future without project conditions. However, there are no anticipated changes that would significantly change Mississippi River hydrology, drainage patterns, or precipitation in the project area.

9) Although changes in agricultural practices are likely under with several alternative conditions (*i.e.,* conversion of soybeans to other more valuable crops based on risk minimization and market conditions), the only anticipated land use change would be a result of lands enrolled in the Wetland Reserve Program.

10) Several alternative conditions assume hydrologic changes (*i.e.,* reduced frequency and durations) without any changes to land use.

Floodplain Waterbodies

Floodplain waterbodies are important floodplain habitats because they support a major proportion of riverine fish fauna (Lubinski *et al.*, 2008). EnviroFish assumes that floodplain waterbodies provide spawning and rearing habitat regardless of river conditions (*i.e.*, since the waterbody retains water regardless of river conditions, fish will utilize it throughout the spawning and rearing season). Therefore, a separate analysis is required than that which is conducted on seasonally inundated lands. Fish find refugia in floodplain waterbodies, tributaries, or the main channel when flood waters recede (Junk *et al.*, 1989). Fish may reside in these waterbodies until subsequent floods re-connect them to the floodplain and or main channel.

ADFA is not calculated for floodplain waterbodies because they are assumed to retain water for the duration of the spawning and rearing period. Therefore, ADFA would be equal to surface acres. Although isolated waterbodies can provide a diverse assemblage of fish, the flood pulse must connect them at some point to be of benefit to the remainder of the floodplain/Mississippi River fishery. As previously stated, the five-year floodplain is the upper limit of the functional floodplain for fish spawning and rearing habitat.

Fish Access

A major concern is fish access to floodplain habitats above gated structures, such as the one proposed for New Madrid Basin. Typical problems at culverts include a perched outlet, water velocities that exceed burst swimming speeds of fish, shallow depths that hamper swimming, and long distances between resting areas. None of these problems will exist for the proposed authorized culvert design in the New Madrid Floodway for the following reasons:

- Water will be flowing into the basin during most operations periods, so excessive water velocity will not be an impediment to movement. In addition, those fishes that were spawned or are rearing in the basin can be easily transported back to the river when water direction is reversed during falling river stages.
- There will be no outlet or inlet drop in elevation.
- Culvert slope is nearly level.
- A relatively short distance will be required for fish to access the backwater.
- Water depth will be equal to the river stage up to the 10-foot height of the culvert, which is more than adequate for swimming fishes.

In order to estimate a “correction factor” to reduce habitat value upstream of structures, fish passage was monitored through the existing St. Johns Bayou gravity outlet structure (see Part II). Since the proposed New Madrid Floodway culverts are of similar design to the existing St. Johns Bayou gravity outlet structure, results from the St. Johns Bayou fish access study can be used to make predictions regarding fish passage in the New Madrid Floodway. A fish access reduction factor was determined based upon the following:

- Fish can pass through an open culvert. Thirteen of the 14 species tagged moved upstream through the structure (93%).
- The fish access study concluded:
    - 100 fish were tagged with transmitters (11 above the St. Johns structure, 85 below the structure at the confluence of the New Madrid Floodway).

  - All 11 fish tagged above the St. Johns structure traveled through the culvert and exited the basin. Therefore, egress is 100% for the year 2010.
  - Of the 85 fish tagged below the structure, all 85 accessed the Floodway at some point during the study. Therefore, assume the existing Floodway has 100% ingress.
  - Of the 85 fish tagged below the structure, 29 accessed the St. Johns Bayou Basin through the structure. Therefore, assume the St. Johns Bayou Basin has 34% ingress.
  - It is important to note that the structure was closed, due to flood conditions in the St. Johns Basin during the study, 34% of the time when fish tagging began (April 14) to the end of the pre-defined spawning season (June 30) in 2010. This assumes that the structure was closed when New Madrid elevation on the Mississippi river reaches 29 feet. Therefore, the 34% ingress occurred prior to gate closure.
- Once fish can access the basin, assume that they can access available inundated habitat within the constraints outlined by EnviroFish (*e.g.*, 5 or 2-year floodplain, spawning and rearing hydrologic criteria, etc.).

- Fish Access = $\frac{\text{(Ingress + Egress)}}{2}$
- Based on the 2010 fish access study, assume egress is 1.0
- Based on the 2010 fish access study, assume ingress is 0.52 based on the following rationale:
  - Ingress without correcting for days gate was closed = 0.34
  - Ingress with correcting for days gate was closed (0.66 - individuals weighted by gate opening):

$$\frac{.34x}{.66} = \frac{x}{1}$$

$$.66x = .34$$

$$x = 0.52$$

  - Considering that 93% of the species and 52% of the total individuals passed through the structure, the fish correction factor was determined to be the mean between the two values.

- Therefore, the fish access reduction factor is 0.73

Results and Discussion

St. Johns Bayou Basin – Agricultural lands and bottomland hardwoods were the most common habitats affected by the project (Table III-1). Overall, mid-season impacts were greatest among the three fish spawning and rearing seasons. There was a reduction of 618 AAHU, or a 31% decrease, for the authorized alternative for mid-season values. Details on alternatives are found in the SEIS. Bootstrapped summary statistics provide the 95% confidence interval in AAHU's (Table III-2). Note that values in Tables III-1 and III-2 did not incorporate the fish passage coefficient.

Table III-1. Average Daily Flood Acres (Acres) and Habitat Units (HU) by alternative, habitat, and season for St. Johns Basin

Alternative/Habitat (n=67)	Spawning and Rearing Season					
	March		1 Apr - 15 May		16 May - 30 Jun	
	Acres	HU	Acres	HU	Acres	HU
Existing						
Agricultural Land	1042.13	208.43	1039.46	207.89	374.78	74.96
Fallow Land	39.88	19.94	40.18	20.09	12.44	6.22
Bottomland Hardwoods	1174.54	1174.54	1256.89	1256.89	558.38	558.38
Herbaceous Wetlands	71.56	71.56	78.16	78.16	33.23	33.23
Permanent Waterbodies	390.38	390.38	390.38	390.38	390.38	390.38
Sum	**2718.48**	**1864.84**	**2805.07**	**1953.41**	**1369.22**	**1063.17**
Authorized						
Agricultural Land	574.47	114.89	555.69	111.14	143.65	28.73
Fallow Land	25.70	12.85	24.00	12.00	5.32	2.66
Bottomland Hardwoods	781.11	781.11	797.61	797.61	298.32	298.32
Herbaceous Wetlands	45.81	45.81	47.55	47.55	16.85	16.85
Permanent Waterbodies	380.54	380.54	380.54	380.54	380.54	380.54
Sum	**1807.62**	**1335.19**	**1805.38**	**1348.83**	**844.67**	**727.09**

Table III-2. Bootstrapped Summary Statistics for Average Daily Flood Acres (Acres) and Habitat Units (HU) by alternative and season for St. Johns Basin

Alternative (n=67)	Spawning and Rearing Season					
	March		1 Apr - 15 May		16 May - 30 Jun	
	Acres	HU	Acres	HU	Acres	HU
Existing						
Mean	2711.195	1860.033	2812.706	1960.922	1367.26	1065.671
St. Dev.	383.4148	212.3229	371.0548	209.3465	201.2108	128.1183

CV	11.53653	12.41957	11.0058	12.07625	13.62113	15.83273
95% lower CL	2015.223	1461.77	2123.22	1527.078	1012.094	825.8855
95% upper CL	3523.434	2303.694	3577.763	2367.026	1779.552	1342.691
Authorized						
Mean	1806.232	1337.582	1815.65	1351.945	848.6981	726.2518
St. Dev.	272.3804	178.5451	255.1608	158.9334	114.5583	77.76353
CV	13.51715	14.22326	12.84113	14.11163	16.61409	18.46708
95% lower CL	1329.784	999.9622	1350.271	1053.992	640.3418	581.6953
95% upper CL	2373.805	1699.007	2326.114	1671.146	1088.965	893.0007

New Madrid Floodway – Similar to the St. Johns Basin, agricultural lands and bottomland hardwoods were the most common habitats affected by the project. However, depending on alternative, different seasons had the greatest impacts (Table III-3). The authorized alternative had a reduction of AAHU ranging from 65-79%, followed by alternative 3.2 that ranged from a 48-61% reduction. Impacts for the recommended alternative (3.1) ranged from 36-51%, whereas alternative 4.1 ranged from 17-27% reduction. Alternative 4.2 had a net increase in AAHU ranging from 24-26%. Bootstrapped summary statistics for all alternatives, including the 95% confidence intervals, are shown in Table III-4. Note that values for Tables III-3 and III-4 did not incorporate the fish passage coefficient.

Table III-3. Average Daily Flood Acres (Acres) and Habitat Units (HU) by alternative, habitat, and season for the New Madrid Floodway

Alternative/Habitat (n=67)	Spawning and Rearing Season					
	March		1 Apr - 15 May		16 May - 30 Jun	
	Acres	HU	Acres	HU	Acres	HU
Existing						
Agricultural Land	3123.44	624.69	3016.56	603.31	933.77	186.75
Fallow Land	21.20	10.60	22.93	11.46	10.08	5.04
Bottomland Hardwoods	1570.06	1570.06	1629.08	1629.08	733.53	733.53
Herbaceous Wetlands	315.20	315.20	306.40	306.40	157.05	157.05
Permanent Waterbodies	728.47	728.47	728.47	728.47	728.47	728.47
Sum	**5758.37**	**3249.02**	**5703.43**	**3278.72**	**2562.91**	**1810.84**
Authorized						
Agricultural Land	23.31	4.66	11.46	2.29	7.45	1.49
Fallow Land	2.44	1.22	2.35	1.18	1.62	0.81
Bottomland Hardwoods	97.08	97.08	88.01	88.01	62.41	62.41
Herbaceous Wetlands	14.30	14.30	14.45	14.45	6.13	6.13
Permanent Waterbodies	557.99	557.99	557.99	557.99	557.99	557.99
Sum	**695.12**	**675.25**	**674.26**	**663.91**	**635.60**	**628.83**
Alternative_3.1						
Agricultural Land	723.01	144.60	311.30	62.26	16.15	3.23

Fallow Land	9.41	4.71	5.75	2.87	2.03	1.02
Bottomland Hardwoods	977.82	977.82	672.08	672.08	151.23	151.23
Herbaceous Wetlands	301.39	301.39	277.80	277.80	75.15	75.15
Permanent Waterbodies	653.03	653.03	653.03	653.03	653.03	653.03
Sum	**2664.65**	**2081.54**	**1919.95**	**1668.04**	**897.58**	**883.65**
Alternative_3.2						
Agricultural Land	365.88	73.18	114.88	22.98	9.05	1.81
Fallow Land	5.17	2.59	3.87	1.94	1.98	0.99
Bottomland Hardwoods	659.64	659.64	405.10	405.10	122.22	122.22
Herbaceous Wetlands	297.59	297.59	211.67	211.67	41.82	41.82
Permanent Waterbodies	644.14	644.14	644.14	644.14	644.14	644.14
Sum	**1972.41**	**1677.12**	**1379.66**	**1285.82**	**819.20**	**810.98**
Alternative_4.1						
Agricultural Land	1134.13	226.83	1216.31	243.26	415.98	83.20
Fallow Land	11.41	5.70	11.67	5.84	4.99	2.50
Bottomland Hardwoods	1161.46	1161.46	1234.73	1234.73	586.38	586.38
Herbaceous Wetlands	303.25	303.25	292.88	292.88	151.96	151.96
Permanent Waterbodies	670.19	670.19	670.19	670.19	670.19	670.19
Sum	**3280.43**	**2367.42**	**3425.78**	**2446.89**	**1829.49**	**1494.21**
Alternative_4.2						
Agricultural Land	26.33	5.27	29.66	5.93	12.60	2.52
Fallow Land	11.41	5.70	11.67	5.84	4.99	2.50
Bottomland Hardwoods	3116.28	3116.28	3434.95	3434.95	1524.09	1524.09
Herbaceous Wetlands	485.01	485.01	497.58	497.58	239.12	239.12
Permanent Waterbodies	670.19	670.19	670.19	670.19	670.19	670.19
Sum	**4309.22**	**4282.45**	**4644.05**	**4614.49**	**2450.99**	**2438.42**

Table III-4. Bootstrapped Summary Statistics for Average Daily Flood Acres (Acres) and Habitat Units (HU) by alternative and season for the New Madrid Floodway

Alternative (n=67)	Spawning and Rearing Season					
	March		1 Apr - 15 May		16 May - 30 Jun	
	Acres	HU	Acres	HU	Acres	HU
Existing						
Mean	5788.41	3247.16	5711.04	3266.39	2575.08	1812.53
St. Dev.	912.85	383.11	879.72	378.31	449.87	218.33
CV	15.78	11.81	15.42	11.59	17.48	12.05
95% lower CL	4196.73	2540.34	4086.67	2571.10	1782.28	1424.44
95% upper CL	7520.08	4000.44	7548.46	4080.37	3532.94	2295.04
Authorized						
Mean	692.56	675.83	674.14	664.66	635.56	629.13

St. Dev.	38.25	29.80	15.46	13.81	10.51	9.99
CV	5.53	4.41	2.30	2.08	1.65	1.59
95% lower CL	638.21	630.76	648.03	642.24	619.21	612.51
95% upper CL	785.32	739.75	708.20	694.87	657.48	652.40
Alternative_3.1						
Mean	2667.21	2087.18	1922.45	1668.14	897.75	883.22
St. Dev.	254.23	158.36	138.09	99.92	26.85	25.62
CV	9.54	7.59	7.19	5.99	2.99	2.90
95% lower CL	2159.31	1792.85	1675.75	1471.65	848.71	833.85
95% upper CL	3148.59	2380.18	2201.12	1862.96	952.80	934.42
Alternative_3.2						
Mean	1964.17	1677.49	1378.07	1287.79	819.88	810.32
St. Dev.	141.59	99.13	67.76	57.85	17.40	16.23
CV	7.21	5.91	4.92	4.50	2.12	2.00
95% lower CL	1689.46	1483.19	1248.06	1183.51	785.96	779.43
95% upper CL	2244.86	1869.28	1517.88	1404.95	854.94	843.00
Alternative_4.1						
Mean	3297.17	2369.82	3408.13	2460.57	1841.43	1496.86
St. Dev.	369.43	211.36	371.53	211.78	220.22	138.23
CV	11.21	8.93	10.91	8.61	11.97	9.24
95% lower CL	2621.97	1994.92	2722.81	2084.60	1437.35	1245.04
95% upper CL	4073.38	2798.02	4145.86	2891.77	2331.38	1799.15
Alternative_4.2						
Mean	4330.18	4293.11	4649.50	4624.24	2453.15	2435.08
St. Dev.	485.72	494.41	507.02	494.56	311.68	308.73
CV	11.23	11.52	10.91	10.70	12.71	12.69
95% lower CL	3404.92	3339.17	3689.24	3671.30	1913.89	1850.81
95% upper CL	5294.88	5267.48	5671.37	5637.60	3138.47	3090.78

Part IV: Acknowledgments

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