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Habitat Selection and Short-Term Movements of Pallid Sturgeon in the Lower Mississippi and Atchafalaya Rivers

Jason Richard Herrala

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By

Jason R. Herrala

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By

Jason R. Herrala

Approved:

Harold L. Schramm, Jr.
(Major Professor)

Jerrold L. Belant
(Committee Member)

Peter J. Allen
(Committee Member)

Eric D. Dibble
(Graduate Coordinator)

George M. Hopper
Dean
College of Forest Resources

Name: Jason R. Herrala

Date of Degree: August 14, 2015

Institution: Mississippi State University

Major Field: Wildlife and Fisheries Science

Major Professor: Dr. Harold L. Schramm, Jr.

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The pallid sturgeon *Scaphirhynchus albus* is an endangered sturgeon distributed throughout the Mississippi River drainage. Habitat selection and movement have been identified as critical conservation information. Seventy-one pallid sturgeon were tagged with acoustic transmitters in the lower Mississippi River (LMR), and 53 sturgeon were tagged in the Atchafalaya River System (ARS). Twenty-two pallid sturgeon in the LMR and 30 in the ARS were monitored using stationary acoustic receivers to assess short-term movement. Pallid sturgeon in the LMR showed positive selection for island tip, outside-bend natural bank, wing dike, sandbar, outside-bend revetted bank, and secondary channel habitats. Pallid sturgeon in the ARS exhibited positive selection for both inside and outside-bend revetted banks, inside-bend natural banks, and water control structures. Fish selected against the main channel in both systems. Short-term movement in the LMR and ARS was minimal and not related to any of the tested environmental factors.

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CHAPTER I

INTRODUCTION

The pallid sturgeon *Scaphirhynchus albus* is a federally endangered riverine sturgeon (USFWS 1993) that occurs in the Missouri and Mississippi rivers as well as the tributaries and distributaries of these rivers (Bailey and Cross 1954; Kallemeyn 1983; Constant et al. 1997). The original description identified pallid sturgeon as adapted to swift waters of large, turbid rivers (Forbes and Richardson 1905). Studies in the Missouri River revealed that pallid sturgeon are rare, and populations in some northern reaches may no longer be self-sustaining (USFWS 2007b). Pallid sturgeon in the lower Missouri River and lower Mississippi River (LMR) are considered to be self-sustaining despite historically low catch rates (Herzog et al. 2005; Hrabik et al. 2007; Boley and Heist 2011). The species' rarity and low catch rates may be related to sampling procedures that are often constrained by river conditions (Kallemeyn 1983; H. Schramm, Mississippi Cooperative Fish and Wildlife Unit, personal communication). Pallid sturgeon are captured below the Old River Control Complex (ORCC) in the vicinity of Old River, a distributary of the LMR that flows into the Red River to form the Atchafalaya River (Constant et al. 1997; Herrala and Schramm 2012). It is uncertain whether pallid sturgeon in the Atchafalaya River are part of a self-sustaining population or are entrained from the LMR (Schramm and Dunn 2009; Herrala and Schramm 2012).

Studies on habitat selection of adult pallid sturgeon are needed to provide information to guide management agencies with habitat conservation and restoration for this endangered species. Little was known about habitat use and selection of pallid sturgeon when it was listed as endangered (USFWS 1993), and the most recent review on the status and management of pallid sturgeon stated a need for habitat studies in the southern portion of the species' range (USFWS 2007a). Habitat-use studies have been conducted in the Missouri River (Bramblett and White 2001; Jordan et al. 2006; Gerrity et al. 2008) and the middle Mississippi River (Hurley 1999; Hurley et al. 2004). No studies on habitat use or selection have been conducted on the lower Mississippi or Atchafalaya rivers.

Pallid sturgeon in the middle Mississippi River were found most often in main channel, main channel border, and wing dike habitats but showed the strongest positive selection for main channel border and island tip habitats and the strongest negative selection (i.e., avoidance) for main channel habitat (Hurley et al. 2004). Koch et al. (2012) reported that pallid sturgeon in the middle Mississippi River had strong positive selection for wing dike habitats but never frequented island tip habitats. Bramblett and White (2001) found that pallid sturgeon in the upper Missouri River were located most frequently in complex river reaches with frequent islands, secondary channels, and backwaters; but habitat selection was not assessed. Jordan et al. (2006) reported that over 90% of juvenile pallid sturgeon in the Missouri River were located in the main channel. Gerrity et al. (2008) also found that juvenile pallid sturgeon in the Missouri River showed positive selection for main channel habitats; additionally, pallid sturgeon in this study selected against areas in the river with islands and avoided secondary channels.

Available habitats in the lower Mississippi and Atchafalaya rivers differ from those in the Missouri and middle Mississippi rivers. The differences in available habitat between these rivers limit the application of habitat selection measured in the middle Mississippi and Missouri rivers to the lower Mississippi and Atchafalaya rivers and can lead to inaccurate and unreliable guidance for habitat conservation and restoration; therefore, studies on habitat selection of pallid sturgeon in the lower Mississippi and Atchafalaya rivers are needed.

Information about short-term movement—the daily or hourly movement in a relatively small area of river—is needed to evaluate habitat use and selection of pallid sturgeon. For example, zero to low movement rates indicate that pallid sturgeon stay in a general area for extended periods of time between detections; and, thus, point-in-time detections are more likely to represent a habitat or location that the fish occupies rather than a point the fish is passing. Short-term movement has been examined in past studies, but these limited assessments have provided mixed findings. Constant et al. (1997) found that continuously monitored pallid sturgeon did not move during 24 h periods in the Atchafalaya River. Erickson (1992) found that constantly monitored pallid sturgeon in Lake Sharpe, SD (Missouri River) moved 0.23 – 0.49 km/h, and movement rate was directly related to water temperature. Constantly monitored pallid sturgeon in the Missouri River, SD moved 0.02 – 0.11 km/h (Jordan et al. 2006). Diel movement patterns (i.e., diurnal, nocturnal, crepuscular) have been examined in several studies. Pallid sturgeon movements in Lake Sharpe, SD were nocturnal (Erickson 1992), but Bramblett and White (2001), Jordan et al. (2006), and Wanner et al. (2007) found no evidence for diel movement patterns in the Yellowstone and Missouri rivers.

These studies provide information regarding pallid sturgeon short-term movement (18 – 72 h) such as possible correlations with water temperature and other environmental variables that can help guide future management, but may not pertain to pallid sturgeon in the LMR and Atchafalaya River. The temperature and hydrologic regimes of the lower Mississippi and Atchafalaya rivers are different from the Yellowstone and Missouri rivers. Movement rates may differ throughout the species' range as a result of environmental factors and habitat differences between rivers, so knowledge of short-term movement behavior measured for the lower Mississippi and Atchafalaya rivers' populations is needed to better understand the similarities and differences in movement throughout the pallid sturgeon's range and to guide research and management of pallid sturgeon in the southern portion of its range.

My objectives were (1) to assess habitat selection of pallid sturgeon in the lower Mississippi and Atchafalaya rivers, (2) to compare short-term (18-72 h) movement of pallid sturgeon between the lower Mississippi and Atchafalaya rivers, and (3) to assess relationships of movement to water temperature, current velocity, river stage, and time of day.

CHAPTER II

STUDY SITES

Lower Mississippi River

The free-flowing LMR is the portion of the Mississippi River that extends 1600 km from the confluence of the Mississippi and Ohio rivers to the Gulf of Mexico. Movements of pallid sturgeon were assessed in a 40-km reach from river kilometer (RKM) 895 to 935 (Figure 1). This reach is typical of the LMR, having a sinuous channel with deep outside bends and shallow sandbars on inside bends. Each of the four bends in the reach contains an island and secondary channel that provides flowing-water habitat at higher river stages. A dike field that diverts flow to the main channel is upstream of three of the four inside bends. One bend (Choctaw Bend) has a notched dike at the upstream end of the secondary channel that allows water flow through the secondary channel even at low river stages. The outside (concave) bank of each bend is armored with articulated concrete mattress and rock rip rap revetment. High river stages provide proportionally more available sandbar habitat; as river stage declines, sandbar area declines, and flow through secondary channels is decreased or zero as the aquatic area dwindles.

Atchafalaya River

The Old River is a natural distributary of the LMR that is now separated from the LMR by the Old River Lock at Mississippi River RKM 488. The lock channel, formerly the channel of Old River, joins the Red River at Red River RKM 11 to form the Atchafalaya River that flows south 234 km into the Gulf of Mexico. A hydroelectric dam operated by Louisiana Hydroelectric and two water control structures (Auxiliary Water Control Structure [AWCS] and Low Sill Water Control Structure [LSWCS]) operated by the U.S. Army Corps of Engineers also pass water from the LMR to the Red River and the Atchafalaya River. Water releases from the LMR via the hydroelectric facility and the water control structures flow into an engineered channel (the outflow channel) that discharges into the Red River at RKM 16. The hydroelectric dam, AWCS, LSWCS, and their tailwaters along with the outflow channel are collectively referred to as water control structures (WCS). The system formed by the Atchafalaya River, the Red River downstream from its confluence with the outflow channel, the Old River, and the outflow channel will be referred to as the Atchafalaya River System (ARS; Figures 2 and 3).

The ARS lacks the habitat diversity present in the lower Missouri River and LMR where pallid sturgeon are considered to be self-sustaining (Herzog et al. 2005; USFWS 2007a). Like the LMR, the main channel is deep (up to 40 m), but the ARS channel is relatively uniform from bank to bank compared to that of the Mississippi and Missouri rivers. Additionally, sandbars that commonly form on inside bends in the LMR are infrequent in the ARS, and the banks of inside bends usually slope steeply to the main channel. Articulated concrete mattress and rock revetments line much of the banks of the ARS, and only four channel-training rock dikes occur throughout its length.

Figure 1 Lower Mississippi River study site encompassing river km 898 to 935

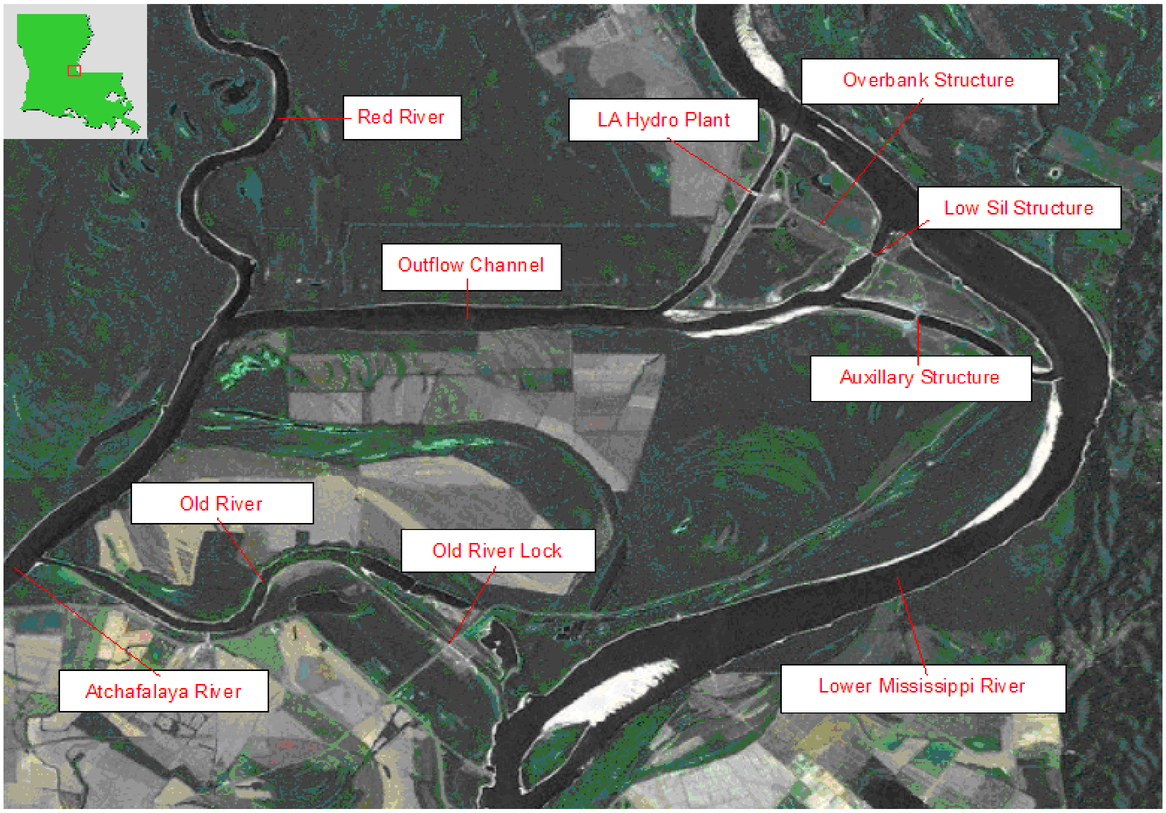

Figure 2 Aerial view of the upper reaches of the Atchafalaya River System

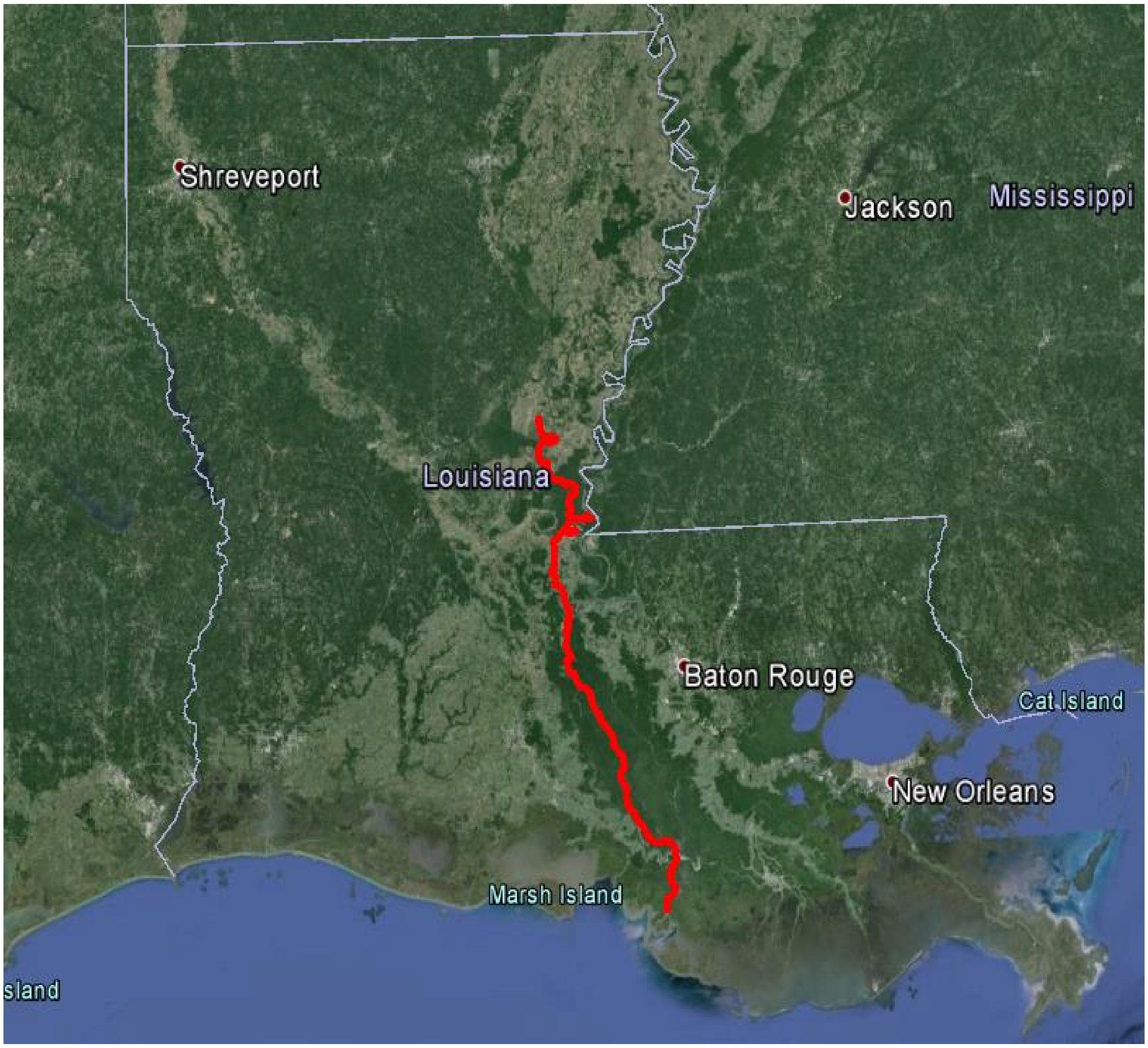

Figure 3 Atchafalaya River System study site encompassing Red River km 56 – 0 and Atchafalaya River km 0 – 250

CHAPTER III

METHODS

Movement of pallid sturgeon was assessed with acoustic telemetry. Although acoustic telemetry becomes less efficient with increased suspended sediment, Constant et al. (1997) determined that acoustic telemetry was more effective than radio telemetry for tracking pallid sturgeon in the high conductivity water (>400 µS) and water depths greater than 30 m common in the ARS. Furthermore, the acoustic tags and detection equipment used in this study were the same as those used by other researchers tracking pallid sturgeon in the Mississippi and Missouri rivers and, therefore, provided the opportunity to detect any fish that may have moved between rivers.

Fish Capture and Identification

Pallid sturgeon were captured in the LMR with trotlines from June 2008 through November 2010. Pallid sturgeon were captured in the ARS with gillnets in February, March, and November 2007, January through March and November 2008, and February 2010. Trotlines were also set in the ARS in February through April 2010. Trotlines were approximately 85 m in length and contained 40 Worm-shank Mustad (Mustad and Sons Inc., Doral, FL) size 2/0 hooks baited with nightcrawlers *Lumbricus terrestris* and fished overnight. Trotlines were set less than 6 h before dark and retrieved no more than 6 h after sunrise the following day. Gill nets were set on the bottom of the river channel below the LSWCS and fished overnight. Following capture, all sturgeon were handled according to established protocols (USFWS 2008) and species was determined.

Pallid sturgeon are known to hybridize with shovelnose sturgeon *S. platorynchus* in the LMR (Schrey et al. 2011), and fish with intermediate morphological characteristics can be found in the LMR and ARS making field identification difficult. Forbes and Richardson (1905) found that pallid sturgeon grew to larger sizes, had a relatively longer head, relatively fewer papillae on the lower lip, a wider mouth, and a scaleless belly compared to shovelnose sturgeon. They also found that the outer barbels of pallid sturgeon were 1.7-2.9 times as long as the inner barbels compared to outer barbels 1.1-1.4 times as long as the inner barbels for shovelnose sturgeon. Specimens in this study were designated as pallid sturgeon if they had a scaleless belly, outer barbels that extended past the mouth and were at least 1.7 times as long as the inner barbels, and inner barbels that were inserted anterior of the outer barbels. Tissue samples from the anal fin of each sturgeon were taken in the field and stored in 10% formalin solution for genetic analysis. Tissue samples were sent to the U.S. Fish and Wildlife Service's Warm Springs Fish Technology Center (Warm Springs, GA) for future confirmation of field identification of species.

Surgical Procedures

Captured pallid sturgeon >650 mm were held in a live well in aerated river water until surgery began. Barbel lengths, head width, and mouth width were measured and interpreted to confirm that the specimen was a pallid sturgeon. Fish were anaesthetized with 150 mg/L of MS-222 (Argent Chemical Laboratories Inc., Redmond, WA) buffered with 150 mg/L of sodium bicarbonate. When the fish became non-responsive to handling, it was removed from the anaesthesia tank and placed on an operating platform with the head immersed in aerated river water. The operating platform acted as a cradle that securely held the sturgeon in place during surgery. A 2-3 cm longitudinal incision was made to the right of the ventral midline, anterior of the pelvic fins, and approximately two-thirds of the distance starting from the pectoral fins back towards the pelvic fins. A transmitter was sterilized with Cidex Plus (Ethicon Inc., Irvine, CA), rinsed in sterile water, and inserted into the body cavity. The incision was closed with sterile Monocryl Plus monofilament sutures and an FS-1 24-mm reverse cutting needle (Ethicon Inc., Irvine, CA). Vemco V16 ultrasonic tags and V16P depth-sensing ultrasonic transmitters (Vemco, Halifax, Nova Scotia) with a life expectancy of approximately 4.5 years were surgically implanted into adult pallid sturgeon. Each tag emitted unique 69 kHz sound trains that allowed for identification of individual fish. Post-operation fish were held in aerated river water until they regained equilibrium and began active swimming, after which they were released at the capture site.

Telemetry

Tagged fish were located by active tracking using Vemco VR100 receivers and Vemco VR110 directional hydrophones. Continuous-recording omnidirectional receivers (stationary receivers [SR]; Vemco VR2W) were used in an array system (Figure 4) to passively monitor local movements of pallid sturgeon.

Diurnal active tracking was conducted by boat from March 2009 – December 2012 on the LMR and August 2009 – September 2011 on the ARS. Boats were operated in a downriver direction at 8-10 km/h speed over ground with dual directional hydrophones directed about 45^{o} lateral (left and right) to the path of the boat. Although detection distance and error should be estimated in future studies, the dual directional hydrophone setup was assumed to provided full lateral coverage of the river, and slow tracking speeds were used to minimized missed detections due to passing over a tagged fish. Two boats were used to track the LMR when possible (one on each bank). When two boats were not available, one boat was used to track each bank separately. At ARS stages below 5.5 m (U.S. Army Corps of Engineers gauge Simmesport, LA) use of a single boat with dual hydrophones was sufficient for detecting fish from bank to bank in the ARS. When river stage exceeded 5.5 m, two boats were used. The LMR study area was tracked in entirety each month, and the ARS was tracked in entirety in alternating months (e.g., January, March).

When a sturgeon was detected, the assigned location of the fish was the boat position at which the hydrophone could be rotated a full 360 ^{o} and still receive the same signal strength at low gain (signal receiving power in decibels). Surface water temperature, GPS coordinates, water depth, and surface current velocity (drift speed over ground of the boat) were measured at each fish's location with a Lowrance® HDS7 depth finder/GPS unit (Navico, Tulsa, OK). Habitat type was indentified at each location based on a hierarchical classification system for each river (Tables 1 and 2). Pallid sturgeon are considered a demersal species (Keenlyne 1989); therefore, water depth at each fish location was considered to be the depth of the fish. As most fish were located in currents >0.6 m/s and water deeper than 3 m, it was not possible to measure the temperature or current velocity near the bottom at the presumed location of the fish with equipment available. River water is well mixed and temperatures are nearly constant from surface to bottom (Allen 1995); surface water temperature was measured and used as an index of bottom water temperature. Current velocity varies throughout the water column in lotic systems, and there is no precise relationship between surface current velocity and bottom current velocity (Allen 1995). Further, contours in the river bottom create turbulent flow that lead to differences in current velocities throughout the water column (Allen 1995). Nevertheless, lacking instrumentation (acoustic Doppler current profiler) necessary to measure bottom current velocity, surface current velocity was measured with a Lowrance HDS7 depthfinder/GPS unit as drift speed of the boat over ground as an index of bottom current velocity at the location of detected pallid sturgeon. Because several factors, primarily wind, can affect boat drift speed, nearby landmarks floating objects such as debris were referenced to ensure the boat was moving at the velocity of other floating objects.

The local movement of two to four randomly selected individual pallid sturgeon was monitored monthly using SR arrays from July 2009 through December 2010. Each array was deployed for 18-72 h and consisted of 4-7 SRs positioned upriver, downriver, and across the river from the fish's location (Figure 4). Each SR was 300-700 m (distance depended on measured detection distances; Appendix A) away from adjacent SRs such that the detection range for each SR overlapped with the adjacent SR by 100 m, with the exception of the across-river SRs whose distance away from the fish's origin was determined by river and navigation channel width (SRs could not be deployed in the navigation channel) and varied depending on river stage and location. For example, if detection distance was determined to be 400 m, the Upriver1 SR was placed approximately 700 m upstream of the fish's origin (detection location), and Upriver2 SR was 700 m upstream of Upriver1 SR (1400 m upstream of the origin SR). Arrays were deployed in the LMR to equally distribute monitoring effort throughout the 40-km study area. This was accomplished by randomly determining *a priori* which portion of the 40-km study reach an array was to be deployed. The array was then deployed at the site of the first fish detected in the selected portion as the study reach was tracked. Arrays were set in the ARS during trips dedicated to array sampling to achieve equal sampling effort throughout the system following the same protocol as in the LMR. Arrays were also deployed when full tracks of the ARS occurred; but, due to time and logistic constraints, arrays deployed during full-system tracks were set in close proximity (<15 km) to boat ramps. Two to four arrays were deployed in the ARS in the intervening months. For example, if a full-system track occurred in January and March, a trip specifically dedicated to deploying arrays to monitor local movement would occur in February and April.

Midpoints and edges (perimeters) of each SR field of detection were used as "landmarks" for position and to estimate movements within the array. For example, a fish detected by only the SR placed at the origin was considered to be located directly beneath that receiver and have made no movements. A fish that moved from its origin downstream into the detection range of Downriver1 SR and completely out of the origin SR made one movement. If this fish then moved so that it was detected by the origin SR and out of detection range of Downriver1 SR, it was considered to have made two movements; this represents a downstream movement to move beyond the detection range of the origin receiver and assumed movement to the midpoint of the Downriver1 SR and then a movement back upstream out of the detection overlap and completely back to the midpoint of the origin SR (Figure 5). Movement frequency rate was calculated by dividing the total number of movements by the length of time the array was deployed.

Origin residency (the percentage of time spent at the origin SR) was also used to describe movement. For example, origin residency values less than 90% imply that a fish was detected at a receiver other than the origin at least 10% of the time the array was deployed.

Data Analysis

Habitat Selection

Habitats (Tables 1 and 2) for the LMR and ARS were mapped using ArcGIS v. 9.2 (ESRI Inc., Redlands, CA) to determine their proportional availability in each river. All measurements were based on U.S. Army Corps of Engineers navigation maps for the LMR and ARS (Mississippi Valley Division 1999). Bathymetric maps were not available, so habitat boundaries and area were estimated for bank-full river stages. Habitat boundaries were estimated on the GIS maps from landmarks on the navigation chart. Revetted banks were assumed to extend from shore to the toe of the revetment as shown on the navigation charts, and the edges of the main channel (toe of the channel) were delineated by straight lines connecting the channel buoys or between a channel buoy and the toe of the revetment. Channel border, wing dike, and island tip habitats extended from shore to the toe of the channel. This mapping technique assumed that the area of each habitat remained constant throughout the year. This assumption was violated largely in the LMR by the fact that the wetted perimeter changes with rising and falling river stage. Changes in water level in the LMR cause the proportional availability of habitats to change. Secondary channels can often become inaccessible during low water, and as a result the area of habitat was excluded from estimation of habitat availability and detections in the secondary channels were excluded from the original analysis. The majority of banks in the ARS are steeply sloping and rising and falling water has less impact on available habitat.

Manly's selectivity index (Manly et al. 2002) was used to assess possible habitat selection by pallid sturgeon in the LMR and ARS. This method uses individual fish as the primary sampling unit, and all statistical inferences are based on individual fish as replicates. Log-likelihood chi-square tests were used to test whether pallid sturgeon selected habitats at random and to determine if they selected for or against specific habitats. All tests were assessed at $\alpha = 0.05$. Selectivity index values >1 indicate positive selection for a habitat, and values <1 indicate negative selection (avoidance) for a habitat. Bonferroni confidence intervals were constructed for each habitat to test for statistical significance; the selectivity index value was considered significant if the confidence intervals excluded 1. Data from the LMR dating March 2012 – December 2012 was excluded from the analysis to eliminate possible bias related to seasonal habitat selection trends in pallid sturgeon. To assess habitat selection of secondary channels in the LMR a second analysis was performed using all data from March 2009 – February 2012 when secondary channel habitat was available and accessible by boat.

Short-term Movement

Twenty-nine percent (41% in LMR and 20% in ARS) of all monitored fish remained at the origin (movement frequency rate = 0 movements/h, origin residency = 100%), precluding meaningful assessment of relationships between movement and environmental conditions by linear regression. General linear mixed models allow for statistical analysis and comparison of data with non-normal distribution and non-constant variance. General linear mixed models (PROC GLIMIX; SAS 2007) were used to determine if environmental variables such as surface water temperature (°C), surface current velocity (m/s), river stage (m), and change in river stage (net change from deployment of array to retrieval; m) were significant ($\alpha = 0.05$) predictors of movement and movement frequency and origin residency in each river. Further, movement rate and origin residency were compared between rivers. Differences in movement frequency rate and origin residency between the LMR and ARS were also tested using the PROC GLIMMIX procedure.

Potential diel movement patterns were also assessed. Diel periods were defined as dawn (1 h before sunrise to 1 h after sunrise), day (1 h after sunrise to 1 h before sunset), dusk (1 h before sunset to 1 h after sunset), and night (1 h after sunset to 1 h before sunrise). All sunrise and sunset times were determined with the National Oceanic and Atmospheric Administration (NOAA) sunrise/sunset records for Scott, MS for the LMR and Simmesport, LA for the ARS. Differences in movement among diel periods were examined by comparing movement frequency rate (number of confirmed movements [detections by different SRs]). Differences in movement frequency rate were analyzed using a Chi-Square test. Additionally, differences in movement frequency rate by period between rivers were also tested with Chi-Square test.

Table 1 Habitat classification used for assessment of pallid sturgeon habitat selection in the lower Mississippi River

Habitat classification	Habitat description	Percent of available habitat*
I. Main Channel	The deep channel that includes the thalweg and navigation channel, extending from the right bank channel border to left bank channel border	63 (55)
II. Channel Border	The zone between the shoreline (mainland or island) and the toe of the channel	
A. Outside Bend	A steeply sloping erosional bank	
1. Revetted Bank	Bank armored with erosion-resistant material placed from the top of the bank to the toe of the channel	11 (9)
2. Natural Bank	Bank lacking revetment material	3 (2)
B. Sandbar	A gradually sloping depositional area	12 (11)
III. Wing Dikes/Dike Fields	The zone from 100 m above the upriver dike to 200 m downriver of the downriver dike and from the shoreline to the toe of the channel	10 (9)
IV. Secondary Channel	Former main channels or channels created when the flow of the river cuts across a point bar forming a new channel	(13)
V. Island Tip	A zone of deep water and swift current from the toe of the channel to the island shore, extending about 100 m upriver and downriver of the downriver tip of an island	1 (1)

* Values in parentheses are percent availability when secondary channels are included

Table 2 Habitat classification used for assessment of pallid sturgeon habitat selection in the Atchafalaya River System

Habitat classification	Habitat description	Percent of available habitat
I. Main channel	The deep channel that includes the thalweg and navigation channel, extending from the right bank channel border to left bank channel border	67
II. Channel border	The zone between the shoreline (mainland or island) and the toe of the channel	
A. Outside bend	A steeply sloping erosional bank	
1. Revetted bank	Bank armored with erosion-resistant material placed from the top of the bank to the toe of the channel	4
2. Natural bank	Steep sloping bank lacking revetment; usually occurs upstream of inside bend-natural banks	10
B. Inside bend	The convex bank of a river bend	
1. Sandbar	Extensive flat of deposited sand substrate	4
2. Revetted bank	Bank armored with erosion-resistant material placed from the top of the bank to the toe of the channel; usually a continuation of outside bend revetment	1
3. Natural bank	Bank with steep slope lacking revetment material; usually occurs downstream of inside bend revetments	9
IV. Wing dikes/dike fields	The zone 100 m upstream of the upstream dike to 200 m downstream of the downstream dike and from the shoreline to the toe of the channel	<1
V. Island tip	A zone of deep water and swift current from the toe of the channel to the island shore, extending about 100 m upstream and downstream of the downstream tip of an island	<1
VI. Water control structures	All area downstream of the water control structures (including the hydro channel) to the confluence of the Outflow Channel and the Red River	5

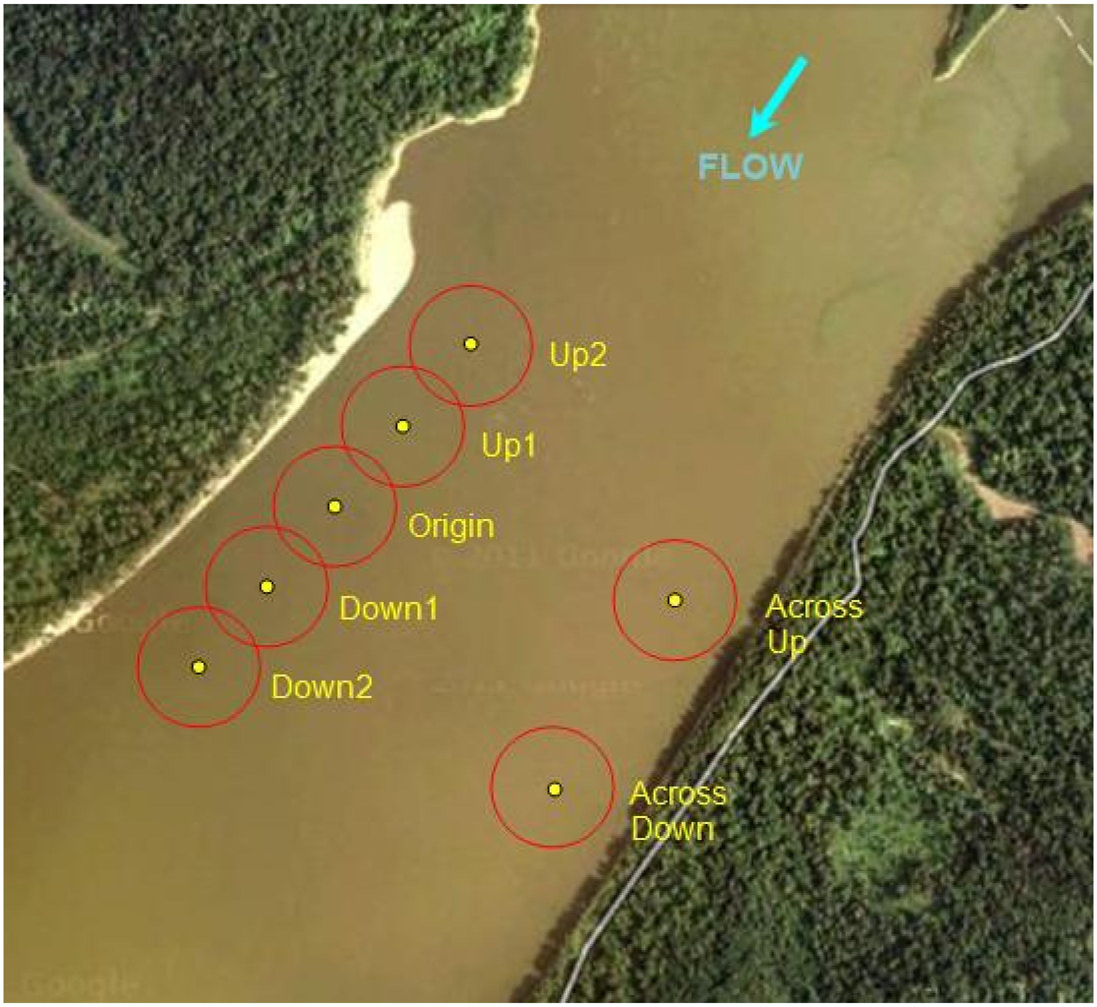

Figure 4 Schematic view of the receiver array system used to track short-term movements of pallid sturgeon

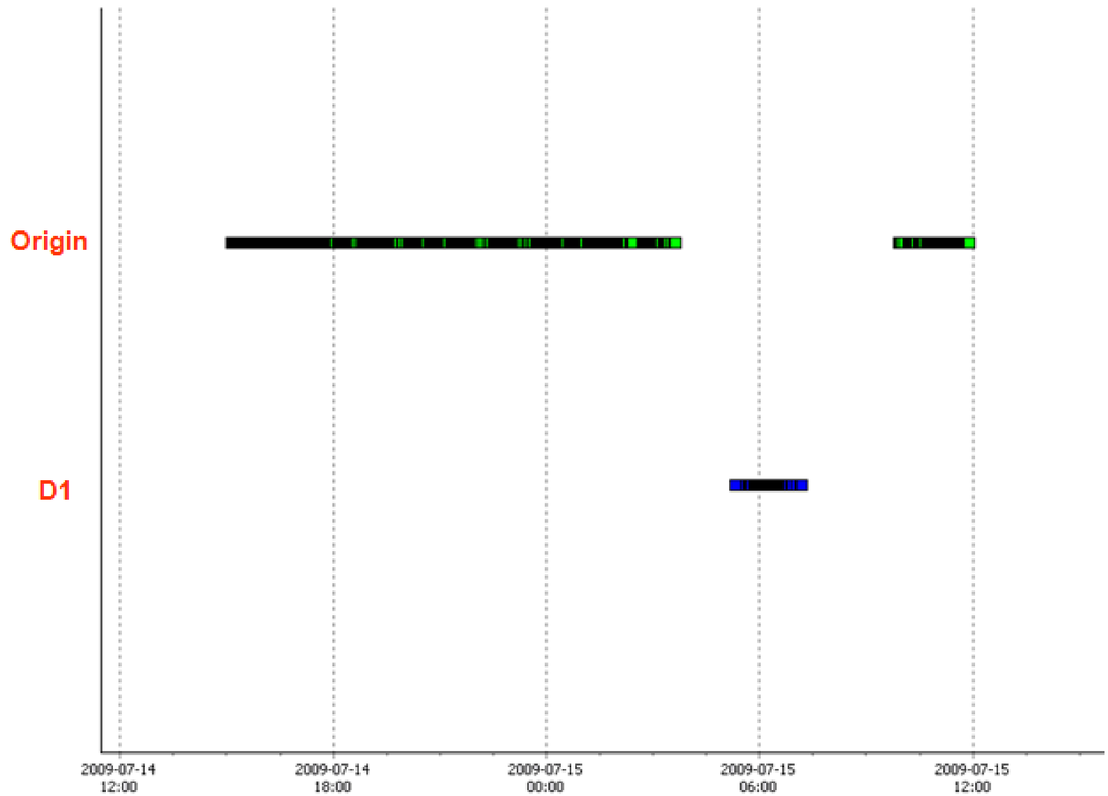

Figure 5 Vemco VUE array graph illustrating downstream movement and return to the origin

CHAPTER IV

RESULTS

Seventy-one pallid sturgeon were surgically implanted with transmitters in the LMR. Mean fork length was 771 mm (SD=80; range=612 – 1013 mm; Table 3). Thirty-four of these fish were detected 2 – 22 times (mean=5.9 SD=4.0). Transmitters were surgically implanted into 53 pallid sturgeon with mean fork length 843 mm (SD=88; range=602 – 983 mm) in the ARS; 27 of these fish were detected 2 to 10 times (mean=5.7; SD=2.4; Table 4).

Habitat Selection

LMR

Excluding secondary channels, the main channel was 63% of available habitat, sandbars were 12% of available habitat, outside-bend revetted banks were 11% of available habitat, and wing dikes were 10% of available habitat. All other habitats were less than 10% of available habitat (Table 1). Habitat use was not random (df=148, χ^2=183.7, P<0.01), and habitats were not used in proportion to their availability (df=147, χ^2=329.1, P<0.01). Pallid sturgeon positively selected island tip, outside-bend natural bank, wing dike, sandbar, and outside-bend revetted bank habitats and avoided main channel habitat (Table 5).

When secondary channels were included in the analysis the main channel was 55% of available habitat, secondary channels were 13% of available habitat, and sandbars were 11% of available habitat. All other habitats were less than 10% of available habitat (Table 1). Habitat use was not random (df=152, χ^2=231.1, P<0.01), and habitats were not used in proportion to their availability (df=151, χ^2=375.7, P<0.01). Pallid sturgeon positively selected island tip, outside-bend natural bank, wing dike, secondary channel, sandbar, and outside-bend revetted bank habitats and avoided main channel habitat (Table 6).

ARS

The main channel was 67% of available habitat and outside-bend natural bank was 10% of available habitat, while no other habitat was more than 10% of available habitat (Table 2). Habitat use was not random (df=218, χ^2=303.2, P<0.01), and habitats were not used in proportion to their availability (df=217, χ^2=564.4, P<0.01). Pallid sturgeon most frequently used main channel, inside-bend natural bank, outside-bend revetted bank, and the WCS habitats (Table 7). Although the WCS is a habitat complex containing a wide range of environmental conditions, sturgeon did not frequent any particular portion of this habitat more than another. Pallid sturgeon selected inside-bend revetted bank, outside-bend revetted bank, WCS, and inside-bend natural bank habitats and avoided main channel, sandbar, wing dike, and island tip habitats.

Short-term Movement

Short-term movement was monitored for 22 pallid sturgeon in the LMR and 30 pallid sturgeon in the ARS. Water temperature ranged from 4.1 – 31.4 °C in the LMR and from 4.1 – 30.3°C in the ARS. A wide range of river stages were observed, ranging from 1.69 – 10.82 m in the LMR and 2.20 – 10.09 m in the ARS. Current velocities ranged from 0.03 – 1.29 m/s in the LMR and 0.13 – 1.53 m/s in the ARS. Change in river stage ranged from -0.94 – 1.26 m in the LMR and -0.05 – 0.15 m in the ARS (negative values indicated indicate a falling river, and positive values indicate a rising river). Only one pallid sturgeon travelled out of an array in the LMR, and only two left an array in the ARS. All three fish were last detected on the Upstream2 SR. Additionally, cross-channel movement was rare as only one fish in the LMR and two fish in the ARS moved across the main channel.

Movement

Pallid sturgeon in both the LMR and ARS displayed little to no measurable movement during short-term monitoring periods (Figure 6). Forty-one percent of pallid sturgeon in the LMR (n=22) did not leave the origin of the array. Movement in the LMR was not related to any of the tested environmental factors (df=1,16, all F<2.07, P=0.16 – 0.79). Pallid sturgeon movement in the ARS (n=30) was not related with any of the tested environmental factors (df=1,24, all F<1.11, P=0.30 – 0.75). Additionally, movement of pallid sturgeon was not significantly different between rivers (df=2,44, F=2.45, P=0.12).

Origin Residency

Mean residency of 22 pallid sturgeon at origin receivers in the LMR was 76% (SD=34; range=4 – 100; Figure 7). Origin residency was not directly related to water temperature, river state, current velocity, or change in river stage (df=1,16, all F<2.12, *P*=0.26 – 0.94). Mean origin residency of 30 pallid sturgeon in the ARS was 72% (SD=35; range=0 – 100; Figure 7). Origin residency of pallid sturgeon was not related with any of the environmental factors that were tested (df=1,24, all $F<1.86$, $P=0.05$ – 0.86). Mean origin residency of pallid sturgeon was not different between the LMR and ARS (df=2,44, $F=0.14$, $P=0.71$). These results again suggest that pallid sturgeon in both systems display minimal short-term movements.

Diel Movement

Movement frequency rate of pallid sturgeon in the LMR did not differ among diel periods (df=63, $\chi^2=0.29$, $P=0.96$). Similarly, movement frequency rate of pallid sturgeon in the ARS did not differ among diel periods (df=87, $\chi^2=3.91$, $P=0.27$). No diel periods differed in movement frequency rate between rivers, except for the night period when movement frequency rate was significantly greater in the ARS than in the LMR (df=51, $\chi^2=5.46$, $P=0.02$; Figure 8).

Table 3 Pallid sturgeon captured and tagged with ultrasonic transmitters in the lower Mississippi River, 2008-2010

Tag	Date captured	Fork length, mm	Detections
10219	6/25/2008	800	0
10222	9/19/2008	790	2
10221	10/15/2008	871	10
10212	10/16/2008	868	9
10218	10/16/2008	686	0
10224	10/17/2008	761	10
10210	10/17/2008	739	0
10217	10/17/2008	856	0
10216	11/5/2008	844	0
10209	11/7/2008	813	0
10215	11/7/2008	730	0
10214	11/7/2008	710	0
10208	11/7/2008	721	9
10200	11/7/2008	737	0
10201	11/7/2008	725	1
10202	11/7/2008	648	0
10213	11/7/2008	713	0
10207	11/7/2008	747	0
54686	12/5/2008	812	0
54690	1/30/2009	935	5
54692	1/30/2009	756	6
54694	2/26/2009	709	0
54696	2/27/2009	755	0
54689	2/28/2009	758	11
54691	2/28/2009	879	2
54693	3/13/2009	674	0
54688	4/12/2009	---	2
54687	4/18/2009	773	7
54714	7/31/2009	798	0
54715	8/10/2009	749	0
56168	9/11/2009	827	0
54710	9/12/2009	827	0
54697	11/24/2009	692	5
54695	11/24/2009	830	5
54713	11/24/2009	920	4
54712	11/24/2009	871	7
56167	11/24/2009	684	0
54711	11/25/2009	730	1
54700	12/9/2009	812	3
54706	12/9/2009	907	2
54701	12/9/2009	822	1
65250	1/24/2010	745	3
65251	1/24/2010	686	0
65255	2/20/2010	761	0
65257	2/20/2010	763	1
65256	2/20/2010	723	1
65253	2/20/2010	710	1
65259	2/20/2010	828	0
65260	2/20/2010	735	4

Table 3 (Continued)

Tag	Date captured	Fork length, mm	Detections
54703	3/4/2010	778	0
54707	4/21/2010	623	1
54705	4/22/2010	612	4
48382	4/22/2010	706	0
48388	4/23/2010	676	0
48387	4/24/2010	834	0
48385	5/27/2010	753	2
48378	6/8/2010	791	1
48390	9/16/2010	724	0
48386	10/7/2010	681	0
48380	11/13/2010	1013	1
46956	12/9/2010	678	0
46960	12/9/2010	698	0
48383	12/9/2010	757	0
65249	12/9/2010	661	0
46959	12/9/2010	747	0
64961	12/9/2010	658	0
48377	12/10/2010	808	0
48389	12/10/2010	911	0

Table 4 Pallid sturgeon captured and tagged with ultrasonic transmitters in the Atchafalaya River System, 2007-2010

Tag	Date captured	Fork length, mm	Detections
2134	2/8/2007	685	0
2135	2/8/2007	935	7
2136	2/8/2007	916	0
2138	2/8/2007	868	0
2137	2/23/2007	807	0
2139	2/23/2007	815	0
2122	3/8/2007	841	0
2123	3/8/2007	887	4
2131	3/8/2007	913	0
2133	3/8/2007	886	0
2124	3/23/07	855	0
2125	3/23/07	915	0
2126	3/23/07	827	0
2127	3/23/07	953	0
2128	3/23/07	960	0
2129	3/23/07	983	0
2130	3/23/07	833	0
2132	3/23/07	824	0
4642	11/16/07	881	0
4643	11/16/07	950	0
4644	11/16/07	971	6
4645	11/16/07	941	5
9083	1/25/08	735	8
9055	2/14/08	822	10
9056	2/14/08	884	6
9058	2/14/08	725	0
9060	3/13/08	774	0
9062	3/13/08	877	10
9064	3/13/08	699	8
9066	3/13/08	821	6
9067	3/13/08	921	8
9068	3/13/08	799	0
9069	3/13/08	740	3
9070	3/13/08	817	3
9071	11/20/08	881	5
9072	11/20/08	812	2
9073	11/20/08	895	0
9074	11/20/08	831	0
9075	11/20/08	814	2
9076	11/20/08	965	3
9077	11/20/08	897	8
9078	11/20/08	966	6
10195	11/20/08	862	1
10196	11/20/08	906	0
10197	11/20/08	764	0
10198	11/20/08	769	1
10199	11/20/08	876	0
10203	11/20/08	804	9
10204	11/20/08	871	5

Table 4 (Continued)

Tag	Date Captured	Fork length, mm	Detections
10205	11/20/08	816	0
10206	11/20/08	830	9
46965	12/15/2010	719	0
46957	12/16/2010	725	0

Table 5 Pallid sturgeon habitat selection in the lower Mississippi River excluding secondary channels

Habitat	Percent availability	Number of detections	Percent detections	Selection index*	95% CI
Island tip	1.4	20	13.4	**9.88**	9.38-10.38
Outside-bend natural	2.5	18	12.1	**4.85**	4.61-5.09
Wing dike	9.9	29	19.5	**1.97**	1.87-2.07
Sandbar	12.4	26	17.4	**1.41**	1.35-1.47
Outside-bend revetted	10.7	20	13.4	**1.25**	1.14-1.36
Main channel	63.1	36	24.2	**0.38**	0.36-0.40

* Significant selection values are in bold

Table 6 Pallid sturgeon habitat selection in the lower Mississippi River when secondary channels were accessible

Habitat	Percent availability	Number of detections	Percent detections	Selection index*	95% CI
Island tip	1.2	20	13.1	**11.06**	10.54-11.57
Outside-bend natural	2.2	13	8.5	**3.92**	3.65-4.19
Wind dike	8.6	23	15.0	**1.75**	1.67-1.84
Secondary channel	12.8	30	19.6	**1.51**	1.42-1.60
Sandbar	10.8	23	15.0	**1.39**	1.33-1.45
Outside-bend revetted	9.4	18	11.8	**1.26**	1.16-1.36
Main channel	55.0	26	17.0	**0.31**	0.30-0.32

* Significant selection index values are in bold

Table 7 Pallid sturgeon habitat selection in the Atchafalaya River System

Habitat	Percent availability	Number of detections	Percent detections	Selection index*	95% CI
Inside-bend revetted	1.2	21	9.6	**7.91**	4.03-11.8
Outside-bend revetted	4.0	39	17.8	**4.49**	2.29-6.69
Water control structures	5.0	39	17.8	**3.55**	1.81-5.30
Inside-bend natural	8.8	46	21.0	**2.41**	1.23-3.59
Outside-bend natural	9.7	17	7.8	0.79	0.41-1.19
Main channel	66.9	54	24.7	**0.37**	0.19-0.55
Sandbar	3.8	3	1.3	**0.37**	0.18-0.54
Island tip	0.2	0	0.0	**0.00**	---
Wing dike	0.4	0	0.0	**0.00**	---

* Significant selection index values are in bold

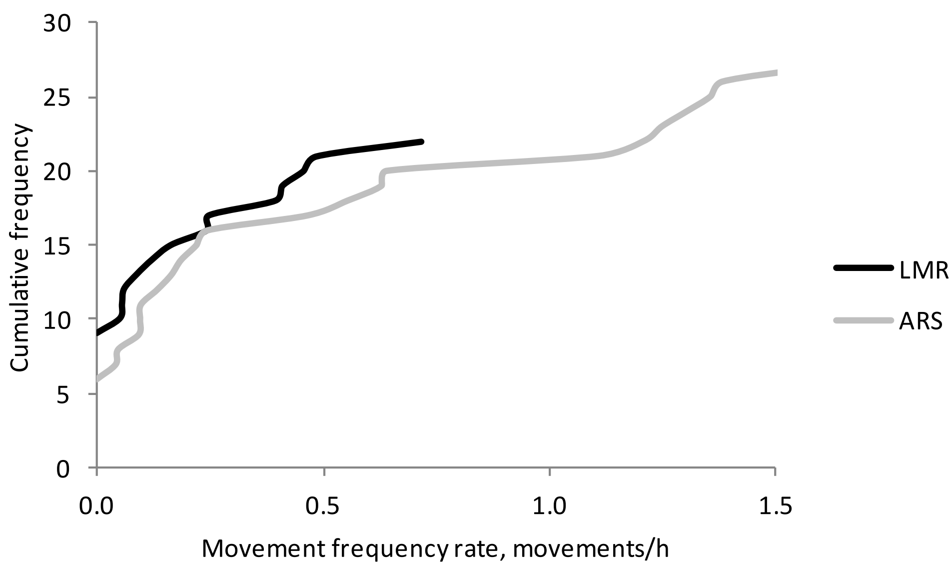

Figure 6 Cumulaive frequency of pallid sturgeon movement frequency rate in the lower Mississippi River (LMR) and Atchafalaya River System (ARS)

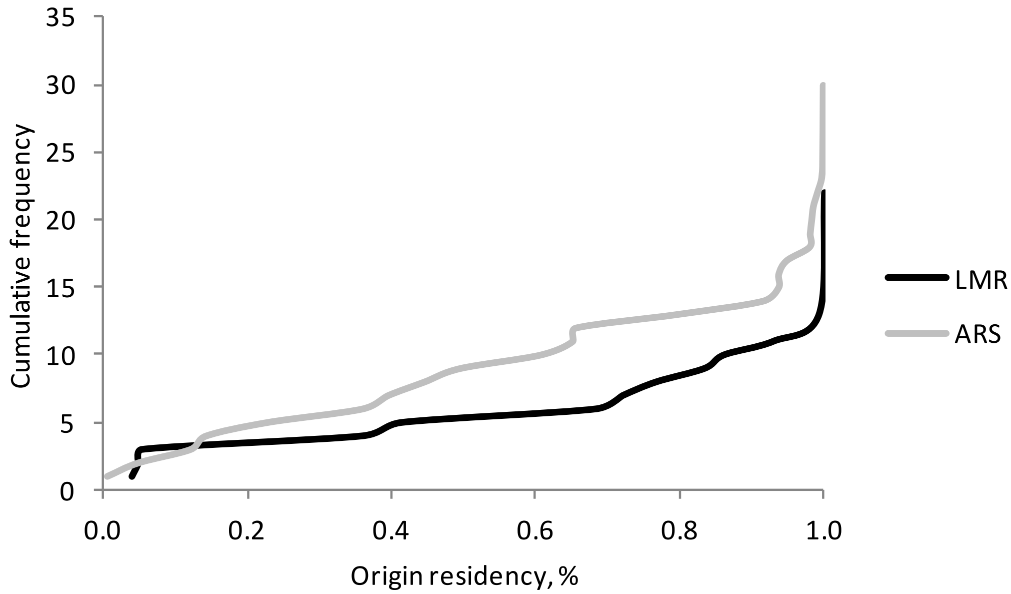

Figure 7 Cumulative frequency of pallid sturgeon origin residency values in the lower Mississippi River (LMR) and Atchafalaya River System (ARS)

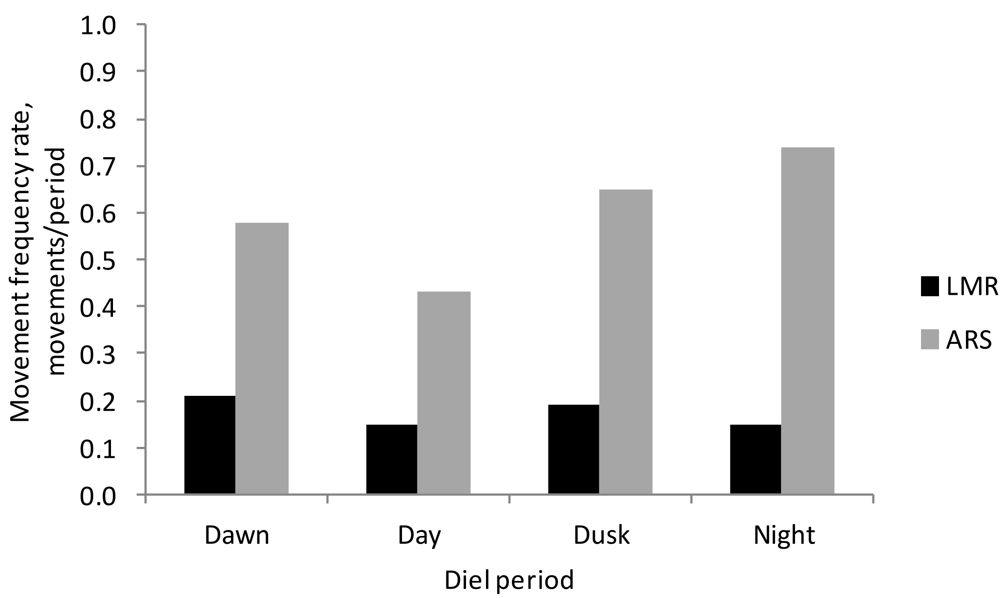

Figure 8 Mean movement frequency rate by diel period of pallid sturgeon in the lower Mississippi River (LMR) and Atchafalaya River System (ARS)

CHAPTER V

DISCUSSION

Habitat Selection

Island tips were the most selected for habitat in the LMR, a result consistent with previous studies in the Mississippi River (Hurley et al. 2004). Pallid sturgeon in the ARS showed negative selection for island tips. Favorable conditions provided by island tips in the LMR may not be provided by outside-bend natural bank and island tip habitat in the ARS. Island tips in the ARS only occurred much further downriver where the river becomes braided and current velocity in the main channel is less than upriver portions of the ARS.

Pallid sturgeon also had strong positive selection for outside-bend natural bank habitat in the LMR. These steeply sloping banks generally occurred downriver of sandbars and island tips and provided areas of moderate current in the LMR. Snook et al. (2002) found that pallid sturgeon in the Platte River were associated with abrupt changes in depth between the downstream edges of sandbars and the main channel, and suggested that these areas may provide abundant prey fishes and invertebrates. These geomorphic characteristics are represented by outside-bend natural bank habitat in the LMR. Outside-bend natural bank was neutrally selected by pallid sturgeon in the ARS. Outside-bend natural bank habitat in the ARS typically occurred downriver of outside-bend revetted banks but provided similar conditions as natural bank habitat in the LMR.

Wing dike habitat was positively selected by pallid sturgeon in the LMR and strongly avoided by pallid sturgeon in the ARS. The results from the ARS should be viewed cautiously as wing dikes account for an extremely small amount of habitat and their distribution is limited to a small (approximately 1 km) stretch of river. Mixed results from other studies have been reported on selection of wing dike habitats. Hurley et al. (2004) found that pallid sturgeon negatively selected wing dikes, but Koch et al. (2012) found that pallid sturgeon positively selected wing dike habitat. While reasons for differences in habitat selection between the LMR and ARS are unclear, the discrepancy is not unprecedented. The lack of consistent findings suggests much remains to be learned about additional variables affecting pallid sturgeon habitat selection.

Pallid sturgeon frequently used and positively selected for sandbar habitat in the LMR. This is consistent with Hurley et al. (2004) that found that pallid sturgeon in the middle Mississippi River positively selected sandbar habitat. Additionally, Jordan et al. (2006) found that pallid sturgeon selected large sandy areas in the main channel (by their classification a habitat that would include sandbar habitat) more than any other habitat. Pallid sturgeon in the ARS negatively selected sandbar habitat, and corroborates the findings of Koch et al. (2012) that pallid sturgeon in the middle Mississippi River negatively selected sandbar habitats. Differences in sandbar habitat selection by pallid sturgeon across systems are not fully understood; however, isolated distribution of sandbar habitat towards the lower third of the ARS where very few fish were located may have played a role. Current velocity begins to decrease in the lower portion of the ARS as the river widens and braids. It is possible that moderate current velocities preferred by pallid sturgeon are not available in sandbar habitat in the ARS as they are in the LMR.

Pallid sturgeon in the LMR and ARS selected revetted banks (on both inside and outside bends in the ARS). Based on acoustic tracking and underwater imagery of pallid sturgeon in the lower Missouri River, DeLonay et al. (2010) hypothesized that pallid sturgeon spawned in deep water on revetted banks in the lower Missouri River. The observations of DeLonay et al. (2010) suggest that pallid sturgeon may spawn in the ARS, an area devoid of rock shoals assumed to be the natural spawning sites of pallid sturgeon (Herzog et al. 2005; Laustrup et al. 2007). Although this may be the case, pallid sturgeon in the ARS were found on revetted banks throughout the year and in a wide range of temperatures. Additionally, pallid sturgeon in the LMR tended to be found on revetted banks when water temperatures were warm (>18°C) and low-flow conditions were present (Herrala et al. 2014), which typically occurred after the pallid sturgeon spawning period (Herzog et al. 2005). The results of these studies indicate that use of revetted banks in the LMR and ARS is not solely a consequence of habitat use during the spawning season, but may be related to other factors such as current and/or foraging.

Pallid sturgeon displayed positive selection for secondary channels when the habitat was available. This indicates that secondary channels are seasonally important habitat. DeLonay et al. (2010) suggested secondary channels may provide energy-efficient migration routes for pallid sturgeon in the Missouri River. For example, if a fish were to move from the furthest downriver edge in the LMR study site to the further upriver edge, that fish would travel 40 km if it were to use the main channel but just 34 km if it were to use all of the secondary channels.

The main channel accounted for the greatest amount of total available habitat in both the LMR and ARS (55 and 67%, respectively). Although pallid sturgeon were frequently detected in the main channel in both rivers, selection measures indicated avoidance of this expansive habitat in the LMR and ARS. Hurley et al. (2004), Jordan et al. (2006), and Koch et al. (2012) also found frequent use but negative selection of the main channel in the middle Mississippi River. Hurley et al. (2004) suggested that frequent detection of pallid sturgeon in the main channel may be a consequence of movement through the main channel to reach more suitable habitat. My study found that pallid sturgeon rarely made cross-channel movements (one of 22 fish in the LMR and two of 30 fish in the ARS). Additionally, pallid sturgeon in the LMR were found more often in the main channel during low-flow months when the availability of other habitats decreased. The main channel is an extremely high energy habitat with flows up to 3 m/s. Constant use of this habitat is not energy efficient during high flows. The results of this study as well as the findings of Hurley et al. (2004), Jordan et al. (2006), and Koch et al. (2012) indicate that pallid sturgeon frequently use the main channel habitat but selection, determined on a year-round basis, is negative.

Water control structures were strongly selected habitat in the ARS. All except five fish tracked in the ARS were captured, implanted, and released at WCS. Some fish were only located at the WCS throughout the study. Of those that left, most remained within 6 km of the WCS for several months. An important question is why these fish remained in this area while others left and occupied the Atchafalaya River. Environmental conditions such as depth, substrate, or food availability may be more suitable below the WCS and contribute to pallid sturgeon remaining in the area. My project and additional habitat-use studies (Kuntz and Schramm 2011; Herrala et al. 2014) in the LMR suggest that pallid sturgeon occupy habitats with at least moderate current velocity and avoid habitats lacking flowing water. Water flows in the vicinity of the water control structures were intermittent, yet pallid sturgeon remained in the WCS and were detected even when flow was minimal. Pallid sturgeon were often located immediately downstream of the LSWCS and AWCS when these structures were closed and there was zero flow. Thus, the persistence of the ARS pallid sturgeon at the WCS does not agree with the behavior of this species in the LMR and suggests that current velocity may not be a primary determinant of habitat use at the WCS. Although several unexplored factors may attract pallid sturgeon to the WCS, low movement frequency during short-term monitoring and repeated/protracted location at the WCS is possibly due to blocked upstream movement.

The patterns of habitat occurrence in the LMR and ARS may help explain differences in habitat selection. Wing dike habitat in the LMR typically occurs at the upriver end of islands with sandbar habitat being located directly downriver, proceeded by adjacent island tips downriver. Secondary channels flow through the back side of the island. These habitats all occur in relative close proximity and throughout the LMR, and can be viewed as an island complex. Additionally, outside-bend natural habitats usually occur directly downstream of secondary channels and island tips. All of these habitats were positively selected by pallid sturgeon in the LMR. Island complexes provide heterogeneous habitat in a short stretch of river that likely provides pallid sturgeon with their preferred depths and current velocities. The sinuous pattern of habitat occurrence in the LMR is not prevalent in the ARS and may point to differences in habitat selection between the systems.

I acknowledge the shortcoming that only 47% of tagged fish in the LMR and 51% of tagged fish in the ARS were used to analyze habitat selection. The inability to successfully locate tagged pallid sturgeon is multifaceted as tagging mortality, tag loss, tag malfunction, habitat obstructions, and the ability of pallid sturgeon to openly migrate in and out of the study areas may have all lead to decreased and infrequent detections. Future habitat studies should expand the study area to incorporate longer stretches of river and potentially major tributaries in the LMR and ARS. Additionally, no fish were found on island tips or wing dikes in the ARS leading to a default result of negative selection. Increased sampling effort to insure or disprove low/no use in these habitats would also strengthen the results of my study.

Short-term Movement

Pallid sturgeon have been found to be a possibly migratory species in the upper Missouri River (Bramblett and White 2001) and in the middle Mississippi River (Hurley 1999). Pallid sturgeon moved the entire length of the Atchafalaya River (247 km; Constant et al. 1997; Herrala and Schramm 2012) and at least 248 km in the lower Mississippi River (H.L. Schramm, unpublished data); but the results of this study indicate that they move little during short time periods, as evidenced by low movement frequencies and high origin residency. The movements estimated from arrays of sentinel receivers in this study are similar to those in other studies that examined short-term movements by intensive, active tracking. Although Erickson (1992) found pallid sturgeon in a Missouri River impoundment had relatively high amounts of movement (up to 2 km/day, Jordan et al. (2006) found low levels of movement (<1 km/day) in the Missouri River below Fort Randall Dam and Constant et al. (1997) observed zero movement in the Athchafalaya River. The movements measured in the LMR and ARS agree with the low movements measured by Constant et al. (1997) and Jordan et al. (2006) in unimpounded river reaches.

Movement and origin residency in both the LMR and ARS was not related with surface water temperature. This supports the findings of Constant et al. (1997), Jordan et al. (2006), and Wanner et al. (2007) that all used intensive tracking and found no correlation between pallid sturgeon movement and water temperature. Corroboration between multiple studies indicates that temperature is not a factor in short-term movement throughout the range of pallid sturgeon.

Rising and falling river stage triggers the movement of anadromous sturgeon (Kieffer and Kynard 1993). While changes in river stage may signal or initiate long-term, migratory movements, river stage and change in river stage were not significant predictors of movement or origin residency in the LMR or ARS, supporting the results of Constant et al. (1997) who observed that river stage was not a significant predictor of pallid sturgeon movement in the Atchafalaya River.

Results regarding current velocities from this study and previous studies should be compared cautiously, because current velocities were based on surface current velocities in this study; whereas past studies (Erickson 1992; Bramblett and White 2001; Jordan et al. 2006) measured bottom current velocities, which are presumed to be more accurate measures of current at the fish. Erickson (1992) and Jordan et al. (2006) found no relation between pallid sturgeon movement and current velocity. My study found pallid sturgeon movement was not related to surface current velocity in the LMR and ARS.

Trends in diel movement have been observed in other studies. Bramblett and White (2001) found that pallid sturgeon in the Yellowstone and Missouri rivers moved more during the day, and hypothesized that pallid sturgeon would become more nocturnal in areas of low turbidity. Erickson (1992) reported greater movement rates during the night in the Lake Sharpe, a low turbidity area of the Missouri River. Pallid sturgeon did not exhibit any diel movement patterns in the LMR and ARS and, although both rivers are turbid, provided no evidence to support the hypothesis put forth by Bramblett and White (2001). This is consistent with findings in the Atchafalaya River (Constant et al. 1997), Platte River (Snook et al. 2002), and Missouri River (Jordan et al. 2006; Wanner et al. 2007).

Implications for Pallid Sturgeon Recovery

This study and others (Erickson 1992: Constant et al. 1997; Bramblett and White 2001; Jordan et al. 2006; Wanner et al. 2007) have documented that pallid sturgeon exhibit periods of little to no movement throughout their range. Short-term movement results from the LMR and ARS help to validate and strengthen the use of intermittent detections of pallid sturgeon from active tracking studies for assessment of habitat selection. Water temperature, river stage, and current velocity did not affect movement, and the minimal movement of pallid sturgeon in the LMR and ARS during short time frames suggests that no single or suite of environmental conditions appears to consistently trigger increased movement in either river.

Positively selected habitats are assumed to represent the preferred habitats of those available for pallid sturgeon in their respective rivers, and the determination of those habitats provides information that can be used for the protection and conservation of the species through targeted habitat management. Although altered, the LMR and ARS provide free-flowing environments that apparently are needed by pallid sturgeon (Hrabik et al. 2007; Boley and Heist 2011). In agreement with Hurley et al. (2004), highly used areas are good candidates for habitat conservation. Complete restoration of riverine habitat will likely never be attainable, but precisely targeted conservation and enhancement projects are well within reach and would help establish or maintain self-sustaining pallid sturgeon populations. Results suggest that conservation of island complexes in the LMR that include island tip, sandbar, wing dike, and secondary channel habitats should be a high management priority for conservation as they were all positively selected by pallid sturgeon. Notched wing dikes at the upriver ends of islands can divert a portion of the river's flow into secondary channels making that habitat available throughout the year and maintain the habitat complexity provide by island complexes.

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APPENDIX A

CALIBRATING DETECTION DISTANCES

Detection distance of receivers is a function of water turbidity, temperature, and probably air entrained in swiftly flowing or turbulent waters (Urick 1983; Etter 1991). Detection distance of SRs varied over sampling periods, so detection distance was determined before arrays were set to provide more accurate results. The efficiency of SRs in detecting tagged pallid sturgeon was also examined to validate movement data and help explain any possible time gaps between detections (Appendix B).

Detection distance was determined on the first day of each array-deployment event at each study area. A V16 transmitter was anchored at the location of the fish within the array. A boat was then anchored in 100 m increments downstream of the anchored transmitter for 5 minute intervals. At each location, a SR was put in the water approximately 0.3 m below the surface and, after 5 minutes, the SR was retrieved and downloaded to determine if any detections of the anchored transmitter had occurred. If detections occurred, the boat was moved downstream to the next 100 m increment and the process was repeated. When no detections occurred, the boat was maneuvered closer to the transmitter in 25 m increments until detection occurred. This same procedure was carried out in upstream and lateral directions to determine whether there were differences in the detection field. Detection distances upstream and laterally were found to be the same as downstream during the first two calibration efforts, so subsequent detection distances were estimated only in a downstream direction

APPENDIX B

ESTIMATING STATIONARY RECEIVER DETECTION EFFICIENCY

Castro-Yerty and Bettoli (2009) found that detection of Vemco V16 acoustic tags by Vemco SRs mounted to bridge piers in the lower Mississippi River was lower in areas obstructed by bridge piers. Clements et al. (2005) found that even small obstructions such as ropes and mounting brackets could negatively impact acoustic tag detection by a VR2 sentinel receiver (SR). Additionally, changes in detection distance caused by water temperature, turbidity, or air entrainment (Urick 1983; Etter 1991) may cause SR detection efficiency to decrease and require that SRs be placed closer together to ensure overlapping fields of detection.

Testing of SR detection efficiency was done by examining data collected by SRs for each pallid sturgeon that was determined to have not left the origin SR. Times between successive detections were determined, recorded, and viewed graphically (Figure 9). Time gaps less than 360 s were considered to contain no missed detections. Time gaps greater than 360 s were considered to be true missed detections; i.e., a signal was emitted from a tag within the detection range of the SR and was not received by the SR. The number of time gaps less than 360 s was divided by the total number of time gaps to determine SR efficiency. The time gap of 360 s was chosen as a cutoff point for two reasons. First, V16 acoustic transmitters have long, randomized delays approximately every 60 – 120 s, but occasional longer delays near 360 s were observed in this study during active tracking efforts. Second, observations from this study and others (Clements et al. 2005; Castro-Yerty and Bettoli 2009) have found obstructions such as bridge piers and wing dikes (both present in the LMR and ARS) interfered with detections of transmitters known to be within range. A single missed detection could be caused by such conditions, but a delay longer than 360 s implied that the fish was consistently not detected while within the range of an SR.

Mean SR detection efficiency in the LMR was 92% (range 87-99%; SD 6.32%). Mean SR detection efficiency in the ARS was also 92% (range 80-100%; SD 7.64%). Therefore, SRs deployed in this study only missed an estimated 8% of detections. The high estimates of detection efficiency of SRs in this study proves that the use of SRs within an array system effectively monitor movement of pallid sturgeon.

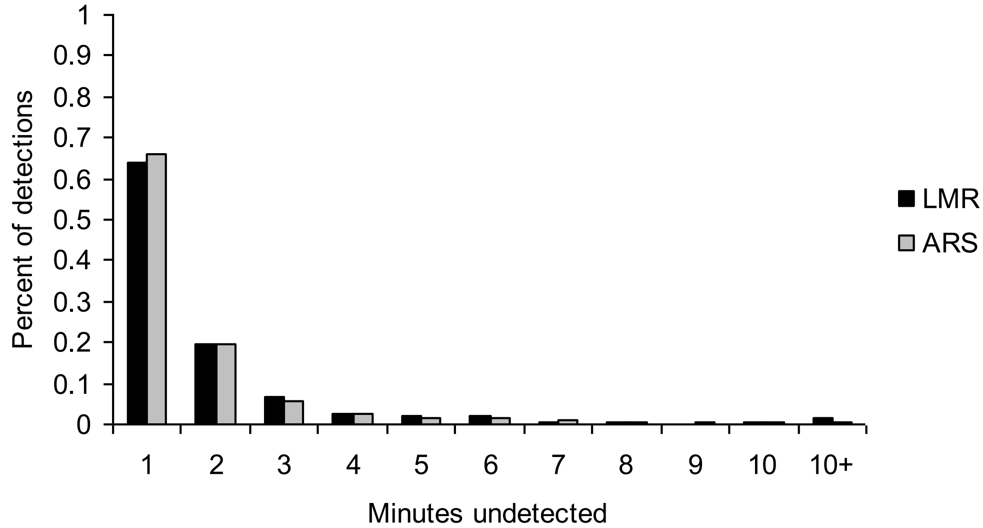

Figure 9 Percent detections by time gap for the lower Mississippi River (LMR) and Atchafalaya River System (ARS)