

2009

**Current Status of the Pallid
Sturgeon in the Middle
Mississippi River**

Current Status of the Pallid Sturgeon (*Scaphirhynchus albus*)
in the Middle Mississippi River: Habitat, Movement, and Demographics

Principle Investigators:

James E. Garvey, Edward J. Heist, and Ronald C. Brooks

Fisheries & Illinois Aquaculture Center &

Department of Zoology

Southern Illinois University, Carbondale 62901-6511

David P. Herzog and Robert A. Hrabik

Open River and Wetlands Field Station

Missouri Department of Conservation

Jackson, Missouri 63755

K. Jack Killgore, Jan Hoover, and Catherine Murphy

Engineer Research and Development Center

US Army Corps of Engineers

Vicksburg, MS 39180

A Final Report Submitted to

St. Louis District, US Army Corps of Engineers

10 May 2009

Pallid Sturgeon Status 3

Suggested citation: Garvey, J.E., E.J. Heist, R.C. Brooks, D.P. Herzog, R. A. Hrabik, K.J. Killgore, J. Hoover, and C. Murphy. 2009. Current status of the pallid sturgeon in the Middle Mississippi River: habitat, movement, and demographics. Saint Louis District, US Army Corps of Engineers. <http://fishdata.siu.edu/pallid>



Synthesis

- This report summarizes the status of the pallid sturgeon (*Scaphirhynchus albus*) in the Middle Mississippi River (MMR; River Miles, RM 0-200) during fall 2002 through spring 2005. The most likely threat to population recovery is reduced reproductive capacity (i) through limited rearing and nursery habitat and (ii) through loss of reproductively mature (primarily ovigerous female) adults. Most of the research conducted during this time has been published in the peer-reviewed scientific literature. All chapters have been reviewed by peer scientists, with corresponding responses included herein (Chapter 12).
- Pallid sturgeon as identified with morphometric indexes were rare relative to their congener, shovelnose or hackleback sturgeon (*S. platyrhynchus*), with ratios of pallid sturgeon in the samples declining with increasing latitude from the lower Mississippi River below Baton Rouge, LA (1:6) to the MMR (1:82) (Killgore et al. 2007a, Chapter 2). This does not reflect total abundance, just the relative numbers of both species in samples.
- 139 pallid sturgeon were sampled with a combination of gears including trot lines, gill nets and trawls (about 0.002 fish/hour); fork length averaged across seasons and gear types was 763 mm. Conventional randomized sampling stratified across habitats would require substantive effort to have sufficient statistical power to detect differences among gears and seasons (Phelps et al. in revision, Chapter 1). Pallid sturgeon are indeed very rare relative to shovelnose sturgeon in the MMR.
- A combined sampling and telemetry effort ($N= 87$ fish tracked) demonstrated that pallid and shovelnose sturgeon use different habitats when non-reproductive, with

pallid adults selecting wing dike areas with sandy substrate (Chi square analysis, $p < 0.0001$); acoustic Doppler profile surveys demonstrated that the ecotone between contrasting flow velocities (average bottom velocity = 0.9 m/s), likely facilitated by bendways created by complexes of island point bars and side channels (and mimicked by wing dikes), appears to be an important component of non-reproductive habitat selection by adults (Koch et al. submitted, Chapter 3). Use of the main channel increased significantly with declining discharge and water level during summer.

- Following a spring rise in water level and temperature, pallid sturgeon moved great distances to apparent upstream (16.9 km/d) or downstream (73.4 km/d) spawning locations; the Chain of Rocks (COR) of the MMR below Low Water Dam 27 (RM 189) was a frequent destination (Chapter 3).
- During May when spawning likely occurs, sonically tagged pallid sturgeon were located < 500 m from known gravel bars in the MMR ($p < 0.05$; Koch et al. submitted; Chapter 3).
- Recaptures of externally tagged pallid sturgeon and telemetry of internally ultrasonically tagged individuals demonstrated movement out of the MMR into the Missouri River and into the lower Mississippi River below the confluence of the Ohio River (Chapter 3).
- Hatchery-produced fish have recruited to the pallid sturgeon population, with at least 6% of adults sampled after 2004 being recognizable hatchery fish. More individuals were likely of hatchery origin because checking for tags was inconsistent among years. The length-weight relationship of hatchery pallids was similar to wild individuals (ANCOVA, $p > 0.05$). However, insufficient numbers of known hatchery

fish were tracked with telemetry to determine whether wild and hatchery individuals behave similarly (e.g., spring movement, habitat use).

- Using a morphomeristic character index (Wills et al. 2001), putative hybrids between shovelnose and pallid sturgeon appeared to be rare among adults (< 1% of total sturgeon catch; $N \approx 100$; Murphy et al. 2007a, Chapter 4); however, we typically only used a character index to confirm suspected pallids. Hybrid characters in putative shovelnose were most likely underestimated.
- Annual mortality rate of pallid sturgeon based on catch-curve analysis was high (31-37%, depending on gear type, $p < 0.05$) for a sturgeon species and similar to independently derived estimates for commercially fished shovelnose sturgeon (Colombo et al. 2007a, Killgore et al. 2007b; Chapters 7-8).
- In this Executive Summary, we combine data from the various published chapters with unpublished data to demonstrate that adult (probably > 6 years) pallid population density based on mark-recapture techniques and estimates of mortality in the MMR likely was less than 4,900 and perhaps as low as 1,600 individuals.
- Yield-per-recruit harvest modeling for shovelnose sturgeon in the MMR suggested that overfishing, likely combined with limited habitat, was reducing both biomass and offspring production (Colombo et al. 2007a, Chapter 7). Given that pallid sturgeon have a similar mortality rate and mature later, then more severe demographic responses to harvest likely occur for this species (Tripp et al. 2009, Chapter 11).
- Genetic markers (nuclear DNA microsatellites) distinguished among pallid, shovelnose, and putative hybrid sturgeon ($p < 0.05$; Schrey et al. 2007a, Chapter 5).

Genetic and morphological identification was largely concordant; “hybrids” were genetically more similar to shovelnose, indicating they were backcrosses.

- Pallid sturgeon exhibited significant differences in DNA microsatellite allele frequencies among reaches across their range indicating historical restrictions to gene flow (Schrey et al. 2007b, Chapter 6). Thus, stocking programs should employ local broodstock where available to prevent outbreeding depression (i.e., introducing potentially “non-adaptive” genetic traits into locally specialized populations).
- Production of annual cohorts in shovelnose sturgeon declined with increasing harvest in the MMR. Although not yet derived, a relationship between adult stock and the production of offspring likely exists. Assuming a similar response to harvest of pallid sturgeon, then incidental or intentional harvest will greatly curtail pallid reproductive success (Tripp et al. 2009, Chapter 11).
- Morphological anomalies are relative common (9%) in adult pallid sturgeon, typically caused by anthropogenic sources (Murphy et al. 2007b, Chapter 9).
- Diets revealed that piscivory is prevalent in pallid sturgeon and thus fish are likely an important energy source (Hoover et al. 2007, Chapter 10).
- Habitat for adult pallid sturgeon foraging and residence (i.e., holding station in flow) in the MMR appears to be adequate and related primarily to wing dike areas, although all habitats with the exception of the inside of tributary mouths have been occupied. We hypothesize that some wing dikes (some were used preferentially over others) mimic natural depositional areas adjacent to the main channel (e.g., upstream island tips within the main channel). If adult pallid sturgeon densities increase, wing dikes creating preferred habitat will likely become limited and habitat restoration that

creates needed main-channel conditions (i.e., island areas that provide an ecotone between flow with deposition, causing an accumulation of insects and small insectivorous fish) likely will facilitate foraging, growth, and ultimately reproductive condition.

- The availability and quality of reproductive habitat for spawning and production of offspring in the MMR is currently the greatest gap in our knowledge (Figure 2) and likely the key for developing a fruitful conservation plan for recovery (see DeLonay et al. 2007, Wildhaber et al. 2007 for similar issues in the Missouri River basin). The future of the pallid population in the MMR depends on high survival of adults through maturity combined with high survival of eggs, embryos, and larvae at several likely spawning and nursery areas within the MMR, which include the COR (but consider the caveat that the lowhead dam at this area may be a barrier during low flow), near tributary confluences in the main channel, and perhaps side channels.
- Pallid sturgeon capture data are available on the web in a GIS format (<http://fishdata.siu.edu/move.htm>).

Justification and Approach.

Distributed throughout the Mississippi and Missouri River basins, pallid sturgeon have always been considered a rarity (Bailey and Cross 1954). Nearly two decades ago, concerns about declining abundance and failing reproduction throughout the range prompted the federal government to list this species under the Endangered Species Act (Federal Register 1990). One reason cited for the decline has been habitat alteration by the US Army Corps Engineers (ACE), which occurs to enhance navigation and control

flooding (US Fish and Wildlife Service 2000, USFWS). To mitigate environmental effects of navigation maintenance activities in the MMR, the St. Louis District of the ACE sought to assess the status of the regional pallid sturgeon population and determine its habitat needs. This study was a response to the issuance of the USFWS's Final Biological Opinion for Operation and Maintenance of the 9-Foot Navigation Channel on the Upper Mississippi River in 2000 (US Fish and Wildlife Service 2000). The primary goal was to identify habitat needs of pallid sturgeon in the context of their life history. This research also sought to assess the status of the species relative to expectations from other reaches and historical accounts.

The 200-mile long MMR is a geologically unique, transitional zone between the lower Mississippi River and the Missouri River (Figure 1). It is relatively narrow compared to reaches below the Ohio River confluence; channel depth for navigation is maintained by channel training structures such as wing dikes plus revetments and by an active program of dredging. Confinement and simplification of the main channel likely reduce habitat features such as instream islands and side channels, although there is some suggestion that pre-settlement physical characteristics (e.g., channel width) of the MMR are somewhat similar to present conditions (US Army Corps of Engineers 2005). Water quality in the last century was very poor in the MMR, largely due to the marked influence of the developing urban, St. Louis area (Kittrell 1958). More than likely many aspects of water quality in the MMR have improved in recent decades (but see Koch et al. 2006 for some contemporary concerns).

During fall 2002 through spring 2005, we sought to quantify potential habitat characteristics necessary for facilitating growth and survival of pallid sturgeon (primarily

adults) in the MMR. We also determined whether habitat needs changed seasonally by documenting movement patterns. In particular, nothing was known about dispersal of adults, particularly relative to reproduction. Other sturgeon populations contain individuals that migrate long distances to specific spawning areas (Bramblett and White 2001) and we presumed the same for pallid sturgeon in the MMR. We used sampling and telemetry to overlay the spatial distribution of individuals on a precise habitat template of the MMR and then quantify selection for habitat features. We also used telemetry to quantify movement of adults in a preliminary attempt to determine seasonal movement and identify spawning areas. When possible, fish were uniquely tagged at capture to estimate population density.

At the inception of this project, no baseline demographic information existed for pallid sturgeon in the MMR. A baseline was needed to establish current conditions and evaluate population responses to management. We determined basic demographic features of the population including size and age structure, mortality, and abundance. Hybridization between the pallid sturgeon and its more abundant congener is suspected (Wills et al. 2001; Schrey et al. 2007a; this report). If this is true, degradation of the population may occur through introgression – alleles unique to the shovelnose population will enter the pallid population as hybrid individuals backcross with the parental stock. Thus, to determine whether pallids are genetically distinct and whether hybridization does occur, we used DNA microsatellite markers and screened individuals across a range of morphomerisitic characteristics.

Since the study began, the Caspian Sea and Volga River sturgeon fisheries were recognized as collapsed (Pala 2005). Importation of caviar into the US was restricted,

increasing demand for domestically produced caviar. We quantified commercial harvest of shovelnose sturgeon relative to their abundance in the MMR. Given that pallid sturgeon are difficult to distinguish physically without using complex indexes and reach large sizes, harvest of this species likely occurs unintentionally (Bettoli et al. 2009); illegal harvest also continues to occur, despite the best efforts of conservation law enforcement. Therefore, we considered pallid sturgeon population dynamics in the context of potential harvest. Because harvest is preferential for sexually mature, “black-egg” females, sturgeon populations should be particularly sensitive.

Although we have approached this research from the perspective of identifying habitat needs for adults and generating baseline information about the species, we ultimately need to organize our research in the context of the entire life history (Figure 2; Wildhaber et al. 2007). Schedules of maturation in pallid sturgeon are not well known, but it is likely that males probably do not mature until age 5-7 (or older) and females at age 10 or greater (Figure 2; Tripp et al. 2009). Females may spawn as infrequently as every 3-10 years. In many fishes, reproductive potential is unlimited in the adult populations because of high inherent fecundity and frequent spawning (Garvey et al. 2009). However, given infrequent spawning and small population size, it is likely that variation in spawning success translates to variation in cohort production in pallid sturgeon (Figure 2). Responses of shovelnose sturgeon to harvest and contribution to cohort strength should shed light on potential responses of pallid sturgeon to declining adult abundance in its population. If habitat is limited for adult spawning or the survival of eggs and larvae, then the population will be in jeopardy (Figure 2).

Goals.

Given the justification outlined above, we pursued the following goals for pallid sturgeon in the MMR (Figure 2):

- Quantify gear effectiveness for assessing available adult non-reproductive habitat (Chapters 1, 2, 3)
- Determine preference for adult habitat (Chapter 3)
- Assess seasonal movement of adults in the context of reproduction (Chapter 3)
- Estimate population growth, size and age structure, mortality rate, and energy sources (Chapters 2,4,7,8,9,10)
- Develop genetic tools for identifying hybridization and separation between species (Chapters 5,6)
- Assess the impact of other human-induced factors such as harvest and pollution (Chapter 7,9,11)
- Generate strategies for mitigating human effects (e.g., identify habitat characteristics to be emulated in the MMR; reduce harvest of sensitive individuals) and develop techniques to quantify benefits to the species.

Contributions.

During the course of this study, we lost two important participants in this research effort, Dr. Robert Sheehan and Mr. Dan Erickson. They played integral roles in the development and implementation of this research. Their good sense, insight, and friendship will be sorely missed. Many of the chapters describing results herein are manuscripts that are submitted, in press, or published in the peer-reviewed literature.

Resulting data have been presented at several regional and national meetings; two oral presentations won Best Paper awards. This research also has contributed to the training of four masters students (Jackson, Colombo, Koch, and Tripp), two PhD students (Schrey, Phelps), and one post-doctoral associate (Spier) at SIUC. A cast of thousands was involved in this research and many are listed as authors on the chapters contained in this report. Several members of the commercial fishing community were contracted to help sample pallid sturgeon. Funding was provided by the St. Louis District; Dr. Tom Keevin provided technical guidance. Funding also was provided by the Mississippi Valley Division for pallid sturgeon studies in the lower Mississippi River. Much of the genetics analysis was funded by the US Fish and Wildlife Service. Reviews were provided by the US Fish and Wildlife Service, Missouri Department of Conservation, Illinois Department of Natural Resources, and several anonymous scientists. We appreciate their comments, incorporating necessary changes in this section as well as the published and unpublished chapters. We address all specific comments in Chapter 12.

Major Results.

General.

During each season (fall, spring, summer, winter) of fall 2002 through late spring 2005, we sampled a total of 143 pallid sturgeon, of which four fish were recaptured (Table 1). Of those four recaptured fish, one fish at Chain of Rocks (COR; RM 189-190) was recaptured twice below the lowhead dam. During the course of the study, sampling effort was distributed across gillnets, trawling, and trotlining, with over 64,000 hours of fishing expended (0.002 pallids/hour; Table 1; see Chapter 1). In addition to capturing

pallid sturgeon, 11,459 shovelnose sturgeon were sampled resulting in a ratio of pallid to shovelnose of 1:82 (0.2 shovelnose/hour; Table 1). Mean fork length \pm 1 standard deviation (mm FL) of all pallids sampled across all gear types was 763 ± 101 (Figure 3). The relationship between FL and wet weight (kg) was $\text{Weight} = 7.285\text{E-}10 * \text{Length}^{3.26}$ ($R^2=0.89$). From combined sampling by Missouri Department of Conservation and SIUC, we successfully aged 75 MMR pallids using pectoral fin ray sections, of which the same age was agreed upon by two independent readers. No asymptote to length was found; growth was linear from age 6 through age 15 (no older fish occurred; fork length in mm = $37.2 \times \text{age in years} + 421$; $R^2=0.65$; Figure 4). For pallid sturgeon collected using random stratified sampling across all gear types, we had insufficient statistical power to detect differences in abundance among seasons or habitats (Chapter 1, Phelps et al. in revision).

In a related effort, trotlining by ERDC personnel was conducted along the Mississippi River from the MMR RM 190 to lower Mississippi RM 100 (Chapter 2, Killgore et al. 2007a; Figure 5). In this analysis, the ratio of pallid to shovelnose declined from 1:6 at lower Mississippi RM 100-310 to the COR in the MMR (MMR RM 189) where the ratio was 1:77 (Table 2). Catch rates of both pallid and shovelnose were quite high at COR relative to other reaches (Table 2). The high vulnerability of shovelnose sturgeon to trotlines and concentration of sturgeons at COR relative to other reaches probably contributed to this distinctly lower ratio between the congeners at the northernmost sampling reach. Length of trotlined pallid sturgeon increased from 620 mm mean FL to 756 mm FL along this broad latitudinal gradient (Table 3; Chapter 2). This pattern is predicted by Bergmann's Rule for many taxa (see Garvey and Marschall 2005).

Habitat.

It was hypothesized that habitat for pallid sturgeon in the MMR was related to the physical structure of the main channel. Sampling with multiple gear types revealed that pallid sturgeon were vulnerable to trotlining and 3-inch mesh gill nets, typically set adjacent to the open main channel, often near wing dikes and at times near island areas (see Chapter 1). Small sample sizes restricted our ability to assess these patterns statistically. Although impossible to standardize, drifting trammel nets also effectively sampled pallid sturgeon adults. Randomly setting gear across habitat types very rarely sampled pallid sturgeon. Only when gears were set in areas known to contain pallid sturgeon (i.e., “directed sampling”) were individuals captured. Statistical analysis did show that shovelnose sturgeon were more vulnerable to capture behind wing dike areas and, being typically smaller bodied and perhaps residing in different habitats, they were more frequently selected by 2-inch mesh gill nets and trawling (Chapter 1). However, shovelnose sturgeon probably are not a good surrogate for inferring seasonal habitat use of pallid sturgeon due to apparent differences in gear vulnerability (and low power of stratified sampling for pallid sturgeon, Chapter 1).

Because our research demonstrated that pallid sturgeon are too rare to effectively sample across habitats with a stratified random program of trawling, gillnets, and other gears (Chapter 1), we surgically implanted ultrasonic tags in 87 adult pallid sturgeon, and tracked 5,362 miles with boat-mounted hydrophones (Chapter 3). By 2005, a network of

stationary, automatically logging hydrophones also was in place in the MMR (Table 4). The Cobb classification scheme (US Army Corps of Engineers 1999) was modified to include more resolution relative to wing dike habitats in the river. Confirming the results of the sampling survey, statistical analysis of preference demonstrated that the tagged pallid sturgeon occupied wing dike areas in far greater proportion than expected. Surveys of bottom flow velocities with Acoustic Doppler Current Profiling (ADCP) and substrate with qualitative benthic grabs demonstrated that pallid sturgeon used areas of contrasting flow (average of 0.9 m/s) with sandy bottoms. Island tips and inside tributary mouths were never used by tagged adult fish and unconsolidated, muddy bottoms were avoided.

Moving in a river is typically energetically expensive and is usually related to some important life history event such as reproduction. During each year, we found that pallid sturgeon individuals often remained relatively stationary for months only to move great distances upstream or downstream during spring (> 16 km/d or 10 miles/d for one individual; average 0.6 km/d or 0.4 miles/d). This movement was statistically associated with a combined spring rise in water temperature and water level (Chapter 3; Figure 6). The automated receiver network was essential for collecting this information.

The COR at RM 189-190 was a frequent destination of migrating fish (Figure 6), which is congruent with the high catch rates of sturgeon at this area (Chapter 2). We are unsure whether the lowhead dam at COR (Low Water Dam Number 27) was a barrier to movement of adult sturgeon or a reproductive and staging area given that large gravel and sand deposits are located below the dam. Supposedly, a barrier would cause an aggregation of fish as they attempted to pass. However, we have documented three pallid sturgeon moving across this dam and into the Missouri River during spring when river

stage was about 16 feet (St. Louis Gage, Chapter 3). Thus, the role of the lowhead dam as a barrier during spring migration is questionable, although we do not know about effects at lower river stages. Other spring aggregations occurred in the MMR (Meramec River confluence, RM 158-163; Kaskaskia River confluence, RM 115-117; Grand Tower area, RM 79-81; Thebes area, RM 29-44) and may be destinations for staging and spawning.

These results demonstrate that a combination of physical sampling and telemetry provided complementary information about the habitat use and movement of pallid sturgeon in the MMR (also see DeLonay et al. 2007). The ability for wing dikes to concentrate flow and simultaneously provide refuge in shear zones of lower velocity next to swiftwater is an important component of adult life histories. These channel training structures probably provide a function similar to that historically provided by islands, side channels, and perhaps braided channels. Although we suspect that the simultaneous spring movements among fish and increased proximity to gravel bars are due to spawning, we have yet to link the movements to the production of eggs and larvae at the purported migratory destinations, although this has recently been accomplished in the Missouri River (Aaron Delonay, USGS, unpublished data).

Given that we documented multiple spring aggregations and assuming a relationship to spawning, it is quite likely that reproductive segregation occurs in the MMR. Clearly, morphological variation is marked throughout the Mississippi River basin (see Chapters 2 and 4) and these differences may be due to both environmental and genetic differences. Genetic differences were very small among shovelnose sturgeon from different river reaches (Schrey et al. in press). Allele frequency differences among

reaches were greater in pallid sturgeon and were probably due to some reproductive isolation as a function of reproductive site fidelity among individuals (Chapter 6, Schrey et al. 2007b). Identifying spawning aggregations and determining whether this leads to genetic structure within the MMR and other reaches is paramount to developing conservation plans for this species, with the goal of preserving genetic diversity.

In shovelnose sturgeon, we have found strong variation among individuals in contamination by organochlorine pesticides (Koch et al. 2006). Contaminant loading in the brain–hypothalamic-pituitary complex is positively related to intersexuals in the MMR and it is likely that exposure occurs during early life before and during sexual determination and maturation (Koch et al. 2006). It is not unlikely that similar patterns occur in pallid sturgeon and early exposure is probably due to the contaminant loads in spawning sites selected by adults and nursery areas used by offspring. Identifying areas of adult fidelity for spawning and areas of juvenile settlement is important for assessing risk of contaminant exposure and degree of future reproductive problems in the population.

Demographics, Life History, and Density.

The late age at maturity, large and relatively sparse eggs, migratory spawning behavior, and special spawning needs (e.g., depositing demersal, adhesive eggs in a large river with a moving, unstable bed may reduce survival) of sturgeon make them particularly susceptible to loss of spawning habitat or interference with reproduction. To compensate for these conditions and successfully produce on average one successful generation during a lifetime, species with these life history characteristics must commit to

long life spans with multiple spawning forays. The population's engine relies on high survival of adults, particularly mature females; any perturbation that prevents adults from reproducing including loss of spawning and nursery habitat, impedance of fish passage, or selective mortality of mature adults will place the population in jeopardy (Wildhaber et al. 2007).

Before we quantify the current status of the pallid sturgeon population, we need to determine what exactly a pallid sturgeon is. To address the debate about whether "pure" pallid sturgeon remain in the MMR, we assessed current morphomeristic indices (Chapter 4) and DNA microsatellite markers (Chapter 5) to evaluate the degree of hybridization with shovelnose sturgeon. Considerable variation exists in the performance of current character indices used by biologists in the field to identify pallid sturgeon (Chapter 4). Only with sophisticated ordination techniques might individuals be separated based on morphological and meristic characters (Chapter 4).

Genetic analyses (N= 157 fish) conducted independently of morphological identification confirmed that there are two genetic groups of *Scaphirhynchus* in the MMR and that these groups were concordant with morphologically identified pallids and shovelnose (Chapter 5). Morphological intermediates varied in their genetic affinity to either pallid or shovelnose groups but many were more similar to shovelnose, indicating F1 hybrids were backcrossing to the numerically dominant shovelnose. Although a large random sample from both populations has not been screened for the degree of hybridization, less than 1% of the putative pallid sturgeon that we screened morphomeristically were identified as hybrids. However, it is important to note that only pallid sturgeon that were suspected to have intermediate characteristics were screened.

Because hybrids appear to be closer genetically and perhaps morphologically to shovelnose, a concerted effort where all *Scaphirhynchus* sturgeon are screened genetically needs to be done to quantify the true rate of hybridization among the two populations in the MMR.

Although behavior, habitat use, and trophic status of pallid sturgeon were all different than those of shovelnose, both species probably undergo similar demographic responses to perturbations associated with reproduction such as loss of spawning and rearing habitat and loss of adults due to harvest. Thus, demographic characteristics of the abundant shovelnose sturgeon such as mortality rate and recruitment variability might have some similarity to that of the rare pallid. We quantified annual mortality rates of shovelnose sturgeon from their age structure (via annuli on pectoral fin rays) and discovered that rates were quite high (up to 37%) relative to other, unharvested shovelnose populations which experience less than 10% annual mortality (Chapter 6). More alarming was the sharp, highly significant negative relationship between an index of annual year-class strength and the harvest of shovelnose (Figure 7). Given that harvest of shovelnose sturgeon is increasing in the upper Mississippi River system, this suggests that production of year-classes will be reduced concurrently. Recruitment appears to be declining through time. During the past 5 years of standardized sampling in the MMR, the age distribution of shovelnose sturgeon in the MMR has been shifting toward older individuals with fewer apparent recruits comprising the population (Figure 8; Tripp et al. 2009).

Given that we had sufficient information about mortality and vital rates in shovelnose sturgeon and it is legally harvested, we modeled responses of biomass and

offspring production in the population to a range of fishing mortality rates and size-selective harvest limits for this species (Chapter 7; Colombo et al. 2007a). The model revealed that current rates of size-dependent harvest of shovelnose sturgeon in the MMR are not sustainable and that a substantive reduction in production was occurring. This further supported our conclusion that the mortality rates we quantified exceed those of a stable sturgeon population.

Given our limited sample size for pallid sturgeon, making population inferences was difficult. However, aging data from the combined sampling effort across three years demonstrated that pallid mortality rate (37% per year) was similar to that of shovelnose sturgeon (Chapter 7; Figure 9). A separate, independently derived annual mortality estimate solely from trotlining was similar (31% per year; Chapter 8). This was much higher than a mortality estimate by our group of 17% derived for trotlined pallids from the lower Mississippi River (Chapter 8), where harvest for all sturgeon is illegal but some poaching may be occurring. Although pallid individuals from the Missouri River have been found to live for 60 years, the oldest individual we captured in the MMR was 15 years (Figure 9) and growth had not yet decelerated (see previous section). We suggest that the similarity in mortality and truncated age structure with this species' commercially fished congener is not coincidental and likely related at least in part to harvest (see Bettoli et al. 2009). Population growth is typically quite sensitive to age at maturity. Given that pallid sturgeon likely mature later than shovelnose, then this species is likely more sensitive to size-dependent harvesting, which likely is occurring.

Our mark-recapture effort (unpublished data) for shovelnose sturgeon yielded sufficient individuals to generate a crude population estimate. This is likely for

individuals > 6 years, because this is the age when they are typically fully recruited to our sampling gear. We were limited by the small sample of recaptures to a modified Schnabel multiple census effort (Ricker 1975). Because we extended the effort across multiple years of the study, we assumed that marked individuals had an annual mortality probability of 37% and applied an annual exponential decay to the sample size of marked individuals at large (Table 5). From this, we generated an estimate of 136,000 shovelnose adults (upper 95%: 160,000; lower 95%: 116,000). A separate approach using the catch relationship

$$C_t = \left(\frac{F_t}{Z} \right) N_t (1 - e^{-(F_t + M)})$$

where C_t is current harvest in the fishery (in numbers), F_t is instantaneous fishing mortality, Z is total instantaneous mortality, and M is natural mortality can be used to estimate N_t , population size (in numbers). Our last robust catch estimate from the MMR was in 2001, which was about 36,250 individuals, assuming that the average shovelnose sturgeon in the creel was 0.8 kg (see Chapter 7 for harvest estimates). Assuming about 10% natural annual mortality and including 37% total mortality, our estimate of N from this catch equation for 2001 was 155,159 individuals, well within the confidence intervals around the mark-recapture estimate.

If we assume a ratio between congeners of 1:82, then the pallid population may only be comprised of 1,600 individuals in the MMR. Conversely, given the four recaptures of pallids out of 139 at large in the MMR, a crude Petersen estimate would be 4,900 individuals, although the error is very high and we cannot account for mortality of marked individuals at large in the population across years.

Clearly the pallid population is small in the MMR and it is no surprise that hatchery reared individuals, confirmed by coded wire tag to be fish released from Blind Pony Fish Hatchery, Missouri in 1994, began to recruit to our gear by 2004. One 1994 hatchery fish that we captured in 2004 was confirmed to be 10 years old from aging its sectioned pectoral fin ray. The total proportion of known hatchery-reared pallid in our samples was 9 of 139 fish (6%). However, if we restrict our analysis to fish that were routinely scanned for coded wire tags after Fall 2004 (the tags placed in some hatchery fish), then the proportion in our samples increased to 22% of pallids captured (also see Chapter 2). These pallids were aged and their ages compared to the population at large. Fork lengths at age were similar to that predicted for the entire population using the linear regression model provided earlier (all FL in mm; Age 6: predicted = 645, hatchery = 541; Age 7: predicted = 682, hatchery = 689; Age 8: predicted = 719, hatchery = 684; Age 12: predicted = 868, hatchery = 802; Age 14: predicted = 942, hatchery = 879). An Analysis of Covariance confirmed that there was no effect of origin (hatchery or wild) on length at age; however, given that only seven hatchery fish could be included in the analysis, our power was poor. Given the recent preponderance of hatchery-reared individuals in the population, it likely is the transition from adult spawning to production of offspring that is the bottleneck for population production in the MMR (Figure 2).

Summary and Conservation Implications.

We have not yet amassed sufficient data to generate a relationship between the abundance of adult spawners and the number of young produced and recruiting to the population (Figure 2). However, indirect evidence (i.e., from relationships between

cohort strength and harvest) suggests that a strong one exists for shovelnose sturgeon and likely for its congener. These sorts of relationships typically arise in fish populations that are declining and that have limited access to reproductive habitat such as those of Pacific salmon and Atlantic cod (see Chapter 7, 11). If the pallid population is reaching low numbers- a difficult conclusion to make given its historical rarity relative to shovelnose and a lack of historical data- then concerns about hybridization and limited numbers of recruits come into sharp focus.

Assuming that our population estimate is remotely accurate, the number of females contributing eggs to the population during each year is likely quite limited. To illustrate, recall that female *Scaphirhynchus* sturgeon mature late – perhaps at age 10 or greater - and may only spawn once every 3-5 years (Colombo 2004, Tripp et al. in press; Chapter 7). If age-10 pallid sturgeon comprise perhaps 10% of the population and of that 50% are females, then only 5% of the individuals are sexually mature females. If only 33% of those mature females are ovigerous during any one year, then only about 2% of the population is contributing eggs during any given year. If the population is as small as 1,600 individuals, then only 32 females spawn each year. Obviously, egg harvest of a single female will negatively affect reproduction in the population. Although anecdotal, our ability to capture and sonically tag mature, black-egg females was limited (see Chapter 3). On one date in December 2004 at COR we tagged 11 fish including a black-egg female. It was the only fish that we were unable to relocate. Although this female may have rapidly moved out of the area, it also may have been harvested. Without adults to drive reproduction in the population, attempts to enhance and protect spawning habitat will be futile without supplemental stocking.

Clearly, pallid sturgeon did not evolve with wing dikes, although this is the habitat selected in the MMR. Habitat with complex, contrasting flow patterns and areas of sand deposition appears to be ideal, likely facilitating foraging. We suspect that the choice of wing dike habitats is associated with foraging and we have good evidence that pallid sturgeon are piscivorous (Chapter 10; Hoover et al. 2007), even early in life (Gerrity et al. 2006). Because we are speculating about the foraging benefits of wing dikes, better evidence of prey availability in these areas plus better resolution of habitat use and position are needed. But, given that adults grew linearly in length through the oldest age in our samples, it is unlikely that growth is limited by residing at these habitats. Further, water quality has been improving in the MMR since the last century, so this habitat characteristic may be recovering for pallid sturgeon. It is important to note that pallid sturgeon densities are likely low in the MMR relative to historical levels. If so, then as densities increase with successful natural recovery or hatchery-reared individuals recruit well to the population, habitat and associated energetic costs/benefits might become an important limiting factor for adults.

Following the installation of the stationary hydrophone array and our intensive tracking effort during late 2004 through spring 2005, we began to enhance our understanding of spring movement and its potential relationship to spawning. However, we failed to link these movements with reproduction. In our view, a central key to enhancing pallid sturgeon is getting adults to arrive unharmed (i.e., unmolested and unharvested by fishers and unaffected by navigation) at spawning areas and allowing them to spawn successfully. Black-egg female pallid sturgeon are very rare in the population (only four were identified during our tagging study). The conservation

community needs to improve its ability to capture and then follow these individuals to purported spawning aggregations, similar to efforts occurring in the Missouri River.

We have collected larvae and small juveniles in our trawling (Chapter 1), of which some have been confirmed to be pure pallids (Schrey 2007; Heist and Boley, unpublished data). Fall spawning of shovelnose sturgeon and perhaps pallid sturgeon has been confirmed (Tripp et al. in press). However, aging these young sturgeon and thus determining their origin and linking this to adult activity at sites within the MMR is challenging. To identify important spawning and rearing areas, the origin and destination for young sturgeon as well as their growth and survival at these locations need to be quantified.

For any population, the ultimate measure of success is the successful transition of offspring to reproductive age, typically known as recruitment. This is currently the largest gap in our knowledge of the life history of pallid sturgeon (Figure 2). We know little about the species composition and degree of hybridization of young produced at sites described herein (Chapter 5). A preliminary screen of larval sturgeon from the lower Missouri River and the MMR suggests a high degree of hybridization, although one genetically pure pallid was found (Heist and Boley, unpublished data). Given that embryos and larvae are impossible to identify physically, biologists must rely on genetics for identification of larvae and assessment of spawning success.

As with adults, we recommend that larval and juvenile production be monitored regularly throughout the MMR using the appropriate gear types (Chapter 1). As mentioned earlier, a relationship between adult spawners and the production of young has not yet been established. If one exists, then we might be able to predict the reproductive

potential of the population by quantifying adult abundance. However, how this reproductive potential is realized can only be determined by sampling young produced. Developing a standardized index of offspring abundance and following trajectories of growth and survival will likely be a sensitive indicator of population status, variable adult (i.e., black egg female) survival, and response to habitat enhancement.

Literature Cited.

Bailey, R.M. and F.B. Cross. 1954. River sturgeons of the American genus *Scaphirhynchus*: characters, distribution, and synonymy. Papers of the Michigan Academy of Sciences, Arts, and Letters 39:169-208.

Bettoli, P. W., M. Casto-Yerty, G. D. Scholten, and E. J. Heist. 2009. Bycatch of the endangered pallid sturgeon (*Scaphirhynchus albus*) in a commercial fishery for shovelnose sturgeon (*Scaphirhynchus platorynchus*). Journal of Applied Ichthyology 25(1):1-4.

Bramblett, R.G. and R.G. White. 2001. Habitat use and movements of pallid and shovelnose sturgeon in the Yellowstone and Missouri Rivers in Montana and North Dakota. Transactions of the American Fisheries Society 130:1006-1025.

Colombo, R. E. 2004. Reproductive demographics of the shovelnose sturgeon (*Scaphirhynchus platorynchus*). Masters thesis, Southern Illinois University.

Colombo, R.E., J.E. Garvey, N.D. Jackson, R. Brooks, D.P. Herzog, R.A. Hrabik, and T.W. Spier. 2007. Harvest of Mississippi River sturgeon drives abundance and reproductive success: a harbinger of collapse? Journal of Applied Ichthyology 23:444-451.

DeLonay, A.J., D.M., Papoulia, M.J. Wildhaber, G.E. Mestl, D.W. Everitt, and K.A. Chojnacki. 2007. Movement, habitat use, and reproductive behavior of shovelnose sturgeon and pallid sturgeon in the Lower Missouri River. Pages 23-102, C.Korschgen, editor. Factors affecting the reproduction, recruitment, habitat, and population dynamics of pallid sturgeon and shovelnose sturgeon in the Missouri River. USGS Open-File Report 2007-1262.

Federal Register. 1990. Determination of the endangered status for the pallid sturgeon, final rule. Sept 6, 1990. 55(173): 36641-36647.

Garvey, J.E., and E.A. Marschall. 2003. Understanding latitudinal trends in fish body size through models of optimal seasonal energy allocation. Canadian Journal of Fisheries and Aquatic Sciences 60(8):938-948.

Garvey, J.E., R.A. Wright, and E.A. Marschall. 2009. Searching for threshold shifts in spawner recruit relationships. Canadian Journal of Fisheries and Aquatic Sciences 66:312-320.

Gerrity, P.C., C.S. Guy, and W.M Gardner. 2006. Juvenile pallid sturgeon are piscivorous: a call for conserving native cyprinids. Transactions of the American Fisheries Society 135:604-609.

Hoover, J.J., S.G. George, and K.J. Killgore. 2007. Diet of shovelnose sturgeon and pallid sturgeon in the free-flowing Mississippi River. *Journal of Applied Ichthyology* 23:494-499.

Killgore, K.J., J.J. Hoover, S.G. George, B.R. Lewis, C.E. Murphy, and W. E. Lancaster. 2007. Distribution, relative abundance and movements of pallid sturgeon in the free-flowing Mississippi River. *Journal of Applied Ichthyology* 23:476-483.

Killgore, K.J., J.J. Hoover, J.P. Kirk, S.G. George, B.R. Lewis, and C.E. Murphy. 2007. Age and growth of pallid sturgeon in the free-flowing Mississippi River. *Journal of Applied Ichthyology* 23:452-456.

Kittrell, F.W., 1958. Pollution of interstate waters of the Mississippi River in the St. Louis metropolitan area. Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio PB-216 902; Distributed by US Department of Commerce, National Technical Information Service.

Koch, B.T, J.E. Garvey, M.J. Lydy. 2006. Elevated organochlorines in the brain-hypothalamic-pituitary complex of intersexual shovelnose sturgeon. *Environmental Toxicology and Chemistry* 25:1689-1697.

Murphy, C.E., J.J. Hoover, S.G. George, and K.J. Killgore. 2007. Morphometric variation among river sturgeons (*Scaphirhynchus* spp.) of the Middle and Lower Mississippi River.

Murphy, C.E., J.J. Hoover, S.G. George, B.R. Lewis, and K.J. Killgore. 2007. Types and occurrence of morphological anomalies in *Scaphirhynchus* spp. of the Middle and Lower Mississippi River. *Journal of Applied Ichthyology* 23:354-358.

Pala, C. 2005. Ban on beluga sturgeon caviar points to sturgeon's worldwide decline. *Science* 310:37.

Phelps, Q.E., D.P. Herzog, R.C. Brooks, V.A. Barko, D.E. Ostendorf, J.W. Ridings, S.J. Tripp, J.E. Garvey, and R.A. Hrabik. In revision. Comparison of three common gear types to sample sturgeons in the Middle Mississippi River. *North American Journal of Fisheries Management*.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada* 175.

Schrey, A.W., and E.J. Heist. 2007. Stock structure of pallid sturgeon analyzed with microsatellite loci. *Journal of Applied Ichthyology* 23:297-303.

Schrey, A.W., B.L. Sloss, R.J. Sheehan, R.C. Heidinger, and E.J. Heist. 2007. Genetic discrimination of middle Mississippi River *Scaphirhynchus* sturgeon into pallid, shovelnose, and putative hybrids using multiple microsatellite loci. *Conservation Genetics* 8:683-693.

Schrey, A., R. Colombo, J. Garvey, and E. Heist. In press. Stock structure of shovelnose sturgeon analyzed with microsatellite DNA and morphological characters. *Journal of Applied Ichthyology*.

Tripp, S.J, R.E. Colombo, and J.E. Garvey. 2009. Declining recruitment and growth of shovelnose sturgeon in the Middle Mississippi River: implications for conservation. *Transactions of the American Fisheries Society* 138:416-422.

Tripp, S., Q. Phelps, R. Colombo, J. Garvey, B. Burr, D. Herzog, and R. Hrabik. In press. Maturation and reproduction of shovelnose sturgeon in the Middle Mississippi River. *North American Journal of Fisheries Management*.

US Army Corps of Engineers, St. Louis District. 2005. Geomorphology study of the Middle Mississippi River. *Applied River Engineering Center Publication*.

US Fish and Wildlife Service. 2000. Final biological opinion for the operation and maintenance of the 9-foot navigation channel of the Upper Mississippi River. Prepared

by the US Fish and Wildlife Service Rock Island Field Office, Rock Island, Illinois; Marion, Illinois; Twin Cities Field Office, Bloomington, Minnesota, USA.

Wildhaber, M.L., DeLonay, A.J., Papoulias, D.M., Galat, D.L., Jacobson, R.B., Simpkins, D.G., Braaten, P.J., Korschgen, C.E., and Mac, M.J., 2007, A conceptual life-history model for pallid and shovelnose sturgeon: U.S. Geological Survey Circular 1315, 18 p.

Wills, P.S., R.J. Sheehan, B.L. Sloss, and R. Clevestine. 2001. Differentiation of pallid sturgeon and shovelnose sturgeon using an index based on meristics and morphometrics. American Fisheries Society Symposium 28:249-258.

Table 1. Total sturgeon sampling effort in the Middle Mississippi River from May 2002 through Summer 2005 by Missouri Department of Conservation, Southern Illinois University-Carbondale, and Corps of Engineers Waterways Experiment Station.				
Stats by Gear	MDC	SIU ¹	CEWES	Total
GILLNETS				
Sample Number	1,308	790	6	2,104
Hours Fished ¹	21,868	12,433	96	34,397
Number of Shovelnose	3,391	2,510	8	5,909
Number of Pallids	23	19	0	42
TRAWLS				
Sample Number	1,657	518	3	2,178
Hours Fished	124.7	50.7	0.5	175.9
Number of Shovelnose	957	130	3	1,090
Number of Pallids	3	0	0	3
TROT LINES				
Sample Number	829	223	359	1,411
Hours Fished	19,224	4,626	5,744	29,594
Number of Shovelnose	1,127	260	3,073	4,460
Number of Pallids	32	2	41	75
TOTAL ALL GEAR				
Sample Number	3,794	1,531	368	5,693
Hours Fished	41,217	17,110	5,841	64,167
Number of Shovelnose	5,475	2,900	3,084	11,459
Number of Pallids	58	21	41	120
¹ Gillnet effort does not include pallid sturgeon captured by commercial fishermen because hours fished could not be determined.				

Table 2. (From Chapter 2) Statistical summary of abundance (catch-per-unit-effort) for pallid and shovelnose sturgeons captured in the Mississippi River using trotlines from 1997 to 1998, and 2000-2006. The lowermost reach of the Mississippi River (Mile 0-100) was not included because no sturgeon were collected (n=25). For analytical purposes, the Middle Mississippi River was divided into two reaches – below Chain of Rocks (CR) to the mouth of the Ohio River and at CR. Values for mean abundances with different letters along a row are significantly ($p < 0.05$) different according to the Student-Newman-Keuls multiple range test.

Species and Statistic	Reach				
	100-310	310-680	680-985	MMR wo/CR	MMR CR
Number of trotlines	144	574	145	273	86
Pallid sturgeon					
Mean	0.31 ^a	0.15 ^b	0.18 ^b	0.12 ^b	0.29 ^a
Standard deviation	0.68	0.47	0.62	0.33	0.59
Coefficient of variation	223	306	346	284	203
Maximum collected per line	4	5	5	2	3
Total collected	44	88	26	32	25
Shovelnose sturgeon					
Mean	1.88 ^a	2.76 ^b	5.41 ^c	4.22 ^c	22.24 ^d
Standard deviation	3.39	3.84	8.39	5.45	12.41
Coefficient of variation	180	138	155	129	56
Maximum collected per line	20	28	50	32	43
Total collected	271	1593	784	1151	1913
pallid:shovelnose (totals)					
	1:6	1:18	1:30	1:36	1:77

Table 3. (From Chapter 2) Statistical summary of fork length (mm) for pallid and shovelnose sturgeons captured in the Mississippi River using trotlines from 1997 to 1998, and 2000-2006. The lowermost reach of the Mississippi River (Mile 0-100) was not included because no sturgeon were collected. For analytical purposes, the Middle Mississippi River was divided into two reaches – below Chain of Rocks (CR) to the mouth of the Ohio River and at CR. Values for mean length with different letters along a row are significantly ($p < 0.05$) different according to the Student-Newman-Keuls multiple range test.

Species and Statistic	Reach				
	100-310	310-680	680-985	MMR wo/CR	MMR CR
Pallid sturgeon					
Number Collected	44	88	26	32	25
Mean	620 ^a	702 ^b	741 ^b	758 ^b	756 ^b
Standard deviation	110	111	65	87	96
Minimum	405	410	540	541	553
Maximum	789	965	854	889	995
Shovelnose sturgeon					
Number Collected	265	1547	775	1123	1887
Mean	539 ^a	587 ^b	599 ^c	621 ^d	578 ^b
Standard deviation	80	81	82	72	77
Minimum	328	265	285	289	273
Maximum	852	860	818	831	790

Table 4. List of VR2 (Vemco Lmtd.) stationary receivers in the MMR during spring 2005.

VR2	Buoy Type	ID	River Mile
3094c	can (#8)	MO River	3.4MO
3064c	can (#5)	COR above 1	194.4
3090c	can (#2)	COR above 2	194.2
3115c	can (#4)	COR below 1	187.7
3095	can (#12)	COR below 2	187.7
3066	nun (#3)	Mosenthein SC	185.3
4945	bottom	Meremac	161.5
3098	can (# none)	Osborn chute	144.5
4940	nun (new)	Osborn chute	144.5
3065	can (#11)	Establishment	130.3
3061	nun (#14)	Moro Island	119.9
4943	can (# new)	Moro Island	119.8
4944	bottom	Kaskaskia	118
3097	can (#4)	Rockwood Island	101
4941	can (# new)	Cottonwood	72
4939	nun (new)	Cottonwood	72
4942	Bottom	Big Muddy	76
3096	nun (#15)	Hamburg	62.5
3093	can (#7)	Thebes	44
3116	nun (new)	Thebes	44
3091	nun (#15)	Boston Bar	9.7
3092	nun (#9)	Cairo	0.5

Table 5. Multiple census mark-recapture data for shovelnose sturgeon captured in the Middle Mississippi River during 2002 through 2005. Adjusted marked individuals at large (Adjusted M column) were generated assuming a 37% annual mortality rate.

	Sum of caught C	Sum of tagged U	Sum of recap		Adjusted M	C X M
			R	M		
Summer 02	95	29	0	0	0	0
Fall 02	468	312	4	29	26	12280
Winter 02	460	383	15	341	306	140784
Spring 03	1990	1725	31	724	623	1240726
Summer 03	212	176	0	2449	2125	450499
Fall 03	211	197	3	2625	2082	439307
Winter 03	286	275	7	2822	2062	589774
Spring 04	1013	966	17	3097	2115	2142229
Summer 04	678	325	3	4063	2788	1889970
Fall 04	847	813	3	4388	2816	2385463
Winter 04	404	352	9	5201	3284	1326731
Spring 05	2347	1933	52	5553	3290	7721576
Summer 05	264	31	0	7486	4726	1247650
					N	136021
					N _{lower 95% CI}	115543
					N _{upper 95% CI}	160131

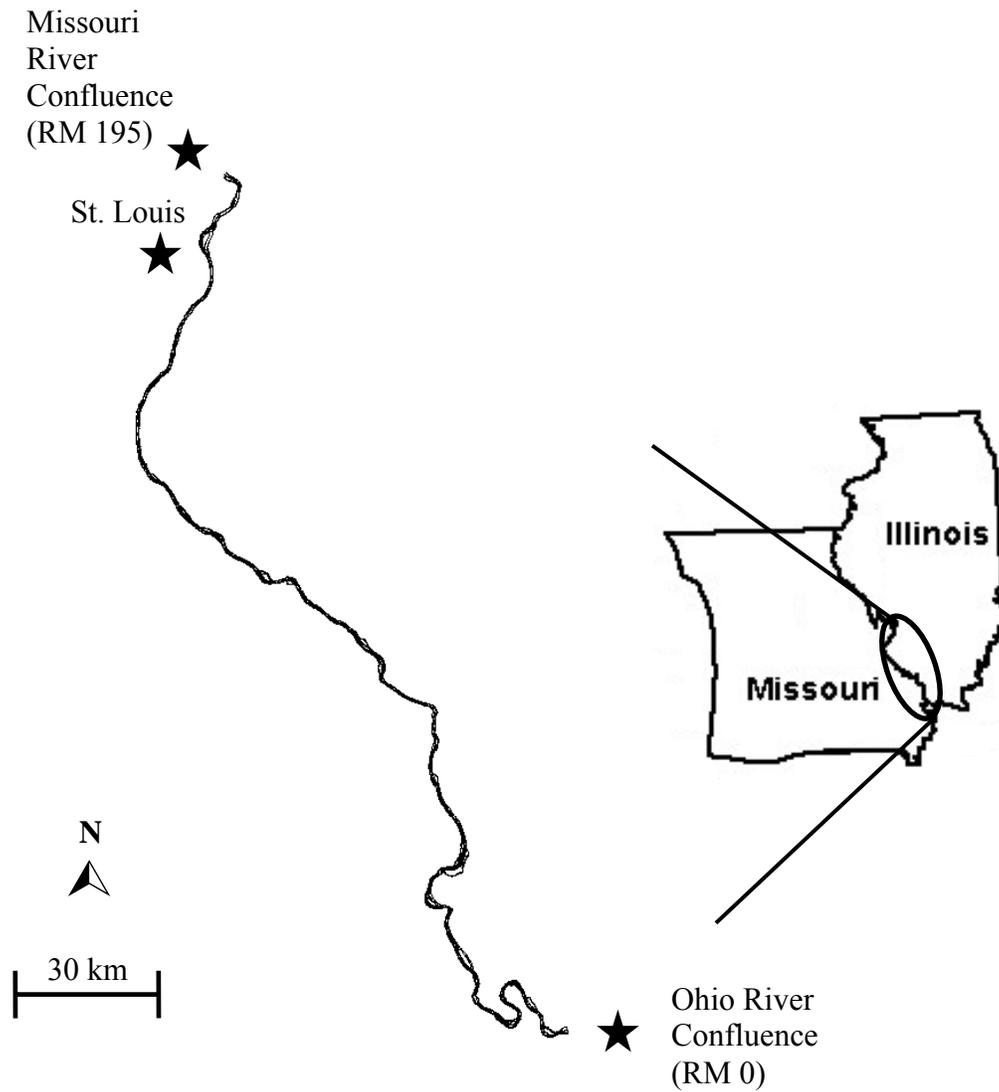


Figure 1. Middle Mississippi River (MMR) in which pallid sturgeon were studied during 2002 through 2005. Stars indicate location of river confluences, which coarsely bound the MMR. The MMR extends upstream to the Mel Price Lock and Dam.

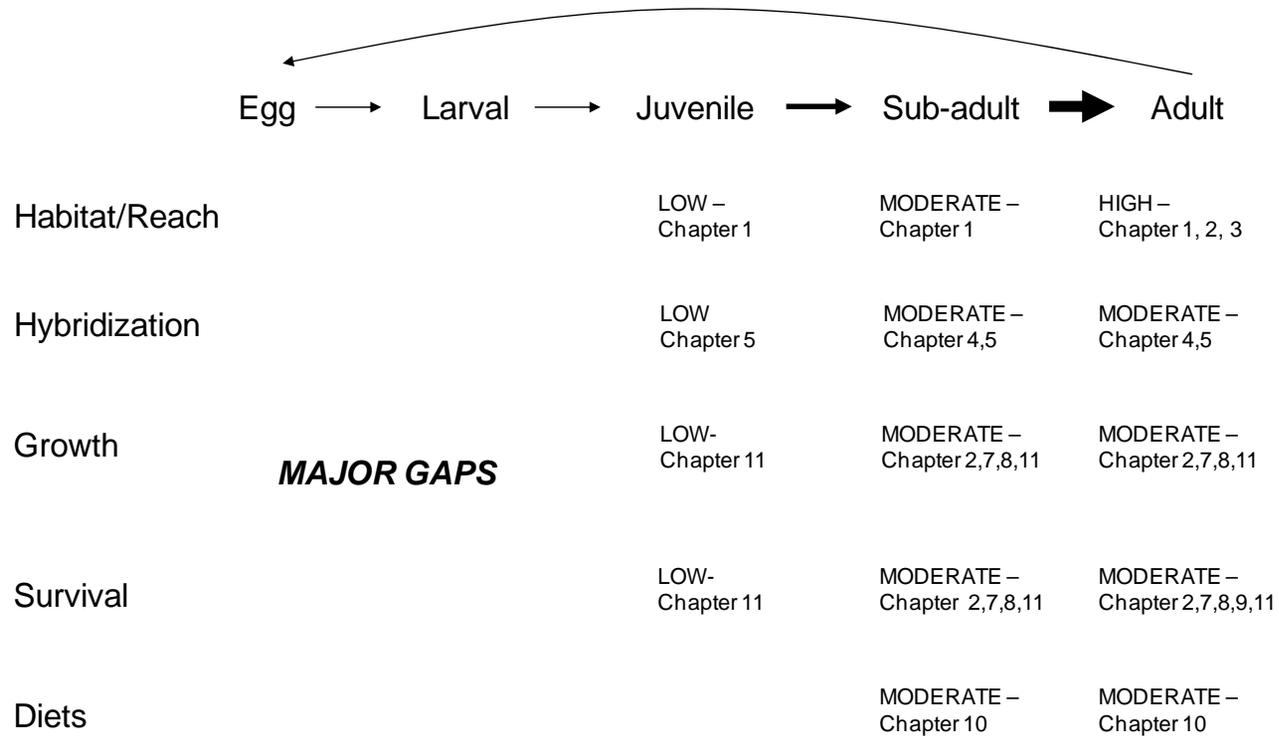


Figure 2. State of the current knowledge of important factors affecting pallid sturgeon in the Middle Mississippi River as a function of important life stages. Arrows depict transitions between life stages; arrow thickness corresponds to the extent of our knowledge about each transition. Chapters correspond to those in the report. See Wildhaber et al. 2007 for a more sophisticated conceptual model.

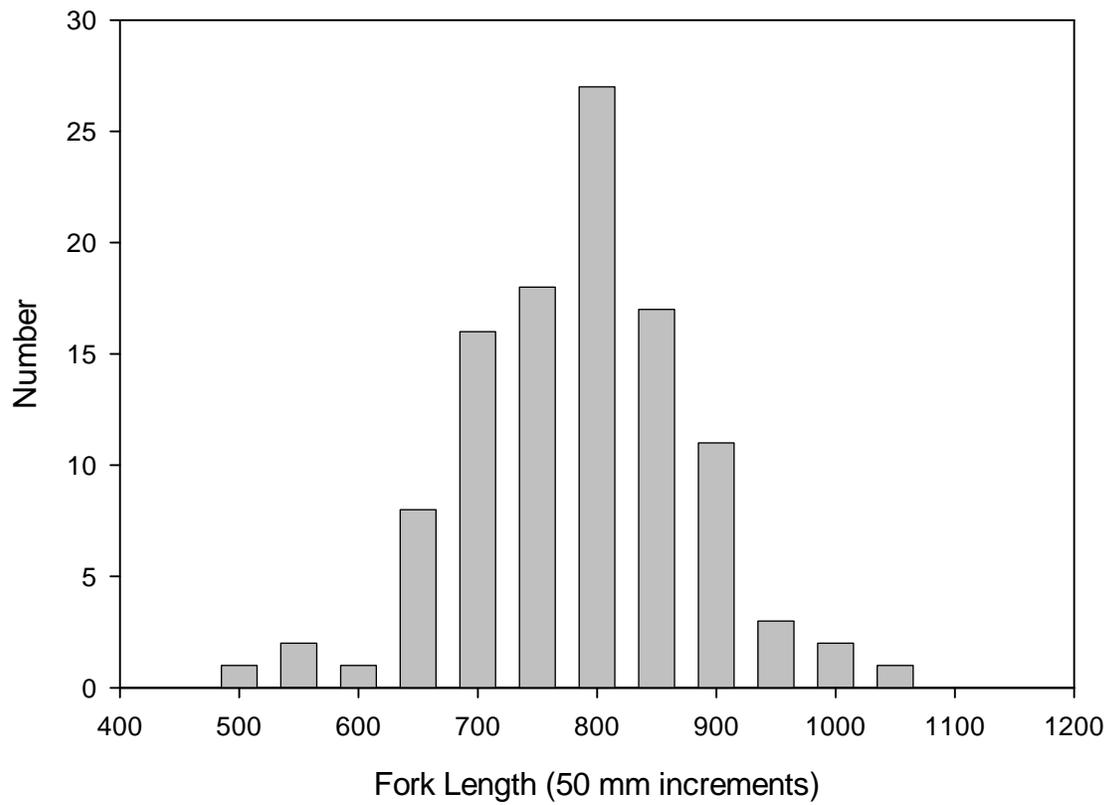


Figure 3. Length frequency distribution of pallid sturgeon in the MMR sampled with gill nets, trawls, and trotlines during 2002 through 2005. Fish greater than 650 mm FL were typically implanted with ultrasonic tags. Smaller pallid sturgeon also likely occurred in samples but were unidentified because of lack of reliable morphometric indexes.

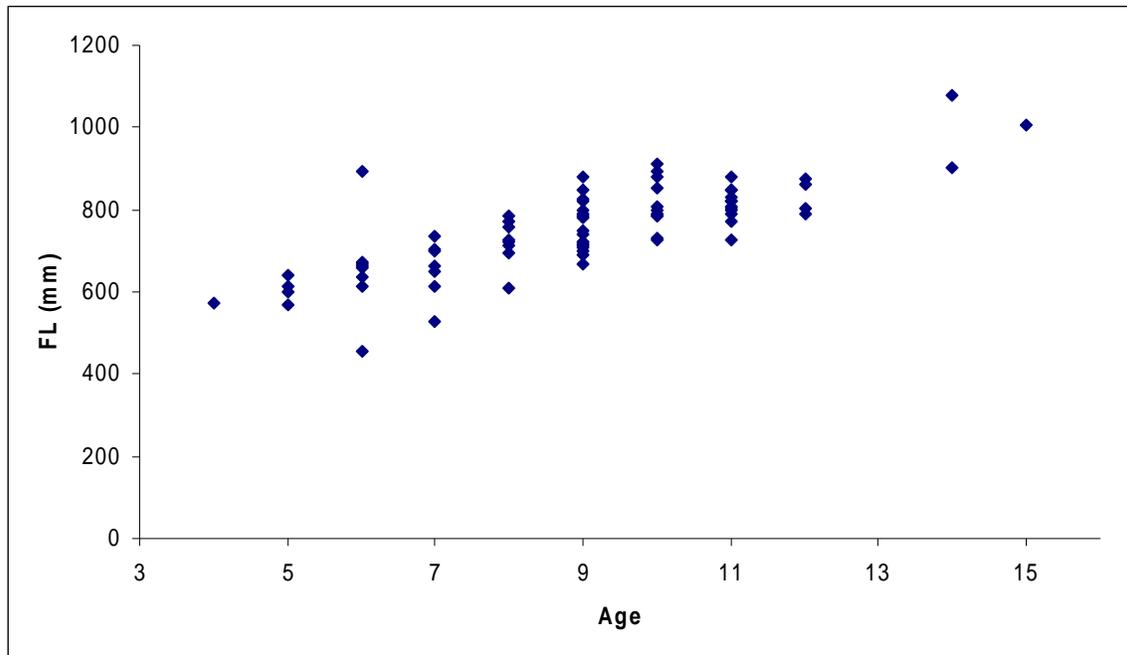


Figure 4. Fork length (FL) at age for 75 pallid sturgeon in the MMR sampled with gill nets, trawls, and trotlines during 2002 through 2005; these fish were aged independently by two SIUC biologists. The relationship was linear, suggesting that adult growth had not decelerated by the oldest age.



Figure 5. Sites of standardized trot-lining conducted to sample pallid and shovelnose sturgeon across a latitudinal gradient in the Mississippi River.

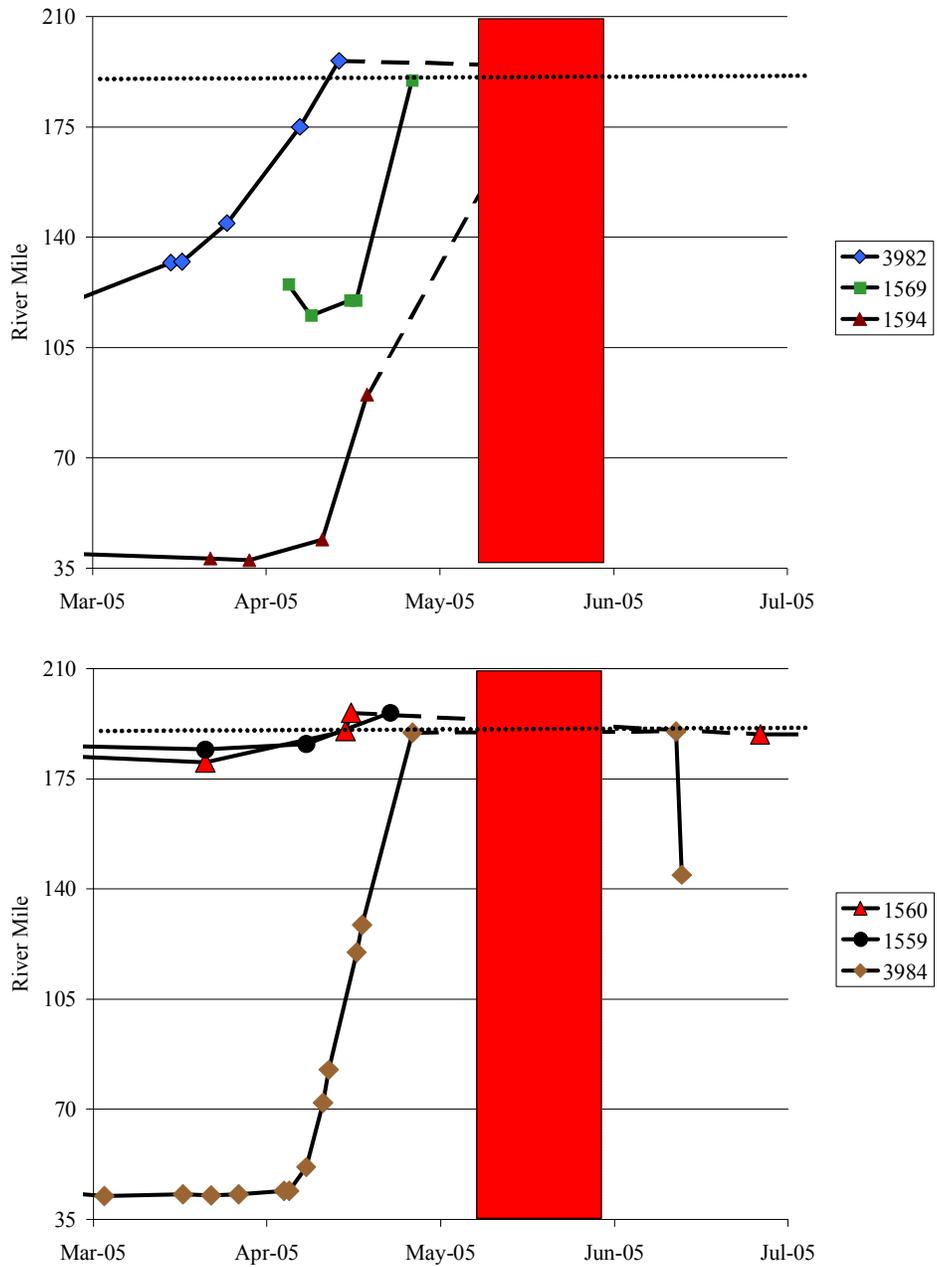


Figure 6. Movement of six adult pallid sturgeon in the MMR during spring 2005. The dashed line is the location of the Chain of Rocks. The highlighted area includes the dates when we hypothesize that temperatures and water levels were optimal for spawning. Each number is the individual tag identification for each fish.

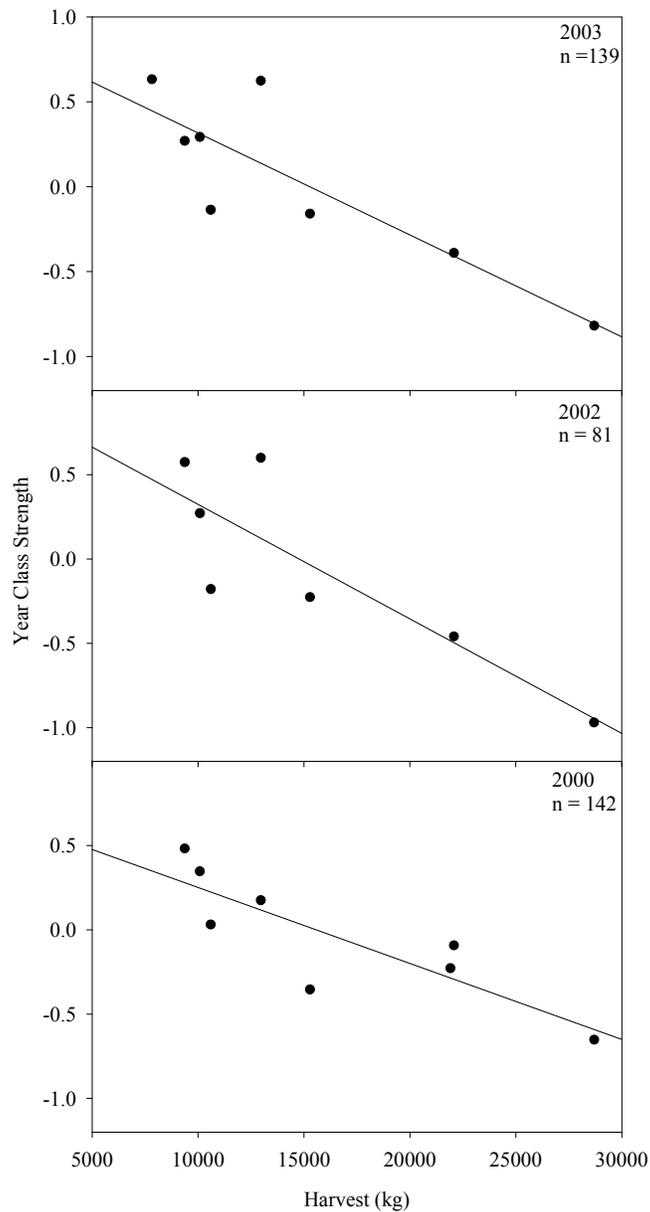


Figure 7. Relationship between Mississippi River harvest by Illinois and Missouri commercial fishers and year class strength as derived from residuals from catch-curves for shovelnose sturgeon sampled during 2003, 2002 and 2000. A value of 0 indicates no deviation from average abundance of an annual cohort. Positive and negative values indicate strong and weak cohorts in the population, respectively.

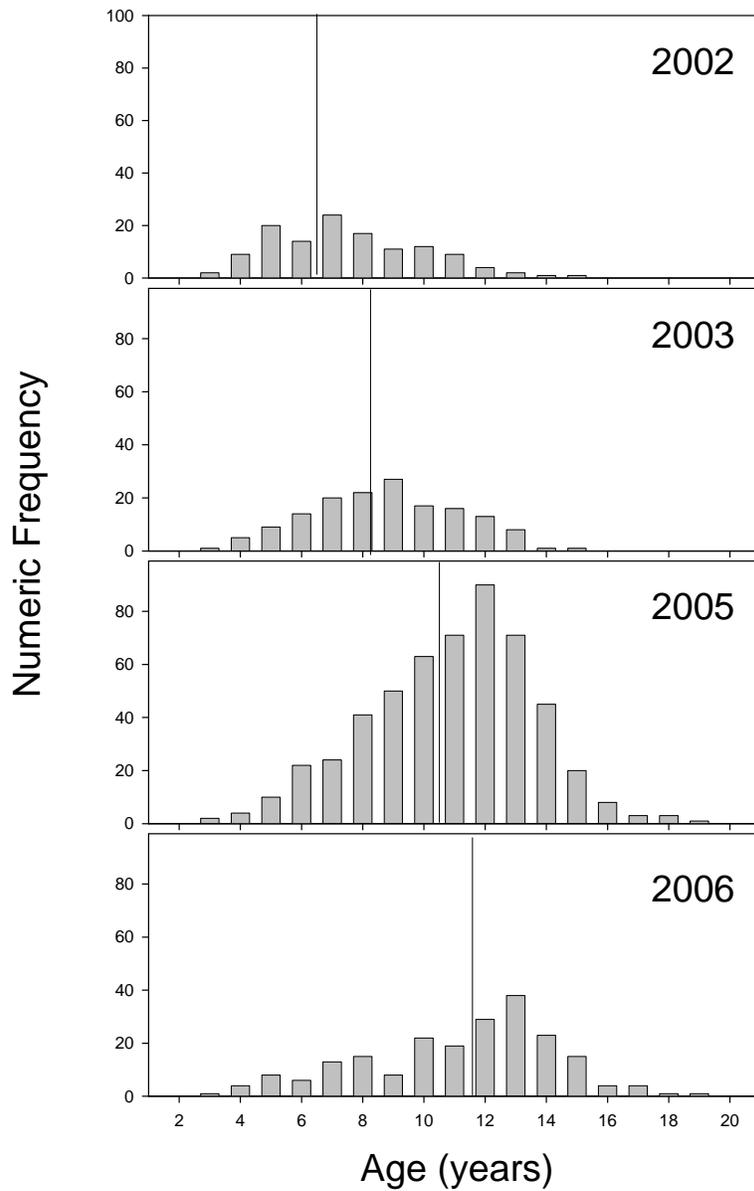


Figure 8. Change in age distribution of shovelnose sturgeon in the Middle Mississippi River during 2002 through 2006 (see Trippet al. 2009). Fish were captured with standardized gill net sets. Vertical lines represent median age within each year. Such shifts toward older individuals indicate declining production of young individuals.

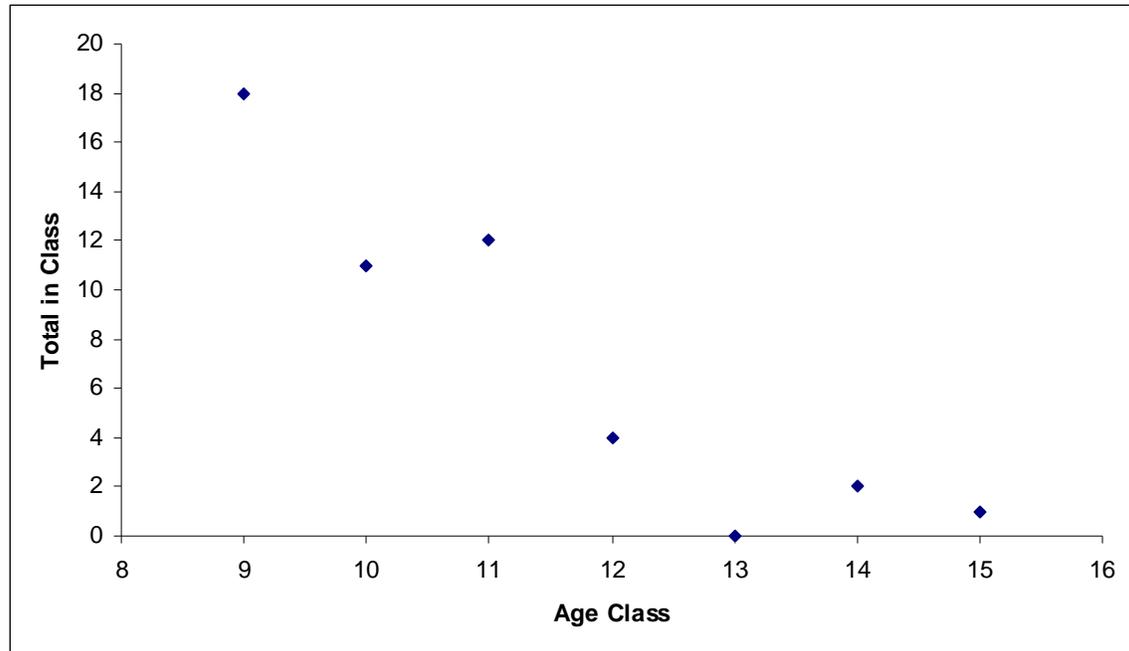


Figure 9. Declining age-dependent catch of pallid sturgeon sampled with gill nets during 2002 through 2005 in the Middle Mississippi River. A log-linear regression best explained this relationship ($R^2=0.73$).

Table of Contents:

Synthesis	1
Chapter 1: Sampling and Sizes (Phelps et al. in revision)	49
Chapter 2: Sizes and Relative Abundance (Killgore et al. 2007a)	79
Chapter 3: Habitat and Movement (Koch et al. submitted)	88
Chapter 4: Morphometrics (Murphy et al. 2007a)	230
Chapter 5: Genetic Discrimination (Schrey et al. 2007a)	242
Chapter 6: Stock Structure (Schrey et al. 2007b)	254
Chapter 7: Mortality and Population Dynamics (Colombo et al. 2007a)	262
Chapter 8: Age and Growth (Killgore et al. 2007b)	271
Chapter 9: Anomalies (Murphy et al. 2007b)	277
Chapter 10: Diets (Hoover et al. 2007)	283
Chapter 11: Declining Recruitment and Growth (Tripp et al. 2009)	291
Chapter 12: Reviewer Comments and Responses	298