APPENDIX C

HABITAT REPORTS

- Patterns of Larval Fish Abundance in a Bottomland Hardwood Wetland (Killgore and Baker, 1996)
- Lower Cache River Basin Restoration: Benefits To Fish and Aquatic Habitat (Killgore and George, 2009)
- A Model to Evaluate Mussel Habitat Improvement by Restoring Connectivity to Isolated Meanders of the Lower Cache River, Arkansas (Payne and Farr, 2009)

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PATTERNS OF LARVAL FISH ABUNDANCE IN A BOTTOMLAND HARDWOOD WETLAND

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Abstract: Larval fishes were collected with light traps and ichthyoplankton nets for two consecutive years during spring and early summer in the channel and floodplain (tupelo and oak forest) of the Cache River, Arkansas. A total of 8,113 individuals were collected between the two gears. Twenty-eight species were confirmed, but total number of taxa, including genus and family level groupings, was 35. Pirate perch (*Aphredoderus sayanus*) was the most abundant species, with 21% of the total catch consisting of this fish. Percidae (darters) was the dominant family, comprising at least seven species and accounting for 57% of the total numbers of fish collected. The families Cyprinidae and Centrarchidae were also common. Specimens that could not be identified to species made up nearly 56% of the catch. Species richness was similar among the three habitats probably due to hydraulic mixing, but individuals in the families Centrarchidae, Cyprinidae, and Percidae were more abundant in tupelo and oak habitats than in channel for net and light trap catches. Mean catch of total individuals in nets and light traps was greater in floodplain habitats than in the channel, particularly during spring 1989. Large catches in spring 1989 corresponded to higher water levels that expanded the aquatic/oak forest transition zone compared to lower water levels in 1988. Thus, late winter and spring floods that inundate the oak forest appear to be a major factor in regulating abundance of larval fishes in this bottomland hardwood wetland.

Key Words: forested wetlands, larval fish, reproduction, hydrology, floodplain

INTRODUCTION

Bottomland hardwood forests are found within the broad floodplains of most major rivers of the southeastern and southcentral United States. These forested wetlands and associated streams are highly productive and are inhabited by a wide array of terrestrial and aquatic organisms (Wharton et al. 1982, Mitsch and Gosselink 1986), including many species of fish. Many fishes undergo regular migrations to utilize inundated floodplains as spawning, nursery, and foraging areas (e.g., Guillory 1979, Ross and Baker 1983, Finger and Stewart 1987, Copp 1989, Scott and Nielson 1989), while others reside year-round in permanent pools and oxbow lakes on the floodplain (Lietman et al. 1991). For both types of fish, seasonally inundated floodplains provide additional feeding areas that coincide with periods of increased energetic needs for reproduction and growth (Whitaker 1977, de la Cruz 1978, Lambou 1990).

Bottomland forests are seasonally inundated, sometimes for months, and may have several hydrographic pulses each year (Brinson 1990). Reproduction of most wetland fishes is closely related to timing, extent, and duration of flooding (Lambou 1963), and annual variations in this pulsed, or periodic flooding of rivers affects reproductive success and year-class strength of many species (Starrett 1951, Guillory 1979, Larson et al. 1981). Flow rate influences abundance of larval fish within different floodplain habitats (Turner et al. 1994) and contributes to downstream movement of ichthyoplankton (Harvey 1987, Copp and Cellot 1988). Lateral movements of adult fish on the floodplain, however, decrease exponentially with reductions in discharge (Kwak 1988). Spawning failure may occur if water levels remain low and population numbers are high (Starrett 1951).

We examined a larval fish assemblage within a large tract of bottomland hardwoods associated with the Cache River, northeastern Arkansas. Our objectives were to describe species composition of larval fishes in the wetland and to evaluate differences in abundance of larval fish between channel and floodplain habitats over a two-year period.

STUDY SITE

The Cache River flows generally south-southwestward along the western edge of the Mississippi Embayment for approximately 229 km to its confluence with the White River near Clarendon, Arkansas. The basin, including tributaries, has a drainage area of approximately 5,227 km². Mean annual rainfall is about 125 cm, with the highest amounts falling during winter and spring (Mauney and Harp 1979). Discharge in the Cache River ranges from zero to 374 m^3/sec with a mean annual flow of 35.7 m^3/sec (unpubl. data; U.S. Army Engineer District, Memphis).

Flooding typically occurs from late February through May. Water depths on the floodplain range from a few centimeters to over 2 meters. The forested floodplain ranges from 1 to 3 km in width, and includes areas of tupelo gum (*Nyssa aquatica* L.) and bald cypress (*Taxodium distichium* (L.) Rich.). Despite channelization and deforestation, the lower reaches of the Cache River support some of the largest contiguous tracts of bottomland hardwood forest remaining in the Lower Mississippi River Valley, part of which comprise the Rex Hancock/Black Swamp Wildlife Management Area (U.S. Army Corps of Engineers 1974, Mauney and Harp 1979, Clairain and Kleiss 1989).

Fishes were collected in a fourth-order reach of the Cache River south of Gregory, Arkansas in the Rex Hancock Wildlife Management Area. Three habitats were sampled (Figure 1): stream channel, regularly flooded stands of tupelo gum and some bald cypress, and irregularly flooded oak forest.

The river channel was 0.5 to 3.0 m deep, and water velocities ranged from 0 to 75 cm/sec over sand and mud. The tupelo habitat was adjacent to the western side of the channel and extended approximately 365 m from it and 550 m along it. Tupelo gum was the dominant structure; bald cypress, buttonbush (*Cephalanthus occidentalis* L.) and swamp privet (*Forestiera acuminata* (Michx.)(Poir.) were less abundant. Depths ranged from 0.5 to 2.0 m, water velocity was slow (0–30 cm/sec), and the substrate was primarily mud. The oak habitat was adjacent to the tupelo forest and extended up to the permanent terrestrial zone. The maximum elevation difference between the oak and tupelo habitats was approximately 1 meter msl. The oak habitat flooded to a depth of less than 1 m; water velocity was near 0 during the majority of sampling events and always less than 30 cm/sec. The substrate was mud and sand. Overcup oak (*Quercus lyrata* Walt.) and bitter pecan (*Carya aquatica* (Michx. f.) Nutt.) were the dominant trees, with willow, nuttall and water oaks (*Quercus phellos* L., *Q. nuttallii* Palmer, and *Q. nigra* L.) and swamp red maple (*Acer rubrum* L.) also present.

METHODS

Larval fishes were collected during three sampling periods in 1988 and 1989, corresponding to early spring (March, 13–17 °C), late spring (April–early May, 18–22 °C), and early summer (late May–early June, 23–25 °C). Fishes were collected with a standard 0.5-m diameter, 505-μm mesh ichthyoplankton net and light traps, as conditions allowed. During each sampling period, number of net and light trap samples collected in each habitat ranged from 6 to 29 and 6 to 32, respectively. However, oak habitat could not be sampled with nets during April or May 1988 due to low water, and only a single net sample was taken in May 1989. Similarly, high channel velocities in March 1988 and lack of overbank flooding in May 1988 precluded light traps in channel and oak habitats, respectively.

A single ichthyoplankton net attached to a 2.5-m-long steel handle was mounted to the side of a 4.6-m square-stern canoe approximately 1 m behind the bow. The net was fished stationary from the anchored canoe in moving water or pushed slowly in static water. Duration of net samples ranged from 4.5 to 5.5 minutes, but were usually 5 minutes. A General Oceanics Model 2035-B flow meter was mounted in the mouth of the ichthyoplankton net to monitor flow volume. Meter readings and duration of sampling were converted to an estimate of volume filtered for each sample. An equal number of net samples were collected during day and night in 1988. In 1989, approximately 70% of the samples were collected at night.

Plexiglass light traps were fished in all three habitats. The design was based on a slotting trapping system originally described by Floyd et al. (1984) and modified for this study (Killgore 1994). A 12-hour Cyalume yellow chemical light stick was used as a light source for attracting fishes. Turbidity ranged from 40 to >300 NTU but was similar among the three habitats during any given sampling period. The floating traps were set 1–2 hours before dark and retrieved the following morning; thus, sampling times were about 14 hours per set. Trap contents were filtered through a 505-μ ichthyoplankton net. All samples were immediately preserved in 5% buffered formalin and later transferred to 70% ethanol. Identification was to the lowest possible taxonomic category.

Ichthyoplankton net and light trap catches were analyzed using a Model I (fixed effects) two-way analysis of variance (ANOVA). Prior to ANOVA, net and light trap data were transformed to $\log_{10} + 1$ values because means were not normally distributed (Shapiro-Wilk statistic, $P<0.01$). Main effects were sampling period (6) and habitat (3). Catches for nets and light traps were number of larvae per m^3 and number of larvae per night, respectively. Following significant ANOVA results, the Student-Newman-Keuls multiple range test was used to compare means among individual sampling periods and habitats. All data summaries

Table 1. Comparison of taxa and total numbers of larval fishes collected by light traps and ichthyoplankton net in channel (CH), tupelo (TUP) and oak habitats, Cache River, Arkansas, 1988–1989.

Scientific Name	Common Name	Light Trap CH	Light Trap TUP	Light Trap OAK	Net CH	Net TUP	Net OAK	Total
Lepisosteidae								
Lepisosteus oculatus (Winchell)	Spotted gar	0	1	0	5	8	0	14
L. osseus (Linnaeus)	Longnose gar	1	1	0	0	0	0	2
Lepisosteus sp.	Gars	1	0	0	0	0	0	1
Clupeidae								
Dorosoma cepedianum (Lesueur)	Gizzard shad	1	0	0	15	32	12	60
Dorosoma sp.	Shad	0	0	25	0	2	0	27
Cyprinidae								
Notemigonus crysoleucas (Mitchill)	Golden shiner	0	0	1	0	0	0	1
Opsopoedus emiliae Hay	Pugnose minnow	3	12	0	2	6	0	23
Pimephales vigilax (Baird and Girard)	Bullhead minnow	0	7	5	5	7	4	28
Notropis sp.	Minnows/shiners	8	62	4	0	9	22	105
Unidentified Cyprinidae	—	2	377	409	0	32	7	827
Catostomidae								
Erimyzon sucetta (Lacépède)	Lake chubsucker	1	0	0	0	0	0	1
Ictiobus sp.	Buffalo	0	3	0	0	4	0	7
Minytrema melanops (Rafinesque)	Spotted sucker	41	14	1	21	62	0	139
Ictaluridae								
Ameiurus natalis (Lesueur)	Yellow bullhead	0	1	0	1	0	1	3
Ictalurus punctatus (Rafinesque)	Channel catfish	0	0	0	7	8	0	15
Noturus gyrinus (Mitchill)	Tadpole madtom	0	0	0	9	16	1	26
Aphredoderidae								
Aphredoderus sayanus (Gilliams)	Pirate perch	95	262	741	255	277	65	1695
Cyprinodontidae								
Fundulus olivaceus (Storer)	Black spotted topminnow	3	1	1	0	4	2	11
Fundulus sp.	Topminnows	0	0	0	1	0	0	1
Centrarchidae								
Centrarchus macropterus (Lacépède)	Flier	0	0	346	0	0	0	346
Elassoma zonatum Jordan	Banded pigmy sunfish	0	2	1	3	2	0	8
Lepomis sp.	Sunfish	2	2	34	4	4	8	54
Micropterus sp.	Black bass	0	0	1	2	0	3	6
Pomoxis annularis Rafinesque	White crappie	1	3	1	0	0	1	6
P. nigromaculatus (Lesueur)	Black crappie	0	2	30	0	0	0	32
Pomoxis sp.	Crappie	0	2	0	1	0	0	3
Unidentified Centrarchidae	—	0	1	32	0	0	4	37
Percidae								
Etheostoma asprigene (Forbes)	Mud darter	1	16	16	2	1	25	61
E. chlorosomum (Hay)	Bluntnose darter	3	51	18	4	9	90	175
E. gracile (Girard)	Slough darter	5	21	20	0	2	5	53
E. proeliare (Hay)	Cypress darter	0	69	167	3	1	5	245
E. stigmaeum (Jordan)	Speckled darter	0	58	31	2	4	2	97
Etheostoma sp.	Darters	24	552	1717	0	40	11	2344
Percina caprodes (Rafinesque)	Logperch	3	17	9	3	39	0	71
P. shumardi (Girard)	River darter	19	126	222	27	12	115	521
Unidentified Percidae	—	12	88	952	4	5	7	1068
Sample size		76	128	95	84	59	16	
Total Catch		226	1751	4784	376	586	390	8113

sponded to high water levels in both winter and spring 1989, whereas high water occurred only during winter in 1988 (Figure 2).

Species richness (excluding genus and family level groupings) was similar among the three habitats, ranging from 19 to 21 species for net and light traps combined. High species richness in the channel was partly due to the presence of five species represented by only one individual. However, the families Centrarchidae, Cyprinidae, and Percidae were more abundant in tu-

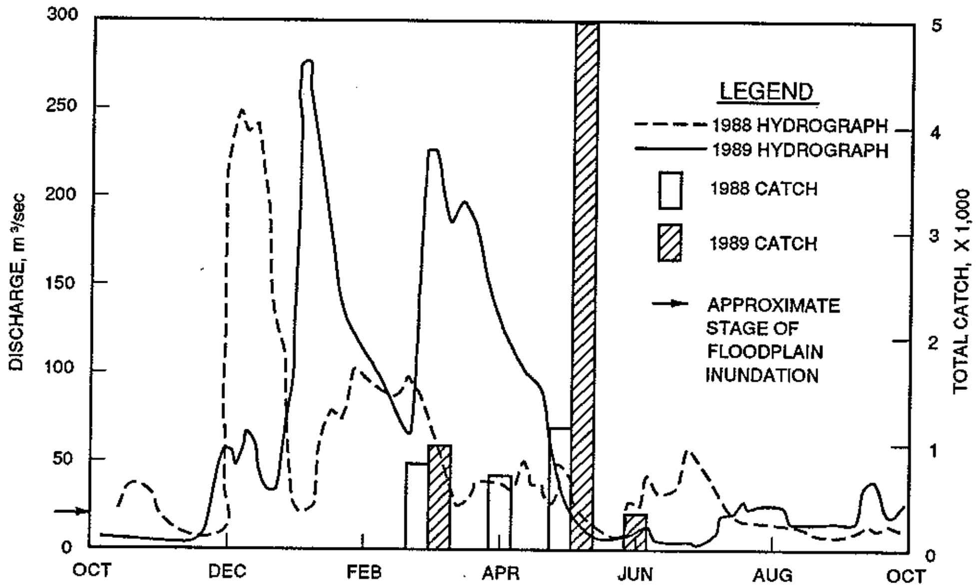

Figure 2. Mean daily discharge in the Cache River at Patterson, Arkansas, and total number of larval fish collected for water years 1988 and 1989.

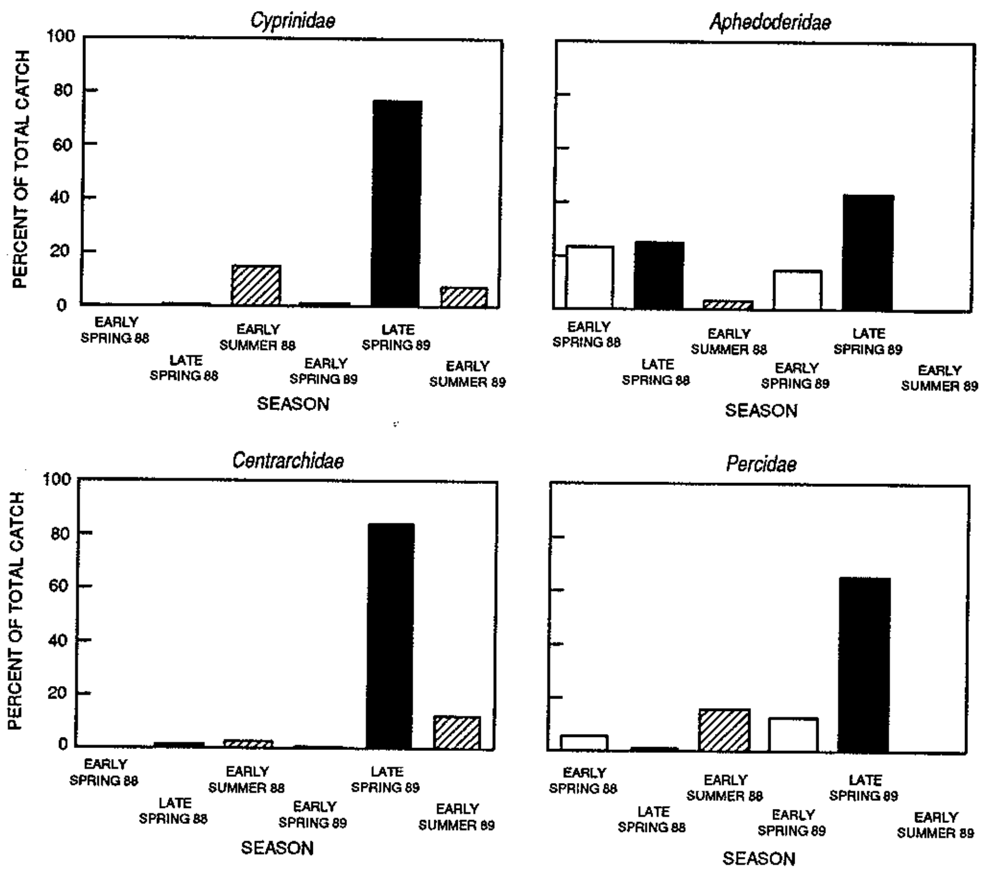

Figure 3. Percent of total catch by season for the four dominant families of larval fish collected in the Cache River during 1988–1989. All gear types are pooled.

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Lower Cache River Basin Restoration: Benefits To Fish and Aquatic Habitat

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Introduction

The Cache River is located in northeastern Arkansas and is a tributary of the White River. It is 213 miles long, meandering through the Mississippi River alluvial valley forming sloughs and oxbow lakes. The Cache River National Wildlife Refuge occurs along the lower river and is one of the largest contiguous bottomland hardwood forests in the United States. Most of the river was channelized in the 1920-30 period, and the lowermost reach was straightened in the 1970's for greater floodwater conveyance. Despite flood control projects in the lowermost reach of the river, the Cache River supports a high diversity of fishes compared to other stream systems in the lower Mississippi River valley (Figure 1). Furthermore, the floodplain is extensive and provides spawning and rearing habitat for important wetland and riverine fish species (Killgore and Baker 1996). Given the diverse fish community and the relatively pristine condition of some reaches of the river and floodplain, restoration and conservation efforts in the Cache River should yield high environmental benefits.

The Memphis District has developed a Preliminary Restoration Plan (PRP) to restore flow in six river meanders near the mouth of the river that were plugged during flood reduction activities in the 1970's (Memphis District 2005). Flow was diverted from the meanders into a straight, channelized reach. According to the PRP, the meanders range from approximately 7 to 32 acres. The preferred alternative is for complete removal of the plugs and the placement of rock weirs in the channel immediately downstream of the entrance to each meander at a height sufficient to restore flow in the meander while not impeding flood event flows from passing through the channelized section (Memphis District 2005). According to MVM, the reconnected meanders will receive all of the water during non-flood conditions. ERDC conducted a field study and evaluated existing information to describe baseline habitat conditions of the meanders and develop models to predict benefits of the project on fishes of the lower Cache River.

Methods

Field Assessment

In March 2009, fishes were sampled in each of the six meanders, the intersecting channelized reach, and a natural bendway immediately upstream of the channelized reach. Fishes were collected at three sites at each of the eight locations, whereas water quality was measured once at the middle of each location. For the meanders and natural bendway, sample sites corresponded to the lower (most downstream), middle, and upper portions of the waterbody; the straight, channelized reach was sampled at three representative locations.

Fishes were collected with a boat-mounted electrofishing unit. One sample consisted of 5-minutes of shocking time and three samples were taken per location. During shocking, attempts were made to collect all fish that were stunned. Fish were identified to species, and each individual was enumerated and measured for total length. A hydrolab and turbidity meter was used to measure water temperature, conductivity, pH, dissolved oxygen, and turbidity. Maximum water depth was recorded and velocity, if any, was measured.

Benefit Analysis

A species abundance table was developed comparing fish assemblages among the three primary habitats (meanders, channelized, natural). In addition, all species were classified as either riverine or lacustrine, and these two groups were used as the biological response to the restoration project. Riverine species require moderate- to swift-flowing water to complete one or more of their life stages. All species in this guild are either intolerant or moderately intolerant of habitat changes, and were impacted the greatest during the 1970 channel work. Therefore, the restoration project will have direct, positive benefits on riverine species. Lacustrine species are locally abundant, widely distributed, and all are tolerant or moderately tolerant of habitat changes. This guild generally prefers non-flowing conditions and is morphologically adapted to deeper, slower water of lakes and large pools of rivers.

Benefits of the project were calculated as the difference between post-project Habitat Units and pre-project Habitat Units. Habitat Units were calculated as:

Habitat Units = Habitat Suitability Index X Habitat Area

in which the Habitat Suitability Index (HSI) is a relative index of habitat quality, ranging from poor (0) to excellent (1.0) habitat, and habitat area is the surface area of water for an individual river reach or pool.

Empirically-based HSI models were used from a library of habitat models (Killgore et al. 2008). One of these models developed from data collected in the Red River System for riverine and lacustrine species were used in the Cache River analysis. Fish assemblages and river habitats are similar in many respects; both are in the lower Mississippi River drainage and both have a sinuous, geomorphic pattern. Existing and post-project acreages were either derived from field measurements taken in March 2009, or provided by MVM for each major habitat (meanders, channelized reach, and natural bendway). For each habitat, the appropriate HSI value was multiplied by the corresponding acres to obtain Habitat Units. It was assumed that once the plugs were removed, flow would quickly create a riverine habitat with no long-term degradation in channel conditions. Therefore, annualization was not necessary and it was assumed that Habitat Units would remain constant during the life of the project.

Results and Discussion

Existing Conditions

The Meanders have a sinuous pattern occurring on both sides of the river over a 7-mile reach (Figure 1). Meanders range in size from 7-32 acres (MVM, unpublished data):

Meander	Acres
1	17
2	7
3	32
4	13
5	25
6	17

Meanders are relatively stable with similar water quality conditions (Table 1). An exception was Meander 4 where turbidity was 30 NTU's compared to an average among all meanders of 153 NTU's. Meander 4 was more isolated, and consequently, silver carp were detected only in this meander likely due to clearer water and higher plankton production, which is silver carp's primary diet. Exotic species, such as silver carp, tend to increase with isolation (Lasne et al. 2007). The meanders lie within a floodplain that extends throughout the Cache River. Flooding and connectivity of the meanders (the downstream opening) with the River occurs from late February through May. The riparian vegetation of the meanders is similar to the forested floodplain in the Cache River and includes areas of tupelo gum (*Nyssa aquatica* L.) and bald cypress (*Taxodium distichium* (L.) Rich.). The maximum depth of the meanders was 10.6 feet, slightly less than the natural bendway but shallower than the channelized reach. Water velocity was not detected in the meanders during sampling, except through a small cut in Meander 3. Depth and channel morphology of the meanders indicate a stable channel suggesting long-term benefits of the restoration project.

The six meanders currently provide marginal habitat for riverine species, which is the group of fishes directly impacted from channel straightening. During the March 2009 sampling, 17 out of 38 total species collected were considered riverine (Table 2). However, there are additional riverine species in the Cache/White River drainage that could potentially utilize the meanders once flow is restored. A total of 97 fish species have been collected in the lower

White River system, many of which are riverine, taxonomically dominated by minnows (26 species), darters (19 species), sunfishes (13 species), and suckers (11 species) (Killgore and Hoover, unpublished data). Except for the absence of darters (seining would be required to capture this group), the March 2009 collections in the Cache River reflect the overall fish assemblage structure in the lower White River system.

Species richness (i.e., number of species) varied among the three primary habitats sampled. In the six meanders, richness ranged from 16-20 (Figure 3). Sixteen species were collected in the natural bendway immediately upstream of the channelized reach, similar to the meanders, but only 7 species were collected in the channelized reach. Although the meanders had relatively high species richness, the natural bendway had the highest percent number of riverine species (Figure 4), further justifying the restoration of flows through the cut-off Meanders.

Benefit Analysis

The Habitat Suitability Index value of the Meanders for riverine fishes increased from 0.2 for baseline conditions to 1.0 with project (Table 3). The Meanders currently provide adequate to excellent habitat conditions for lacustrine fishes at baseline (HSI=1.0) and only a slight reduction in HSI value occurred with project (HSI=0.8). Lacustrine fishes are well adapted to live along littoral areas of flowing water habitats, exploiting the deep holes and woody debris. Once the Meanders are connected, slackwater areas will be reduced (decrease in HSI), but adequate habitat will persist in the Meanders for most lacustrine fishes.

The channelized reach under baseline conditions provides flowing water habitat. However, based on low numbers of riverine fishes collected in the channelized reach and the homogenous channel conditions compared to natural bendways, the riverine HSI value was set at 0.2 for both baseline and with project conditions. Conversely, the channelized reach is suitable for lacustrine fishes under baseline conditions although flowing water reduces habitat quality for lacustrine fishes that prefer slackwater conditions (HSI=0.6). Once the channelized reach becomes disconnected from the main channel, pool habitat is formed that and habitat quality increases for lacustrine fishes (HSI=1.0).

Tradeoffs between species guilds are apparent, but overall, a net increase in Habitat Units (HU) will occur post-project (Table 3). As HU's increase for riverine fishes in the restored meanders, they decrease slightly for lacustrine fishes. However, an increase in HU's in the channelized reach for lacustrine fishes offset any decreases. Assuming no changes in acres for pre- and post-project conditions, a total increase of 89 and 80 HU's will occur post-project for riverine and lacustrine fishes, respectively. For riverine fishes, which are the most sensitive to habitat degradation in river systems, numbers will increase with connectivity leading to an important contribution of conserving native fish diversity (Lasne et el. 2007).

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Table 1. Mean water quality and hydraulic parameters measured on March 25, 2009 in the lower Cache River.

Reach	Variable	N	Mean	Std Dev
Channelized	Temperature, C	1	16.1	.
	Conductivity, µmhos/cm	1	165.0	.
	pH	1	7.7	.
	Dissolved oxygen, mg/l	1	7.3	.
	Turbidity, NTU	1	153.0	.
	Maximum depth, ft	1	12.5	.
	Water velocity, cm/s	1	33	.
Meanders	Temperature, C	6	16.3	1.3
	Conductivity, µmhos/cm	6	176.3	24.0
	pH	6	7.7	0.1
	Dissolved oxygen, mg/l	6	7.5	0.6
	Turbidity, NTU	6	77.0	28.9
	Maximum depth, ft	6	10.6	1.1
	Water velocity, cm/s	6	0	0
Natural bendway	Temperature, C	1	15.1	.
	Conductivity, µmhos/cm	1	167.0	.
	pH	1	7.8	.
	Dissolved oxygen, mg/l	1	7.3	.
	Turbidity, NTU	1	153.0	.
	Maximum depth, ft	1	16.3	.

Table 2. Number of fish by species and location collected in the lower Cache River on 25 Mar 2009 using a boat-mounted electroshocker. Locations sampled were the six cut-off meanders, an intersecting channelized reach, and a natural bendway. Guilds correspond to R=riverine, L=lacustrine.

Scientific name	Common name	Guild	Meanders	Channelized	Natural	Total
Family Petromyzontidae						
Ichthyomyzon castaneus	Chestnut lamprey	R	1			1
Family Polyodontidae						
Polyodon spathula	Paddelfish	R	2			2
Family Lepisosteidae						
Lepisosteus oculatus	Spotted gar	L	28	3		31
L. osseus	Longnose gar	R	16	3	2	21
L. platostomus	Shortnose gar	R	4			4
Family Amiidae						
Amia calva	Bowfin	L	1			1
Family Clupeidae						
Dorosoma cepedianum	Gizzard shad	L	20			20
D. petenense	Threadfin shad	L	5		1	6
Family Cyprinidae						
Cyprinus carpio	Common carp	L	8			8
Cyprinella venusta	Blacktail shiner	R	2		2	4
Hypophthalmichthys molitrix	Silver carp	L	2			2
Notropis amnis	Pallid shiner	R			1	1
Notropis atherinoides	Emerald shiner	R	7	2	1	10
Opsopoeodus emiliae	Pugnose minnow	L	1			1
Pimephales vigilax	Bullhead minnow	R			3	3
Family Catostomidae						
Carpiodes carpio	River carpsucker	R	2			2
Ictiobus bubalus	Smallmouth buffalo	R	23	1		24
I. cyprinellus	Bigmouth buffalo	L	14	1		15
I. niger	Black buffalo	R	5			5
Minytrema melanops	Spotted sucker	R	2			2
Family Ictaluridae						
I. punctatus	Channel catfish	L	1	2	1	4
Pylodictus olivaris	Flathead catfish	R	2			2
Family Aphredoderidae						
Aphredoderus sayanus	Pirate perch	L	2			2
Family Fundulidae						
Fundulus olivaceus	Blackspotted topminnow	L			1	1
Family Atherinidae						
Labidesthes sicculus	Brook silverside	L	4			4

Table 2. Number of fish by species and location collected in the lower Cache River on 25 Mar 2009 using a boat-mounted electroshocker. Locations sampled were the six cut-off meanders, an intersecting channelized reach, and a natural bendway. Guilds correspond to R=riverine, L=lacustrine.

Scientific name	Common name	Guild	Meanders	Channelized	Natural	Total
Family Moronidae						
Morone chrysops	White bass	R	2		1	3
M. mississippiensis	Yellow bass	R	4			4
Family Centrarchidae						
Lepomis cyanellus	Green sunfish	L	1			1
L. gulosus	Warmouth	L	3			3
L. humilis	Orangespotted sunfish	L	19		1	20
L. macrochirus	Bluegill	L	45	1	4	50
L. megalotis	Longear sunfish	R	45		23	68
L. miniatus	Redspotted sunfish	L	1			1
Micropterus punctulatus	Spotted bass	R	6		3	9
M. salmoides	Largemouth bass	L	6		2	8
Pomoxis annularis	White crappie	L	19		1	20
P. nigromaculatus	Black crappie	L	2			2
Family Sciaenidae						
Aplodinotus grunniens	Freshwater drum	R	18		2	20
Total Shocking Time, minutes			90	15	15	120
Total number of species			35	7	16	38
Total number of individuals			323	13	49	385

Table 3. Gains in Habitat Suitability Index values and Habitat Units for riverine and lacustrine fish species resulting from restoring flow into Meanders in the lower Cache River, AR

Alternative	Taxa	Meanders			Channelized			Total HU's
		HSI	Acres	Habitat Units	HSI	Acres[1]	Habitat Units	
Baseline	Riverine	0.2	111	22	0.2	256	51	73
	Lacustrine	1.0	111	111	0.6	256	154	265
With Project	Riverine	1.0	111	111	0.2	256	51	162
	Lacustrine	0.8	111	89	1.0	256	256	345
Net Gain in Habitat	Riverine	+0.6	0	+89	0	0	0	+89
	Lacustrine	-0.2	0	-22	+0.4	0	+102	+80

[1]Acres calculated assuming seven miles in length and an average channel width of 303 ft (measured in the field 25 Mar 2009)

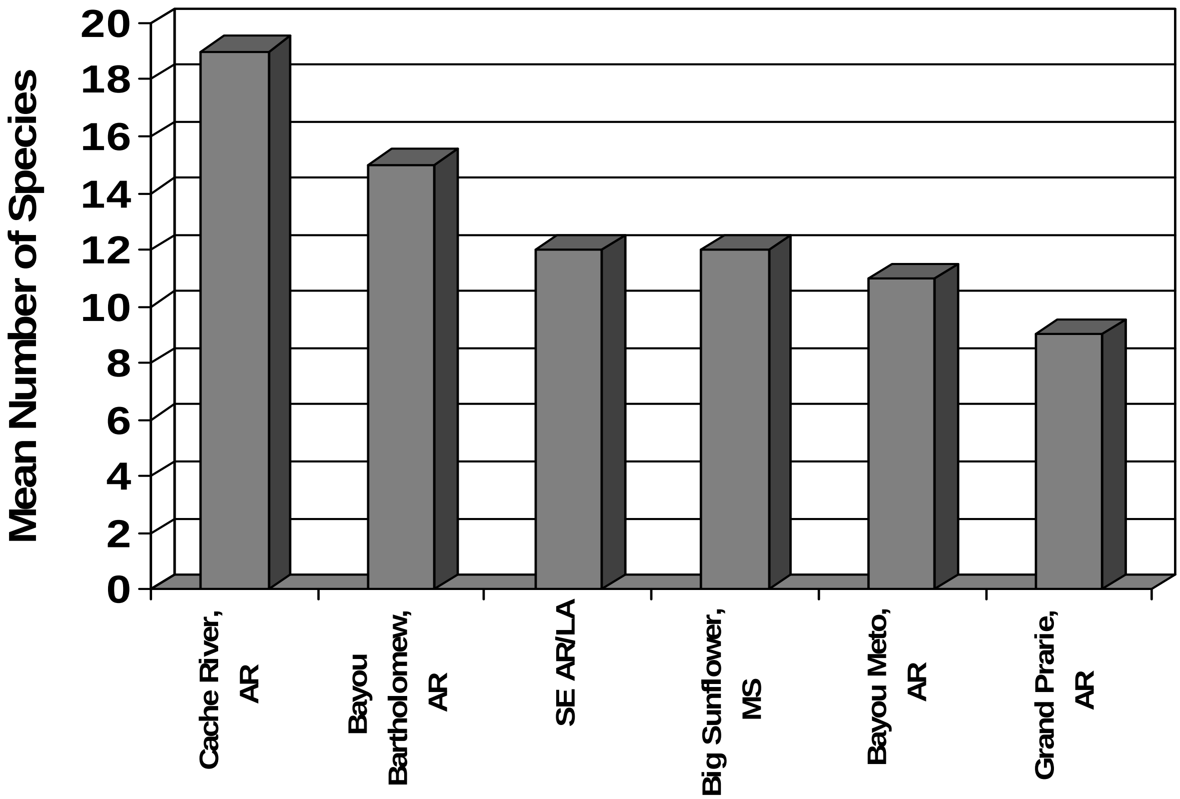

Figure 1. Mean number of fish species collected with seines in different streams of the lower Mississippi River valley (from ERDC data base).

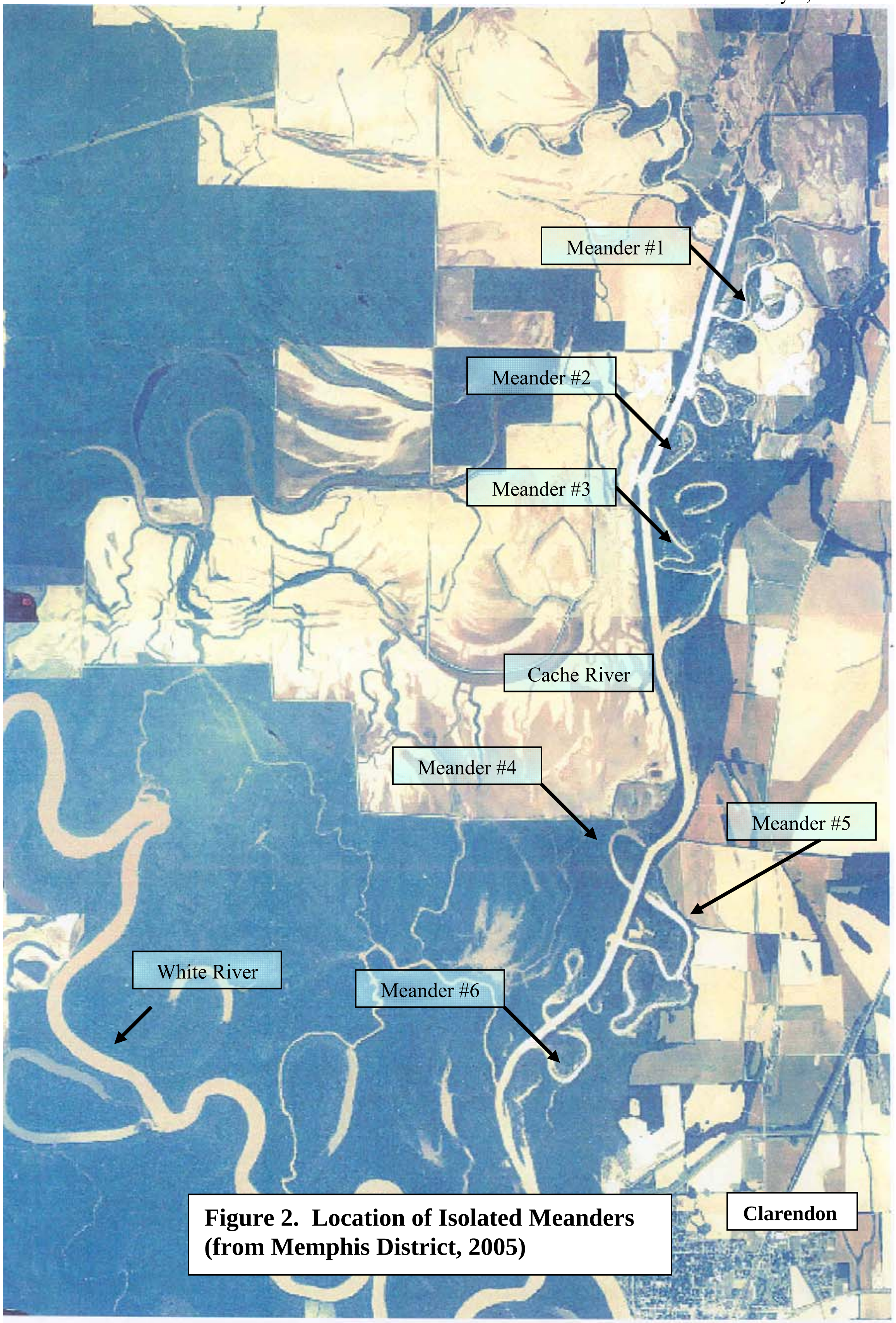

Figure 2. Location of Isolated Meanders (from Memphis District, 2005)

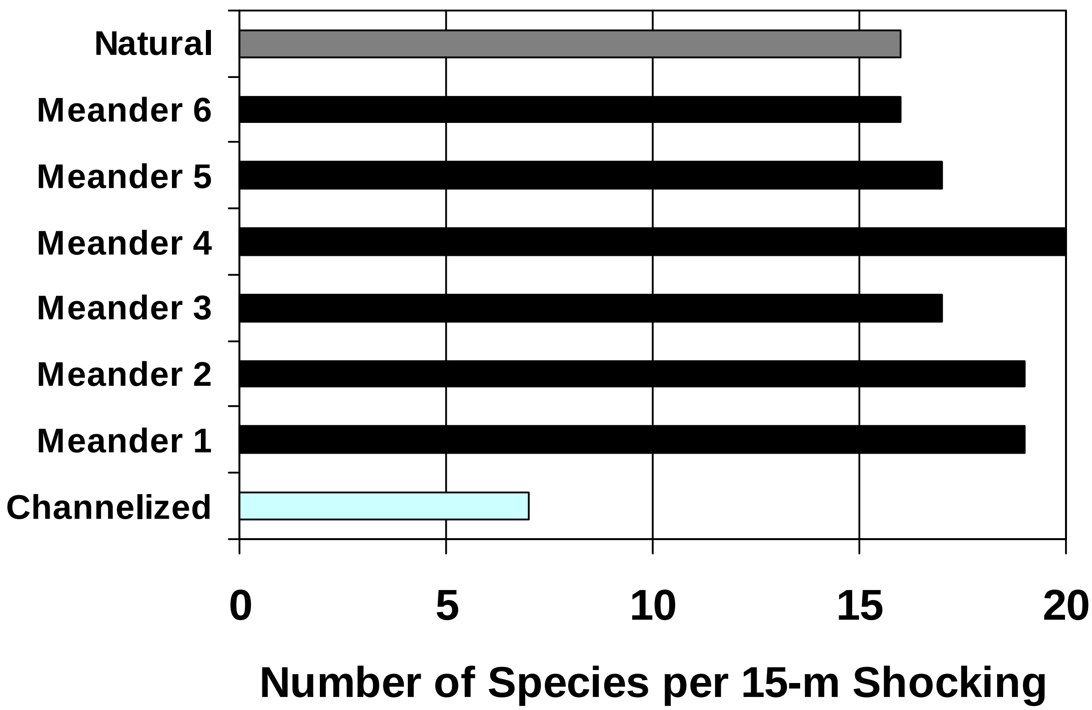

Figure 3. Number of fish species per 15-minutes shocking in the lower Cache River, AR in March 2009.

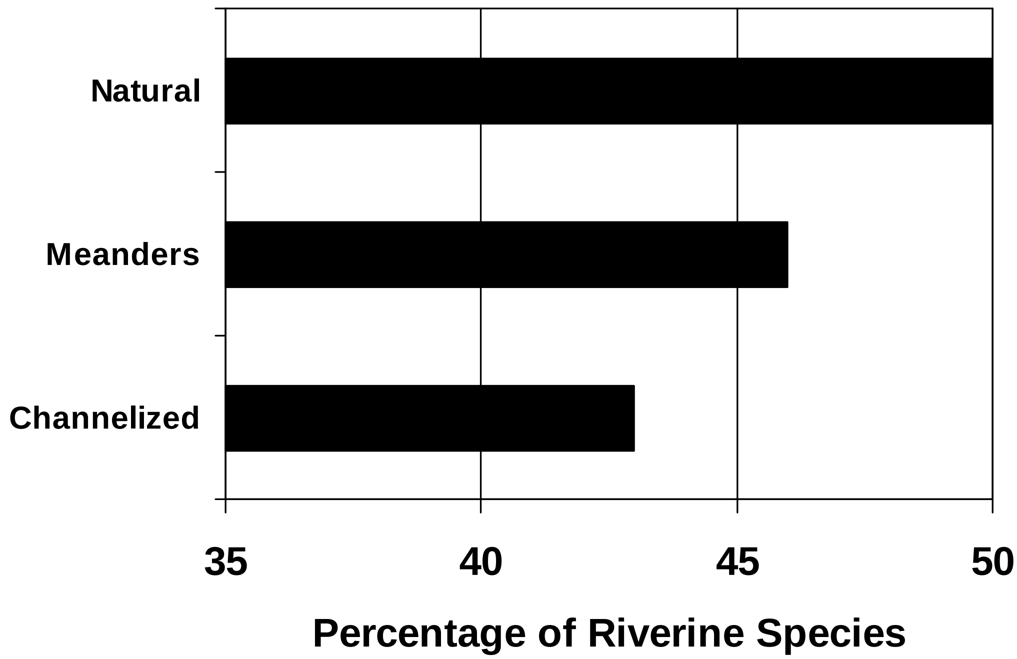

Figure 4. Percent number of riverine species (see Table 1 for classification) collected in the three primary habitats in the Cache River, March 2009.

A Model to Evaluate Mussel Habitat Improvement by Restoring Connectivity to Isolated Meanders of the Lower Cache River, Arkansas

by

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Background

The Project. The U.S. Army Corps of Engineers Memphis District is proposing to restore more natural flow to isolated meanders along a channelized reach of the lower Cache River. These meanders were isolated by earlier flood protection work. The sediment plugs isolating the meanders might be intersected with culverts or completely removed. Flow might be forced into the meanders by placing rock weirs across the channelized reach or completely refilling the straightened channel, leaving only the historic meandering configuration. Preliminary analysis suggests the most feasible alternative consists of complete removal of the plugs and the placement of rock weirs in the channel immediately downstream of the entrance to each meander at a height sufficient to restore flow in the meander while not impeding conveyance of flood flows in the channelized section. Thus, the authorized purpose of the original flood control project would not be compromised.

Previously authorized flood control work in the 1970’s cut off the meanders and changed them from a riverine ecosystem into a series of lentic pools. The proposed restoration targets a seven mile reach of the lower Cache River for return of a more natural hydrology within the river and its adjacent wetlands. This reach is located in Monroe County, Arkansas, almost entirely within the boundaries of the Cache River National Wildlife Refuge (Figure 1). The reach of the Cache River under study begins approximately 1.5 miles north of Clarendon, Arkansas and extends upstream to approximately 8.5 miles north of Clarendon. The project area includes six isolated river meanders, all plugged by the Cache River Basin Project in the early 1970’s that diverted flow of the river into a straight channel dissecting the historic river configuration. The meanders range from approximately 7 acres in meander 2 to approximately 32 acres in meander 3.

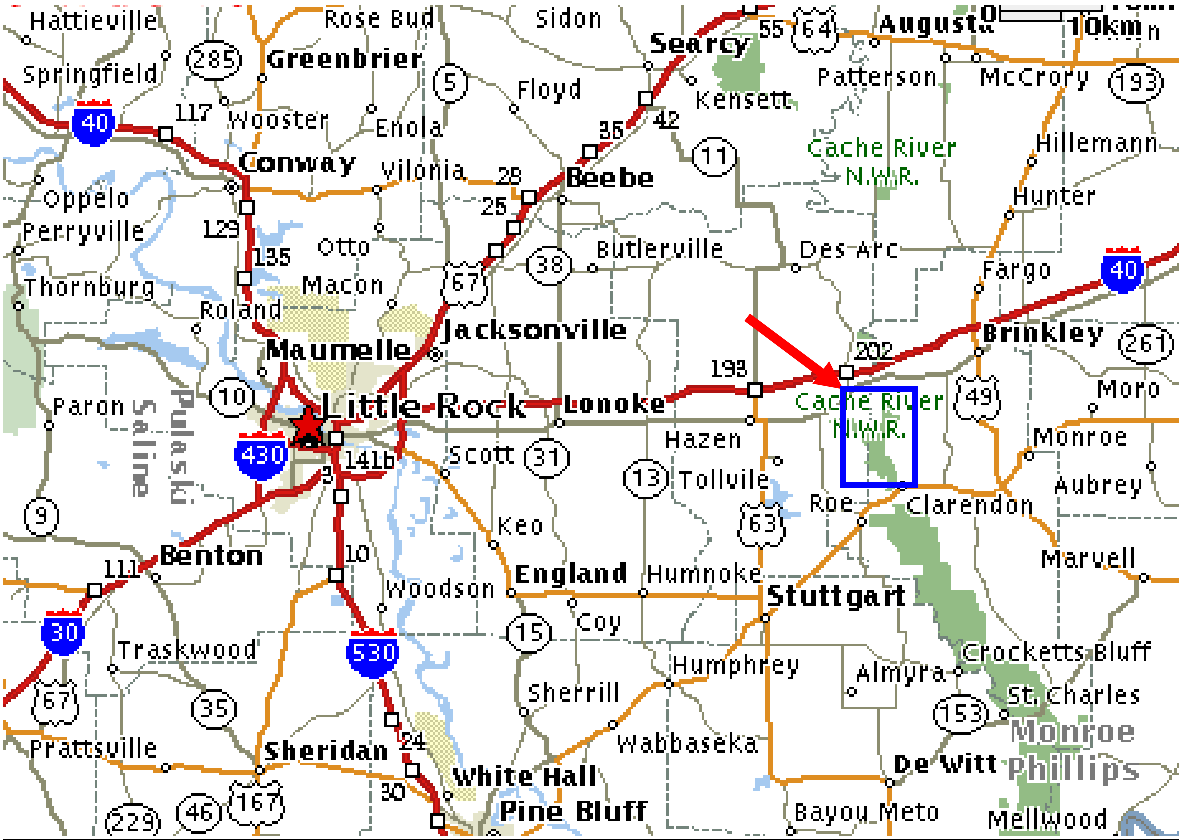

Figure 1. Project Vicinity Map.

The initial Cache River Basin, Arkansas, Project general design memorandum was approved in 1970; the accompanying environmental impact statement (EIS) was filed with the U.S. Environmental Protection Agency (EPA). The authorized project consisted of channel excavation on 140.0 miles of the Cache River, 14.6 miles of the Cache's upper tributaries, and 76.9 miles of Bayou DeView. Construction was started in 1972, and approximately four miles of channel enlargement were completed on the lower Cache River before work was halted by a federal court injunction in March 1973. This injunction resulted from a lawsuit filed by the Environmental Defense Fund and others. In 1974, a revised EIS was filed with EPA and a petition was filed in federal court. The injunction was removed in March 1976, and three additional miles of channel enlargement were completed on the lower Cache River. Although the courts sustained the adequacy of the 1974 EIS, construction of the authorized project was not continued because of EPA objections and widespread environmental opposition. In June 1987, a general reevaluation study was initiated at the request of the Cache River-Bayou DeView Improvement District to develop a flood-control plan generally acceptable to environmental interests. This study was terminated in December 1994 due to a lack of local sponsorship.

<u>The Mussel Resource in the Lower Cache River</u>. Results of 1991-1997 surveys by Christian and his associates (Christian et al. 2005) and the Corps in 2007 (USACE 2007) indicate that the project reach, the highly straightened, 200-ft wide channel that extends approximately 7.5 miles upstream of the confluence of the Cache with the White River, supports a low density and moderately diverse community of native freshwater mussels. The 1991-1997 survey effort is summarized first.

Christian and his associates identified 37 major or minor mussel beds in a 46-mile long section of river reaching from the Cache-White confluence to Arkansas Highway 39 near Des Arc (see Figure 1). Only two of these beds were located in the restoration project reach (both within 2.5 miles of the White-Cache confluence). Major beds were defined as having more than 10 mussels per m^2 and an area of at least 500 m^2; minor beds had similar density but less area or lower density but an area of at least 500 m^2. This distinction is not particularly important herein. What is more important is that these investigators were focused on recognizable aggregations (beds) of mussels and attempted a combination of mussel density and bed area estimates that allowed computation of numerical standing crop. The large majority of mussels (31 beds accounting for nearly 45% of the total standing crop) were in the uppermost 16 miles of their study reach. This 16-mile reach was a highly meandering 75 to 100-foot wide channel. Although the next 15 miles of river downstream had far fewer mussel beds (5), two of these were such major beds that this 15-mile reach accounted contributed nearly 46% of the total standing crop of mussels.

We closely examined result reported by Christian et al. in an attempt to identify trends in mussel abundance and either upstream distance or river sinuosity, or both. We divided their 46-mile study reach into 6 approximately equal segments (reaches A, B, C, D, E, and F, moving upstream as shown in Table 1). We translated the location of each mussel bed from Figure 1 of Christian et al. (2005) onto the Google Earth photomosaic of the river. Then, using the ruler and path tools of Google Earth, we estimated each bed's distance upstream of the Cache-White confluence. In addition, we estimated channel sinuosity (described in more detail latter) for each 1-mile segment of river, beginning at the Cache-White confluence and moving systematically upriver to Arkansas Highway 38. From this analysis, there is evidence of a downstream-to-upstream gradient in mussel abundance (Table 1). However, due to low mussel abundance in one of four sinuous reaches (reach B), there was less than compelling evidence of a gradient in mussel abundance and sinuosity. Nonetheless, four of five river reaches with high mussel abundance also had high sinuosity, while the highly straightened lowermost reach that is the topic of the present report, had low mussel abundance and low sinuosity (Table 1). Christian et al. discussed river sinuosity in relation to depth, substratum, and water velocity diversity, and suggested that habitat diversity associated with sinuosity helped explain the location of many mussel beds.

Table 1. Mussel abundance, river sinuosity, and upstream distance for six reaches of the lower Cache River, based on data reported in Christian et al. 2005. River miles (RM) are such that RM 0 is the Cache-White confluence and RM 46 is where the Cache crosses under Arkansas Highway 38.

Reach	RM Range	Average Number of Mussel per Mile	Average Sinuosity per Mile	Average Distance Upriver
A	0-7.5	1643	1.10	3.75
B	7.5-15.0	0	1.83	11.25
C	15.0-22.5	14621	1.53	18.75
D	22.5-30.0	18906	1.63	26.25
E	30.0-37.5	12501	1.74	33.75
F	37.5-46.0	16385	1.69	41.75

The Corps 2007 survey (USACE 2007) was intensively focused on the present study reach in the lowermost 7 miles of the Cache River. This effort looked not at mussel beds but rather at channel sites, in general or adjacent to six mostly disconnected meanders in the lowermost river, and within these meanders that convey little or no flow (Figure 2). Like Christian et al. (2005), this study indicated that mussels, while generally not abundant in the lowermost 7 miles, were somewhat more abundant nearer the Cache-White confluence. Not being restricted to "beds," the Corps survey suggested that mussels occurred at low density throughout the 7-mile reach. Furthermore and not surprisingly, mussel density in the isolated meanders was a small fraction of that in the flowing channel.

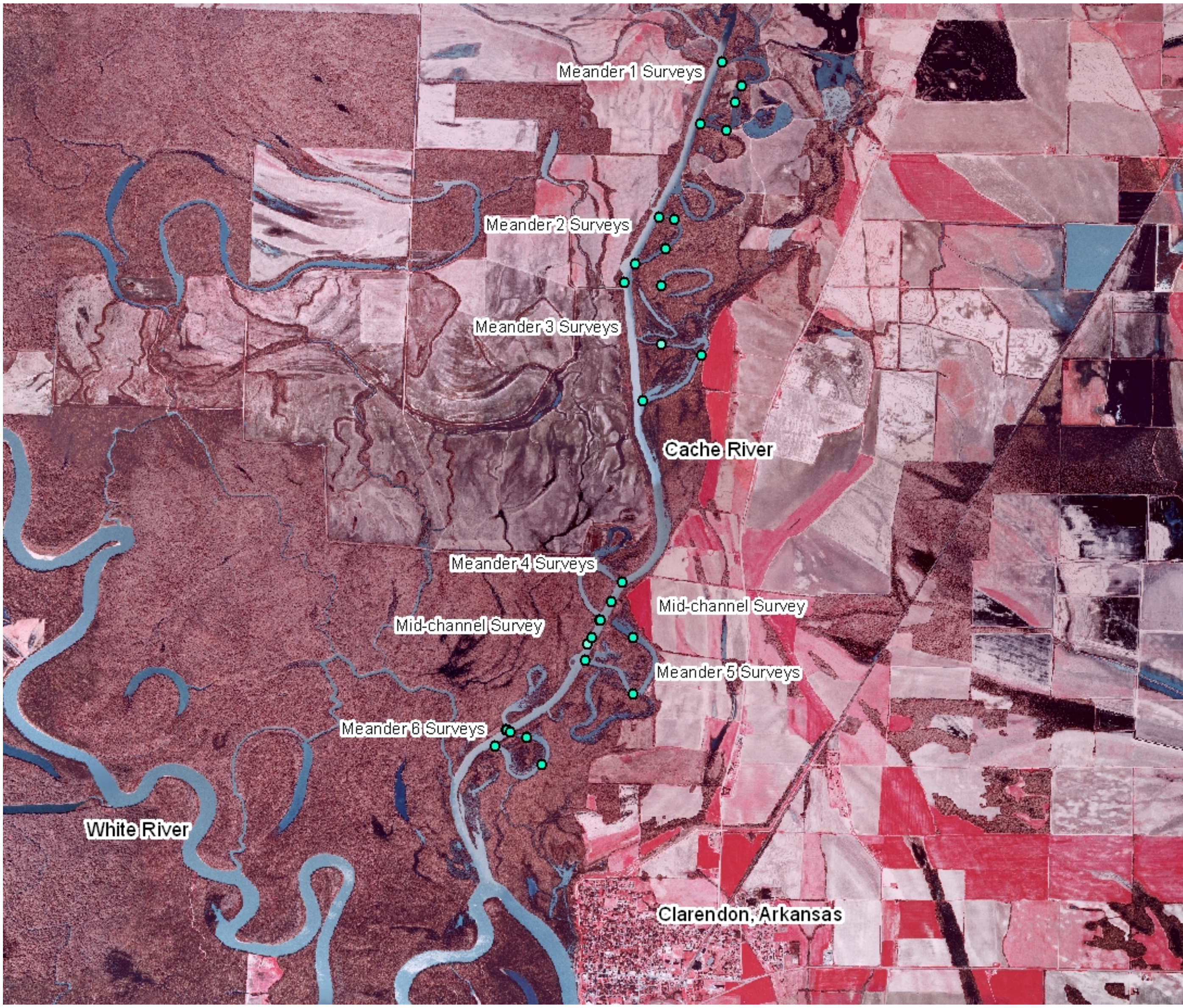

Figure 2. Locations of the mussel surveys conducted during July 2007. Surveys consisted of qualitatively sampling locations in the channelized portion of the lower Cache River and areas within the partially isolated meanders.

Table 2 summarizes the 2007 survey results and provides a composite representation of the reference condition of the mussel community of the lowermost Cache River. Consistent with Christian et al. (2005), the Corps results indicates that three species dominate this lowermost reach; these taxa are *Amblema plicata*, *Plectomerus dombeyanus*, and *Quadrual quadrula*. In addition, *Megalonaias nervosa* and *Quadrula nodulata* are moderately abundant. Overall, the mussel community in the lowermost Cache River is one that is often found in a southern alluvial river and is dominated by species tolerant of depositional substratum and dominated by riverine species that tolerate impoundment and relatively depositional conditions. Recruitment is evident for most species (Christian et al. 2005).

Table 2. Results of mussel surveys conducted in the lower Cache River, July, 2007 (USACE 2007).

Species		**Mid-Reach Channel Sites**	**Near Meander Channel Sites**	**Meander Sites**
Amblema plicata	Threeridge	70	98	41
Arcidens confragosus	Rock pocketbook	1	6	1
Lampsilis teres	Yellow sandshell	0	1	0
Megalonaias nervosa	Washboard	6	38	5
Obliquaria reflexa	Threehorn wartyback	7	17	1
Plectomerus dombeyanus	Bankclimber	27	25	17
Potamilus ohiensis	Pink papershell	0	0	1
Potamilus purpuratus	Bleufer	1	0	0
Pyganodon grandis	Giant floater	3	16	9
Quadrula nodulata	Wartyback	16	32	15
Quadrula pustulosa	Pimpleback	1	6	0
Quadrula quadrula	Mapleleaf	50	192	22
Toxolasma sp.	Lilliput	0	1	0
Truncilla donaciformis	Fawnsfoot	1	0	0
Truncilla truncata	Deertoe	0	6	1
Search Time (minutes)		**78**	**207**	**195**
Total Number of Individuals		**183**	**438**	**113**
Total Number of Species		**11**	**12**	**10**

Mussel Habitat Model

Background

In 1987 investigators at ERDC, in cooperation with W.D. Russell-Hunter, published a community HSI model to help guide habitat analyses with respect to those relatively thick-shelled mussels typically associated with a large river gravelly shoal (Miller et al. 1987). Genera in mind during the construction of the 1987 ERDC HSI model (Miller et al. 1987) were *Quadrula*, *Amblema*, *Megalonaias*, *Obliquaria*, and *Obovaria*. Thus, it is especially relevant to the present project. Subsequently, this model was largely incorporated into a mechanistic model of substrate and hydrodynamic effects on the formation of mussel beds in the upper Mississippi River (Morales et al. 2006). Several other investigators have similarly focused primarily on physical habitat variables as determinants of low, moderate, or high quality habitat and associated mussel distribution. Physical habitat variables including depth, water velocity, substratum particle size, substratum roughness, and substratum stability dominate recent models of freshwater mussel habitat (Hastie et al. 2000, Holland-Bartels 1990, Sherraden-Chance and Edds 2000, Strayer 1999, and Strayer and Ralley 1993). Some models also incorporate basic water quality variable such as calcium, conductivity, and dissolved oxygen (Johnson and Brown 2000, Johnson et al. 2001, and Miller et al. 1987), especially if the range of habitat conditions to be considered makes these basic life requirements of special interest (e.g., Johnson and Brown 2000, Johnson et al. 2001). In general, physical habitat variables related to substratum stability and depth in relation the hydrodynamic conditions dominate riverine models. Other basic water quality parameters such as dissolved oxygen and calcium become important additional considerations if, as is the case herein, oxbows or other habitats that can seasonally disconnect from the main channel can present especially challenging water quality conditions.

Modeling Approach for the Lower Cache River

The approach taken herein invokes the basic logic of these prior modeling attempts, focusing on depth, substratum type, and substratum deposition in relation to hydrodynamic variability in addition to potentially stressful conditions of temperature and dissolved oxygen that can be especially stressful in hydraulically disconnected bendways of the lower Cache River, especially in summer. However, river conditions with respect to such habitat variables, and especially spatial heterogeneity in those variables, has not been described for the pre-project condition, nor have post-project prediction been made that could support spatially explicit models. Thus, we propose to substitute pre- and post-project estimates of distinct habitat types for such measured or predicted variables. We feel the habitat types reflect distinct composite combinations of the more typically used variables, but can be applied from existing information considered at a landscape level. Our approach is described in more detail in the following paragraphs. Appendix 1 contains the detailed habitat quantification data.

Habitat Types and Their Quantity

Four habitat types are recommended for use in evaluating pre- and post- project conditions with respect to mussel resources of the present study reach of the lowermost Cache River. These are: *straight channel*, *sinuous channe*l, *hydraulically disconnected off-channel*, and *hydraulically connected off-channel*. Channel habitats are those that convey flow at all discharges. Off-channel habitats are either always slack water habitats or usually slack water habitats that provide flood relief conveyance at near bank full or higher flow. The two types of channel and off-channel habitat are discussed in more detail in the following paragraphs, as are the methods by which we identified and quantified each.

Straight channel habitat is the only lotic habitat that presently exists in the study reach. Due to simplicity of flow a straight channel almost certainly supports less habitat diversity than a sinuous channel, especially in relation to substratum type, water velocity, and depth. Whether considering a straight or sinuous channel reach, spatial scale is important. A sinuosity index can be computed for a river segment of any length. Sinuosity index equals the linear distance of an actual channel path divided by the length of a straight line from the origin and end of that path.

In the Cache River, there is evidence (Christian et al. 2005) that meaningful differences in mussel abundance and diversity relate to channel geomorphology considered at no less than approximately a 5-10 mile reach length. In the lower Cache River, this reach length is sufficient to include several bendways and channel crossings in the more naturally sinuous parts of the river. Physical forces associated with flow diversity around bendways and through channel crossings are responsible for creating physical habitat diversity. Such diversity essentially is the goal of restoration of flow through natural bendways. As briefly reviewed earlier, we carefully evaluated the morphology of the river course over the entire 46-mile reach surveyed by Christian et al. (2005), and concluded that by considering this entire reach in six approximately equal-length segments (each approximately 7.5 miles long) we able to both capture the large scale differences in mussel abundance and diversity and relate these in an objective and meaningful way to river morphology. Segments of river 7-8 miles long are sufficient to contain multiple bendways in more sinuous reaches but only one or two bendways in modestly sinuous reaches. Furthermore, the highly straightened reach that is the present study area is approximately 7 miles long and thus such a length has inherent meaning to this project.

However, we did not think it wise for two reasons to simply measure the path and origin to endpoint distance for the entire reach and assume this is the best approximation of sinuosity. First, random aspects of such measurements argue against a single estimate. Second, we cannot be certain of the physical scale at which straightness or sinuosity begins to act on habitat in a way that manifests itself in mussel distribution. Therefore, we measured sinuosity for nominal 1-mile segments of the channel path in the study area, and then took the average of these measurements (weighted by path length, as few were exactly 1 mile) to represent the sinuosity of the entire reach.

Thus computed, sinuosity per nominal mile ranged only from 1.00 to 1.06 in the highly straightened, existing channel course. The entire length of the existing channel is 35,514 feet. The post-project channel course, with all six meanders reconnected is of course considerable longer, and equals 53, 835 feet. Sinuosity per nominal mile of the post-project channel course ranged from 1.01 to 3.41, with a weighted average of 1.85. Of course, it is not surprising that a few of the one-mile long segments were still quite straight, as the length between meanders exceeded this distance in a couple of places along. When not even a portion of bendway was included in a 1-mile segment, was 1.01 in one instance and 1.06 in the other. When only a small fraction of bendway was included in an otherwise generally straight reach, sinuosity increased only to 1.15 or 1.27. Overall, in the post-project channel relatively straight sections had sinuosity less than 1.20, moderately sinuous sections had sinuosity from 1.20 to 2.10, and a couple of very sinuous segments had sinuosity greater of 3.00.

Off-channel, or typically non-flowing, habitat logically but somewhat imperfectly can be divided into two types. The first type, which we call hydraulically disconnected off-channel habitat, essentially does not ever experience much more than barely detectable water velocity (Andy Gaines, MVD, personal communication) - even at bank full discharge. This condition is largely descriptive of the present, hydraulically isolated meanders that are proposed for re-connection. Despite lack of flow connectivity, each of these remains spatially connected to the main channel at their downstream end. It is not clear at what stage or discharge this spatial connection is lost, and it almost certainly varies among the six meanders. However, at least at relatively high discharge (perhaps 50-75% of bank full flow) these meanders all connect to the river at their downstream (but not upstream) end. Thus, the function as lentic, backwater habitats.

The possible exception to this general description of pre-project off channel habitat is Meander #3. Unlike the other five meanders connected only at their lower ends, Meander #3 also shows a small upstream connection to the river channel in the Google Earth imagery we used for our analyses. The Google Earth photomosaic clearly was made from photographs taken during a moderately high but not bank full discharge.

This description of Meander #3, as well as the designed condition of off-channel habitats that will be created by the proposed project, results in our second off-channel habitat type, namely, hydraulically connected off-channel habitat. Presumably in Meander #3, and certainly in surrogate off-channel habitats that will result from meander restoration, measurable water velocity will at near bank full discharge. The general design of the new off-channel habitats is dictated by a need to convey a portion of flood-threatening flow down the entire, existing straightened channel. At low and moderate discharge, structures placed in the river will direct essentially all flow through the re-connected meanders. However, these structures will be designed so that flood-threatening flows will overtop the structures.

Thus, managed flow conditions will certainly apply to several segments of the straightened channel into which flow will mostly be intercepted. These segments occur between that point at which low and moderate flow will be directed into a newly connected upstream reach of a meander and that point downstream where the same meander re-enters the straight channel segment. During low and moderate flow these special straight channel segments will maintain spatial connection, at their lower ends, where the re-directed flow comes back to the straight channel. Thus, like the now isolated meanders proposed for reconnection, these surrogate off-channel habitats should function as small, backwater lakes. However, at high flow these surrogate habitats will be flushed more than the existing meanders are in their present condition (with the possible exception of Meander #3, as discussed).

The length of each of the presently isolated meanders was measured using the Google Earth path tool to quantify these habitats. We assumed Meanders 1, 2, 4, 5, and 6 are all best described as hydraulically disconnected. Similarly using the path tool of Google Earth, we measured the length of Meander 3 for the pre-project condition, and of those several straight channel reaches that will become surrogate off-channel habitat in the post-project condition. These are best described as hydraulically connected, recognizing that hydraulic connection allows substantial flushing of these habitats only at high discharge. We summed the lengths of each of these off-channel habitats over the entire study reach to estimate the quantity of each in pre- and post-project conditions.

Thus considered and computed, the pre- and post-project the total lengths of these generally linear habitat types are summarized in Table 3. The large increase in channel habitat along with a shift from a straight to a sinuous system is an obvious expectation. Indeed, these shifts are the essence of the restoration project. Less intuitively obvious are quantitative and qualitative changes in off-channel habitat. In linear terms there is much less off-channel habitat in the post- than pre-project condition. However, the qualitative nature of the off-channel habitats also fundamentally changes, as substantial flushing of these otherwise slack water areas will occur during flood-threatening flows in the post-project condition.

Table 3. Summary of habitat lengths of four habitat types relevant to mussel distribution in the lower Cache River, Arkansas. Connectivity of off-channel habitat is meant in relation to conveyance of substantial flow at high water.

Habitat Type	Habitat Length (feet)	
	Pre-Project	Post Project
Straight Channel	35,514	0
Sinuous Channel	0	53,835
Disconnected Off-Channel	21,096	0
Connected Off-Channel	5,809	11,076

If each meander is considered individually,

Table 3. Summary of habitat lengths of four habitat types relevant to mussel distribution in the lower Cache River, Arkansas. Connectivity of off-channel habitat is meant in relation to conveyance of substantial flow at high water.		
Habitat Type	**Habitat Length (feet)**	
	Pre-Project	**Post Project**
Straight Channel	**35,514**	**0**
Sinuous Channel	**0**	**53,835** **1… 20%** **2… 11%** **3… 20%** **4… 12%** **5… 21%** **6… 16%**
Disconnected Off-Channel	**21,096**	**0**
Connected Off-Channel	**5,809**	**11,076** **1… 24%** **2… 19%** **3… 22%** **4… 12%** **5… 16%** **6… 7%**

Habitat Quality

With these quantitative estimates in hand, it is necessary to estimate the quality of each habitat type with respect to the mussel community of the lower Cache River. A number of underlying factors, relevant to mussel habitat quality, is inherent in the naming of these four habitat types. We first consider channel habitat – straight and sinuous.

As is evident from both the 1991-1997 and 2007 surveys conducted by Christian et al. and the Corps, respectively, all channel habitat has at least some value to freshwater mussel whether it is straight or sinuous. Christian et al. (2005), looking only at aggregations or "beds" of mussels, demonstrated that only a small fraction of mussel standing crop is contributed by beds in the lowermost river, while beds farther upstream contributed nearly their entire estimate of standing crop. Although sinuosity alone could not account for this upstream and downstream difference, four of five sinuous reaches examined by those investigators had high abundance and diversity of mussels while the single straight reach contributed little. In addition, their discussion supported an important role of bends, crossings, and the associated diversity of physical habitat conditions in determining the frequency and size of mussel beds. The Corps survey (USACE 2007) of the straight channel section in the lower river showed that mussels, at low density, were more ubiquitously distributed than might be concluded by just consideration of the mussel bed data presented by Christian et al. Large expanses of a river with very low abundance by more or less continuous occurrence of some mussels provide an important buffer in case beds are destroyed by commercial harvests, spills, or infestation by invasive species. Furthermore, the Corps survey showed clearly that channel habitat was substantially more important mussel habitat than are the six now largely isolated meanders (Table 2).

Flowing channels are important to mussels in several ways. Flow brings dissolved oxygen and food to these largely sessile, filter-feeding animals. In addition, a small amount of flow is required for successful fertilization, because mussels have separate sexes and sperm released by males must be brought, by respiratory and feeding currents, over the gills of females, where eggs are brooded. Being long-lived and sessile, mussels can neither have substratum overly eroded from around them nor will they survive for long deep burial by fine sediment. Tiny, settled juveniles are probably especially susceptible to overly depositional conditions and deep deposits of fine silt and clay. Thus, in more lentic areas, some seasonal flushing of sediment is needed. In more lotic areas, a complexity of flow, depth, and substratum conditions is more likely, especially across a range of seasonal flow changes to result in parcels of habitat where substratum occurs that is suitable for mussel burrowing by not overly subject to either severe erosion or deposition. Thus, it is not surprising that more naturally meandering river reaches are generally though more likely to yield mussel beds than are channelized reaches.

In off-channel areas, the greater both the extent and duration of spatial and hydraulic connection to the river channel, the more likely it is that mussels can occur or thrive. Seasonal flushing of fine sediment has already been mentioned, and points out an important role of hydraulic connectivity. In addition, flow and a larger degree of spatial connectivity helps ameliorate high water temperature and low dissolved oxygen, both of which can be problematic in shallow, silt-laden backwater habitats. Indeed, such conditions are likely to be part of the reason that fewer mussels are in the meanders than in nearby parts of the channel (Table 2).

Overall, in terms of habitat quality for mussels the four habitat types are expected to follow the pattern of sinuous channel better than straight channel better than hydraulically connected off channel better than hydraulically disconnected off channel. We propose the following habitat quality scores (on a 0 to 1 scale) are reasonable approximations of with respect to each habitat type:

Sinuous Channel = 0.6
Straight Channel = 0.4
Hydraulically Connected Off Channel = 0.2
Hydraulically Disconnected Off Channel = 0.1

These scores are intended to reflect that channel habitat with flow at low to moderate discharge is substantially better for the riverine mussel community of the Cache River than is the generally slack water condition of off channel habitat. The highest score assigned, 0.6 for sinuous channel, is substantially less than 1 because the lower Cache River is less important for mussels than are reaches farther upstream - presumably because of factors other than just river sinuosity. When off channel habitats are considered, hydraulic connection at high flow is assumed to provide seasonal flushing of fine silts and clays and thus reduce sedimentation rate compared to a relatively disconnected off channel reach.

Computation of Habitat Units

Multiplication of these habitat quality scores and the quantitative estimates of each habitat type in the pre- and post-project condition yield an estimate of habitat units (Table 4).

Table 4. Habitat unit estimates for pre- and post-project conditions, lower Cache River mussel model. Connectivity of off-channel habitat is meant in relation to conveyance of substantial flow at high water.

Habitat Type	Habitat Quality	Habitat Length (ft)		Habitat Units	
		Pre	Post	Pre	Post
Straight Channel	**0.6**	**35,514**	**0**	**14,206**	**0**
Sinuous Channel	**0.4**	**0**	**53,835**	**0**	**32,301**
Disconnected Off-Channel	**0.1**	**21,096**	**0**	**2110**	**0**
Connected Off-Channel	**0.2**	**5,809**	**11,076**	**1,162**	**2,215**

Additional Considerations

Beyond uncertainties that inherently surround such estimates as these, short versus long term considerations affect how physical habitat benefits might translate into biological benefits. Several years will probably be required for physical habitat changes and diversity to approach a new dynamic equilibrium, as the six meanders have not received forceful flow for decades. Five or ten years may be needed for physical conditions to reach a new dynamic equilibrium. Additionally, several mussel generations must pass before changes in mortality and recruitment settle into a new biological dynamic equilibrium. The dominant species in the lower Cache River live 10-20 years (*Megalonaias nervosa* even longer). Thus, even a 50-year period of post-project condition may not be sufficient to observe the biological shifts that will transpire. However, within 10-20 years it is likely that the trajectory of biological shifts will become evident. Evidence of that trajectory is probably the best that biological monitoring will detect in a decade or two, but establishment of that new trajectory is evidence that restoration is successful (Society of Ecosystem Restoration 2004).

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Appendix 1

Pre-Project Conditions

The accompanying data summaries of length and sinuosity estimates of channel segments and length estimates of off-channel segments (meanders) in the pre-project condition. The total channel length is slightly less than 7 miles; thus segment G has path length slightly less than the nomimal 5,280 ft of all the other channel segments. The average sinuosity of 1.02 indicates the very straight nature of channel, consider at the scale of the entire reach. Meander 3 was the only meander with apparently substantial flow at high discharge (upstream and downsream connectivity at high flow).

Straight Channel

Segment	Nominal RM	Path (ft) /Line (ft)	= Sinousity
A	0-1	5271/4964	1.06
B	1-2	5286/5170	1.02
C	2-3	5278/5181	1.02
D	3-4	5287/5231	1.01
E	4-5	5277/5276	1.00
F	5-6	5274/5228	1.01
G	6-7	3841/3838	1.00
	Path Sum =	35514	Avg. = 1.02

Disconnected Off-Channel (Meanders 1, 2, 4, 5, and 6)

Meander	Length (ft)
M1	4599
M2	2860
M4	3262
M5	5924
M6	4451
	Sum = 21,096

Connected Off-Channel (Meander 3)

Meander	Length (ft)
M3	5809

Post-Project Conditions

The following summaries are for channel and off-channel segments in the post-project condition. The sinuous channel in the post project condition has total length much greater (53,835 ft) than the straight channel of the pre-project condition (35,514). At the reach scale, the average sinuosity of the channel, post-project is 1.85.

Segment	Nominal RM	Path (ft) /Line (ft) =	Sinousity
A	0-1	5286/4977	1.06
B	1-2	5283/1551	3.41
C	2-3	5282/4174	1.27
D	3-4	5284/2550	2.07
E	4-5	5285/3212	3.25
F	5-6	5273/5207	1.01
G	6-7	5283/2965	1.78
H	7-8	5280/3689	1.43
I	8-9	5271/4571	1.15
J	9-10	6308/3083	2.05
		Path Sum = 53,835	Avg. = 1.85

Off-channel habitat corresponds to those segments of the pre-project straight channel that will be adjacent to the re-connected meanders and will carry flood-relief flows when discharge is sufficient to overtop the structures directed flow through the re-connected meanders.

Connected Off-Channel

Adjacent to:	Length (ft)
M1	2554
M2	2129
M3	2590
M4	1298
M5	1691
M6	814
	Sum = 11,076