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EVALUATION OF OTTER TRAWLS AND TROTLINES FOR CATCHING PALLID STURGEON IN THE FREE-FLOWING LOWER MISSISSIPPI RIVER

By

Patrick Peterson Mirick

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EVALUATION OF OTTER TRAWLS AND TROTLINES FOR CATCHING PALLID STURGEON IN THE FREE-FLOWING LOWER MISSISSIPPI RIVER

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Stock assessment and behavioral studies are needed to identify habitat use and population dynamics of endangered pallid sturgeon *Scahphirhynchus albus* in the free-flowing lower Mississippi River; however, effective sampling methods have not been evaluated. Trotlines and otter trawls were consequently fished year-round to determine the more effective gear and to determine effects of environmental variables on catch rates. Trotlines were more effective for catching large (> 600 mm FL) pallid sturgeon and neither gear was effective for catching small (100-600 mm FL) pallid sturgeon. Greater predicted probabilities of catching large pallid sturgeon with trotlines were in 9-19 °C water temperatures, 0.7-0.9 m s^{-1} surface current velocities, and in greater depths (up to 12 m). Results of this study provide information that can be used to maximize sampling efficiency.

DEDICATION

My thesis is dedicated to my brother, Mats Mirick, who passed away unexpectedly on May 5, 2011. I am grateful for the 22 years we spent together, not only as brothers, but as best friends. To tight lines, chromer steelies, heaters, elk stalking, 9th hole monster bucks, botulism laced canned tuna, broken bones, Balmertown “beauties”, boat crashes, garden hose bungee jumping, La Forta, and toad pike on purple lures!

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CHAPTER 1

INTRODUCTION

Pallid sturgeon *Scaphirhynchus albus* is an endangered species (Federal Register, 1990) present in the Mississippi and Missouri river systems (Bailey and Cross 1954; Kallemeyn 1983). Unlike the Missouri River (MOR), natural reproduction occurs in the free-flowing lower Mississippi River (LMR) (Hrabik et al. 2007); therefore, conservation efforts should focus on sustaining and increasing wild stocks. Conservation of wild-stock pallid sturgeon in the LMR will require monitoring population changes, as well as protecting and restoring habitats used by the fish; however, habitat use, mortality, and population size are unknown. This needed information can be determined through behavior and stock assessment studies, both of which will require capture of many individuals. Little is currently known about how to catch pallid sturgeon in the LMR. Determining the most effective sampling gear and the best conditions and locations for sampling could save time and effort and result in capture of more pallid sturgeon.

Pallid sturgeon occupy river bottoms in swift, deep water (Bailey and Cross 1954; Kallemeyn 1983), and researchers have attempted to catch them throughout their range with sampling gears that are used commonly in rivers, such as hoop nets, trotlines, and otter trawls. In addition, researchers have attempted to catch them by drifting trammel nets and gill nets. Of these gears, all but hoop nets have caught pallid sturgeon. Killgore et al. (2007) caught 215 pallid sturgeon in 1,247 trotline samples and one in 345 otter trawl samples in the LMR and middle Mississippi River (MMR); Wanner et al. (2007) caught 19 in 1,683 trotline samples, six in 166 otter trawl samples, and zero in 520 hoop net samples in the MOR; and Paul Hartfield caught 11 with otter trawls in the LMR in 2001, although catch rates are unknown (P. Hartfield, USFWS, Jackson, MS, unpublished data). Pallid sturgeon also have been captured with stationary and drifted gill nets and trammel nets in the MOR, MMR, and Atchafalaya rivers (Constant et al. 1997; Phelps et al. 2009); but these nets are not considered viable sampling gears in the LMR where fast currents, deep water, and abundant snags are expected to affect gear efficiency and sampling safety and economy. Thus, otter trawls and trotlines may be effective gears for catching pallid sturgeon in the LMR, and a comparison of catch rates between these gears in paired-gear samples can be used to determine which gear is more effective in terms of pallid sturgeon per time spent sampling.

In addition to selecting the most effective gear, determining the best locations and conditions for sampling may increase catch rates of pallid sturgeon; but little is known about what affects catch rates for either gear except that trotlines caught the most pallid sturgeon in the LMR and MMR when water temperatures were 5-20 °C (Killgore et al. 2007; Phelps et al. 2009), and otter trawls caught the most pallid sturgeon in the LMR when river stage was “relatively low and falling” (Paul Hartfield, USFWS, Jackson, MS, personal communication). It is unknown if catch rate is affected by other variables such as depth, current velocity, and habitat. These variables are likely to affect catch rates because telemetry studies identified that pallid sturgeon are found more commonly in certain habitats, depths, and current velocities. Wing dike tips, main channel borders, and side channels are habitats used more commonly by pallid sturgeon in the MMR and MOR

(Hurley et al. 2004; Dave Herzog, Missouri Department of Conservation, Jefferson City, unpublished data); and pallid sturgeon were most often found in 0.4-1.2 m s^{-1} current and in the deepest relative depths in the Yellowstone River and the MOR (Bramblett and White 2001). Consequently, catch rates in the LMR would be expected to be greater when gears are sampled in 0.4-1.2 m s^{-1} current velocity and in the greatest depths available within wing dike tip, main channel border, and side channel border habitats. Determining optimal conditions for sampling pallid sturgeon with trotlines and otter trawls requires sampling a variety of depths, water temperatures, river stages, habitats, and current velocities.

Trotlines and otter trawls also have been used to catch threatened shovelnose sturgeon *Scaphirhynchus platorynchus* in the LMR (Killgore et al. 2007; Paul Hartfield, USFWS, Jackson, MS, unpublished data). As with pallid sturgeon, researchers also are concerned with the population status of shovelnose sturgeon because their populations are declining throughout their range (Keenlyne 1997; Federal Register 2009). Little is currently known about how to catch shovelnose sturgeon, and such information could be acquired from shovelnose sturgeon catch data obtained while sampling for pallid sturgeon.

One objective of this study was to determine the most effective sampling gear, in terms of fish per effort, for catching pallid sturgeon and shovelnose sturgeon by comparing catch rates of paired otter trawl and trotline samples. Another objective was to determine relationships between environmental variables and catch rates of pallid sturgeon and shovelnose sturgeon.

CHAPTER 2

METHODS

Study site and survey design

The free-flowing LMR extends 1600 km from the confluence of the Ohio River and the Mississippi River to the Gulf of Mexico. Throughout most of its length, the LMR consists of a repetitive, sinuous pattern of bends with the thalweg passing close to the outside bank of each bend. The main channel habitat is the deep portion of the channel that includes the thalweg (Wilcox 1993). Lateral to the main channel is the channel border habitat that extends from the toe of the channel to the shore. Channel border is the habitat used more commonly by pallid sturgeon in the MMR (Hurley et al. 2004). The channel border on the outside of a river bend is usually steeply sloping to the toe of the channel and armored with revetment (articulated concrete mattress overlain by large rock rip rap) to forestall erosion. On the inside of the bend is either an island that separates the main channel from a secondary channel or a sandbar, sometimes referred to as a point bar; whether the island is above water or submersed depends on the river stage (Wilcox 1993). Wing dikes, rock riprap structures that extend from shore towards the main channel, are commonly installed upriver of inside bends to direct water flow away from a secondary channel or the point bar to facilitate maintenance of a navigable channel (Wilcox 1993). A relatively deep scour hole usually forms downstream of each wing dike. The habitat below wing dikes was another habitat commonly used by pallid sturgeon in the MMR (Hurley et al. 2004). There also is backwater habitat such as floodplains and oxbow lakes, which have little to no flow and are unlikely to be used by pallid sturgeon (Bramblett and White 2001; Hurley et al. 2004).

The gear comparisons were conducted at three similar river bends to serve as replicates (Figure 1): Monterey Bend (rkm 927-933), Cypress Bend (rkm 914-917) and Choctaw Bend (rkm 898-908). These bends were selected because they were easily and safely accessed and were representative of other bends throughout the LMR (i.e., armored outside bank, wing dike(s) on inside bend). An example of an atypical bend that was not selected was The Bar (rkm 922-923), which did not have a wing dike on the inside bend. Atypical bends were not sampled because this would have decreased sample size at typical bends and because atypical bends are extremely rare; The Bar was the only atypical bend I observed in the stretch from Memphis, Tennessee (rkm 1167-1191) to Greenville, Mississippi (rkm 864) (atypical bends cannot be quantified by looking at maps because wing dikes can become buried in sediment and are added or removed by the US Army Corps of Engineers).

At each bend, samples were collected in four habitats (Figure 1): (1) below a wing dike (dike); (2) in the channel border habitat near the middle of the island or point bar (middle channel border); (3) in the channel border habitat at the downstream end of the island or point bar (lower channel border); and (4) in the downstream end of the secondary channel when there was visible flow through the secondary channel (SC). The main channel was not sampled because of frequent barge traffic that would have made sampling dangerous and caused loss of trotlines. The channel border along the outside bend was not sampled because trotlines frequently snagged on the revetment during initial sampling efforts and trawling was not possible. Characteristically, the channel border near the middle of the island or point bar has a relatively sharp increase in depth with the deeper water downstream of the shallower water, and the middle channel border habitat samples were collected in association with this bathymetric feature when it existed. At each habitat within each bend, samples were collected in 3-6 m depths (shallow sample) and 6-9 m depths (deep sample); these depth ranges coincided with depths at which pallid sturgeon were more frequently located in the MMR (Dave Herzog, Missouri Department of Conservation, Jefferson City, MO, unpublished data). Sample locations were moved laterally (relative to the thalweg) to obtain the desired depths as the river stage changed.

Sampling design

Monterey, Cypress, and Choctaw bends were sampled in random order each month from June 2008 to May 2009 with trotlines and otter trawls. Trotline specifications and methods were similar to those used by commercial fishermen to catch pallid sturgeon and shovelnose sturgeon in the LMR (Jack Killgore, USACE, Vicksburg, MS, personal communication; Morrow et al. 1998). Each trotline consisted of an 85-m long main line (#36 tarred nylon twine), to which were attached 40 dropper lines (#9 tarred nylon twine). Dropper lines were 25-cm long and had a hook (Mustad Model 34009, size 2/0) attached to a swivel (#7 Laker Brand) on one end and a trotline clip that attached the dropper to the mainline on the other. Six to eight, 150-250 g weights were attached to the trotline throughout the length to ensure that the trotline fished on the bottom. Hooks were baited with pieces of night crawlers *Lumbricus terrestris* threaded onto the entire shank of the hook. The trotlines were set less than 4 hours before dark and retrieved within 6 hours after sunrise the following day. Set time, retrieve time, and number of hooks with bait remaining were recorded for each trotline. Trotline catch rate was expressed as fish per hook-hour and as fish per sample.

Proportion of baited hooks remaining was recorded because it may have affected the ability of trotlines to catch sturgeon. Trotlines that caught more non-sturgeon species and had more bare hooks would be expected to be less effective at catching sturgeon (i.e., fishing effort would not have been equal).

Otter trawling was conducted at each station where a trotline was fished after the trotlines were retrieved. Otter trawl specifications and methods were the same as those used to successfully capture pallid sturgeon and shovelnose sturgeon in the LMR (Paul Hartfield, unpublished data). The otter trawl had a 4.88-m weighted foot rope, 5.1-cm stretch mesh in the body, 3.8-cm stretch mesh in the cod end, and was pulled with 30-m warps attached to 76 cm x 38 cm weighted doors.

All trawling was done by attaching the trawl warps near the bow of the boat and backing the boat downstream to avoid unsafe conditions that occur if the trawl snags when fishing in current velocities that frequently exceeded 0.8 m s^{-1}. By trawling downstream in reverse, the boat can be maneuvered forward easily if the trawl snags; snagging a trawl when trawling off the stern pulls the aft of the boat down and warps must be immediately cut because the boat cannot be backed into the current to free the snagged trawl.

Each trawl sample was approximately 0.40 km. The trawl was pulled at velocities of 1.6-3.2 km h^{-1} faster than the current to keep tension on the warps, which caused the otter boards to spread. Trawl speed over current velocity could not be fixed at a constant speed due to depth and bottom contour, in addition to current velocity, affecting the ability of the otter boards to spread. Distances and boat speed were measured to the nearest 0.02 km and 0.1 km h^{-1}, respectively, by boat-mounted GPS. Trawl samples interrupted by snags were excluded from analysis, and another trawl sample was made at that location.

Catch rate was expressed as fish per m^2 trawled. The area trawled was calculated by multiplying the distance trawled by the length of the foot rope of the trawl. The trawl could not be observed in turbid water. The otter boards probably did not fully tighten the foot rope; and, therefore, the trawl probably did not sample a transect that was a full 4.88-m wide. The opening width of the trawl was assumed to be the same for all transects, and any bias in area sampled was assumed to be proportional for all samples.

Catch rates were calculated for pallid sturgeon and shovelnose sturgeon > 600 mm FL (large) and 100-600 mm FL (small). Although maturity of each sturgeon could not be determined because it would have required visual inspection of gonads, most large sturgeon would have been expected to be adult fish and most small sturgeon would have been expected to be immature fish. Pallid sturgeon are sexually mature when they are 533-584 mm FL (Fogel 1981). Shovelnose sturgeon are believed to mature at ages 5-7 (Helms 1974). That corresponds to 520-580 mm FL in the LMR (Morrow et al. 1998). Although sturgeon < 100 mm FL were captured, these fish were excluded from analyses because they could not be identified to species in the field (Snyder 2002). Differences in catch rates of the gears also were better described by grouping sturgeon into small and large size classes.

Due to different units of effort for each gear, catch rates were converted to fish per person-hour to create equivalent effort units for comparison. Conversion of catch rate to fish per person-hour has been used in other studies to compare catch rates with different gears (Pugh and Schramm 1998; Schultz and Haines 2005). Person-hour was calculated for each gear by multiplying number of people used to collect the sample by the time it took them to obtain the sample. For each trotline sample, it took on average 3 minutes to bait the hooks, 10 minutes to deploy the trotline, and 25 minutes to retrieve it. Therefore, total time to obtain a trotline sample was 38 minutes per line multiplied by number of people used (3), for a total of 114 person-minutes or 1.9 person-hours. In contrast, it only took two people to obtain an otter trawl sample multiplied by 8 minutes of time per trawl for a total of 16 person-minutes or 0.27 person-hours per trawl. Fish per person-hour catch rates were less accurate than fish per hook-hour or fish per m^2 catch rates and were only used to compare catch rates between gears. Fish per person-hour catch rates were less accurate because they included the time required to obtain a standard sample (overnight trotline set with 40 hooks or a 0.40 km otter trawl sample), and trotline samples varied slightly in set time and number of hooks retrieved and otter trawls varied slightly in distance trawled.

In previous gear evaluation studies, researchers compared catch rates of gears by fishing the gears at approximately the same locations and times (Phelps et al. 2009; Pugh and Schramm 1998; Pine 2000). Otter trawls and trotlines could not be fished at the same time because the gears could have become entangled, it would have been dangerous to trawl at night, and it would have been impractical to set trotlines in the morning and to have allocated enough time to retrieve the lines before dark. Therefore, when possible, otter trawl samples were obtained in the same locations where trotlines were sampled after the trotlines had been retrieved. Consequently, although the samples with each gear were paired, they were not fished simultaneously. Only paired samples were used for the comparison of catch rates.

Not all trotline and trawls samples were paired. This primarily occurred during high river stages when trotlines could be set but conditions were deemed too dangerous for trawling. There also were times when extra trawl samples were completed or when trotlines were lost and not resampled. Although unpaired samples were not used to compare catch rates between gears, they were used to determine relationships of environmental variables with catch rates.

Captured sturgeon were measured for fork length (FL, mm) and identified as pallid sturgeon, shovelnose sturgeon, or intermediate sturgeon (pallid sturgeon-shovelnose sturgeon intermediates) based on accepted morphometric characteristics (Appendix A). In compliance with protocols adopted by the Lower Basin Pallid Sturgeon Work Group, all pallid sturgeon and intermediate sturgeon were tagged with Floy T-bar FD-68BC tags and passive integrated transponder tags, and tissue samples were obtained. Age-0 sturgeon (<100 mm FL) could not be identified to species by morphometric characteristics (Snyder 2002) and were preserved to provide samples for future researchers who seek to develop means to field identify age-0 sturgeon to species.

River stage was obtained from the U.S. Army Corps of Engineers gage at Arkansas City, Arkansas and was converted to meters above the low water reference plane. This conversion was necessary to create a standardized river stage that can be compared across gages in the LMR. The most recent (2007) low water reference plane

(LWRP) for the Arkansas City gage was 29.1 m above sea level (Wayland Hill, USACE, Vicksburg, MS, personal communication). Zero on the gage corresponded to 29.4 m above sea level or 0.3 m above the LWRP. Therefore, river stage in meters above the LWRP was calculated by adding 0.3 m to gage readings. Surface current velocity, depth, and water temperature were recorded at all sample stations. Surface current velocities were measured to the nearest 0.1 km h^{-1} by boat-mounted GPS by allowing the boat to freely drift with the current. Depth was the average of maximum and minimum depths (± 0.1 m) recorded during each sample and was measured by sonar.

Data analysis

Shovelnose sturgeon length comparison

To determine if differences in lengths of shovelnose sturgeon existed between the gears, average lengths of shovelnose sturgeon caught with trotlines and otter trawls were compared with a Wilcoxon test. Additionally, length-frequency distribution of shovelnose sturgeon caught with trotlines and otter trawls were compared with a Kolmogorov-Smirnov test.

Shovelnose sturgeon catch rate comparisons

Small (100-600 mm FL) and large (> 600 mm FL) shovelnose sturgeon catch rates (fish per person-hour) from paired samples were ranked and compared with a three-level nested ANOVA due to a nested sample design. Ranking was necessary because the data were not normally distributed and could not be transformed to a normal distribution (i.e., Shapiro-Wilk $P < 0.1$ for log, natural log, square root, and inverse transformations). Sampling effort with the trotlines and otter trawls was allocated by bend and habitat type;

therefore, habitat type was nested within river bend and river bend was nested within gear type. The nested ANOVAs partitioned variance according to river bend and habitat type, allowing insight about the relative importance of different levels on catch rates (i.e., whether catch rate was more affected by gear type, by river bend, or by habitat type within a bend). In contrast, a simple comparison of catch rates between gears (e.g., with a Wilcoxon test) would have only been able to determine which gear was more effective overall.

Nested ANOVAs were performed using SAS 9.2 (SAS Institute, Cary, North Carolina). The PROC GLM procedure was used to determine if the variances of groups were different at each level (i.e., if variation differed among gears, among bends within a gear, or within habitats within a gear and bend). The LSMEANS procedure was then used to determine where any differences may have occurred (e.g., if catch rates differed between trawl samples at secondary channel habitat at Cypress Bend and trotlines samples at wing dike habitat at Choctaw Bend).

Statistical difference was declared at $\alpha = 0.10$ instead of the more commonly used $\alpha = 0.05$. Since little is known about how to catch shovelnose sturgeon in the LMR and because there is not much difference in the cost, safety, or skills necessary to fish each gear, I decided that the benefits of using a greater than normal α value, which allowed detection of smaller differences in catch rates, outweighed the increased risk of making a Type I error.

Relationship between environmental variables and catch rates of shovelnose sturgeon and the probability of catching one or more pallid sturgeon

Nested ANOVA analyses were useful to compare catch rates of shovelnose sturgeon; but only data from paired samples could be used, and the effects of environmental variables other than habitat type and river bend could not be analyzed (e.g., water temperature, depth, etc.) Therefore, regression analyses were used to evaluate the most parsimonious suite of all environmental variables that accounted for variation in catch rates of shovelnose sturgeon and the probability of catching a pallid sturgeon. Models were built that included single variables or combinations of environmental variables that were hypothesized to affect the catch rates of shovelnose sturgeon or frequency of pallid sturgeon catches. Akaike's information criterion (AIC) scores were used to determine the best supported model; lesser scores represent better supported models.

The regression models included the class variables habitat (dike, SC, middle channel border, lower channel border), river bend (Monterey, Cypress, Choctaw), change in water temperature from the previous month ($\Delta_{temperature}$, increase or decrease), and daily change in river stage ($\Delta_{stage,}$ rise, fall, or stable); and the continuous variables surface current velocity (m s^{-1}), water temperature (°C), depth (m), and river stage (m above the LWRP).

Although sampling occurred primarily in shallow and deep depth bins, depth was considered a continuous variable because the channel border habitat was often narrow and trotlines were often placed to avoid entanglement of gear, regardless of depth. Hence, samples occurred in shallower or deeper water than the shallow and deep bins and two lines were often set in the same depth class. The depths sampled were consequently random and depth was accordingly analyzed as a continuous variable.

Habitat, water temperature, stage, Δ_{stage}, current velocity, and depth were included in the models because they have been found to affect catch rates of pallid sturgeon and shovelnose sturgeon with trotlines and otter trawls or to affect habitat use of pallid sturgeon (Bramblett and White 2002; Killgore et al. 2007; Phelps et al. 2009; Paul Hartfield, USFWS, Jackson, MS, unpublished data). Phelps et al. (2009) also determined that catch rates of pallid and shovelnose sturgeon were greater during fall and winter. Use of calendar seasons as a class variable may not be the most appropriate means to determine if seasonality affects catch rates; water temperatures and river stages in the LMR can vary dramatically among years during calendar seasons, and calendar-based seasons may have little biological meaning. Seasonal variability was incorporated into the regression models as $\Delta_{temperature}$.

Regression analyses were performed using SAS 9.2 (SAS Institute, Cary, North Carolina). Curvilinear relationships between several variables and catch rates (shovelnose sturgeon) or frequency of catch (pallid sturgeon) were examined by inspection of biplots (Figures 2-5), and these relationships were accounted for by adding second-order terms to variables. A velocity-depth interaction was included to account for the relationship between depth and surface current velocity.

Catches of pallid sturgeon were infrequent, and typically only one fish was caught per line when catches occurred. Thus, pallid sturgeon catch resembled a binomial distribution, and the relationship between the probability of catching a large pallid sturgeon with a trotline sample and environmental variables was determined with logistic regression using PROC LOGISTIC with SAS 9.2 (SAS Institute, Cary, North Carolina). Goodness of fit for each model was measured by Somer's D. Somer's D is the preferred goodness of fit measure for logistic regression models because statistical programs calculate a pseudo R^2 that is misleading to most audiences (Hosmer and Lemeshow 2000). Somer's D ranges from -1 to 1; -1 signifies a perfect inverse relationship with the data, 0 corresponds to no relationship, and 1 is a perfect positive relationship. Although subjective, a value of above 0.6 indicates good fit (Leandro Miranda, Mississippi State University, Mississippi State, MS, personal communication).

General linear regression (PROC GLM) with SAS 9.2 (SAS Institute, Cary, North Carolina) was used to determine the relationship between environmental variables and catch rates (fish per hook-hour) of large shovelnose sturgeon with trotline samples because one or more fish were caught with most trotline samples. PROC GLM was used also to determine the relationship between environmental variables and the catch rates of small shovelnose sturgeon with trotlines and otter trawls. R^2 and AIC model scores were calculated with PROC REG (SAS 9.2; SAS Institute, Cary, North Carolina) with dummy coding for class variables because PROC GLM does not calculate AIC scores and because PROC REG does not recognize class variables.

CHAPTER 3

RESULTS

Total fishing effort included 174 trotline nights or 113,842 hook hours and 153 otter trawls or 299,680 m^2 trawled during 12 samples from June 2008 to May 2009 (Table 1). One hundred and five samples were paired. Only four trotline sets and no trawl samples were collected in December due to boat-motor problems. Trawl and trotline samples were not collected at Choctaw Bend in March 2009 due to unsafe wind and wave conditions.

A wide variety of water temperatures and river stages occurred during sampling (Figure 7). Water temperatures were warmest in July and August (30°C), steadily cooled from August until January (3 °C), and then steadily warmed from February to May. River stage declined from 8 m in June to near 2 m in October and November and, except for a decline in February, increased to 12 m in May.

The proportion of baited hooks retrieved without fish decreased as water temperature increased (Figure 8). Catch rates of non-sturgeon fish species varied little in different water temperatures (Figure 9).

Twenty-eight large and one small pallid sturgeon were caught in trotline samples. Paired trotlines caught 22 large (1 per 4.8 samples) and one small (589 mm FL) pallid sturgeon. Total catch of shovelnose sturgeon with trotlines was 252 large and 158 small fish. Paired trotlines caught 158 large shovelnose sturgeon and 86 small shovelnose sturgeon. In addition, 12 large and one small intermediate sturgeon were caught with trotline samples.

Otter trawls caught one pallid sturgeon (1 per 105 samples). This fish was 686 mm FL and was caught in the middle channel border habitat at Cypress Bend in 8 m of water. The total catch of shovelnose sturgeon with otter trawls was 9 large and 137 small fish. Paired otter trawls caught 5 large and 63 small shovelnose sturgeon. No intermediate sturgeon were captured with otter trawls.

Shovelnose sturgeon length comparison

Otter trawls tended to catch primarily small shovelnose sturgeon and trotlines tended to catch primarily large shovelnose sturgeon and large pallid sturgeon (Figure 7). Mean length of shovelnose sturgeon caught with trotlines (612 mm; SD = 70.3 mm; range = 355-810 mm) was significantly greater (Wilcoxon test; Z = -13.2; *P* <.001*)* than mean length of shovelnose sturgeon caught with otter trawls (374 mm; SD = 195 mm; range = 45.0-685 mm) in paired samples. In addition, length frequency distributions of shovelnose sturgeon differed between otter trawls and trotlines in paired samples (Kolmogorov-Smirnov test; D=0.606; *P*<0.001). Trotlines appeared to be selective for 350-850 mm FL shovelnose sturgeon, and the fish did not appear to fully recruit to the gear until they were 600 mm FL (Figure 7). Otter trawls appeared to be selective for 50-700 mm FL shovelnose sturgeon and the fish did not appear to fully recruit to the gear until they were 100 mm FL.

Shovelnose sturgeon catch rate comparisons

Differences in catch rates of small pallid sturgeon between gears were not compared because only one small pallid sturgeon was caught by trotlines and no small pallid sturgeon were caught by otter trawls. In addition, differences in catch rates of large pallid sturgeon between gears were not compared because it was apparent that trotlines were a more effective gear; 23 large pallid sturgeon were caught with trotlines and only one was caught with otter trawls.

For large shovelnose sturgeon, mean fish per person-hour was significantly greater (F = 62.09; $P < 0.001$; Table 2) for trotlines (0.798; SD = 1.296) than otter trawls (0.143; SD = 0.721). Catch rates did not differ among bends sampled for each gear type (F = 0.71; $P = 0.584$); mean catch rates at each bend were similar for trotlines (Choctaw Bend = 1.221; SD = 1.620; Cypress Bend = 0.644; SD = 1.235; Monterey Bend = 0.578; SD = 0.975) and otter trawls (Choctaw Bend = 0.227; SD = 0.909; Cypress Bend = 0.129; SD = 0.696; Monterey Bend = 0.087; SD = 0.572) (Table 3). Trotline catch rates were greater at each bend than for otter trawls (Table 3). Differences in catch rates occurred for each gear type when sampled at different habitats within a specific bend (F = 1.93; $P = 0.016$; Tables 2,4,5). Catch rates with different gears in different bends and habitat types are provided in Table 5.

For small shovelnose sturgeon, mean fish per person-hour was not different (F = 1.34; $P = 0.248$; Table 6) for trotlines (0.434; SD = 0.784) and otter trawls (2.250; SD = 5.058). Catch rates did not differ among bends sampled for each gear type (F = 1.17; $P = 0.323$); mean catch rates at each bend were similar for trotlines (Choctaw Bend = 0.578; SD = 1.055; Cypress Bend = 0.265; SD = 0.421; Monterey Bend = 0.434; SD = 0.716) and otter trawls (Choctaw Bend = 3.523; SD = 5.850; Cypress Bend = 1.164; SD = 4.264; Monterey Bend = 2.006; SD = 4.796) (Table 7). Trotline catch rates were greater at each bend than for otter trawls (Table 7). Differences in catch rates occurred for each gear type when sampled at different habitats within a specific bend (F = 1.51; $P = 0.088$; Tables 7,8,9). Catch rates with different gears in different bends and habitat types are provided in Table 9.

Relationship between environmental variables and catch rates of shovelnose sturgeon and the probability of catching one or more pallid sturgeon

More than 200 possible models were assessed for probability of catching pallid sturgeon and for catch rates of shovelnose sturgeon. The three best-supported models are reported for each regression. Model results are also reported for all single-variable models to show which environmental variables did and did not affect probability of catching one or more pallid sturgeon and catch rates of shovelnose sturgeon.

Greater probabilities of catching one or more large pallid sturgeon with trotlines appeared to occur as depth increased, as stage decreased, when water temperatures were 12-18 °C, and when the surface current velocity was 0.5-1.0 m s^{-1} (Figure 2); but single-variable models explained little of the differences in the probability of catching pallid sturgeon with an overnight trotline sample (Somer's D < 0.184) (Table 10). The best-supported model (Model 1) included water temperature, surface current velocity, depth, and an interaction between depth and surface current velocity. The best-supported model had only moderate fit to the data (Somer's D = 0.515), and confidence intervals were relatively large for each model parameter (Table 11). The model predicted greater probabilities of catching one or more large pallid sturgeon when water temperatures were

9-19 °C (greatest at °15 C), when surface current velocities were 0.7-0.9 m s^{-1}, and as depth increased (Figure 10). Probability of capture in depths > 12 m could not be determined because these depths were not sampled; depths > 12 m are associated generally with the navigation channel.

Large shovelnose sturgeon catch rates (fish per hook-hour) with trotlines appeared to be greater in slower current velocities, in shallower depths, at Choctaw Bend, and in 10-16°C water temperatures (Figure 3); but single-variable models explained little of the variability of catch rates ($R^2 < 0.137$; Table 12). The best-supported model (Model 1) included water temperature, depth, and river bend; but this model accounted for only 18% of the variation, and confidence intervals were relatively large for each parameter (Table 13). The model predicted greater catch rates for trotlines fished when water temperatures were 9-15 °C and as depth decreased within the channel border habitat (Figure 11). The same trend occurred for all bends, but catch rates were predicted to be greater at Choctaw Bend.

Small shovelnose sturgeon catch rates (fish per hook-hour) appeared to be greater when water temperatures were 7-16 °C, in slower current velocities, and at Choctaw Bend (Figure 4), but single-variable models explained little of the variability of catch rates ($R^2 < 0.097$) (Table 14). The best-supported model (Model 1) included water temperature and surface current velocity, but this model accounted for only 18% of the variation, and confidence intervals were relatively large for each parameter (Table 15). The model predicted greater catch rates for trotlines fished in colder water temperatures and in slower surface current velocities (Figure 12).

Small shovelnose sturgeon catch rates (fish per m^2) with otter trawls appeared to be greater when water velocities were 0.8-1.2 m s^{-1}, in warmer water temperatures, in higher river stages, and when Δ_{stage} was falling (Figure 5), but little of the variability of catch rates were explained by single-variable models. The best-supported model included temperature, stage, and Δ_{stage} (Table 16; Model 1), but this model accounted for only 15% of the variation, and confidence intervals were relatively large for each parameter (Table 17). The model predicted greater catch rates for otter trawls fished when river stage had fallen from the previous, during lower river stages, and during warmer water temperatures (Figure 13).

CHAPTER 4

DISCUSSION

Trotlines were more effective than otter trawls for catching pallid sturgeon in the Mississippi River in previous studies. Trotlines had a mean catch rate of 0.03 fish per sample and otter trawls did not catch pallid sturgeon in the MMR (Phelps et al. 2009). Although they did not compare catch rates of sturgeon species, Killgore et al. (2007) had a greater ratio of pallid sturgeon per trotline sample (1 per 6.6 samples) than pallid sturgeon per otter trawl sample (1 per 345 samples) in the LMR and MMR. Neither study compared catch rates or ratios of different size classes of pallid sturgeon. In agreement with previous findings, I determined that trotlines were more effective for catching large pallid sturgeon than otter trawls. Although one small pallid sturgeon was captured with trotlines, neither trotlines or otter trawls were effective for catching small pallid sturgeon.

Although pallid sturgeon were captured in other studies in the LMR, the sampling efforts were not designed to identify optimal times and locations for collecting sturgeon. This was the first study to systematically evaluate if environmental variables affected probability of catching a pallid sturgeon with a trotline. Times and locations of greater probabilities of catching large pallid sturgeon were consequently identified; however, they could not be identified for small pallid sturgeon because only one was captured. Greater probabilities of catching large pallid sturgeon were predicted to occur at 9-19 °C water temperatures. These temperatures occur during autumn, when water temperatures are cooling, and during spring, when water temperatures are warming. Because $\Delta_{temperature}$ was not in the best supported model, the probability of catching a pallid sturgeon would be expected to be similar when water temperatures are 9-19 °C, regardless of the season. To further increase the probability of catching large pallid sturgeon during these temperature ranges, sampling should occur in 0.7-0.9 m s^{-1} surface current velocities and in the deepest water (up to 12 m) in channel border habitat. River stage, bend, and habitat sampled did not appear to substantially affect probability of catching a pallid sturgeon.

Greater probabilities of catching one or more large pallid sturgeon with a trotline in the LMR were in similar current velocities and depths more commonly used by pallid sturgeon in the Missouri and Yellowstone rivers. Bramblett and White (2001) found that pallid sturgeon in these rivers were more common in 0.6-1.2 m s^{-1} current velocities (0.0-2.0 m s^{-1} available) and in the deepest water at their location (0-10 m available). Greater probabilities of catching one or more large pallid sturgeon in the LMR were in 0.7-0.9 m s^{-1}surface current velocities (0.3-2.0 m s^{-1} sampled) and in the deepest water available (up to 12 m; 2-12 m sampled). Little is known about habitat use of pallid sturgeon in the LMR; however, these findings suggest that preferred habitat in the LMR is similar to the preferred habitat in the Yellowstone and Missouri rivers.

More work is needed to determine the relationship between depths > 12 m and the probability of catching one or more large pallid sturgeon with a trotline sample. Deeper water existed at sampling stations during high river stages, but could not be sampled due to excessive current (> 2.2 m s^{-1}) because the current pulled trotline anchors from the bottom and also submerged the floats. There were areas within the channel border habitat, typically eddies, where depths were > 12 m and current velocities were < 2.2 m s^{-1}. However, > 12 m depths in these areas have non-linear current and sturgeon catch results would not be comparable to > 12 m depths with linear current.

Decreases in the probabilities of catching one or more pallid sturgeon with trotline samples as water temperature cooled below 15 °C were expected. Chipps et al. (in press) measured juvenile pallid sturgeon food consumption rates from 13-28 °C and found that consumption rates were similar when water temperatures were 25-28 °C (0.12 g g^{-1} d^{-1}), and steadily decreased as water temperature cooled to 13 °C (0.007 g g^{-1} d^{-1}). Although food consumption rates in water cooler than 13 °C are unknown, the rates would be expected to further decline as water cooled.

Decreases in probabilities of catching one or more pallid sturgeon with trotline samples as water temperatures warmed above 15 °C were unexpected. If water temperature affected food consumption of pallid sturgeon, then greater catch rates would have been expected in the warmest water, but this did not occur. Decreases may have been due to decreased effectiveness of the trotlines to catch pallid sturgeon in warmer water. The proportion of baited hooks retrieved (without fish) decreased as water temperature increased.

It is unclear why fewer baited hooks (without fish) were retrieved in warm water temperatures. Absence of bait on hooks that did not catch sturgeon or other fish is presumed to result from small fish “stripping” the bait. Catch rates of non-sturgeon species were similar during all water temperatures. Effects of individuals of the species stripping baits from the hooks would therefore be expected to be proportional to the number of hooks that did not catch fish during all water temperatures. There may, however, have been other fish species that were too small to hook and stripped the baits more often during warmer water temperatures.

As with other sturgeon studies in the free-flowing Mississippi River, all captured pallid sturgeon were relatively large; the smallest of 30 pallid sturgeon in this study was 589 mm FL, the smallest of 208 fish was 405 mm FL in samples collected by Killgore et al. (2007) in the LMR and MMR, and the smallest of 31 fish was 455 mm FL in samples collected by Phelps et al. (2009) in the MMR. Small pallid sturgeon (< 600 mm FL) would have been expected to have been caught more frequently because otter trawls and trotlines used in these studies were effective for catching small shovelnose sturgeon.

It is possible that small pallid sturgeon were caught more frequently but were misidentified as shovelnose sturgeon or intermediates. When character indices were used to indentify 48 known pallid sturgeon (309-413 mm FL) from the Atchafalaya River to species, 46 were misidentified as intermediates, and the other two were misidentified as shovelnose sturgeon (Jan Dean, USFWS, Natchitoches, LA, unpublished data). In addition, Kuhajda and Mayden (2001) determined character indices could not be used to accurately distinguish pallid sturgeon and intermediate sturgeon less than 600 mm SL.

The ratio of shovelnose sturgeon to pallid sturgeon may have consequently been inaccurate due to misidentification of the fish. Catch ratios have been suggested as a means to determine relative abundances of pallid sturgeon and shovelnose sturgeon (Killgore et al. 2007). For example, a 7:1 ratio of shovelnose sturgeon to pallid sturgeon captured during sampling would mean that there are seven times as many shovelnose sturgeon in the river. Use of catch ratios to determine relative abundances of the species would assume that catches were proportional to the population size of both species. Effects of depth on catches of shovelnose sturgeon and pallid sturgeon strongly suggest that individual samples did not equally represent the relative abundance of both sturgeon species. Samples primarily occurred in 3-9 m depths, and catch rates of shovelnose sturgeon were predicted to be greater in shallow water and the probability of catching one or more pallid sturgeon was predicted to be greater in deeper water. Unless effectively stratified for depth, samples would not be expected to equally represent shovelnose sturgeon and pallid sturgeon relative abundances.

Little was known about how to catch shovelnose sturgeon in the Mississippi River, except that the fish had been caught with trotlines and otter trawls (Killgore et al. 2007; Phelps et al. 2009; Paul Hartfield, unpublished data). I determined that trotlines were more effective than otter trawls for catching large, presumably adult, shovelnose sturgeon. Shovelnose sturgeon mature at ages 5-7 (Helms 1974), and these ages correspond to 520-580 mm FL in the LMR (Morrow et al. 1998). To achieve greater catch rates of large shovelnose sturgeon, trotlines should be fished in shallower water (< 3 m) within the channel border habitat when water temperatures are 9-15 °C.

Both gears had similar catch rates of small shovelnose sturgeon; however, only otter trawls caught presumed age 0-2 shovelnose sturgeon, which are < 350 mm FL in the LMR (Morrow et al. 1998). Similarly, presumed age 0-2 have been captured commonly with otter trawls in the MMR (Herzog and Barko 2005; Phelps et al. 2009) but not with trotlines (Killgore et al. 2007; Phelps et al. 2009). The use of smaller hooks could make trotlines effective at catching shovelnose sturgeon < 350 mm FL. Elliot and Beamesderfer (1990) used different hook sizes to catch white sturgeon *Acipenser* *transmontanus* and found that hook size affected size selectivity; smaller hooks could catch smaller white sturgeon than larger hooks.

Although some of the variability in probability of catching a pallid sturgeon or in catch rates of shovelnose sturgeon may have been explained by the variables used in the regression analyses, much of the variability remained unexplained, and may be inherent with sampling using trotlines in swiftly flowing water. The unexplained variability caused model parameters to have relatively large confidence intervals. Thus, the models appeared to have limited predictive ability and should be used cautiously (or descriptively). The predictive ability of the models could be improved by including additional variables that may affect ability of gears to catch shovelnose sturgeon and pallid sturgeon. For example, I observed that trotlines rarely caught sturgeon when the hooks were thought to be buried in sand, when the hooks were completely covered in detritus, or when the droppers wrapped around the main line. Each of these could have been entered as class variables, but clearly determining these and similar fishing conditions is extremely difficult; e.g., determining if a dropper was entangled in the main line before it was raised or if dropper lines were buried in the sand.

Although this study examined variability in shovelnose sturgeon catch rates and probability of catching pallid sturgeon at a fine scale (e.g., effects of river bend, habitat, depth, etc.), it did not investigate possible effects of location along the length of the LMR. Had sampling occurred throughout the entire free-flowing Mississippi River (mouth to the Chain of Rocks Dam), differences in catch rates would have been expected. Killgore et al. (2007) sampled with trotlines from New Orleans, Louisiana (LMR) to the Chain of Rocks Dam (MMR) for pallid sturgeon and shovelnose sturgeon and found that catch rates varied greatly in different river stretches. Catch rates of pallid sturgeon were greater near the COR and from the Atchafalaya River to New Orleans (0.3 per trotline) than the rest of the river (0.12-.23 per trotline). Catch rates of shovelnose sturgeon increased from 0.2 per trotline in the lower reaches to 22 per trotline near the COR.

Much of the variability of catch rates of shovelnose sturgeon and probability of catching one or more pallid sturgeon remains to be explained; however, this is the first study to systematically sample throughout a year, and probability outputs provide, although imprecise, direction for improving sampling efficiency and catches of pallid sturgeon and shovelnose sturgeon. Results of this study can be used to increase the efficiency of sampling pallid sturgeon or shovelnose sturgeon of desired size classes. This could save time, money, and effort. In addition, future stock assessment and behavioral studies of pallid sturgeon or shovelnose sturgeon could benefit from the capture of more individuals.

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Table 1

Sampling effort with otter trawls and trotlines in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

	Otter trawls		Trotlines	
Month	Area trawled (m^2)	Samples	Hook hours	Samples
2008				
June	1962	2	2584	4
July	29508	13	10100	16
August	52346	24	11660	18
September	32962	17	7820	12
October	44696	25	12162	18
November	45283	21	12404	18
December	0	0	2550	4
2009				
January	34924	18	12735	17
February	0	0	13092	19
March	17187	9	8227	12
April	21191	14	8977	18
May	19621	10	11531	18
Total	299680	153	113842	174

Table 2

Variation of large (> 600 mm FL) shovelnose sturgeon per person-hour by gear type, bend nested within gear type (bend-gear), and habitat type nested within bend for each gear type (habitat-bend-gear) in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Source	DF	Type III SS	Mean square	F	*P*
Gear	1	97108.069	97108.069	62.09	<.001
Bend-gear	4	4456.342	1114.086	0.71	0.584
Habitat-bend-gear	18	54333.467	3018.526	1.93	0.016

Table 3

Comparison of large (> 600 mm FL) shovelnose sturgeon per person-hour for trotlines and otter trawls among river bends (*P* values) in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

	ID					
ID	1	2	3	4	5	6
1		0.2885	0.1115	<0.0001	<0.0001	<0.0001
2	0.2885		0.7828	0.0002	0.0003	<0.0001
3	0.1115	0.7828		<0.0001	0.0001	<0.0001
4	<0.0001	0.0002	<0.0001		0.8030	0.6972
5	<0.0001	0.0003	0.0001	0.8030		0.9354
6	<0.0001	<0.0001	<0.0001	0.6972	0.9354	

ID
1 = trotline, Choctaw Bend
2 = trotline, Cypress Bend
3 = trotline, Monterey Bend
4 = trawl, Choctaw Bend
5 = trawl, Cypress Bend
6 = trawl, Monterey Bend

Table 4

Mean ranks of large (> 600 mm FL) shovelnose sturgeon per person-hour for trotlines and otter trawls by bend and by habitat type in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Habitat	Gear	Bend	Within group mean rank	Score	ID
dike	trotline	Choctaw	146.1	3	1
lcb	trotline	Choctaw	176.5	1	2
mcb	trotline	Choctaw	138.9	5	3
sc	trotline	Choctaw	93.1	11	4
dike	trotline	Cypress	141.9	4	5
lcb	trotline	Cypress	86.3	15	6
mcb	trotline	Cypress	158.1	2	7
sc	trotline	Cypress	118.8	9	8
dike	trotline	Monterey	120.4	8	9
lcb	trotline	Monterey	123.3	7	10
mcb	trotline	Monterey	118.5	10	11
sc	trotline	Monterey	130.4	6	12
dike	trawl	Choctaw	76.1	17	13
lcb	trawl	Choctaw	88.8	12	14
mcb	trawl	Choctaw	87.6	14	15
sc	trawl	Choctaw	76.1	18	16
dike	trawl	Cypress	76.1	19	17
lcb	trawl	Cypress	88.8	13	18
mcb	trawl	Cypress	76.1	20	19
sc	trawl	Cypress	76.1	21	20
dike	trawl	Monterey	76.1	22	21
lcb	trawl	Monterey	85.1	16	22
mcb	trawl	Monterey	76.1	23	23
sc	trawl	Monterey	76.1	24	24

Rankings are scored from highest catch rates to lowest. dike = wing dike, lcb= lower channel border, mcb = middle channel border, sc = secondary channel

Table 5

Comparison of large (> 600 mm FL) shovelnose sturgeon per person-hour for trotlines and otter trawls among river bends and habitat types (*P* values) in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

	ID number							
ID	1	2	3	4	5	6	7	8
1		0.1207	0.7102	0.0233	0.8448	0.0025	0.5484	0.3900
2	0.1207		0.0313	0.0002	0.0781	<.0001	0.3127	0.0612
3	0.7102	0.0313		0.0329	0.8766	0.0026	0.2839	0.5071
4	0.0233	0.0002	0.0329		0.0363	0.7522	0.0036	0.4392
5	0.8448	0.0781	0.8766	0.0363		0.0048	0.4194	0.4657
6	0.0025	<.0001	0.0026	0.7522	0.0048		0.0001	0.2901
7	0.5484	0.3127	0.2839	0.0036	0.4194	0.0001		0.2052
8	0.3900	0.0612	0.5071	0.4392	0.4657	0.2901	0.2052	
9	0.2120	0.0032	0.3149	0.2268	0.2951	0.0700	0.0518	0.9570
10	0.2141	0.0014	0.3256	0.1451	0.3089	0.0250	0.0408	0.8805
11	0.1261	0.0004	0.1889	0.2110	0.1933	0.0443	0.0174	0.9941
12	0.4776	0.0254	0.6710	0.1209	0.6014	0.0318	0.1864	0.7183
13	0.0011	<.0001	0.0012	0.4612	0.0021	0.5996	<.0001	0.1792
14	0.0037	<.0001	0.0041	0.8411	0.0070	0.8877	0.0002	0.3287
15	0.0026	<.0001	0.0227	0.7965	0.0050	0.9382	0.0001	0.3067
16	0.0028	<.0001	0.0036	0.4950	0.0049	0.6366	0.0003	0.1979
17	0.0011	<.0001	0.0012	0.4612	0.0021	0.5996	<.0001	0.1792
18	0.0037	<.0001	0.0041	0.8411	0.0070	0.8877	0.0002	0.3287
19	0.0004	<.0001	0.0003	0.4308	0.0009	0.5629	<.0001	0.1645
20	0.0283	0.0012	0.0397	0.6059	0.0390	0.7383	0.0086	0.2811
21	0.0011	<.0001	0.0012	0.4612	0.0021	0.5996	<.0001	0.1792
22	0.0010	<.0001	0.0009	0.6985	0.0022	0.9444	<.0001	0.2619
23	0.0001	<.0001	<.0001	0.3998	0.0003	0.5210	<.0001	0.1512
24	0.0017	<.0001	0.0020	0.4761	0.0031	0.6163	0.0001	0.1871

Table 4 defines ID numbers

Table 5 (continued)

	ID number							
ID	9	10	11	12	13	14	15	16
1	0.2120	0.2141	0.1261	0.4776	0.0011	0.0037	0.0026	0.0028
2	0.0032	0.0014	0.0004	0.0254	<.0001	<.0001	<.0001	<.0001
3	0.3149	0.3256	0.1889	0.6710	0.0012	0.0041	0.0027	0.0036
4	0.2268	0.1451	0.2110	0.1209	0.4612	0.8411	0.7965	0.4950
5	0.2951	0.3089	0.1933	0.6014	0.0021	0.0070	0.0050	0.0049
6	0.0700	0.0250	0.0443	0.0318	0.5996	0.8877	0.9382	0.6366
7	0.0518	0.0408	0.0174	0.1864	<.0001	0.0002	0.0001	0.0003
8	0.9570	0.8805	0.9941	0.7183	0.1792	0.3287	0.3067	0.1979
9		0.8727	0.9115	0.6409	0.0312	0.0928	0.0755	0.0502
10	0.8727		0.7448	0.7108	0.0106	0.0365	0.0264	0.0229
11	0.9115	0.7448		0.5309	0.0187	0.0633	0.0472	0.0372
12	0.6409	0.7108	0.5309		0.0143	0.0427	0.0342	0.0242
13	0.0312	0.0106	0.0187	0.0143		0.5138	0.5451	1.0000
14	0.0928	0.0365	0.0633	0.0427	0.5138		0.9466	0.5568
15	0.0755	0.0264	0.0472	0.0342	0.5451	0.6704		0.5875
16	0.0502	0.0229	0.0372	0.0242	1.0000	0.5568	0.5875	
17	0.0312	0.0106	0.0187	0.0143	1.0000	0.5138	0.5451	1.0000
18	0.0928	0.0365	0.0633	0.0427	0.5138	1.0000	0.9466	0.5568
19	0.0189	0.0044	0.0083	0.0084	1.0000	0.4719	0.5032	1.0000
20	0.1569	0.1157	0.1533	0.0936	1.0000	0.6777	0.7034	1.0000
21	0.0312	0.0106	0.0187	0.0143	1.0000	0.5138	0.5451	1.0000
22	0.0453	0.0115	0.0220	0.0199	0.6194	0.8242	0.8763	0.6590
23	0.0102	0.0013	0.0027	0.0045	1.0000	0.4248	0.4552	1.0000
24	0.0388	0.0153	0.0258	0.0182	1.0000	0.5332	0.5643	1.0000

Table 4 defines ID numbers

Table 5 (continued)

	ID number							
ID	17	18	19	20	21	22	23	24
17		0.5138	1.0000	1.0000	1.0000	0.6194	1.0000	1.0000
18	0.5138		0.4719	0.6777	0.5138	0.8242	0.4248	0.5332
19	1.0000	0.4719		1.0000	1.0000	0.5787	1.0000	1.0000
20	1.0000	0.6777	1.0000		1.0000	0.7610	1.0000	1.0000
21	1.0000	0.5138	1.0000	1.0000		0.6194	1.0000	1.0000
22	0.6194	0.8242	0.5787	0.7610	0.6194		0.5299	0.6375
23	1.0000	0.4248	1.0000	1.0000	1.0000	0.5299		1.0000
24	1.0000	0.5332	1.0000	1.0000	1.0000	0.6375	1.0000	

Table 4 defines ID numbers

Table 6

Variation of small (100-600 mm FL) shovelnose sturgeon per person-hour by gear type, bend nested within gear type (bend-gear), and habitat type nested within bend for each gear type (habitat-bend-gear) in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Source	DF	Type III SS	Mean square	F	*P*
Gear	1	3277.931	3277.931	1.34	0.248
Bend-gear	4	11453.360	2863.340	1.17	0.323
Habitat-bend-gear	18	66438.154	3691.009	1.51	0.088

Table 7

Comparison of small (100-600 mm FL) shovelnose sturgeon per person-hour for trotlines and otter trawls among river bends (*P* values) in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

	ID					
ID	1	2	3	4	5	6
1		0.8009	0.8216	0.5703	0.1257	0.5626
2	0.8009		0.9463	0.7417	0.1083	0.4455
3	0.8216	0.9463		0.6354	0.0737	0.3951
4	0.5073	0.7417	0.6354		0.0351	0.2041
5	0.1257	0.1083	0.0737	0.0351		0.2790
6	0.5626	0.4455	0.3951	0.2041	0.2790	

ID
1 = trotline, Choctaw Bend
2 = trotline, Cypress Bend
3 = trotline, Monterey Bend
4 = trawl, Choctaw Bend
5 = trawl, Cypress Bend
6 = trawl, Monterey Bend

Table 8

Mean ranks of small (100-600 mm FL) shovelnose sturgeon per person-hour for trotlines and otter trawls by bend and by habitat type in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Habitat	Gear	Bend	Within group mean rank	Score	ID
dike	trotline	Choctaw	114.1	10	1
lcb	trotline	Choctaw	133.8	3	2
mcb	trotline	Choctaw	96.8	15	3
sc	trotline	Choctaw	86.8	18	4
dike	trotline	Cypress	96.6	16	5
lcb	trotline	Cypress	80.1	21	6
mcb	trotline	Cypress	117.4	9	7
sc	trotline	Cypress	151.9	1	8
dike	trotline	Monterey	127.6	4	9
lcb	trotline	Monterey	98.5	14	10
mcb	trotline	Monterey	96.1	17	11
sc	trotline	Monterey	120.3	7	12
dike	trawl	Choctaw	124.1	6	13
lcb	trawl	Choctaw	119.4	8	14
mcb	trawl	Choctaw	151.4	2	15
sc	trawl	Choctaw	70.5	22	16
dike	trawl	Cypress	107.1	11	17
lcb	trawl	Cypress	82.4	19	18
mcb	trawl	Cypress	82.4	20	19
sc	trawl	Cypress	70.5	23	20
dike	trawl	Monterey	124.9	5	21
lcb	trawl	Monterey	106.9	12	22
mcb	trawl	Monterey	100.8	13	23
sc	trawl	Monterey	70.5	24	24

Rankings are scored from highest catch rates to lowest. dike = wing dike, lcb= lower channel border, mcb = middle channel border, sc = secondary channel

Table 9

Comparison of small (100-600 mm FL) shovelnose sturgeon per person-hour for trotlines and otter trawls among river bends and habitat types (*P* values) in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

	ID number							
ID	1	2	3	4	5	6	7	8
1		0.4185	0.4695	0.3467	0.5098	0.1643	0.8941	0.8941
2	0.4185		0.0877	0.0838	0.1284	0.0160	0.4703	0.6347
3	0.4695	0.0877		0.7084	0.9957	0.4406	0.3541	0.1473
4	0.3467	0.0838	0.7084		0.7339	0.8046	0.2681	0.1162
5	0.5098	0.1284	0.9957	0.7339		0.4974	0.4051	0.1636
6	0.1643	0.0160	0.4406	0.8046	0.4974		0.1019	0.0617
7	0.8941	0.4703	0.3541	0.2681	0.4054	0.1019		0.3710
8	0.3392	0.6347	0.1473	0.1162	0.1636	0.3710	0.3710	
9	0.5981	0.7903	0.1812	0.1492	0.2278	0.6720	0.6720	0.5320
10	0.4965	0.0858	0.9309	0.6497	0.9353	0.3717	0.3717	0.1534
11	0.4195	0.0589	0.9669	0.7174	0.9760	0.2991	0.2991	0.1319
12	0.8199	0.5980	0.3483	0.2634	0.3895	0.1162	0.9100	0.4331
13	0.7052	0.6897	0.2542	0.1989	0.3000	0.0723	0.7885	0.4813
14	0.8285	0.5136	0.2966	0.2302	0.3519	0.0771	0.9312	0.3943
15	0.1195	0.4154	0.0102	0.0162	0.0229	0.0011	0.1269	0.9876
16	0.1334	0.0203	0.3251	0.6023	0.3670	0.7230	0.0903	0.0500
17	0.7932	0.2746	0.6645	0.4825	0.6912	0.2678	0.6809	0.2586
18	0.1939	0.0209	0.5046	0.8695	0.5576	0.9189	0.1241	0.0702
19	0.1939	0.0209	0.5046	0.8695	0.5576	0.9189	0.1241	0.0702
20	0.2724	0.0996	0.4896	0.6936	0.5098	0.8021	0.2259	0.1005
21	0.6812	0.7158	0.2397	0.1888	0.2852	0.0670	0.7622	0.4949
22	0.7538	0.1897	0.6115	0.4357	0.6543	0.1916	0.6194	0.2283
23	0.5541	0.0991	0.8347	0.5803	0.8524	0.2993	0.4214	0.1685
24	0.1144	0.0139	0.2957	0.5862	0.3424	0.7069	0.0732	0.0446

Table 8 defines ID numbers

Table 9 (continued)

	ID number							
ID	9	10	11	12	13	14	15	16
1	0.5981	0.4965	0.4195	0.8199	0.7052	0.8285	0.1195	0.1334
2	0.7903	0.0858	0.0589	0.5989	0.6895	0.5136	0.4153	0.0203
3	0.1812	0.9309	0.9669	0.3483	0.2542	0.2966	0.0102	0.3251
4	0.1492	0.6497	0.7174	0.2634	0.1989	0.2302	0.0162	0.6023
5	0.2278	0.9353	0.9760	0.3895	0.3000	0.3519	0.0229	0.3670
6	0.0441	0.3692	0.4263	0.1162	0.0723	0.0771	0.0011	0.7230
7	0.6720	0.3717	0.2991	0.0100	0.7885	0.9312	0.1269	0.0903
8	0.5320	0.1534	0.1319	0.4331	0.4814	0.3943	0.9876	0.0500
9		0.1857	0.1411	0.7866	0.8915	0.7262	0.2999	0.0440
10	0.1857		0.8887	0.3659	0.2646	0.3091	0.0085	0.3777
11	0.1411	0.8887		0.3039	0.2107	0.2416	0.0046	0.3153
12	0.7866	0.3659	0.3039		0.8919	0.9693	0.2164	0.0972
13	0.8915	0.2646	0.2107	0.8919		0.8463	0.2536	0.0654
14	0.7262	0.3091	0.2416	0.9693	0.8463		0.1389	0.0725
15	0.2999	0.0085	0.0046	0.2164	0.2536	0.1389		0.0027
16	0.0440	0.2777	0.3153	0.3153	0.0654	0.0725	0.0027	
17	0.4252	0.7057	0.6181	0.6316	0.5220	0.6164	0.0653	0.2065
18	0.0550	0.4305	0.4946	0.1380	0.0880	0.0950	0.0016	0.6617
19	0.0550	0.4305	0.4946	0.1380	0.0880	0.0950	0.0016	0.6617
20	0.1454	0.4540	0.4924	0.2179	0.1776	0.2031	0.0343	1.0000
21	0.9180	0.2490	0.1971	0.8673	0.9741	0.8189	0.2687	0.0613
22	0.3461	0.6534	0.5462	0.5776	0.4532	0.5430	0.0264	0.1588
23	0.2124	0.8983	0.7817	0.4099	0.2999	0.3528	0.0096	0.2323
24	0.0336	0.2466	0.2826	0.0821	0.0526	0.0569	0.0015	1.0000

Table 8 defines ID numbers

Table 9 (continued)

	ID number							
ID	17	18	19	20	21	22	23	24
17		0.3095	0.3095	0.3558	0.5012	0.9913	0.7775	0.1838
18	0.3095		1.0000	0.7570	0.0818	0.2314	0.3548	0.6426
19	0.3095	1.0000		0.7570	0.0818	0.2314	0.3548	0.6426
20	0.3558	0.7570	0.7570		0.1708	0.3308	0.4140	1.0000
21	0.5012	0.0818	0.0818	0.1708		0.4310	0.2825	0.0490
22	0.9913	0.2314	0.2314	0.3308	0.4310		0.7368	0.1326
23	0.7775	0.3548	0.3548	0.4140	0.2825	0.7368		0.2012
24	0.1838	0.6426	0.6426	1.0000	0.0490	0.1326	0.2012	

Table 8 defines ID numbers

Table 10

Logistic regression models for evaluating environmental variables to predict probability of catching one or more large (> 600 mm FL) pallid sturgeon with an overnight trotline sample in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Model	AIC	Somer's D	Concordance
1. $t + t^2 + v + v^2 + v*d$	113.1	0.515	73.0
2. $t + t^2 + v^2 + v + v*d + d^2$	114.7	0.520	75.7
3. $t + t^2 + v^2 + v + v*d + d$	114.7	0.515	75.5
4. d	120.4	0.184	57.3
5. v	122.0	0.080	50.0
6. Δt	122.2	0.383	56.8
7. *stage*	124.2	0.233	59.9
8. t	125.6	0.172	54.4
9. Δ*stage*	128.9	0.053	30.3
10. *habitat*	129.0	0.179	44.2
11. *bend*	131.4	0.137	40.6

t = water temperature, v = surface current velocity, d = water depth, Δt= increase or decrease in water temperature from previous month, $v*d$ = velocity-depth interaction term, and Δ*stage*=rise or fall in river stage from previous day

Table 11

Logistic regression model parameter estimates of the best-supported model (Model 1,Table 10) for catching a large (> 600 mm FL) pallid sturgeon with an overnight trotline sample in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Variable	Estimate	SE	95% confidence intervals	
			Lower	Upper
Intercept	-6.354	2.256	-10.711	-1.982
T	0.277	0.145	-0.005	0.559
t^2	-0.010	0.005	-0.190	-0.001
V	8.072	5.115	-1.792	17.897
v^2	-6.929	3.273	-13.249	-0.588
$v*d$	0.273	0.131	0.016	0.530

t = water temperature, v = surface current velocity, and $v*d$ = velocity-depth interaction term

Table 12

General linear models for evaluating the relationship between environmental variables and large (> 600 mm FL) shovelnose sturgeon per hook-hour with an overnight trotline sample in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Model	AIC	R^2
1. $t + t^2 + d^2 + bend$	-1918.15	0.183
2. $t + t^2 + d + bend$	-1918.01	0.182
3. $t + t^2 + v*d + bend$	-1916.35	0.174
4. t	-1910.28	0.111
5. *bend*	-1894.85	0.026
6. d	-1893.42	0.017
7. *habitat*	-1890.58	0.001
8. v	-1890.55	<0.001
9. Δt	-1890.53	<0.001
10. *stage*	-1890.53	<0.001
11. $\Delta stage$	-1890.53	<0.001

t=water temperature, v=surface current velocity, d = water depth, Δt = increase or decrease in water temperature from previous month,$\Delta stage$ = fall or rise in river stage from previous day,and $v*d$ = depth and velocity interaction term

Table 13

General linear model parameter estimates of the best-supported model (Model 1, Table 12) for predicting large (> 600 mm FL) shovelnose sturgeon per hook-hour with an overnight trotline sample in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Variable	Estimate	SE	95% Confidence intervals	
			Lower	Upper
Intercept	0.00289112	0.00097140	0.00097746	0.00480478
T	0.00018986	0.00012146	-0.00004941	0.00042914
t^2	-0.00000923	0.00000346	-0.00001605	-0.00000242
d^2	-0.00000923	0.00000588	-0.00002082	0.00000235
Monterey Bend	-0.00040000	0.00190000	-0.00414300	0.00334300
Cypress Bend	-0.00030000	0.00190000	-0.00404300	0.00344300
Choctaw Bend	0.00080000	0.00190000	-0.00294300	0.00454300

t = water temperature and d = depth

Table 14

General linear models for evaluating the relationship between environmental variables and small (100-600 mm FL) shovelnose sturgeon per hook-hour with an overnight trotline sample in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Model	AIC	R^2
1. $t^2 + v^2$	-1990.26	0.124
2. $t^2 + v*d$	-1990.00	0.122
3. $t + t^2 + v*d$	-1989.31	0.129
4. t	-1961.54	0.096
5. v	-1948.58	0.021
6. *Δstage*	-1947.74	0.016
7. *depth*	-1947.21	0.013
8. *bend*	-1946.30	0.007
9. Δt	-1945.42	0.002
10. *stage*	-1945.20	0.001
11. *habitat*	-1945.12	<0.001

t = water temperature, v = surface current velocity, d = water depth, Δt = increase or decrease in temperature from previous month, *Δstage*=fall or rise in river stage from previous day and $v*d$= depth and velocity interaction term

Table 15

General linear model parameter estimates of the best-supported model (Model 1, Table 14) for predicting small (100-600 mm FL) shovelnose sturgeon per hook-hour with an overnight trotline sample in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

			95% confidence intervals	
Variable	Estimate	SE	Lower	Upper
Intercept	0.0028911	0.00033304	0.0018944	0.0032129
t^2	-0.0000026	0.00000059	-0.0000038	-0.0000014
v^2	-0.0004492	0.00027107	-0.0002985	-0.0000861

t = water temperature and v = surface current velocity

Table 16

General linear models for evaluating the relationship between environmental variables and small (100-600 mm FL) shovelnose sturgeon per m^2 trawled with a 0.40 km otter trawl sample in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Model	AIC	R^2
1. *stage* + *Δstage* + *t*	-1839.26	0.151
2. *stage* + *Δstage* + *t* + t^2	-1839.13	0.165
3. *stage* + *Δstage* + *t* + *d*	-1838.80	0.163
4. *stage*	-1829.33	0.047
5. *t*	-1825.27	0.014
6. *Δt*	-1824.59	0.008
7. *v*	-1824.52	0.008
8. *Δstage*	-1824.32	0.007
9. *d*	-1824.27	0.005
10. *bend*	-1823.89	0.003
11. *habitat*	-1823.50	<0.001

t = water temperature, v = surface current velocity, d = water depth, *Δt* = increase or decrease in temperature from previous month, *Δstage*=fall or rise in river stage from previous day and $v*d$ = depth and velocity interaction term

Table 17

General linear model parameter estimates of the best-supported model
(Model 1, Table 16) for predicting small (100-600 mm FL) shovelnose
sturgeon per m^2 trawled with a 0.40 km otter trawl sample
in the Lower Mississippi River (river km 898-933),
June 2008 to May 2009

			95% confidence intervals	
Variable	Estimate	SE	Lower	Upper
Intercept	0.0003441	0.000128	0.0000910	0.000597
Stage	-0.0000580	0.000023	-0.0000921	-0.000024
t	0.0000108	0.000005	0.0000021	0.000022
Δstage, fall	0.0004237	0.000213	0.0000737	0.000774
Δstage, rise	-0.0000311	0.000027	-0.0000127	0.000075

t = water temperature and *Δstage* = fall or rise in river stage from previous day

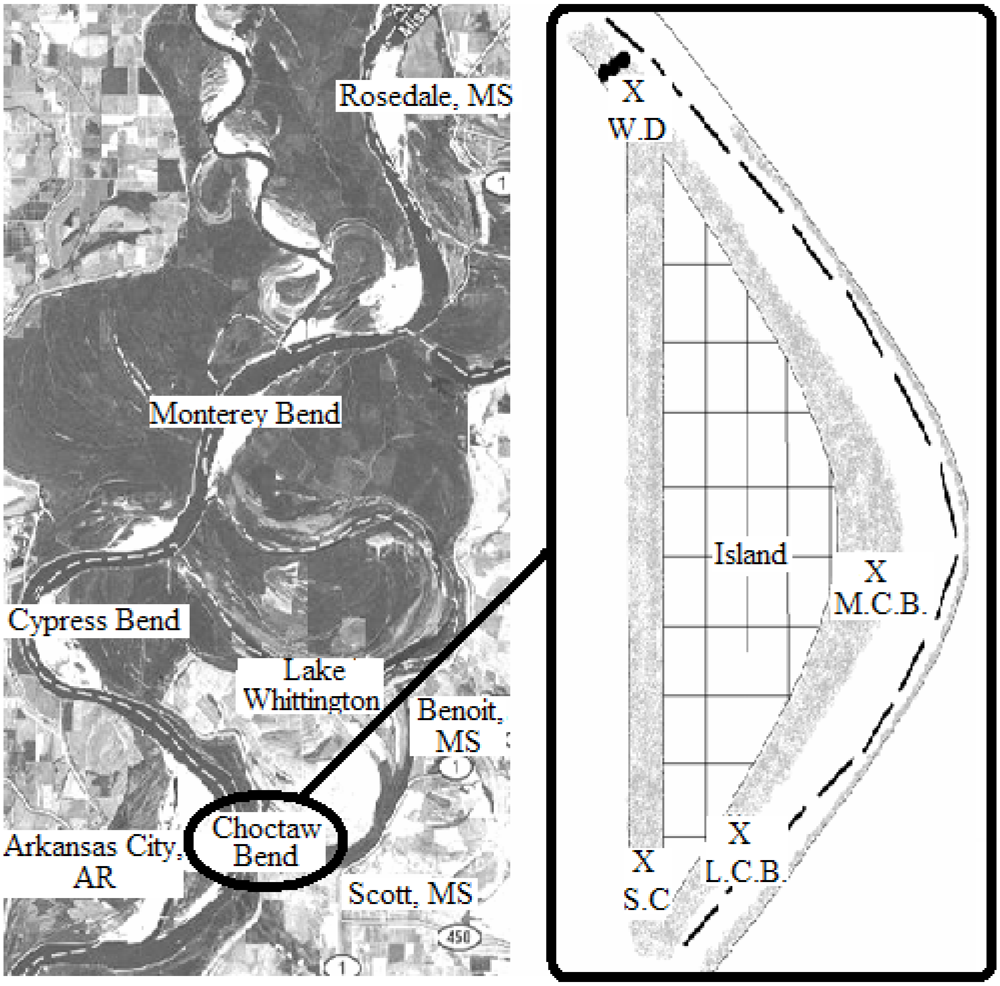

Figure 1

Map of bends sampled (left) and habitats sampled at each bend (right)

Grey shading on the drawing (right) indicates channel border habitat, white indicates main channel habitat, the dashed line indicates the thalweg, and the checked section indicates an island. L.C.B.= lower channel border, M.C.B.= middle channel border, W.D.= wing dike, S.C. = secondary channel.

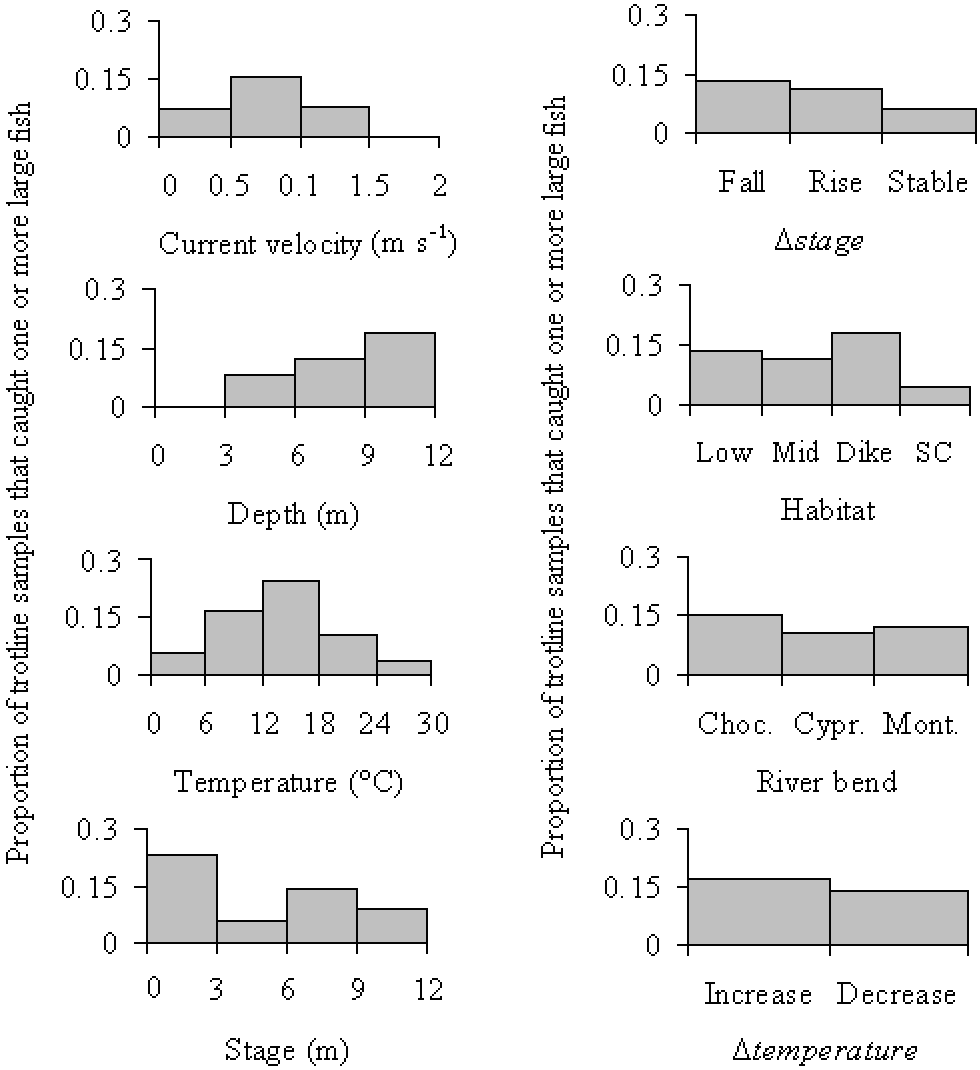

Figure 2

Proportion of trotline samples that caught one or more large (> 600 mm FL) pallid sturgeon for continuous (left figures) and class (right figures) environmental variables in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Proportions were given for continuous variables instead of scatter plots because the fish were infrequently captured and trends were difficult to observe

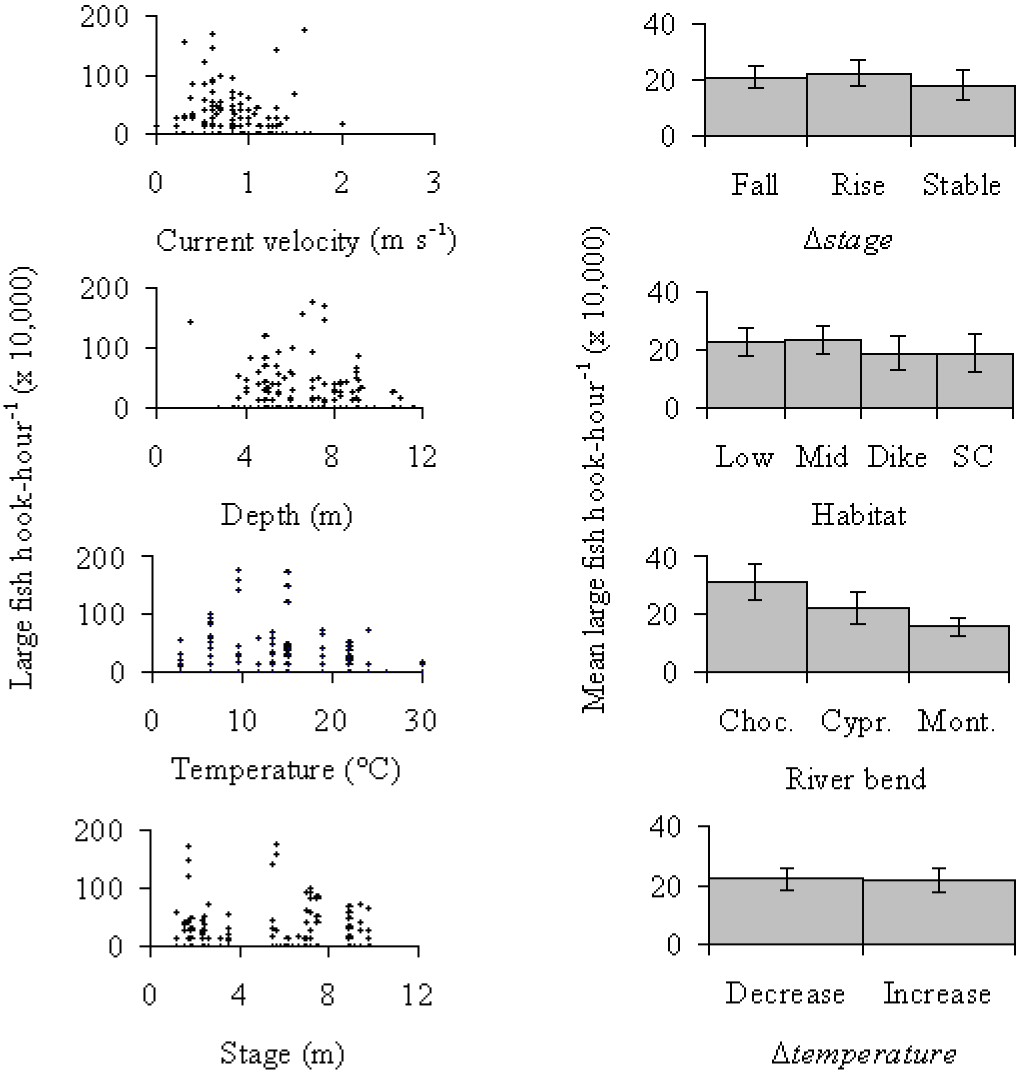

Figure 3

Large (> 600 mm FL) shovelnose sturgeon per hook-hour for continuous variables and mean catch rates for class variables in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Whiskers represent standard error

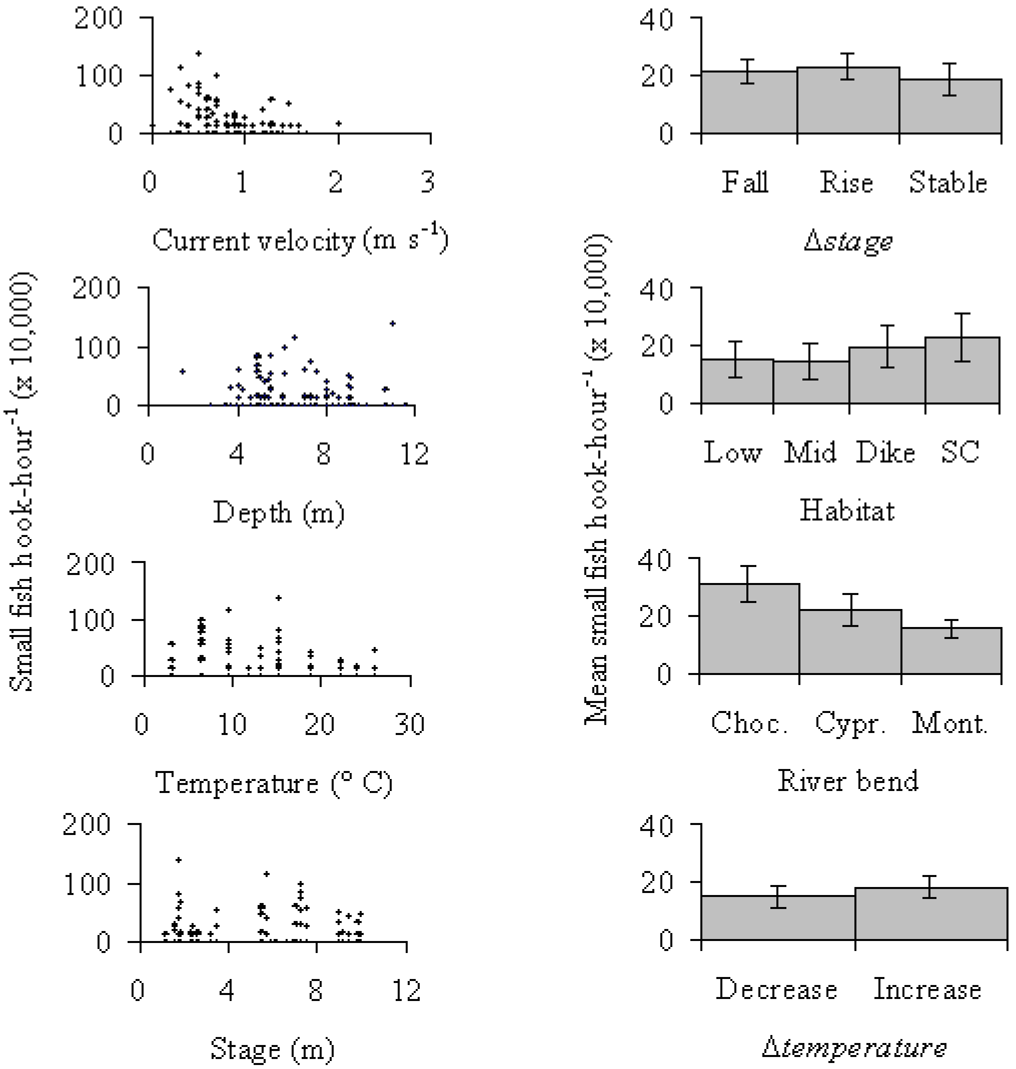

Figure 4

Small (100-600 mm FL) shovelnose sturgeon per hook-hour of trotlines for continuous variables and mean catch rates for class variables in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Whiskers represent standard error

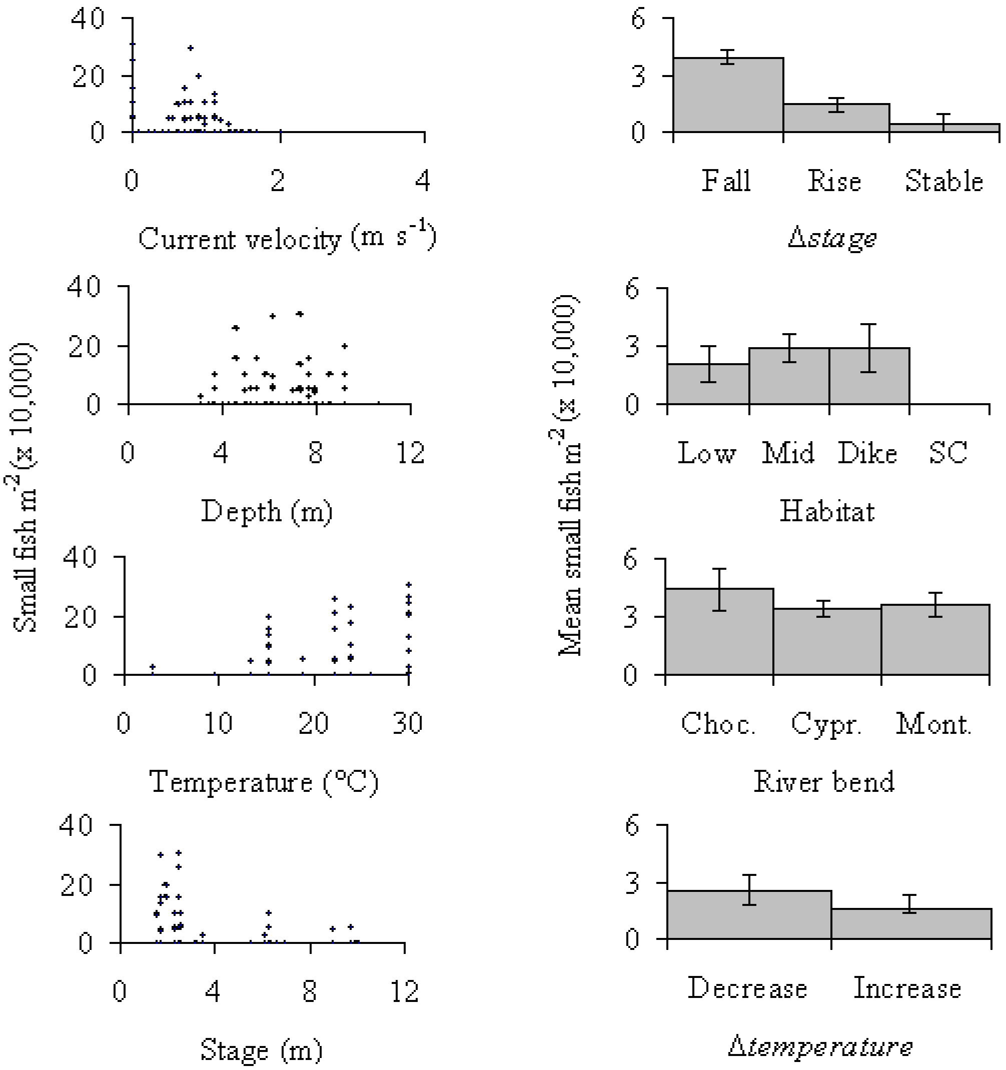

Figure 5

Small (100-600 mm FL) shovelnose sturgeon per m^2 of otter trawls for continuous variables and mean catch rates for class variables in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Whiskers represent standard error

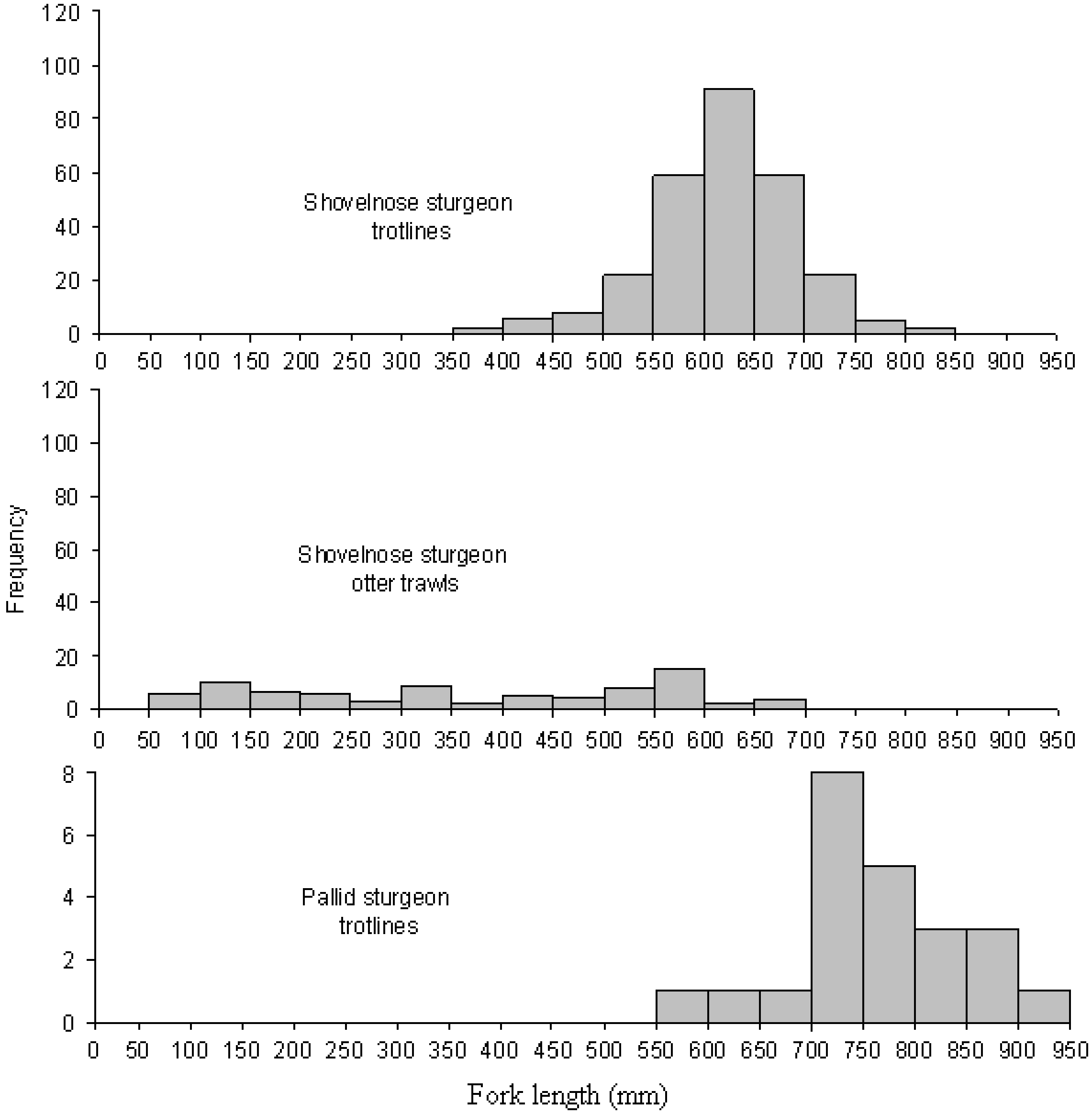

Figure 6

Length distribution of shovelnose sturgeon and pallid sturgeon captured with paired trotline and otter trawl samples in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

Note the difference in y-axis scale for pallid sturgeon

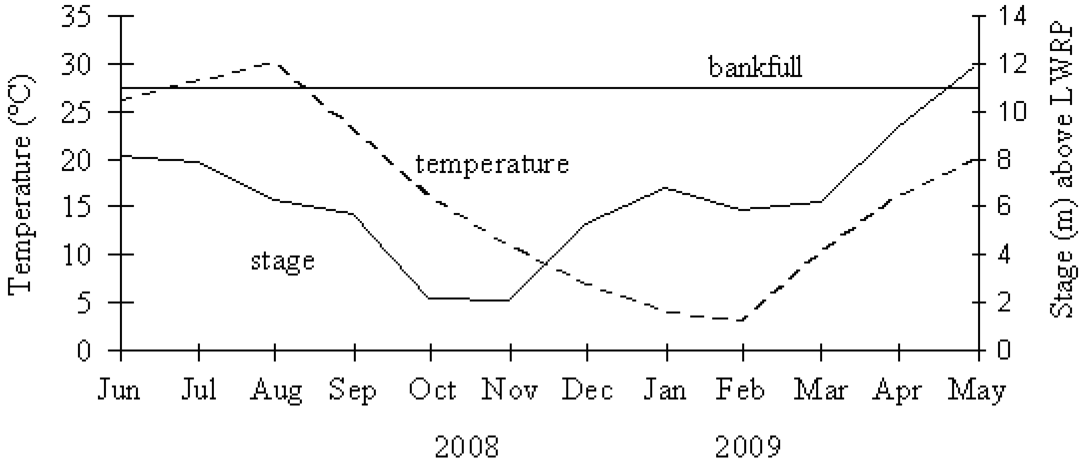

Figure 7

Water temperatures and river stages above the low water reference plane (LWRP) for each sampling month in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

The horizontal line indicates bankfull stage. Data from the US Army Corps of Engineers Arkansas City, Arkansas gage

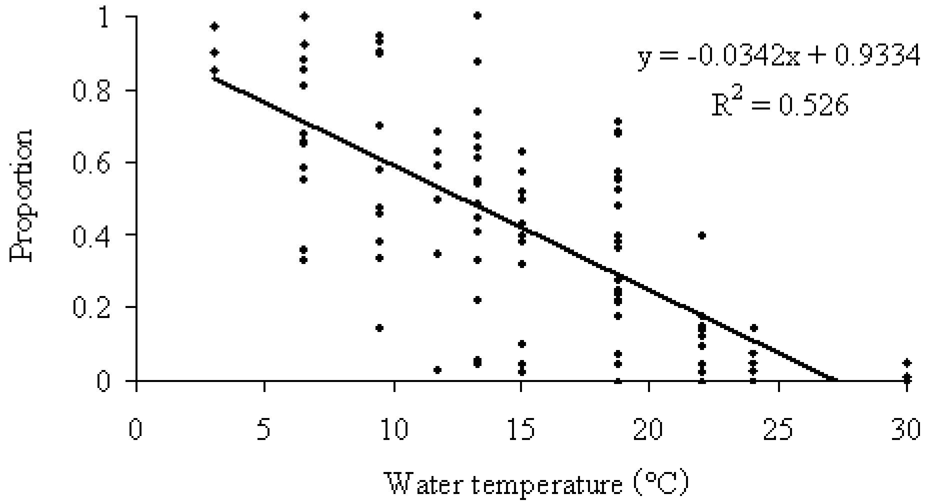

Figure 8

Relationship between the proportion of baited hooks retrieved* and water temperature in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

*Hooks that did not catch fish that also were with bait upon retrieval of the trotline

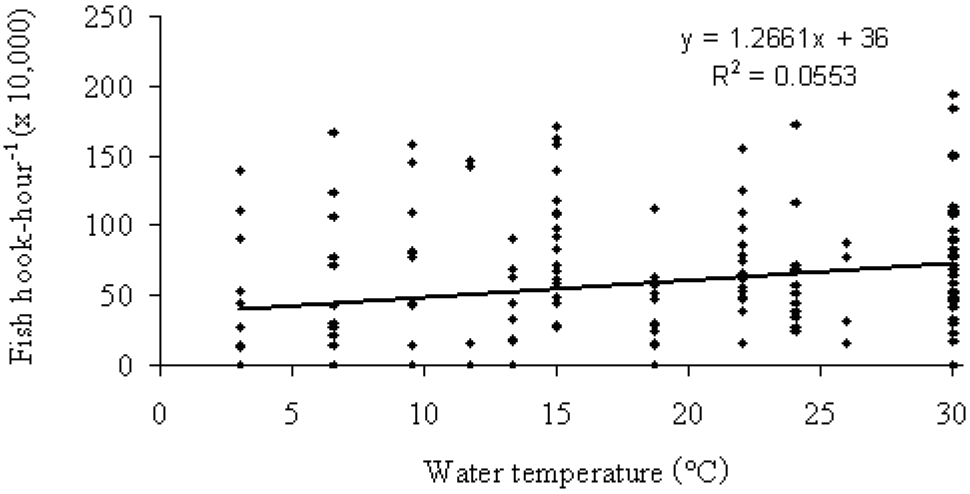

Figure 9

Relationship between non-sturgeon species per hook-hour of trotlines and water temperature in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

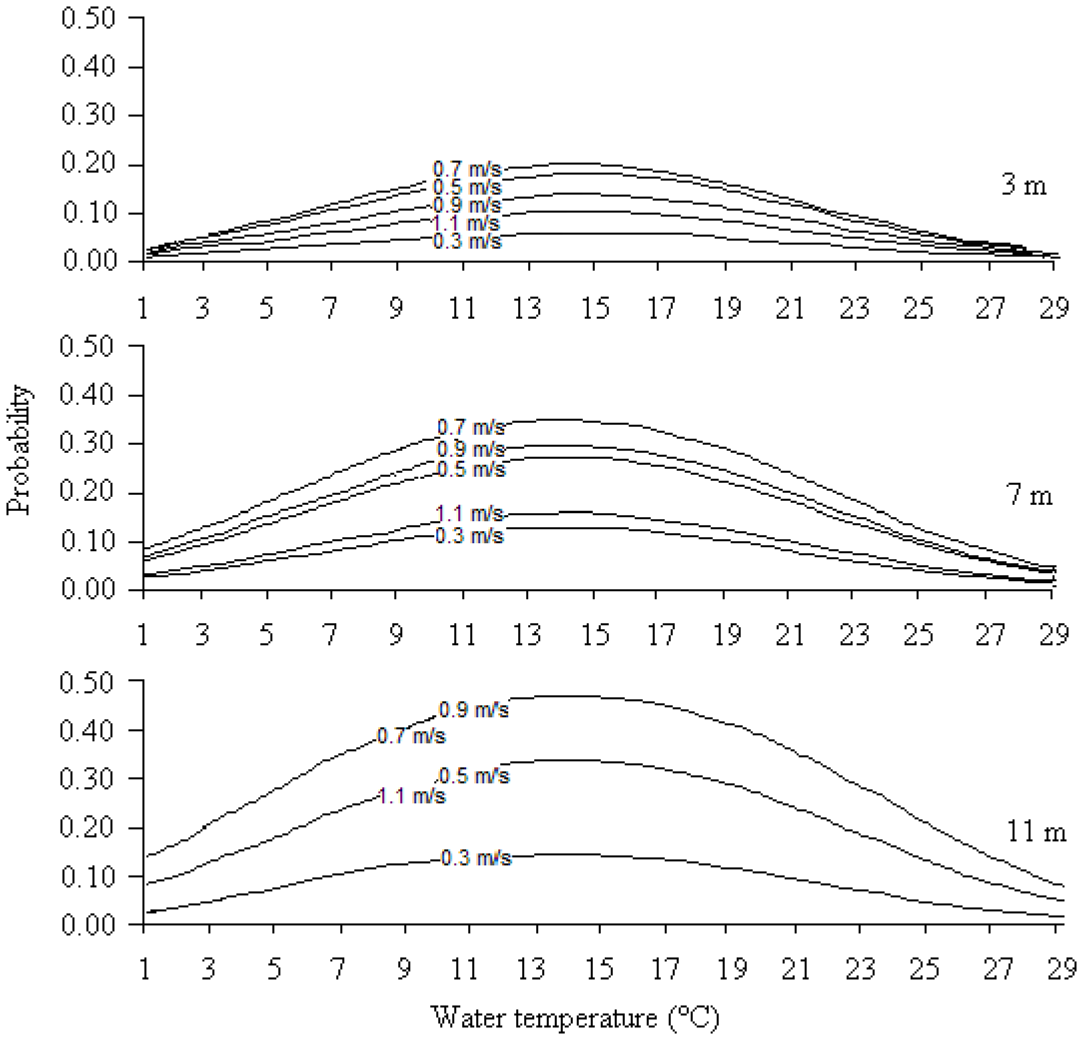

Figure 10

Probability of catching one or more large (> 600 mm FL) pallid sturgeon with an overnight trotline sample at different current velocities, depths, and water temperatures in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

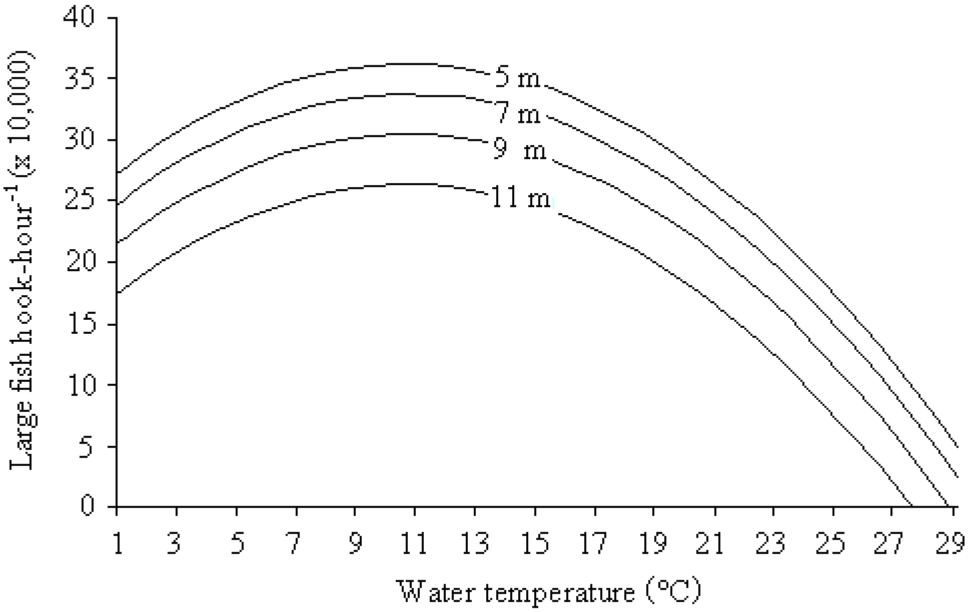

Figure 11

Relationship of large (> 600 mm FL) shovelnose sturgeon per hook-hour of trotlines to water temperature and depth in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

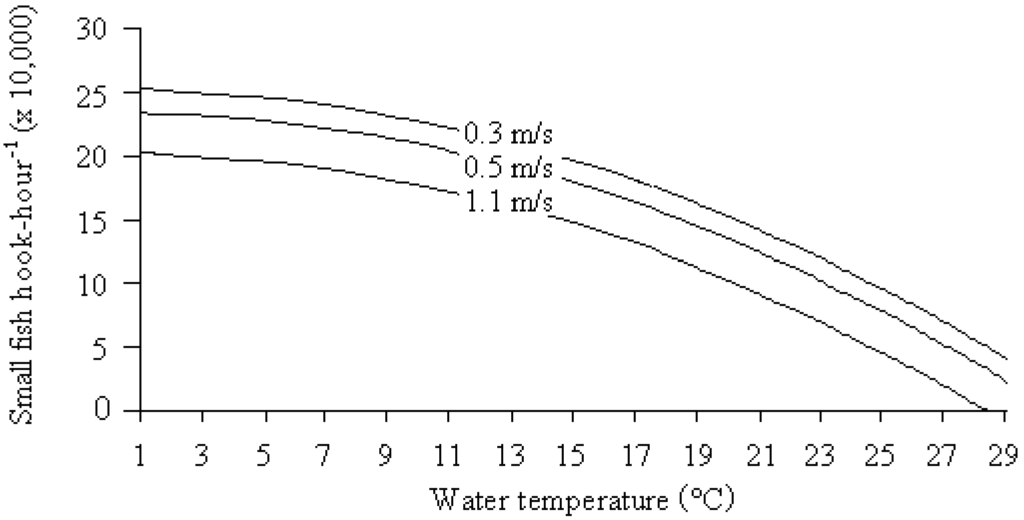

Figure 12

Relationship of small (100-600 mm FL) shovelnose per hook-hour of trotlines to water temperature and surface current velocity with an overnight trotline sample in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

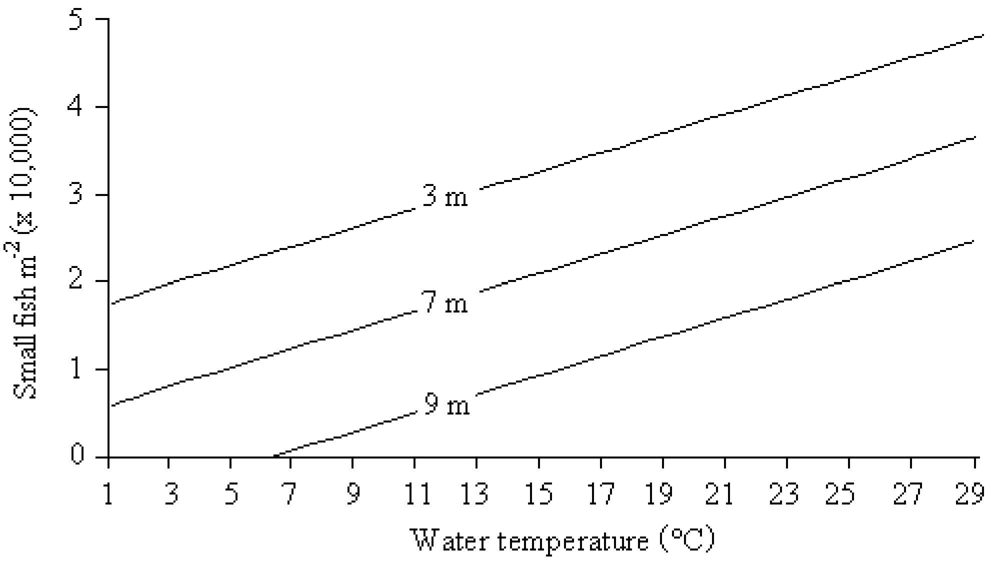

Figure 13

Relationship of small (100-600 mm FL) shovelnose sturgeon per m^2 of otter trawls to water temperature and river stage above the low water reference plane (LWRP) in the Lower Mississippi River (river km 898-933), June 2008 to May 2009

APPENDIX A

IDENTIFICATION OF PALLID STURGEON, SHOVELNOSE STURGEON, AND THEIR INTERMEDIATES

Pallid sturgeon *Scaphirynchus albus,* shovelnose sturgeon *Scaphirynchus platorynchus*, and morphometric intermediates (presumed to be pallid sturgeon x shovelnose hybrids) are present in the lower Mississippi River. The two species can be morphologically relatively distinct, but presence of fish with intermediate characteristics makes species assignment difficult and somewhat unreliable. Characteristics have been proposed that can be used to designate specimens as pallid sturgeon, shovelnose sturgeon, or as an intermediate.

Forbes and Richardson (1905) were the first to document pallid sturgeon. They found that compared to shovelnose sturgeon, pallid sturgeon had a lighter color, grew to a larger size, had a relatively longer head, fewer papillae on the lower lip, and a relatively larger mouth. Additionally, they found that shovelnose sturgeon had a scaled belly, and pallid sturgeon had a naked or scaleless belly. They also found that the outer barbels were 1.7-2.9 times as long as the inner barbels for pallid sturgeon compared to 1.1-1.4 times as long for shovelnose sturgeon.

Bailey and Cross (1954) also examined pallid and shovelnose sturgeon to determine distinguishing morphological features. They found that the quickest and most reliable way to identify sturgeon species was to examine the barbels. Unlike shovelnose sturgeon, the outer barbels extended past the mouth in pallid sturgeon. Pallid sturgeon generally had less developed barbel fringes compared to shovelnose sturgeon. They also noted similar inner barbel:outer barbel ratios to those reported by Forbes and Richardson. Pflieger (1975) found the barbel insertion points are in a straight line in shovelnose sturgeon compared to pallid sturgeon that have forward insertion of the inner barbels.

Bailey and Cross found that pallid sturgeon were typically lighter in color than shovelnose, but coloration should not be a distinguishing characteristic.

Carlson et al. (1985) were the first to document morphologically intermediate forms of *Scaphirynchus* that they described as hybrids. They examined 12 of these sturgeon and found overlap of characteristics used to identify pallid sturgeon and shovelnose sturgeon (coloration, barbel size, and barbel location).

In conclusion, I used defining morphological characteristics developed in previous studies to identify sturgeon. I designated a specimen as a pallid sturgeon if it had a scaleless belly, outer barbels with limited fringing that extended past the mouth, outer barbels at least 1.6 times as long as the inner barbels, and if the insertion points of the inner barbels were above the insertion points of the outer barbels. I designated specimens as shovelnose sturgeon if they had a heavily scaled belly, heavy fringing of barbels, outer barbels that were less than 1.5 times the length of the inner barbels, and had level insertion points of all barbels. In agreement with Bailey and Cross, I found that skin color is not a distinguishing characteristic. There was variation in morphological features in sturgeon we identified; however, I only designated a sturgeon an intermediate-hybrid if it had considerable overlap of characteristics used to identify sturgeon. For example, I designated a specimen as an intermediate if it had characteristics of a pallid (e.g., outer barbels past mouth, outer barbels twice as long as inter barbels, insertion points of inter barbels above outer barbels and a wide mouth) and characteristics of a shovelnose (e.g., heavy fringing of barbels and a scaled belly). I took tissue samples from all specimens designated as pallid or intermediate sturgeon for subsequent genetic analysis.