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Effects of commercial harvest on shovelnose sturgeon populations in the upper Mississippi River

by

Jeff Koch

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ABSTRACT

Shovelnose sturgeon *Scaphirhynchus platorynchus* have become an increasingly important commercial species in the upper Mississippi River (UMR) due to collapsing foreign sturgeon populations and bans on imported caviar. In response to concerns about the sustainability of the shovelnose sturgeon fishery in the UMR, we began this study to describe shovelnose sturgeon population demographics and evaluate the influence of commercial harvest on shovelnose sturgeon populations in the UMR. A total of 1,682 shovelnose sturgeon were collected from eight study pools of the UMR in 2006 and 2007 (i.e., Pools 4, 7, 9, 11, 13, 14, 16 and 18). Shovelnose sturgeon from upstream pools generally had greater lengths, weights, and ages than shovelnose sturgeon from downstream pools. Additionally, mortality estimates were also lower in upstream pools (i.e., Pools 4, 7, 9, and 11) compared to downstream pools (i.e., Pools 13, 14, 16, and 18). Analyses indicated that decreased growth of shovelnose sturgeon may be a consequence of commercial harvest in the UMR. Modeling of potential management scenarios suggest a 27-inch minimum length limit is necessary to prevent growth and recruitment overfishing of shovelnose sturgeon in the UMR.

INTRODUCTION

Sturgeons (Acipenseridae) are slow-growing, long-lived, late-maturing fish that do not spawn annually (Birstein 1993; Boreman 1997). Because of these factors, sturgeon are vulnerable to human activities such as flow and temperature alterations, changes in sediment dynamics, overfishing, and pollution (Birstein 1993; Boreman 1997). Birstein (1993) reported that nearly all Eurasian sturgeon species have declined, and some populations have experienced local extinctions, with more species facing a similar plight. Of the eight sturgeon species native to North America, two-thirds are listed as endangered, threatened, or of special concern (Williams et al. 1989).

Three species of river sturgeon (genus *Scaphirhynchus*) are present in North America, including the shovelnose sturgeon *S. platorynchus*, pallid sturgeon *S. albus*, and Alabama sturgeon *S. suttkusi.* The pallid sturgeon and Alabama sturgeon have experienced significant declines in distribution and abundance and are both federally endangered. Although shovelnose sturgeon are the most abundant and widespread of the river sturgeons, alterations to large river habitats and commercial harvest have reduced their distribution and abundance (Bailey and Cross 1954; Birstein 1993; Boreman 1997; Keenlyne 1997). Carlson et al. (1985) states that shovelnose sturgeon are classified as extirpated or at risk of extirpation in 50% of the states within their native distribution. In other states where shovelnose sturgeon are native, they have either declined in abundance or their status is unknown (Keenlyne 1997). Shovelnose sturgeon have been extirpated from the Rio Grande River and from upstream reaches of many large western and midwestern rivers where habitat has been altered and movement has been blocked by water development activities (Keenlyne 1997).

Shovelnose sturgeon were considered a nuisance by those commercially fishing for lake sturgeon *Acipenser fulvescens* in the late 1880s (Barnickol and Starret 1951; Moos 1978). Destruction of shovelnose sturgeon was common during this time where thousands were caught in nets and burned to "clean" the area of shovelnose sturgeon (Carufel 1953). It was not until the early 1900s that shovelnose sturgeon became commercially important when markets developed for their meat and roe (i.e., eggs). In addition to roe, which was highly valued as caviar, the smoked flesh was considered one of the finest fish products from the Mississippi River (Coker 1930). Currently, shovelnose sturgeon roe, often sold under the name "American Hackleback", retails for around US$770 per kilogram, whereas smoked flesh sells for about US$9 per kilogram.

Concern has been raised that commercial fishing pressure on shovelnose sturgeon for roe will continue to increase due to collapsing sturgeon populations in the Caspian, Black, and Adriatic seas (Birstein 1993; Keenlyne 1997; Colombo et al. 2007). In 1992, over 108 metric tons of shovelnose sturgeon flesh and roe were harvested from the waters of Arkansas, Illinois, Iowa, Missouri, and Wisconsin. Iowa was the leading producer of shovelnose sturgeon in 1992, yielding 34,603 kg of roe and flesh (Keenlyne 1997). In 2004, the Iowa Department of Natural Resources (DNR) reported that the total harvest of shovelnose sturgeon roe by licensed commercial harvesters was 1,492 kg. In 2005, harvest increased to 1,595 kg, with a value of approximately US$158,000 (G. Jones, Iowa DNR, personal communication). In response to concerns associated with increasing harvest, Iowa increased their minimum length limit for commercial shovelnose sturgeon harvest from 635 mm to 685 mm in August 2006. Iowa is not the only state in the upper Mississippi River (UMR) basin with concerns about increased commercial harvest of shovelnose sturgeon. Harvest by licensed Illinois fisherman has increased almost 10-fold since the late 1990s in Pools 12-26. In Wisconsin, commercial harvest has tripled since 2001 (P. Short, Wisconsin DNR, personal communication).

Shovelnose sturgeon are considered to be the least vulnerable of the North American sturgeons to commercial harvest due to their relatively early age of maturation and fast growth (Keenlyne 1997; Morrow et al. 1998). Quist et al. (2002) reported that exploitation rates of 20% on the Missouri River could effect size structure and lifetime egg production of shovelnose sturgeon, and that restrictive harvest regulations (e.g., length limits) could reduce the effects of harvest on shovelnose sturgeon populations. Similarly, Colombo et al. (2007) suggested that current harvest regulations were not adequate to prevent overfishing of shovelnose sturgeon populations in the middle Mississippi River. While these studies have provided important insight on the management of shovelnose sturgeon, they were conducted on populations outside of the UMR. In response to increasing harvest of shovelnose sturgeon, similar insight is needed to guide management of the commercial shovelnose sturgeon fishery in the UMR. The objectives of this study were to describe population parameters (e.g., length and age structure, mortality, growth, sex ratios) and evaluate potential management scenarios for shovelnose sturgeon populations in the UMR.

STUDY AREA

The UMR is defined by the Upper Mississippi River Conservation Committee as the 1,490 km portion of the Mississippi between Hastings, Minnesota, and Caruthersville, Missouri (Pitlo and Rassmussen 2004; Figure 1). Before large-scale channelization began in 1816, the UMR was characterized as having deep pools separated by shallow rapids (Hurley et al. 1987). The first modifications to the Mississippi River were simple snag and debris removal from the river's main channel to improve navigation. Over the last 150 years, several additional habitat modifications have occurred. The depth of the navigation channel was increased from 1.4 m in 1878 to 1.8 m in 1907. During the 1930s, the U.S. Army Corps of Engineers further increased the depth of the navigation channel by constructing a series of locks and dams, as well as over 3,100 wing dams. Eleven locks and dams exist along the Iowa border and serve to maintain a navigation channel of at least 2.7 m in depth and 122 m in width (Hurley et al. 1987). Commercial traffic on the river was also enhanced via closures of chutes and backwaters, dredging, and bank stabilization via revetment (Pitlo and Rasmussen 2004).

Eight pools representing a diversity of habitats and a variety of shovelnose sturgeon harvest rates were selected as study pools (i.e., Pools 4, 7, 9, 11, 13, 14, 16, and 18; Figure 1). The two most upstream pools (i.e., Pools 4 and 7) are north of the Iowa-Minnesota border where shovelnose sturgeon harvest is limited to recreational anglers and commercial trot-line harvesters. Thus, exploitation of shovelnose sturgeon in Pools 4 and 7 is likely very low. The regulation for commercial shovelnose sturgeon harvest in Wisconsin-Minnesota border waters is a 635-mm minimum length limit (Table 1). The Iowa-Minnesota border intersects Pool 9 approximately 8 km downstream of Lock and Dam 8. Downstream of the

Iowa-Minnesota border, harvest of shovelnose sturgeon is allowed via traditional commercial fishing gear (e.g., entanglement gear, hoop nets, and trot lines) and is regulated by a 685-mm minimum length limit for Iowa harvesters and a 685-mm to 813-mm harvestable slot limit for Wisconsin commercial harvesters. The Wisconsin-Illinois border intersects Pool 12 near Dubuque, Iowa. Similar to Iowa-Wisconsin border waters, the shovelnose sturgeon fishery in Iowa is regulated with a 685-mm minimum length limit. The Illinois regulation for commercial shovelnose sturgeon harvest is a more liberal 610-mm to 813-mm harvestable slot limit. Shovelnose sturgeon harvest has traditionally increased downstream of this location (Figure 2). Although the lower bound of the Illinois slot limit is 610 mm, no shovelnose sturgeon less than 685 mm (i.e., the Iowa minimum length limit for commercial shovelnose sturgeon harvest) can be possessed in Iowa waters by commercial harvesters.

METHODS

Fish collection.**—**Shovelnose sturgeon were sampled with 30.5-m drifted trammel nets, consisting of 13.6-kg lead-core line and 12.7-mm foam-core float line. Consistent with standard trammel nets used in the UMR, nets were constructed with three panels of mesh. The outer wallings were 1.8-m deep panels with 304.8-mm bar-measure mesh (#9 multifilament nylon twine). A single 2.4-m deep panel of inner mesh was constructed of 50.8-mm bar-measure mesh (#139 multifilament nylon twine). Wooden “mules” were attached to both ends of the net to help the net drift more efficiently and to prevent the net from closing while deployed. Trammel nets were drifted downstream perpendicular to the thalweg and were generally fished in main channel, channel border, and tailwater habitats. Shovelnose sturgeon were collected in mid- to late-summer to avoid sampling bias associated with aggregations of spawning fish.

All shovelnose sturgeon were measured to the nearest mm (fork length; FL) and weighed to the nearest gram. In six of the study pools (i.e., Pools 9, 11, 13, 14, 16, and 18), 100 shovelnose sturgeon were randomly euthanized with a lethal dose of Tricaine Methanesulfonate (MS-222) to obtain information on age- and length-at-maturity, gonad weight, and sex ratio. Sacrificed fish were identified as male or female. Gonads from stage-V females (Moos 1978) were preserved in formalin and transported to the laboratory. A marginal pectoral fin ray was removed from 10 shovelnose sturgeon per one-cm length group per pool using methods described by Koch et al. (2008). Fin rays were placed in a numbered coin envelope and air-dried for at least one week prior to mounting and sectioning.

Laboratory methods and data analysis.—Fin rays were cleaned of residual tissue and mounted in epoxy in preparation for sectioning (Koch and Quist 2007). Encapsulated fin rays were sectioned with a Buehler Isomet low-speed saw (Buehler, Lake Bluff, Illinois). Three 0.6-mm thick cross-sections were removed from the region immediately distal to the conspicuous curve near the articulating process of the fin ray (Koch et al. 2008). Three sections were taken from each fin ray to ensure at least one section of high readability was available for age and growth analyses. Fin ray sections were aged with the aid of a compound light microscope equipped with a camera linked to an image analysis system (Image-Pro Plus; Media Cybernetics, Silver Springs, Maryland). Annuli were measured from all fin rays. Mean back-calculated lengths (MBCL) at age were estimated using the Dahl-Lea method (DeVries and Frie 1996):

$$L_i = (L_c / R_c) * R_i$$

where L_i = length at annulus i, L_c = length at capture, R_c = fin ray radius at capture, and R_i = fin ray radius at annulus i. A von Bertalanffy growth function was also used to describe growth of shovelnose sturgeon:

$$L_t = L_\infty * (1 - e^{-K(t - t_0)})$$

where L_t = length at time t, L_∞ = the theoretical maximum length, K = the growth coefficient (the rate at which fish approach L_∞), and t_0 = the time when length would theoretically equal 0 mm. Fecundity was estimated by weighing and counting three subsamples of eggs from each third of both preserved ovaries (i.e., eighteen subsamples per fish). The number of eggs per gram for each subsample was calculated and averaged for each third of each ovary. The resulting average eggs per gram was then multiplied by the weight of each respective third and summed for each ovary to obtain a total estimate of fecundity for each ovary. Estimates for each ovary were summed to obtain a total fecundity estimate for each fish. Non-linear regression was used to develop a fecundity-length equation. Mean relative weight (W_r; Anderson and Neumann 1996) was calculated to evaluate the somatic condition of shovelnose sturgeon in each study pool. Relative weight was calculated as:

$$W_r = 100 * W/W_s$$

where W is the observed weight and W_s is the length-specific standard weight for the species. The standard weight for shovelnose sturgeon was estimated as:

$$\log_{10} W_s = -6.287 + 3.330 * \log_{10} FL,$$

where W_s is the length-specific standard weight in grams and FL is fork length in millimeters (Quist et al. 1998). Size structure of shovelnose sturgeon sampled from each pool was assessed using proportional size distributions (PSDs; Anderson and Neumann 1996; Guy et al. 2007; Neumann and Allen 2007). Proportional size distribution was calculated as the number of fish greater than or equal to quality length (380 mm) divided by the number of fish greater than or equal to stock length (250 mm; Quist et al. 1998). Additional proportional size distribution indices were calculated as the number of fish greater than or equal to a specified length divided by the number of stock-length fish. Specified lengths included preferred (PSD-P; 510 mm), memorable (PSD-M; 640 mm), and trophy lengths (PSD-T; 810 mm; Quist et al. 1998). Subsampled age data were extrapolated to the entire sample using an age-length key (DeVries and Frie 1996). Using the resulting age structure data, total annual mortality (A) of age-6 and older shovelnose sturgeon was estimated with a weighted catch curve (Ricker 1975; Van Den Avyle 1999; Miranda and Bettoli 2007).

Differences in size structure, sex ratio, mean back-calculated length at age, and mean relative weights were examined for all study pools. Differences in size structure and sex ratios among pools were analyzed using chi-square (χ^2) analysis (Neumann and Allen 2007). Mean back-calculated length at age 5 and mean relative weights were compared among pools using analysis of variance (ANOVA). A difference in mean back-calculated length at age 5 of male and female shovelnose sturgeon was analyzed with a Student's *t*-test. Pairwise comparisons (i.e., between pools) of mean back-calculated length at age and W_r were analyzed using least-squared means. Statistical analyses were performed in SAS (SAS Institute 2003) with $\alpha = 0.05$.

Population simulations.—The effects of minimum length limits on harvest of shovelnose sturgeon were simulated using a Beverton-Holt yield-per-recruit model. Yield per recruit (Y) was estimated using the following equation (Slipke and Maceina 2001):

$$Y = (F * N_t * e^{Zr} * W_\infty) * \mathrm{K}^{-1} * [\beta(X, P, Q)] - [\beta(X_1, P, Q)],$$

where F = the instantaneous rate of fishing mortality, $N_t = N_0 \cdot e^{-M(t_r - t_n)}$; the number of recruits entering the fishery at some minimum length at time t; N_0 = the initial population size; M = the instantaneous rate of natural mortality; t_r = the age of recruitment to the fishery; $r = (t_r - t_0)$, the time to recruit to the fishery; t_0 = the age when length would theoretically be 0 mm from the von Bertalanffy model; Z = the instantaneous rate of total mortality ($F + M$); W_∞ = the asymptotic weight, derived from the length–weight relationship and L_∞; β = the incomplete beta function, $X = e^{-Kr}$; K = the growth coefficient from the von Bertalanffy model; $X_1 = e^{-K(Age_{max} - t_o)}$; $\mathrm{Age}_{\mathrm{max}}$ is the maximum age from the sample; $P = Z/K$; and $Q = 1 +$ the slope of the length-weight relationship.

In addition to information on growth, maximum age, and length-weight relationships, rates of conditional natural mortality (*cm*; mortality that occurs in absence of fishing mortality) and conditional fishing mortality (*cf*; mortality due to fishing in absence of natural mortality) were specified in the models. Previous research has estimated low rates (e.g., approximately 10%) of total annual mortality of shovelnose sturgeon in unexploited reaches of the Missouri River (Quist et al. 2002). Colombo et al. (2007) estimated natural mortality rates of 10% in the middle Mississippi River. As such, harvest simulations were conducted with a *cm* of 10%. Conditional fishing mortality was modeled at levels varying from 0% (i.e., an unexploited fishery) to 90%. Simulations were conducted using five different minimum length limits (i.e., 250 mm, 535 mm, 610 mm, 685 mm, and 710 mm). The 250-mm length limit represented a scenario of unregulated harvest, as it is the approximate length of the smallest shovelnose sturgeon collected in commercial gears. The 535-mm length limit represents the approximate length that shovelnose sturgeon in the UMR are fully recruited to commercial gear. The 610-mm and 685-mm length limits are the current minimum lengths for commercial harvest of shovelnose sturgeon in Illinois and Iowa, respectively (Table 1). Additionally, a 710-mm length limit was evaluated as a more restrictive regulation than currently exists in the UMR. Yield was plotted against exploitation to evaluate the likelihood of growth overfishing. Growth overfishing occurs when yield decreases with increasing levels of exploitation because fish are harvested before they are able to realize their growth potential (Slipke and Maceina 2001).

In addition to assessing the likelihood of growth overfishing, the potential for recruitment overfishing was examined. Recruitment overfishing occurs when fish are harvested from a population before they replace themselves, thus leading to population decline and possible stock collapse. Recruitment overfishing is traditionally examined by assessing the reproductive potential of an exploited population relative to that of an unexploited population (Goodyear 1993; Mace and Sissenwine 1993). Spawning potential ratio (SPR) represents the proportion of lifetime egg production of an exploited population compared to that of an unexploited population. Spawning potential ratio is calculated as:

$$\mathrm{SPR} = [100^{*}\ (P_{\mathrm{exploited}} / P_{\mathrm{unexploited}})],$$

where lifetime egg production (P) of a cohort of recruits is calculated using the formula:

$$P = \sum_{i=1}^{n} E_i \prod_{j=0}^{t=1} \mathrm{S}_{ij}$$

where n = the number of ages in an unfished population, E_i = the mean fecundity of females of age i, $S_{if} = e^{-(F_{ij}+M_{ij})}$, the density-dependent annual survival probabilities of females of age i when age j, F_{ij} = the instantaneous fishing mortality of females of age i when age j, and M_{ij} = the instantaneous natural mortality rate of females of age i when age j. An unexploited population has an SPR of 100, and SPR decreases as the population is exploited. Spawning potential ratios were analyzed at different levels of exploitation in response to the five aforementioned minimum length limits. Researchers suggest that an SPR for a population should be maintained above 20% or 30% to avoid recruitment overfishing (e.g., Goodyear 1993). However, analyses similar to the current study have suggested the possibility of recruitment overfishing of shovelnose sturgeon populations at an SPR of 40% (e.g., Colombo et al 2007). As such, a threshold of 40% was considered the minimum SPR to prevent recruitment overfishing. Simulations of yield and SPR were analyzed for each of the study pools using pool-specific population parameter estimates. In addition, study-wide models (hereafter termed pooled models) were evaluated by using pooled population parameter estimates (e.g., von Bertalanffy parameters) from throughout the study area.

Scientists have raised concern about age and growth data obtained from shovelnose sturgeon fin rays (Morrow et al. 1998; Whiteman et al. 2004). Therefore, variation in age and growth parameter estimates was evaluated to provide insight on the potential effects of aging errors. Specifically, maximum ages were altered by 2 and 5 years above and below the maximum observed age of shovelnose sturgeon in our study while holding all other parameters constant. Similarly, growth estimates were manipulated by increasing and decreasing all mean back-calculated lengths at age by 5% and 10%. Once again, all other parameters were held constant. These analyses were only performed using pooled models.

The multijurisdictional nature of the UMR commercial shovelnose sturgeon fishery (i.e., differing regulations by state) was mimicked to assess the potential effects of differing regulations on SPR. We analyzed our models using a proportion of recruits subjected to one regulation and the remaining recruits to the other regulation. This reflected a scenario in which shovelnose sturgeon are harvested from a border water regulated by two different length limits. For example, the fate of 500 recruits were analyzed with a 610-mm length limit (i.e., the minimum length for Illinois harvest), while the remaining 500 recruits were subject to a 685-mm minimum length limit (i.e., the minimum length for Iowa harvest). The number of eggs for each level of exploitation and regulation was summed and divided by the lifetime egg production of the modeled unexploited population to estimate SPR. Scenarios representing a one-quarter, one-half, and three-quarter allocation of harvest between 610-mm and 685-mm minimum length limits (i.e., Illinois and Iowa regulations) were evaluated. Simulations representing allocations with 610-mm and 710-mm minimum length limits were also examined. Finally, models were evaluated to reflect the scenario of a closed shovelnose sturgeon fishery in Iowa (i.e., no shovelnose sturgeon harvest for Iowa's proportion of the recruits) and a 610-mm minimum length limit. Similar to models evaluating possible aging errors, these models were only performed using pooled models. All simulations were analyzed with an initial population of 1,000 recruits using Fisheries Analysis and Simulation Tools (FAST) software, version 2.1 (Slipke and Maceina 2001).

RESULTS

Population characteristics.-A total of 1,682 shovelnose sturgeon was sampled from the eight study pools during 2006 and 2007 (Figure 3). Shovelnose sturgeon varied in fork length from 233 mm to 850 mm and weighed from 67 g to 3,394 g. Shovelnose sturgeon from Pool 4 had the highest mean length (mean ± SE; 684 ± 3.8 mm), while Pools 13 (569 ± 5.4 mm) and 14 (569 ± 8.3 mm) had the lowest mean lengths. Size structure indices were generally higher in upstream pools (i.e., Pools 4, 7, and 9) since small shovelnose sturgeon (i.e., less than 530 mm) were absent in these samples. For example, PSD-P was significantly higher ($\chi^2 = 7.72$, df = 1, $P = 0.005$) in Pools 4, 7, and 9 than in the other pools. Although shovelnose sturgeon less than 530 mm were present in the samples from all other study pools, they represented less than 16% of the total catch.

The oldest shovelnose sturgeon were generally sampled in upstream pools (Figure 4). The maximum age for shovelnose sturgeon was 17 years, observed in samples from Pools 7 and 9. The minimum age of sampled shovelnose sturgeon was 1 year and was only observed in Pool 13. Samples from Pools 13 and 14 contained a high proportion of young shovelnose sturgeon. For example, age-4 and younger shovelnose sturgeon comprised at least 55% of the samples from Pools 13 and 14, whereas the proportion of age-4 and younger shovelnose sturgeon never exceeded 30% in the other study pools. Estimates of total annual mortality (A) varied from 21% in Pool 9 to 34% in Pool 13 and were generally lower in upstream pools.

Although growth of shovelnose sturgeon was similar among pools (Figure 5), significant differences in MBCL at age 5 between pools were detected ($F_{7,\,1184} = 21.98$; $P =$ 0.0001). For instance, MBCL at age 5 was significantly lower for shovelnose sturgeon from

Pool 16 than all other pools ($P = 0.0001$), whereas MBCL at age 5 for fish in Pool 14 was significantly higher ($P = 0.01$) than all other pools (Figure 6). In addition to a shorter length at age 5, shovelnose sturgeon from Pool 16 appeared to grow at a slower rate throughout their life. No difference was observed between growth (e.g., MBCL at age 5) of male and female shovelnose sturgeon ($t = 0.29$; df = 456; $P = 0.77$). The pooled von Bertalanffy growth equation for shovelnose sturgeon was $L_t = 767 * (1 - e^{-0.219\ (t\ +\ 0.2016)})$.

Fifty-eight percent of all sacrificed shovelnose sturgeon ($N = 600$) were female (1.4 F:M). The sex ratio of shovelnose sturgeon was skewed towards females (Figure 6). In five of the six study pools where shovelnose sturgeon were sacrificed, females outnumbered males, and in three of these pools, the sex ratio (F:M) was greater 1.5. Pool 13 had the highest female to male ratio (2.1 F:M), whereas Pool 14 had the only female to male ratio below 1 (0.9 F:M; Figure 7).

Mean W_r varied by pool from 86.6 (SE = 0.006) to 96.3 (SE = 0.006; Figure 6), and the overall mean W_r of shovelnose sturgeon in study area was 91.9 (SE = 0.002). Although shovelnose sturgeon populations in the study area were in good condition, significant differences in mean W_r were observed ($F_{7,\ 1647} = 21.72$; $P = 0.0001$). Mean W_r of shovelnose sturgeon in Pool 13 was significantly lower than all other pools ($P = 0.0405$). Shovelnose sturgeon from Pools 9 (94.2 ± 0.007) and 18 (96.3 ± 0.008) had the highest mean relative weights.

Six-hundred shovelnose sturgeon were sacrificed among the study pools. Thirty-two of these fish were stage-V female shovelnose sturgeon that varied from 570 mm to 770 mm. Fecundity varied from 20,120 to 66,303 among fish and averaged 34,908 eggs per female (SE = 2,183). Sufficient numbers of stage-V females were not collected to compare fecundity estimates between pools. Nearly all of the gravid females were greater than 615 mm, and only one gravid female shovelnose sturgeon less than 600 mm was collected (Figure 7). Although the youngest mature female (i.e., as indicated by black eggs or spent ovaries) shovelnose sturgeon was age 6, most (i.e., 97%) female shovelnose sturgeon were mature at age 7 or older. Males appeared to mature at age 5; however, distinguishing mature testes from immature testes was often difficult due to the season when fish were sampled.

Population simulations.-Simulated yields from the Beverton-Holt yield-per-recruit model were generally highest in upstream study pools (Figure 8). Changes in yield in response to the simulated minimum length limits were similar among pools. At low levels of exploitation, the highest yields occurred with a 535-mm or 610-mm minimum length limit. Patterns of yield were similar between the 685-mm and 710-mm length limits; however, yields were higher with a 685-mm length limit compared to a 710-mm length limit at all levels of exploitation. The potential for growth overfishing was evident with the three least-restrictive minimum length limits. Yield generally began decreasing in response to a 535-mm length limit at an exploitation rate of about 30%. In simulations with a 610-mm length limit, growth overfishing became evident at exploitation levels above 40%. Only the three most conservative minimum length limits were evaluated for Pool 16 because the asymptotic length from the von Bertalanffy growth model (681 mm) was less than 685 mm. Results of the pooled model were similar to those from individual study pools, where growth overfishing would likely occur with the three least-restrictive length limits (Figure 9).

The response of yield to changes in growth and maximum age were variable, especially when restrictive length limits were simulated (Figures 10 and 11). Increasing growth and maximum age had a positive effect on yield, whereas decreasing growth and maximum age reduced yield. Although yield estimates were dependent on maximum age and growth estimates, patterns used to assess the likelihood of growth overfishing were consistent with models using observed data. In the simulation using observed data, only the two most restrictive minimum length limits prevented growth overfishing at all levels of exploitation. The only scenario that changed when growth or maximum age was altered was with the 610-mm length limit. Using observed data, the 610-mm protected fish from growth overfishing; however, decreasing growth by 10% resulted in growth overfishing with a 610-mm length limit.

Similar to yield, SPR followed consistent patterns among study pools (Figure 12). Generally, SPR approached or decreased to 40% for the three most liberal length limits at exploitation levels of 20% or lower. Spawning potential ratio did not decrease to levels below 40% for the two most restrictive length limits, except at high levels of exploitation. Spawning potential ratio was generally higher at a given level of exploitation in populations with lower L_∞ values (e.g., Pools 13 and 16). For example, SPR was 79% in Pool 13 at an exploitation of 20% with a 685-mm length limit. In Pool 9, SPR was 66% at the same level of exploitation. Spawning potential ratios estimated with a 685-mm minimum length limit were approximately 20% higher at 10% exploitation than with a 610-mm length limit. At exploitation rates of 30%, SPR was nearly twice that observed with a 610-mm minimum length limit. Theoretical maximum length, sex ratio, and maximum length are factors that influenced the lifetime egg production in a given pool. The highest maximum lifetime egg production was 25.2 x 10^6 eggs (Pool 9) and the lowest was 11.5 x 10^6 eggs (Pool 16). Once again, only the three least-restrictive length limits were evaluated for Pool 16. In the pooled model, SPR was above 40% at all levels of exploitation with the two most-restrictive minimum length limits (Figure 13). Spawning potential ratio decreased below 40% at approximately 20% exploitation or less with the three least-restrictive regulations, suggesting that recruitment overfishing of shovelnose sturgeon is possible at relatively low levels of exploitation.

Similar to yield, spawning potential ratio was sensitive to changes in maximum age (Figure 14) and growth (Figure 15). The greatest effects were observed in simulations with the most restrictive minimum length limits. Increasing maximum age decreased SPR. For example, in the simulation of a 685-mm length limit at an exploitation rate of 30%, decreasing maximum age by 5 years increased SPR by 26%, whereas increasing maximum age by 5 years decreased SPR by 12%. Increasing growth had a negative effect on SPR, as shovelnose sturgeon recruited to the commercial fishery at a younger age. Thus, harvest of younger shovelnose sturgeon increased, decreasing lifetime egg production.

Spawning potential ratios estimated in simulations of multijurisdictional regulations (e.g., 610-mm and 685-mm length limits) followed predictable patterns between the two base regulations (Figure 16). For example, in the assessment of a 50:50 allocation in harvest between two regulations, SPR was the average of the estimated SPR for the two base length limits. In the simulation representing the current regulations of Iowa and Illinois (i.e., 685-mm and 610-mm length limits) spawning potential ratio decreased to below 40% at about 40% exploitation (50:50 harvest scenario), and at about 25% exploitation in the model simulating 25% of the harvest coming from Iowa. Spawning potential ratios were increased in the simulation of a 710 mm-610 mm split as a larger proportion of recruits were protected. In the simulation of a partition between the current Illinois regulation and a closed season in

Iowa, SPR was dramatically increased in response to the complete protection of a proportion of the recruits. If 25% of the recruits are not subjected to harvest because of a closed seaon, SPR does not decrease to levels below 40% until an exploitation of approximately 45%.

DISCUSSION

Mean length and size structure of shovelnose sturgeon was generally highest for upstream populations of shovelnose sturgeon in the UMR. A number of factors may be responsible for this pattern. Larger fish in upstream pools may be the result of relatively low harvest of shovelnose sturgeon in the upper pools of our study area, where shovelnose sturgeon are able to grow to older ages and larger sizes. The absence of small shovelnose sturgeon (i.e., less than 530 mm) in upstream study pools was of particular interest because it may indicate a lack of recruitment. However, this scenario is unlikely since small shovelnose sturgeon were sampled in the tailwaters of Pool 4 with otter trawls during 2006 (J. Meerbeek, Minnesota DNR, personal communication). The paucity of small shovelnose sturgeon in our samples from upstream pools is most likely due to sampling bias. Trammel nets were primarily drifted in tailwater habitats in Pools 4, 7, and 9 because of a lack of flow in other portions of the pool. In other study pools, sufficient current was usually available to enable drifting of trammel nets in main channel and channel border habitats, which may be more suitable for small shovelnose sturgeon. It should be noted however, that small shovelnose sturgeon were collected in downstream study pool tailwaters. Regardless, other studies have also reported difficulties sampling small shovelnose sturgeon, which has commonly led to high size structure indices reported for shovelnose sturgeon populations. For instance, Quist et al. (1998) analyzed data from 32 populations of shovelnose sturgeon and reported that 31 populations had a PSD greater than 79. Hamel and Steffensen (2006) reported that no gears (e.g., gill nets, trammel nets, otter trawls) were effective at sampling substock (i.e., ≤ 249 mm) and stock-length (i.e., 250-379 mm) shovelnose sturgeon in the Missouri River. Kennedy et al. (2007) reported a PSD of 100 and PSD-M of 81 for shovelnose sturgeon in the Wabash River, Indiana, where shovelnose sturgeon less than 550 mm represented only 0.2% of the total sample.

Many studies have documented the longevity of shovelnose sturgeon. Quist et al. (2002) reported that in the southern portion of the shovelnose sturgeon's distribution, maximum ages vary from 12 to 16 years. Our data corroborate these findings since maximum observed age varied from 14 to 17 in the UMR. Shovelnose sturgeon have been observed as old as 30 years in the Wabash River, Indiana (Kennedy et al. 2007), and 43 years old in the upper Missouri River (Everett et al. 2003). Lower maximum ages of shovelnose sturgeon in the UMR may be due to harvest, as the Missouri and Wabash rivers have relatively low levels of exploitation (Quist et al. 2002; Kennedy and Sutton 2007). Although our results may have been confounded by sampling bias, age structures of shovelnose sturgeon populations were skewed towards older individuals in the upstream pools. In addition to possibly affecting maximum age, harvest may also be a factor contributing to differences in age structures of shovelnose sturgeon. For example, the Wisconsin-Illinois border intersects the upstream reaches of Pool 12. Downstream of this point, the regulation for shovelnose sturgeon harvest changes from a 685-mm minimum length limit to a 610-mm minimum length limit. From 1995 to 2005, an average of 17,866 kg of shovelnose sturgeon was harvested from Pools 9, 10, and 11 (i.e., pools north of Illinois). In pools bordering Illinois (i.e., Pools 12-19), harvest was 24% higher (i.e., 22,229 kg). Our results indicate that in the four study pools upstream of the Illinois border, 34% of age-6 and older shovelnose sturgeon were older than age 10. In the four study pools downstream this point, only 17% of age-6 shovelnose sturgeon were older than age 10. These results indicate that restrictive length limits may affect age structure of shovelnose sturgeon.

Mortality rates of shovelnose sturgeon are variable throughout North America and are most likely influenced by anthropogenic factors such as commercial harvest and habitat alterations (Quist et al. 2002; Jackson 2004). Quist et al. (2002) reported total annual mortality rates of approximately 10% from commercially unexploited reaches of the upper and middle Missouri River, whereas estimates of total annual mortality from the Mississippi River vary from 20% (lower Mississippi River; Morrow et al. 1998) to 41% (middle Mississippi River; Jackson 2004). Our results indicate mortality rates of shovelnose sturgeon were generally higher in downstream study pools. Pools 13 and 16 had the highest observed mortality rates in the study. Interestingly, harvest records from 1995-2005 indicate that Pools 13 and 16 had the highest shovelnose sturgeon harvest of any study pool (Figure 2).

Growth of shovelnose sturgeon is another population characteristic that is highly variable throughout their distribution. Mean back-calculated length at age 5 of shovelnose sturgeon varies from 576 mm in the upper Missouri River to 470 mm in the lower Missouri River (Quist et al. 2002). Everett et al. (2003) reported that growth of shovelnose sturgeon was significantly greater in the Yellowstone River than in upper Missouri River. Our results indicate similar spatial differences in growth of shovelnose sturgeon. Possible explanations for differences in growth include habitat quality, abundance of prey, influence of tributaries, and density-dependent interactions (i.e., competition). Everett et al. (2003) suggested that alterations in hydrology may account for spatial differences in shovelnose sturgeon growth between the Missouri and Yellowstone rivers. Modde and Schmulbach (1977) indicated that shovelnose sturgeon had lower condition factors during periods of high discharge because increased velocities mobilized food items and reduced aggregations of prey. High harvest rates may also influence growth estimates of shovelnose sturgeon due to commercial harvesters selecting the largest, fastest-growing individuals; thus resulting in a population dominated by slow-growing fish. If harvesters are selecting the fastest-growing shovelnose sturgeon from each age-class, back-calculated lengths at age would be smaller for older individuals than for younger individuals (i.e., Lee's phenomenon; Ricker 1975; DeVries and Frie 1996). Such patterns may explain the slow growth exhibited by shovelnose sturgeon in Pool 16, which has historically had the highest levels of harvest in our study area. We examined this further by compiling mean back-calculated lengths at age 1 for each age-class in each pool. Not only was mean back-calculated length at age 1 was lower for older year classes of shovelnose sturgeon in Pool 16, but several of the other study pools as well (Figure 17). A primary hypothesis for Lee's phenomena is that slow-growing individuals have decreased vulnerability to fishing mortality because they do not recruit to fishing gear as early as the fast-growing individuals in the cohort (Ricker 1975; DeVries and Frie 1996). Our results appear to support this hypothesis, as no evidence of Lee's phenomena was shown in the pools with low exploitation (i.e., Pools 4 and 7). In contrast, significant decreasing trends in MBCL at age 1 of older fish was observed in all other study pools except for Pool 18. These results indicate that growth estimates for shovelnose sturgeon may be influenced by commercial harvest.

Few studies have evaluated sex ratios of shovelnose sturgeon populations, and those that have examined sex ratios provide few consistencies. Colombo et al. (2007) found a sex ratio of 1:1 in the middle Mississippi River. In contrast, Jackson (2004) reported that only 20% of shovelnose sturgeon sampled from the middle Mississippi River were females. Jackson (2004) contends that this estimate was confounded by concentrations of spawning fish, as many female fish had been harvested from the area immediately prior to sampling.

Kennedy (2005) estimated a female to male ratio of 0.6:1 (i.e., 36% female) in the Wabash River. In the UMR, a higher proportion of males might be expected due to a fishery targeted at females. Our results indicate sex ratios are skewed towards a higher number of females. In three of the six study pools where sex ratios were evaluated, the female to male ratio was above 1.5. The skewed sex ratio could be an artifact of sampling bias. However, such bias is unlikely since our sampling was conducted in multiple pools and over a large time span. Regardless, the large proportion of females in shovelnose sturgeon populations may be evidence of a mechanism to balance the sex ratio of spawning fish. Previous research suggests female shovelnose sturgeon have a spawning periodicity of three years, whereas males spawn approximately every two years (Moos 1978). Thus, females would have to comprise approximately 60% of the population to maintain an annual spawning ratio of one female to one male.

No clear spatial patterns in condition (i.e., mean W_r) of shovelnose sturgeon populations were observed in the UMR. Quist et al. (1998) reported that shovelnose sturgeon W_r values varied longitudinally in the Missouri River, where populations from upstream reaches exhibited higher W_r than downstream populations. Quist et al. (1998) suggested a target mean W_r range of 80-90 for non-upper Missouri River shovelnose sturgeon populations. All mean relative weights of shovelnose sturgeon for pools in our study area either fell within or exceeded this range, suggesting that shovelnose sturgeon in the UMR are in good condition. Mean relative weights for shovelnose sturgeon from the UMR were generally higher than those reported from the Missouri River. Hamel and Steffensen (2007) reported a mean W_r of 82 for shovelnose sturgeon in a reach of the Missouri River from

Gavin’s Point Dam to the confluence of the Platte River. In the lower Missouri River, Grady et al. (2001) reported a mean W_r of 87.

Size at maturity is highly variable throughout the distribution of shovelnose sturgeon. In slower growing populations, such as the Missouri River and White River, female shovelnose sturgeon become sexually mature as small as 414 mm (Zweiacker 1967; L. Holt, Arkansas Game and Fish Commission, personal communication). Our data indicate that most female shovelnose sturgeon in the UMR mature at approximately 615 mm and 7 years of age. Monson and Greenback (1947) and Helms (1974) suggested female shovelnose sturgeon in the UMR mature between 615 mm – 635 mm and at age 7. Based on this historical literature, it does not appear that size- or age-at maturity has changed substantially over the last several decades.

In all study pools except Pool 16, population simulations showed the potential for growth overfishing with simulated minimum length limits less than 685 mm. More restrictive length limits allowed shovelnose sturgeon to realize a larger proportion of their growth potential before harvest. Increasing minimum length limits beyond 685 mm actually reduced yield because individuals died naturally instead of being harvested. Our results are concordant with the results of previous research on shovelnose sturgeon populations in the middle Mississippi River. Colombo et al. (2007) reported that a 610-mm minimum length limit was not sufficient to prevent growth overfishing in the middle Mississippi River. Consequently, they recommended the implementation of a 685-mm minimum length limit.

Although the consequences of growth overfishing are important to consider, recruitment overfishing is a much greater concern as it can lead to population decline and extirpation. Our simulations indicate that there is the potential for recruitment overfishing at exploitation levels of 20% and greater with a 610-mm length limit. Increasing the minimum length limit for shovelnose sturgeon harvest to 685 mm could prevent recruitment overfishing in the UMR as SPR increased to levels above the minimum thresholds (i.e., 20% to 40%) suggested by previous research (e.g., Goodyear 1993; Colombo et al. 2007). Due to the unique and complex reproductive ecology of shovelnose sturgeon, researchers have suggested higher SPR thresholds for assessing recruitment overfishing for shovelnose sturgeon. Quist et al. (2002) suggested the possibility of a minimum SPR target value of 40-50%, which would further strengthen the argument for more restrictive shovelnose sturgeon harvest regulations in the UMR. Given the conservation status of the majority of the world's sturgeon species (Birstein 1993; Boreman 1997), conservative approaches to shovelnose sturgeon harvest regulations are warranted.

Yield was more sensitive to changes in growth than to changes in maximum age in our simulations. In a given simulation, the potential for growth overfishing was not altered by changes in growth and maximum age except for the 610-mm length limit with a 10% decrease in growth. Therefore, although estimates of yield may differ due to aging error, the conclusions regarding growth overfishing remain consistent. Spawning potential ratio was also sensitive to changes in growth and maximum age. Increasing maximum age resulted in lower SPR values since more eggs were produced over the recruits' lifetime in the simulated unexploited population. Decreasing maximum age had the opposite effect on SPR. If we underestimated maximum age by five years (i.e., a 29% change in maximum age), SPR did not decrease to levels below 40% until exploitation reached 35% with a 610-mm length limit. In the original model, SPR reached 40% at 20% exploitation. In the simulations of the two most restrictive length limits, SPR did not decrease to levels below 40% when maximum age was altered until the highest levels of exploitation. As such, a 685-mm or longer minimum length limit is still recommended if errors in maximum age occur. Simulated errors in growth also affected SPR. Increasing growth decreased the amount of time required for shovelnose sturgeon to recruit to the commercial fishery. As a result, more fish were harvested earlier in life, thus decreasing egg production. Conversely, decreasing growth increased SPR and allowed shovelnose sturgeon to reach reproductive age well before they were recruited to the fishery. Spawning potential ratio was more affected by varying growth in scenarios where more restrictive length limits were evaluated. At 30% exploitation with a 535-mm length, decreasing growth by 10% increased SPR from 17% to 28%, whereas in the 610-mm length limit simulation, SPR increased from 32% to 56%. In the 685-mm simulation using observed data, SPR does not fall below 40% until high levels of exploitation. When growth is increased by 5% and 10%, SPR decreases to levels below 40% at exploitation levels of 35% and 25%, respectively. Age-validation studies conducted on white sturgeon *Acipenser transmontanus* and pallid sturgeon (e.g., Rien and Beamesderfer 1994; Paragamian and Beamesderfer 2003; Hurley et al. 2004) indicate that true ages are underestimated by pectoral fin rays. Although age estimates have not been validated for shovelnose sturgeon, any aging errors are likely to be underestimates of age. Such errors would result in lower SPR, while simulated yields may be increased. Despite these considerations, a 685-mm or longer minimum length limit would still be recommended to prevent recruitment overfishing.

Many studies have shown longitudinal differences in population parameters of shovelnose sturgeon. The current study largely corroborates these findings, as significant differences were found among pools with regard to size and age structure, mortality, growth, condition, and sex ratios. Although some movement of shovelnose sturgeon between navigation pools of the UMR has been documented (Hurley 1983), this study suggests that local effects such as harvest may influence population parameters of shovelnose sturgeon. In light of the recent increase in shovelnose sturgeon exploitation, our results indicate that the implementation of a basin-wide 685-mm or longer length limit on shovelnose sturgeon harvest is needed to provide a sustainable shovelnose sturgeon fishery. A 685-mm minimum length limit approximately doubles SPR values estimated with a 610-mm length limit. Our models of multijurisdictional regulations attempt to predict the effects of multiple minimum length limits on border waters. With empirical harvest data, the percentage of harvest from each state could be calculated, thus increasing the resolution and specificity of these models. Unfortunately, current data with the necessary resolution to evaluate the proportion of harvest between states is unavailable. Although analyses examining yield and SPR are sensitive to errors in input parameters, simulations suggest more restrictive harvest regulations (i.e., 685-mm length limit) are prudent in management of the species. Additionally, our results are corroborated by research from the middle Mississippi River (i.e., Colombo et al. 2007), which also reports that current regulations (i.e., 610-mm length limit) are not sufficient to prevent growth and recruitment overfishing. The conservation of shovelnose sturgeon should be a high priority in the Mississippi River due to the threatened nature of the world’s sturgeon species. As such, sturgeon populations should be monitored closely, and similar analyses should be conducted in the future to ensure the sustainability of the shovelnose sturgeon fishery.

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Table 1. States of the upper Mississippi River and current harvest regulations for shovelnose sturgeon.

State	River	Recreational size and bag limits	Commercial regulation	Commercial Season
Iowa	Mississippi River	No regulation	685 mm minimum	Oct 15 – May 15
	Missouri River	No length limit, 10 per day	No harvest	None
Wisconsin	Mississippi River-MN Border	No length limit, 10 per day	635 mm minimum (set lines only)	Annual
	Mississippi River-IA Border	No regulation	685 mm – 813 mm harvestable slot	Oct 15 – May 15
Illinois	Mississippi River	No regulation	610 mm – 813 mm harvestable slot	Oct 1 – May 31
	Wabash River	No regulation	635 mm minimum	Oct 1 – May 31
	Ohio River	No regulation	610 mm – 813 mm harvestable slot	Oct 1 – May 31
Missouri	Mississippi River	762 mm maximum, 10 per day	610 mm – 813 mm harvestable slot	Oct 15 – May 15
	Missouri River	762 mm maximum, 10 per day	610 mm – 762 mm harvestable slot	Nov 1 – May 15

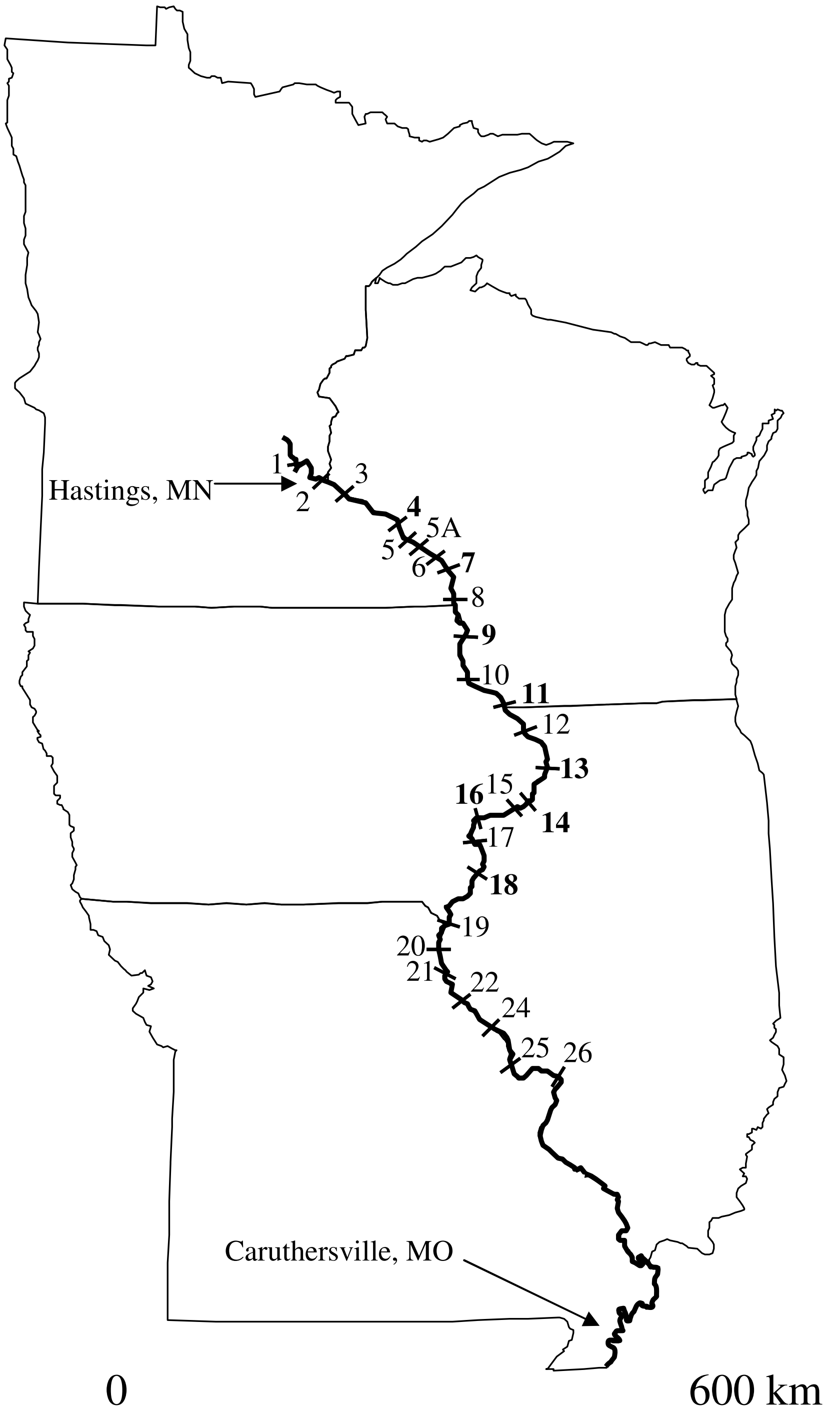

Figure 1. Upper Mississippi River with numbers indicating lock and dams. Bold numbers indicate locations of study pools.

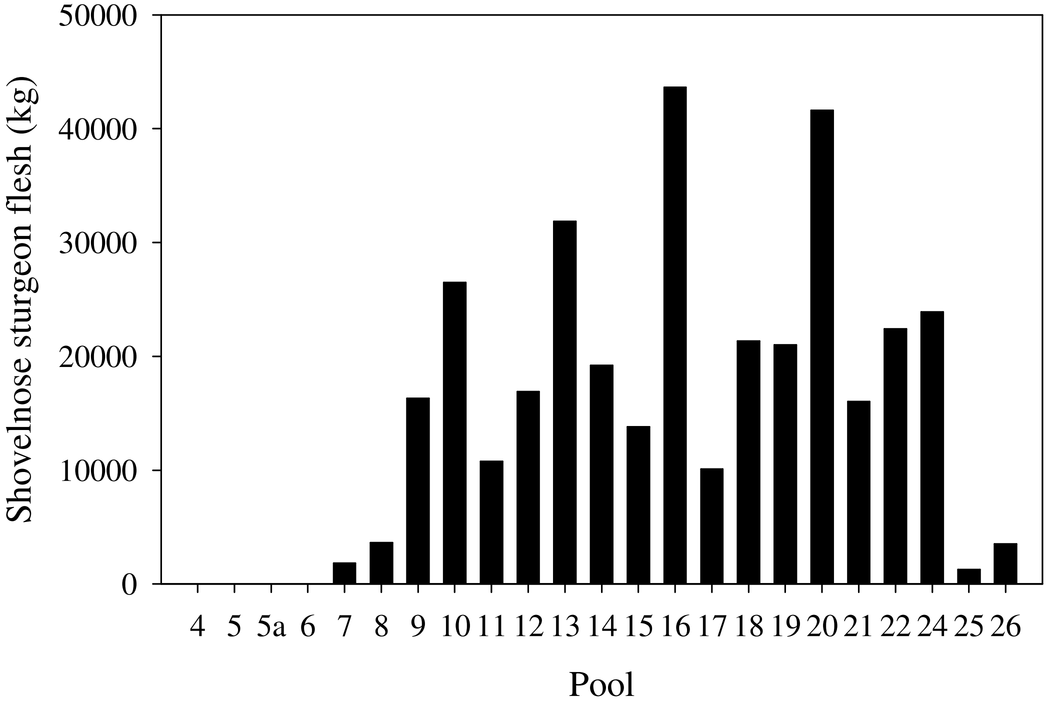

Figure 2. Reported shovelnose sturgeon flesh harvest (kg) by pool of the upper Mississippi River from 1995 to 2005.

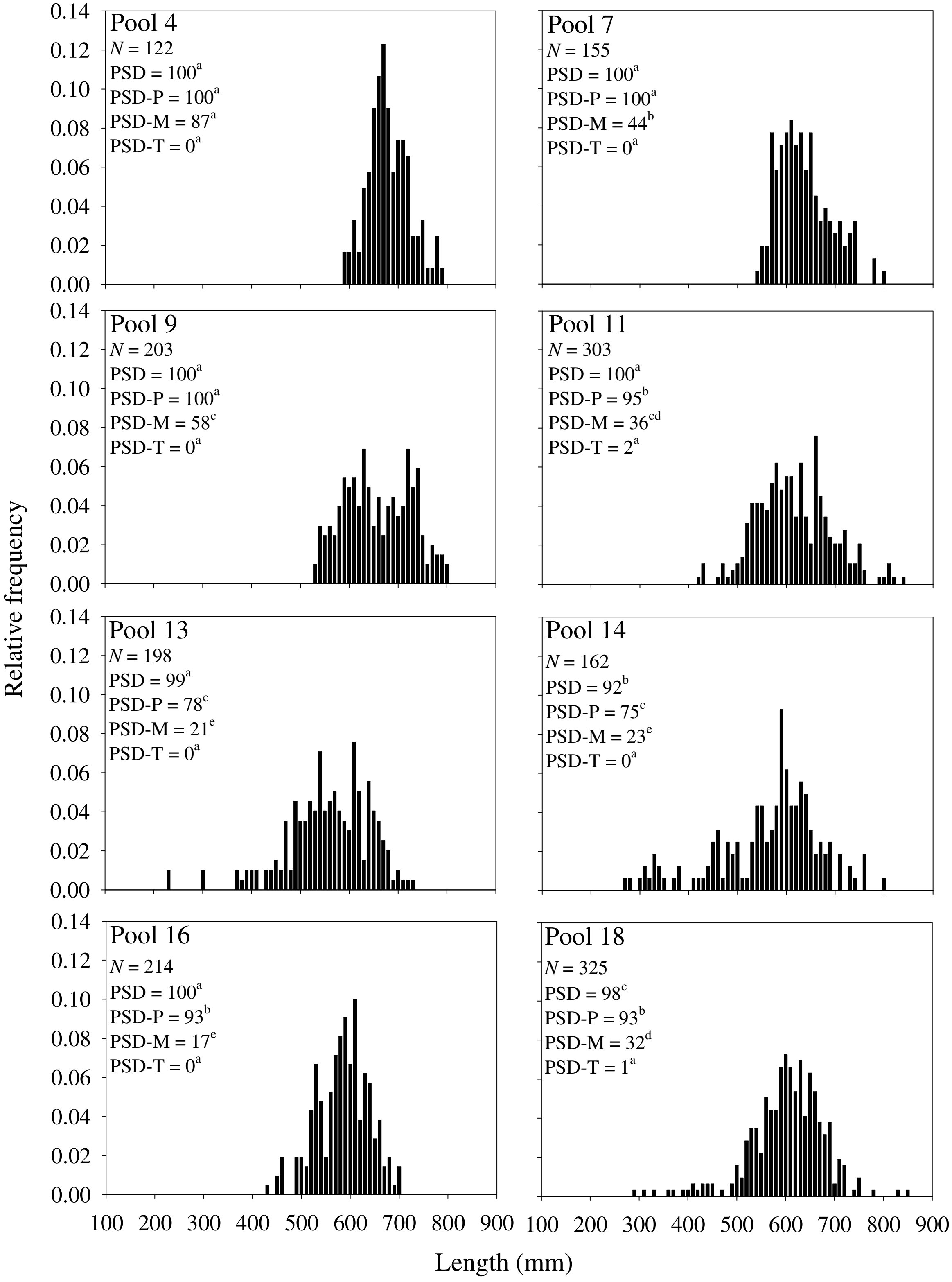
Relative frequency
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Pool 4
N = 122
PSD = 100^a
PSD-P = 100^a
PSD-M = 87^a
PSD-T = 0^a
Pool 7
N = 155
PSD = 100^a
PSD-P = 100^a
PSD-M = 44^b
PSD-T = 0^a
Pool 9
N = 203
PSD = 100^a
PSD-P = 100^a
PSD-M = 58^c
PSD-T = 0^a
Pool 11
N = 303
PSD = 100^a
PSD-P = 95^b
PSD-M = 36^{cd}
PSD-T = 2^a
Pool 13
N = 198
PSD = 99^a
PSD-P = 78^c
PSD-M = 21^e
PSD-T = 0^a
Pool 14
N = 162
PSD = 92^b
PSD-P = 75^c
PSD-M = 23^e
PSD-T = 0^a
Pool 16
N = 214
PSD = 100^a
PSD-P = 93^b
PSD-M = 17^e
PSD-T = 0^a
Pool 18
N = 325
PSD = 98^c
PSD-P = 93^b
PSD-M = 32^d
PSD-T = 1^a
100
200
300
400
500
600
700
800
900
Length (mm)

Figure 3. Length frequency distributions of shovelnose sturgeon sampled from eight pools of the upper Mississippi River, 2006-2007. Size structure indices include proportional size distribution (PSD) and PSD of preferred-(PSD-P), memorable-(PSD-M) and trophy-length (PSD-T) shovelnose sturgeon. Differences among pools were examined for each size structure index. Size structure index values with the same letter were not significantly different ($P < 0.05$) among pools.

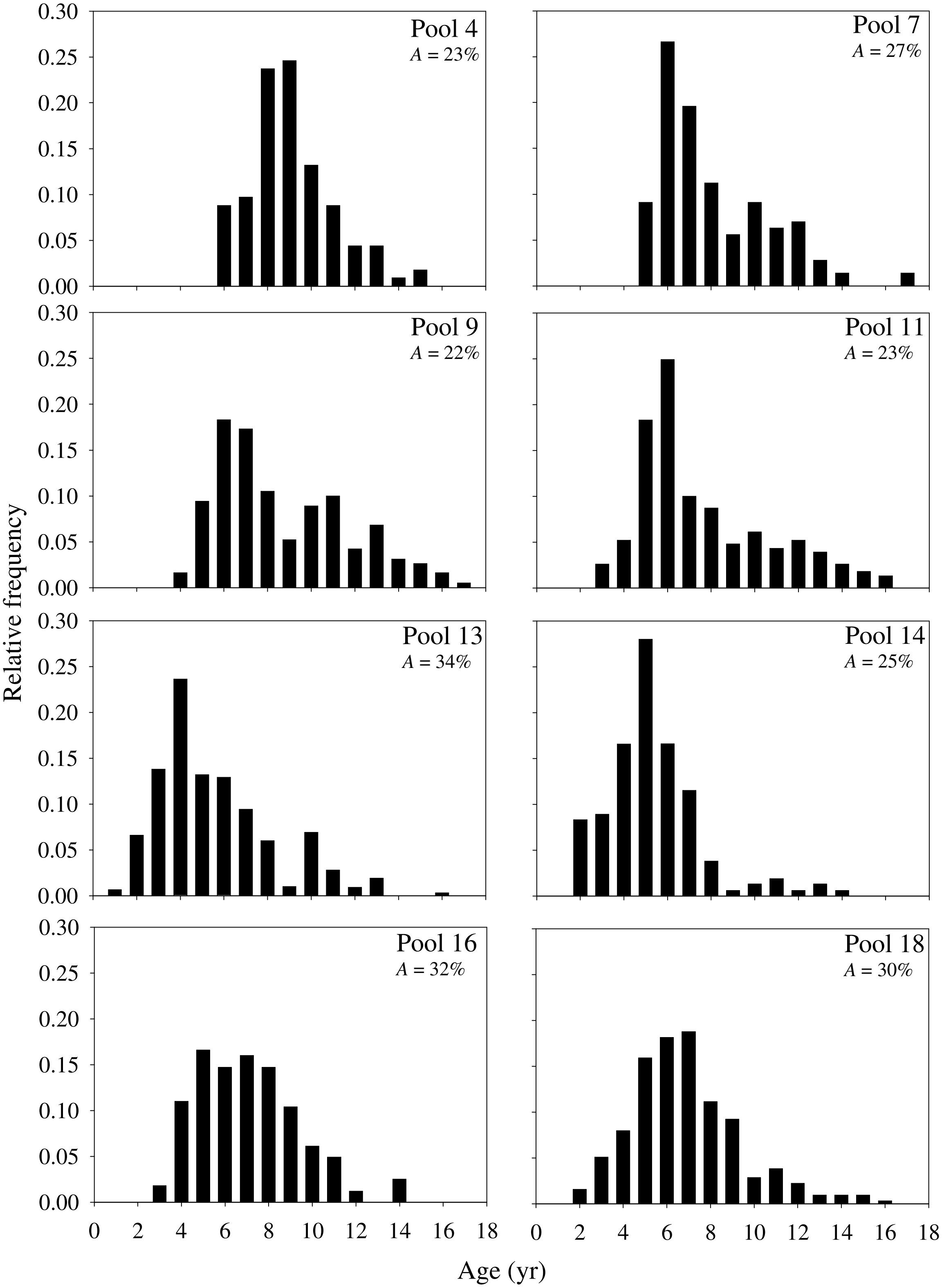
Pool 4
A = 23%
Pool 7
A = 27%
Pool 9
A = 22%
Pool 11
A = 23%
Pool 13
A = 34%
Pool 14
A = 25%
Pool 16
A = 32%
Pool 18
A = 30%
Relative frequency
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Age (yr)
0
2
4
6
8
10
12
14
16
18

Figure 4. Age frequency distributions for shovelnose sturgeon sampled from eight pools of the upper Mississippi River, 2006-2007. Total annual mortality (*A*) of age-6 and older shovelnose sturgeon is provided for each pool.

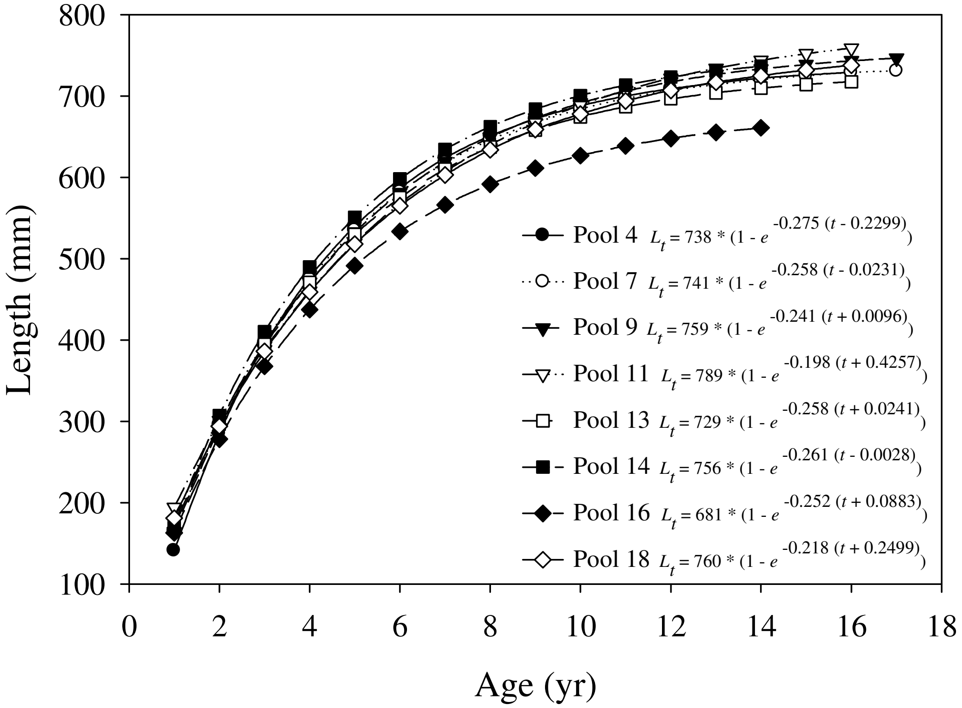

Figure 5. Predicted von Bertalanffy growth curves fitted from mean back-calculated length at age of shovelnose sturgeon sampled from eight pools of the upper Mississippi River, 2006-2007.

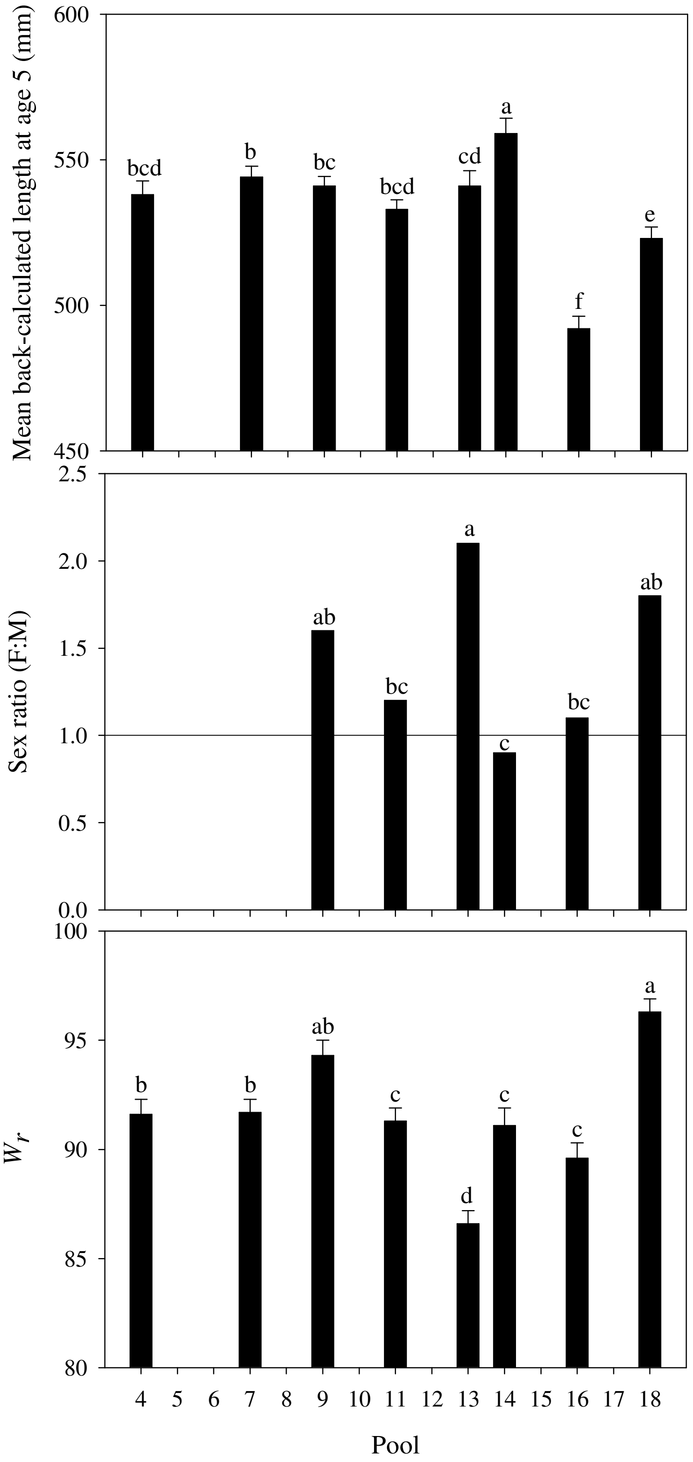

Figure 6. Mean back-calculated length at age 5 (upper panel), sex ratios estimated from a subsample of 100 shovelnose sturgeon from six study pools (middle panel), and mean relative weights (W_r) of shovelnose sturgeon sampled from the upper Mississippi River (lower panel), 2006-2007. Error bars represent one standard error. Pools with the same letter were not significantly different ($P < 0.05$).

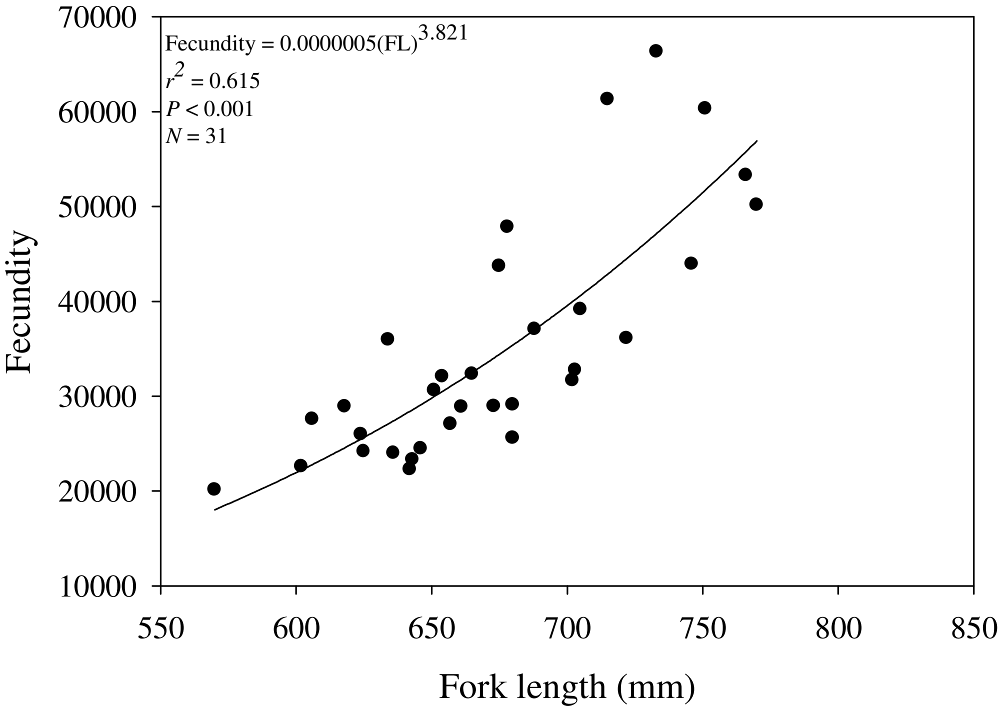

Figure 7. Fecundity of gravid female shovelnose sturgeon versus fork length (FL) for shovelnose sturgeon sampled in the upper Mississippi River, 2006-2007.

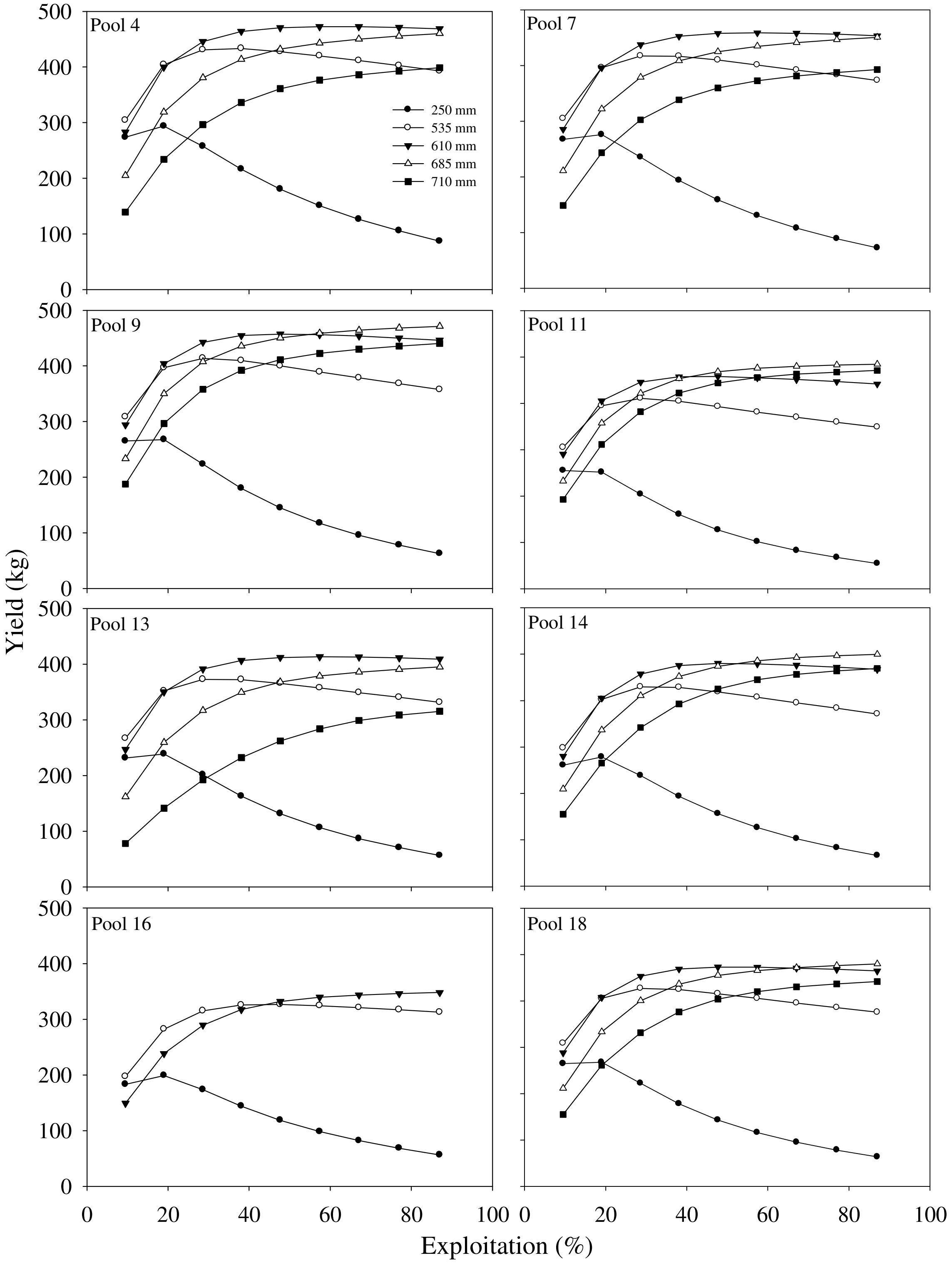
Pool 4
Pool 7
Pool 9
Pool 11
Pool 13
Pool 14
Pool 16
Pool 18
250 mm
535 mm
610 mm
685 mm
710 mm
Yield (kg)
Exploitation (%)
0
100
200
300
400
500
0
20
40
60
80
100

Figure 8. Simulated yields for shovelnose sturgeon populations in the upper Mississippi River with a conditional natural mortality (*cm*) of 10%. Simulations were conducted with five different minimum length limits (i.e., 250 mm, 535 mm, 610 mm, 685 mm, and 710 mm). Note that Pool 16 only has three minimum length limits simulated due to the 685-mm and 710-mm minimum length limits exceeding the asymptotic maximum length (L_∞) of the pool.

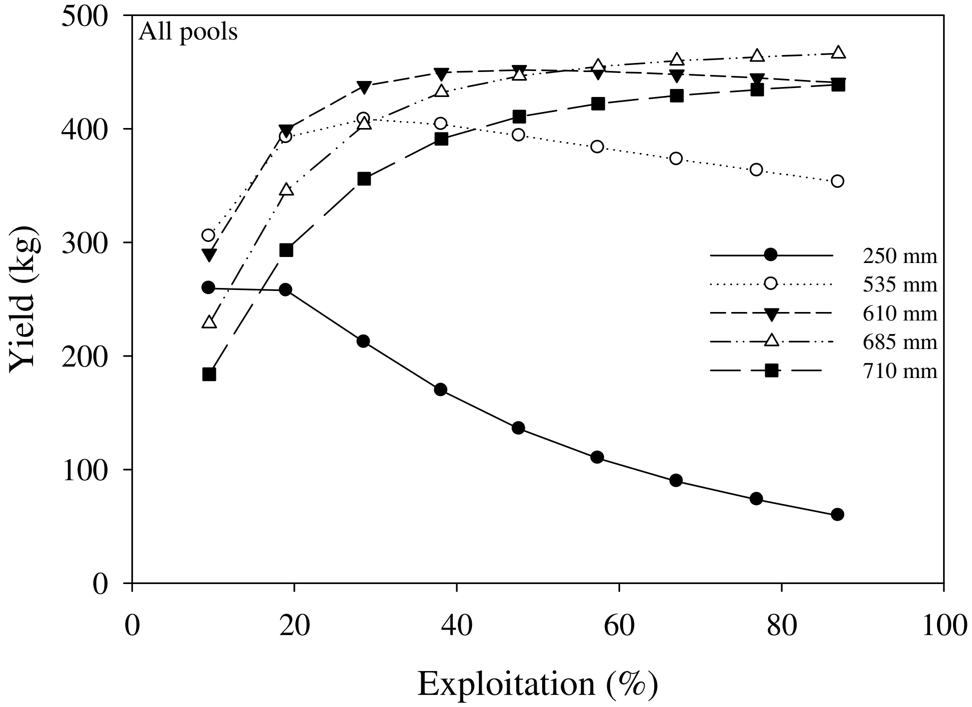

Figure 9. Simulated yields of shovelnose sturgeon in the upper Mississippi River with a conditional natural mortality (*cm*) of 10%. The simulations were conducted with five different minimum length limits (i.e., 250 mm, 535 mm, 610 mm, 685 mm, and 710 mm).

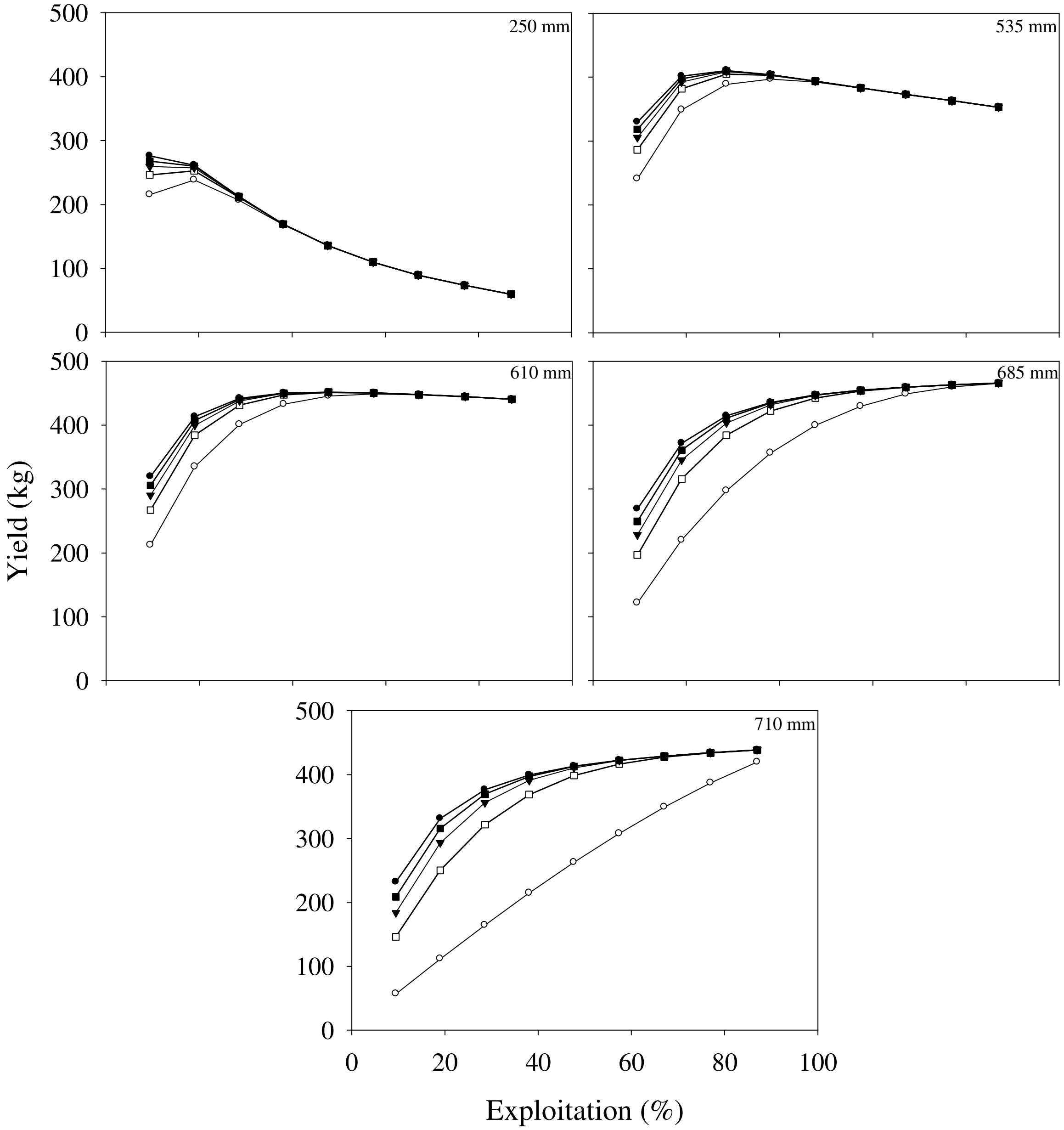

Figure 10. Simulated yields for shovelnose sturgeon in the upper Mississippi River (i.e., combined parameters from all study pools) with a conditional natural mortality rate (*cm*) of 10%. Each panel represents a different minimum length limit (i.e., 250 mm, 535 mm, 610 mm, 685 mm, and 710 mm). The middle line (indicated by solid triangles) represents yields calculated using the observed maximum age of 17 years, whereas the two lines above the observed line represent yields calculated with maximum ages of 19 (solid squares) and 22 (solid circles). The two lines below the observed line represent yields calculated with maximum ages of 15 (open squares) and 12 (open circles).

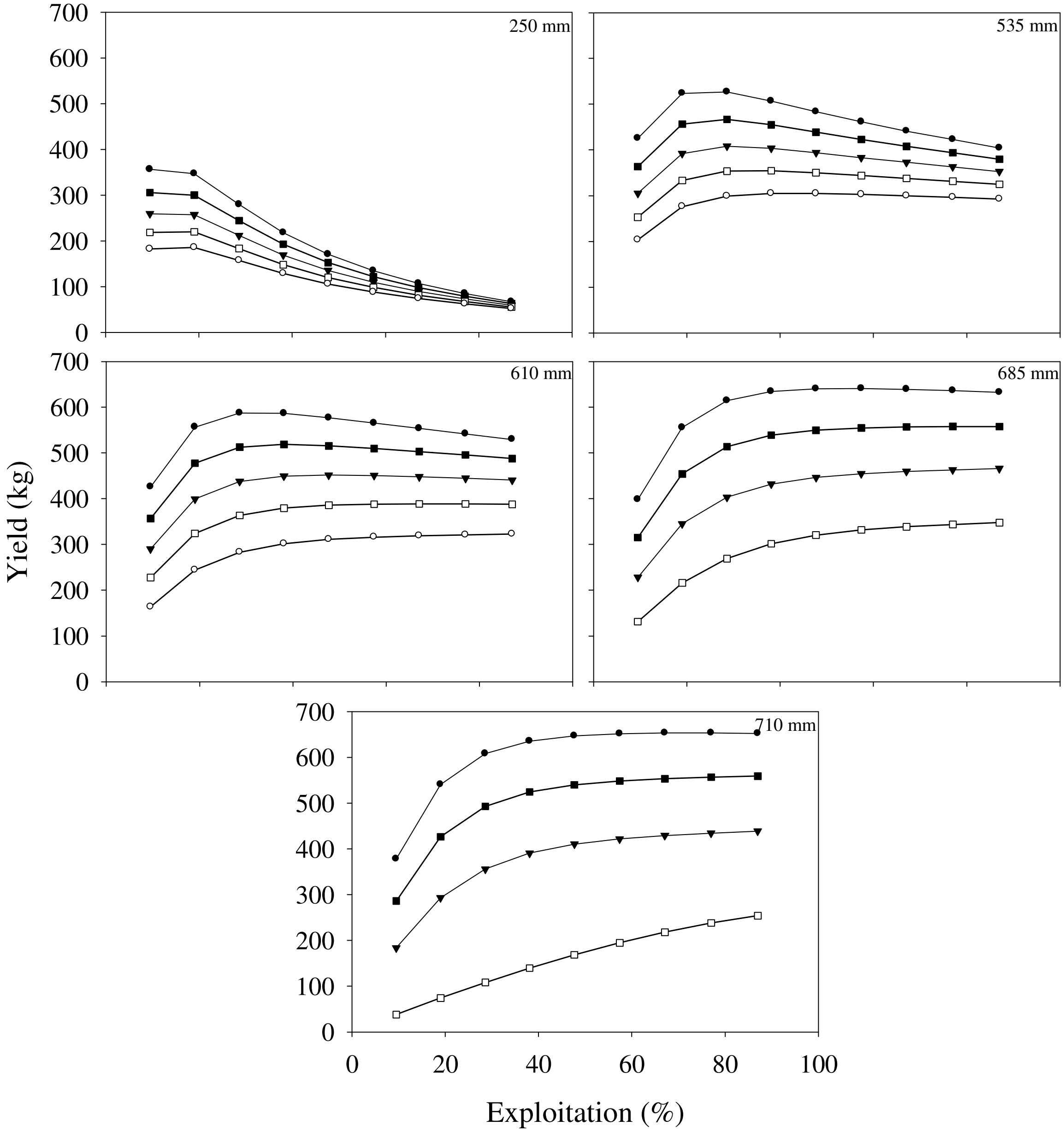

Figure 11. Simulated yields for shovelnose sturgeon in the upper Mississippi River (i.e., combined parameters from all study pools) with a conditional natural mortality rate (*cm*) of 10%. Each panel represents a different minimum length limit (i.e., 250 mm, 535 mm, 610 mm, 685 mm, and 710 mm). The middle line (indicated by solid triangles) represents yields calculated using observed growth parameters, whereas the two lines above the observed line represent yields calculated with growth increased by 5% (solid squares) and 10% (solid circles). The two lines below the observed line represent yields calculated with growth decreased by 5% (open squares) and 10% (open circles). Note that in 685-mm and 710-mm simulations, no simulation representing a 10% decrease in growth is shown. A 10% decrease in growth in these scenarios decreases the asymptotic maximum length (L_∞) below the respective minimum length limit.

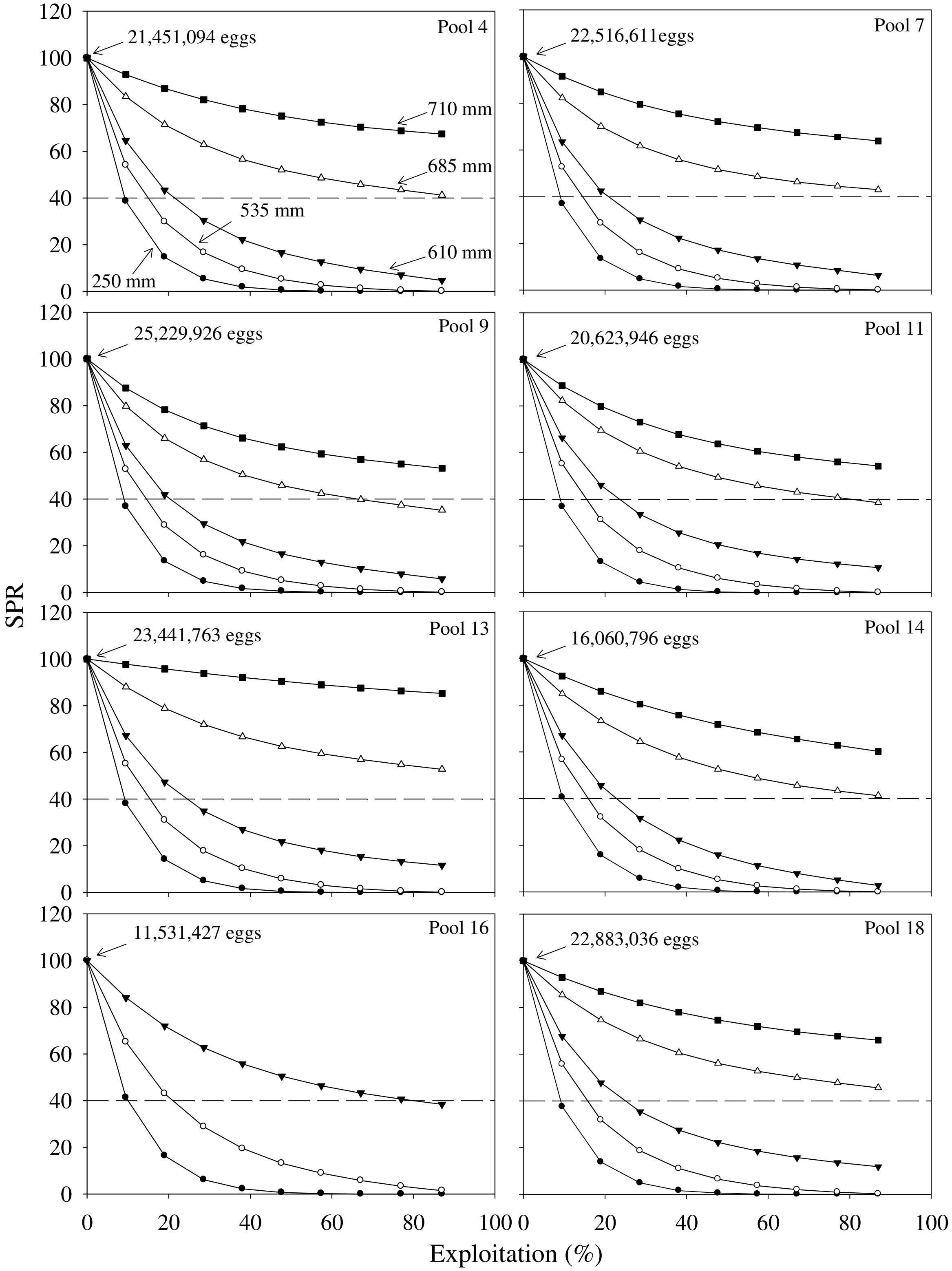
Pool 4
21,451,094 eggs
710 mm
685 mm
535 mm
610 mm
250 mm
Pool 7
22,516,611eggs
Pool 9
25,229,926 eggs
Pool 11
20,623,946 eggs
Pool 13
23,441,763 eggs
Pool 14
16,060,796 eggs
Pool 16
11,531,427 eggs
Pool 18
22,883,036 eggs
SPR
0
20
40
60
80
100
120
Exploitation (%)
0
20
40
60
80
100

Figure 12. Simulated spawning potential ratios (SPR) for shovelnose sturgeon populations in the upper Mississippi River in response to five minimum length limits (i.e., 250 mm, 535 mm, 610 mm, 685 mm, and 710 mm). Simulations were conducted with a conditional natural mortality rate (*cm*) of 10%. Maximum lifetime egg production is provided for each pool. The horizontal dashed line represents the recruitment overfishing threshold of 40%. Note that Pool 16 only has three minimum length limits simulated due to the 685-mm and 710-mm minimum length limits exceeding the asymptotic maximum length of shovelnose sturgeon (L_∞) for the pool.

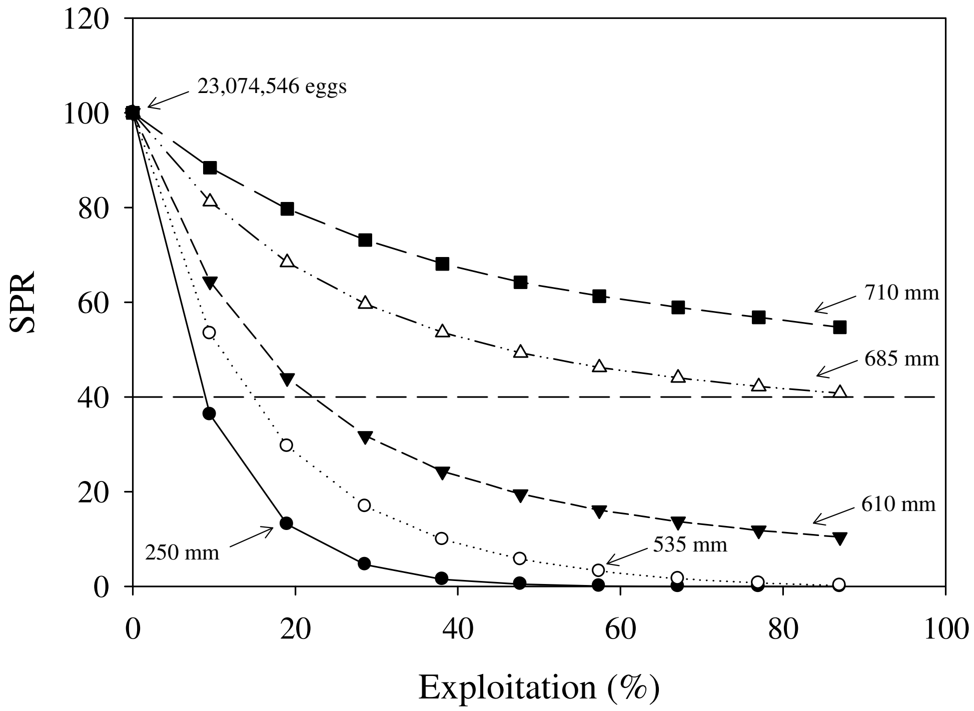

Figure 13. Simulated spawning potential ratios (SPR) for shovelnose sturgeon in the upper Mississippi River (i.e., combined parameters from all study pools) in response to five minimum length limits (i.e., 250 mm, 535 mm, 610 mm, 685 mm, and 710 mm). The simulation was conducted with a conditional natural mortality rate (*cm*) of 10%. Maximum lifetime egg production is provided. The horizontal dashed line represents the recruitment overfishing threshold of 40%.

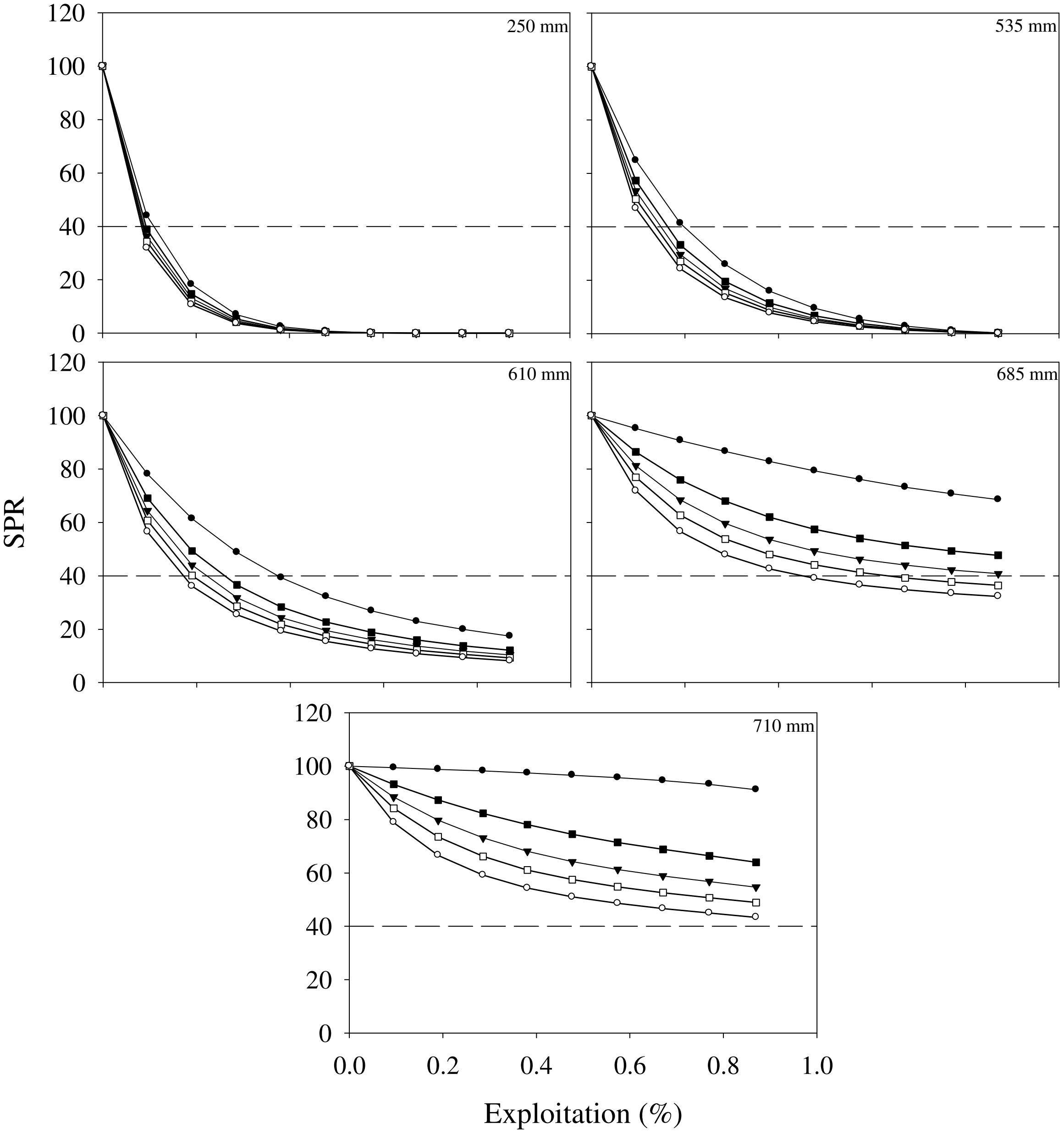

Figure 14. Simulated yields for shovelnose sturgeon in the upper Mississippi River (i.e., combined parameters from all study pools) with a conditional natural mortality rate (*cm*) of 10%. Each panel represents a different minimum length limit (i.e., 250 mm, 535 mm, 610 mm, 685 mm, and 710 mm). The horizontal dashed line represents the recruitment overfishing threshold of 40%. The middle line (indicated by triangles) represents SPR calculated using the observed maximum age of 17 years, whereas the two lines above the observed line represent SPR calculated with maximum ages of 15 (solid squares) and 12 (solid circles). The two lines below the observed line represent SPR calculated with maximum ages of 19 (open squares) and 22 (open circles).

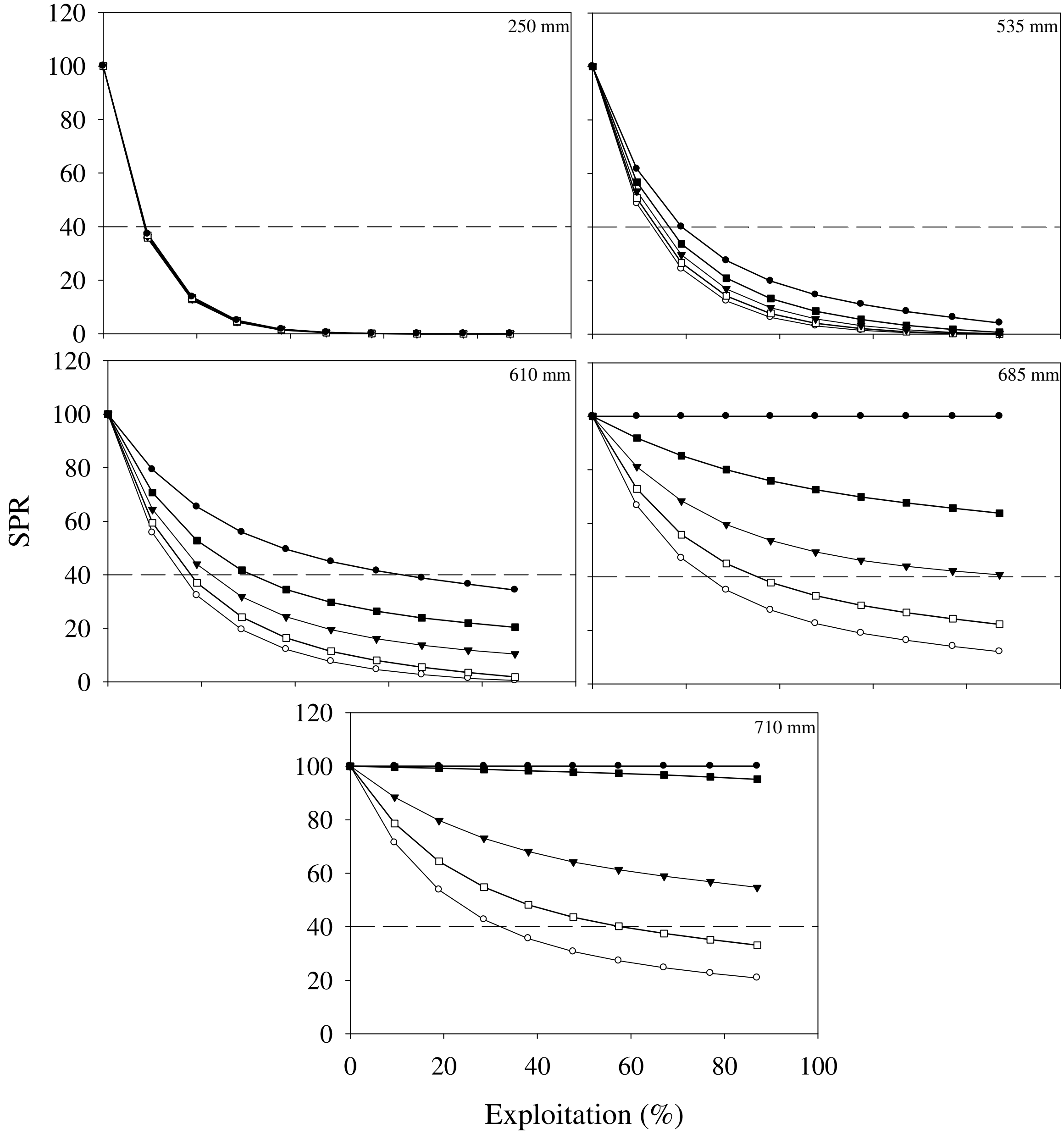

Figure 15. Simulated yields for shovelnose sturgeon in the upper Mississippi River (i.e., combined parameters from all study pools) with a conditional natural mortality rate (*cm*) of 10%. Each panel represents a different minimum length limit (i.e., 250 mm, 535 mm, 610 mm, 685 mm, and 710 mm). The horizontal dashed line represents the recruitment overfishing threshold of 40% SPR. The middle line (indicated by triangles) represents SPR calculated using observed growth parameters, whereas the two lines above the observed line represent SPR calculated with growth reduced by 5% (solid squares) and 10% (solid circles). The two lines below the observed line represent SPR calculated with growth increased by 5% (open squares) and 10% (open circles).

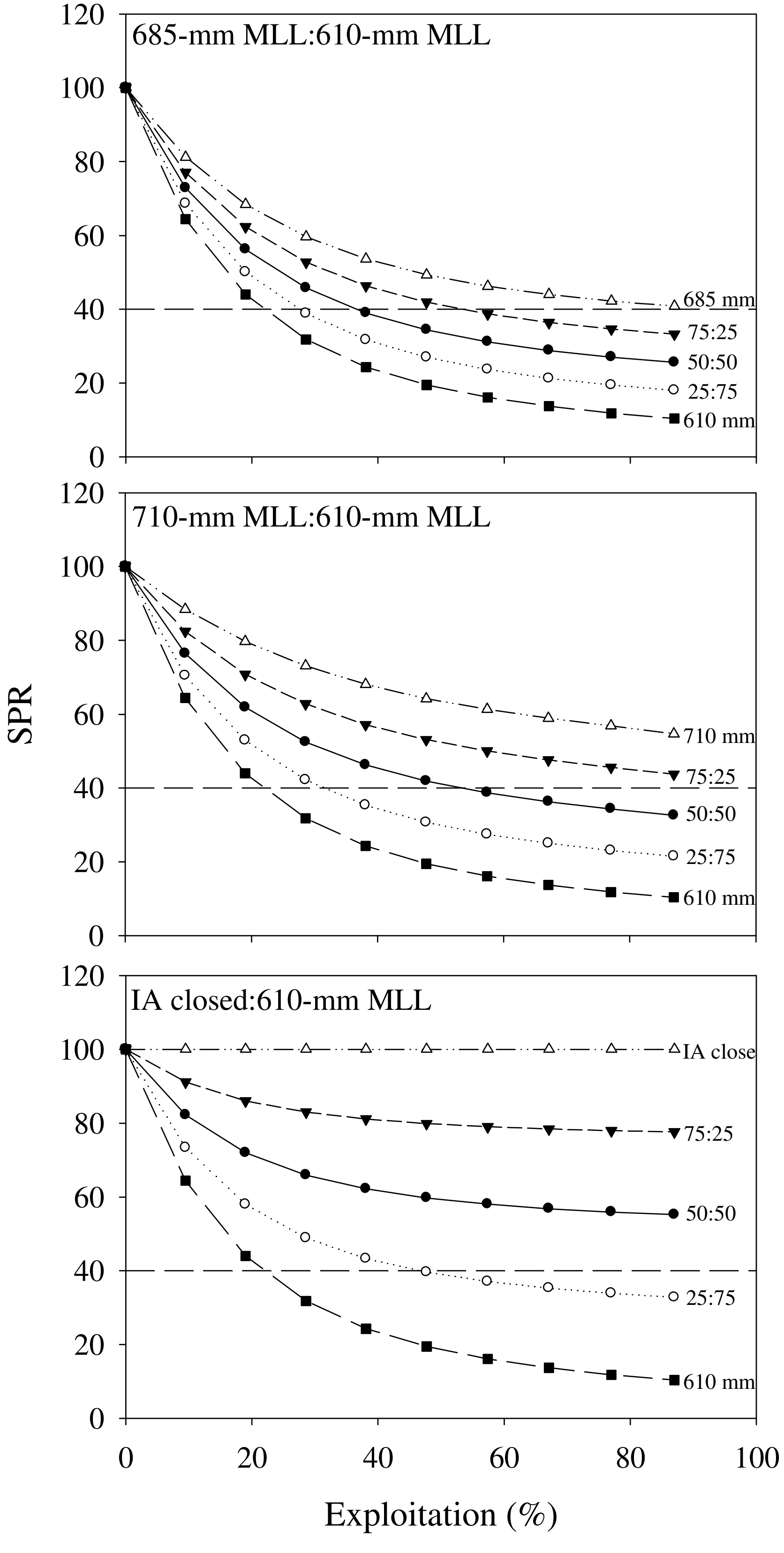
685-mm MLL:610-mm MLL
685 mm
75:25
50:50
25:75
610 mm
710-mm MLL:610-mm MLL
710 mm
75:25
50:50
25:75
610 mm
IA closed:610-mm MLL
IA close
75:25
50:50
25:75
610 mm
SPR
0
20
40
60
80
100
120
0
20
40
60
80
100
Exploitation (%)

Figure 16. Simulated spawning potential ratios (SPR) for shovelnose sturgeon populations in the upper Mississippi River (i.e., combined parameters from all study pools) with a conditional natural mortality rate (*cm*) of 10%. The horizontal dashed line represents the recruitment overfishing threshold of 40%. Curves indicate SPR for shovelnose sturgeon in response to a 610-mm minimum length split with a 685-mm and a 710-mm minimum length limit at differing levels of state-specific harvest proportions. The bottom panel represents the combination of a 610-mm minimum length limit and a closed season. Ratios symbolize the percentage of harvest from Iowa and Illinois commercial anglers, respectively (i.e., 75:25 represents 75% of shovelnose sturgeon harvest regulated by the more restrictive minimum length limit or closed season, and 25% from waters regulated by a 610-mm minimum length limit).

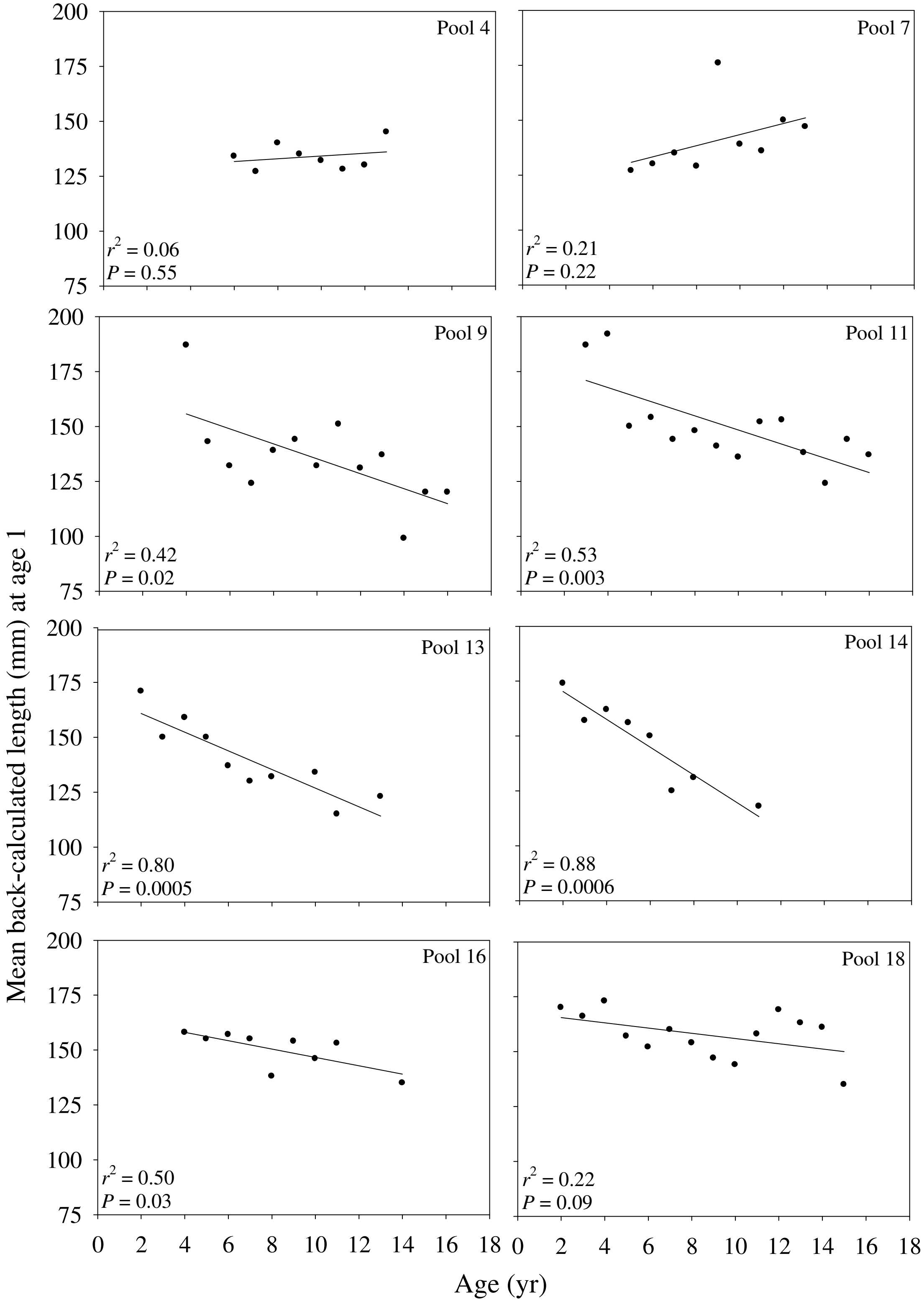

Figure 17. Mean back-calculated lengths at age 1 for different shovelnose sturgeon age classes sampled from eight pools of the upper Mississippi River, 2006-2007.

APPENDIX A. AGE-LENGTH KEY FOR SHOVELNOSE STURGEON IN THE UPPER MISSISSIPPI RIVER

Number of shovelnose sturgeon sampled in each age-class per one-cm length group in eight pools of the upper Mississippi River.

	Pool			
Length group (mm)	4	7	9	11
220	-	-	-	-
230	-	-	-	-
240	-	-	-	-
250	-	-	-	-
260	-	-	-	-
270	-	-	-	-
280	-	-	-	-
290	-	-	-	-
300	-	-	-	-
310	-	-	-	-
320	-	-	-	-
330	-	-	-	-
340	-	-	-	-
350	-	-	-	-
360	-	-	-	-
370	-	-	-	-
380	-	-	-	-
390	-	-	-	-
400	-	-	-	-
410	-	-	-	-
420	-	-	-	1(3)
430	-	-	-	3(3), 1(4)
440	-	-	-	-
450	-	-	-	-
460	-	-	-	1(3)
470	-	-	-	1(3), 2(5)
480	-	-	-	1(5)
490	-	-	-	1(4), 1(5)

Appendix A. Continued (see page 56 for heading).

	Pool			
Length group (mm)	4	7	9	11
500	-	-	-	1(4), 2(5)
510	-	-	-	4(4)
520	-	-	-	2(4), 7(5)
530	-	-	1(4), 1(6)	1(4), 3(5), 4(6), 1(7)
540	-	1(5)	4(5), 1(7)	1(4), 7(5), 2(6)
550	-	2(5), 1(6)	2(5), 3(6)	1(4), 3(5), 6(6)
560	-	2(5), 1(6)	1(4), 2(5), 3(6)	8(5), 2(6)
570	-	3(5), 6(6), 2(7)	4(5), 1(6)	3(5), 5(6), 1(7), 1(9)
580	-	2(5), 5(6), 2(8)	1(4), 2(5), 4(6), 1(7)	2(5), 4(6), 3(7), 1(8)
590	2(6)	5(6), 5(7)	1(5), 7(6), 2(7)	1(5), 9(6)
600	1(6), 1(8)	1(5), 6(6), 4(7), 1(8)	1(5), 5(6), 4(7)	1(5), 6(6), 1(7), 1(8), 1(10)
610	2(6), 1(7), 1(9)	2(5), 6(6), 1(10)	6(6), 3(7), 1(8)	7(6), 2(7), 1(9)
620	1(7), 1(8)	4(6), 4(7), 1(8), 1(9)	1(6), 6(7), 1(8)	5(6), 3(7), 1(8), 1(10)
630	1(7), 4(8), 1(9)	1(6), 6(7), 2(8), 1(10)	1(6), 7(7), 4(8)	3(6), 2(7), 4(8), 1(11)
640	2(6), 3(7), 2(8)	2(6), 3(7), 2(8), 1(9), 1(12)	2(6), 3(7), 4(8), 1(9)	1(5), 1(6), 3(7), 2(8), 2(9)
650	2(6), 4(7), 2(8), 1(9), 1(12)	1(6), 2(7), 3(8), 1(9), 2(11), 1(12)	1(5), 1(6), 1(8), 1(9), 1(10), 1(11)	2(6), 1(7), 2(8), 1(11)
660	1(7), 4(8), 4(9), 1(10)	1(7), 2(8), 3(9), 1(12)	1(5), 2(7), 3(8), 1(9), 1(10), 1(14)	1(6), 3(7), 4(8), 1(9), 1(11)
670	1(6), 6(8), 3(9), 1(10), 1(11)	1(8), 2(10), 1(11), 1(13)	2(7), 1(8), 2(9)	1(7), 2(8), 2(9), 2(11), 3(12)
680	2(8), 5(9), 3(10)	1(7), 1(8), 2(10), 1(11), 1(12)	1(7), 1(8), 3(9), 1(10), 1(13), 1(15)	1(7), 2(8), 1(9), 3(10), 2(11), 1(12)
690	3(8), 1(9), 1(10), 2(11)	1(9), 2(10), 2(11)	1(7), 1(8), 3(10), 3(11), 1(12)	1(7), 3(10), 1(11), 1(13), 1(14)
700	1(8), 4(9), 1(10), 2(11), 1(13)	1(8), 1(9), 1(10), 1(12)	2(8), 2(10), 2(11), 1(15)	1(8), 1(10), 1(11), 2(12)
710	2(9), 4(10), 2(11), 1(13)	1(10), 1(11), 1(13), 1(14)	1(8), 2(9), 2(10), 1(11), 1(12), 1(13)	1(9), 3(10), 1(12), 1(13)
720	1(8), 4(9), 1(10), 1(12), 1(14)	2(10), 1(11)	2(10), 1(11), 5(13), 1(14), 1(15)	1(9), 2(10), 2(12), 2(13), 1(16)
730	1(10), 1(12), 1(16)	1(10), 1(11), 1(12), 1(14)	2(10), 2(11), 3(12), 1(13), 2(14)	2(12), 1(13)
740	1(9), 1(11), 1(12)	2(12), 2(13), 1(17)	2(10), 3(11), 1(12), 2(13), 1(14), 1(15)	1(11), 1(12), 1(14)
750	1(9), 1(10), 1(12), 1(16)	-	1(10), 1(11), 2(12), 1(14)	1(9), 2(13), 3(14)
760	1(13)	-	2(11)	1(13), 1(14)
770	1(10)	-	1(13), 2(16)	-
780	2(11), 1(13)	2(12)	1(11), 1(13), 1(15)	-
790	1(13)	-	2(11), 1(13)	1(15)

Appendix A. Continued (see page 56 for heading).

	Pool			
Length group (mm)	4	-	9	11
800	-	-	1(16), 1(17)	1(15)
810	-	-	-	1(13), 2(15)
820	-	-	-	1(16)
830	-	-	-	-
840	-	-	-	1(16)
850	-	-	-	-

Appendix A. Continued (see page 56 for heading).

	Pool			
Length group (mm)	13	14	16	18
220	1(1)	-	-	-
230	-	-	-	-
240	-	-	-	-
250	-	-	-	-
260	-	-	-	-
270	-	1(2)	-	-
280	-	1(2)	-	-
290	-	-	-	1(2)
300	1(1)	1(2)	-	-
310	1(2)	2(2)	-	1(2)
320	2(2)	1(2)	-	-
330	-	3(2)	-	1(2)
340	-	2(2)	-	-
350	4(2)	-	-	-
360	1(2)	-	-	1(2)
370	5(2)	1(3)	-	1(2)
380	2(2), 1(3)	1(2), 1(4)	-	-
390	4(2), 1(3)	-	-	1(5)
400	2(2), 3(3)	-	-	1(3)
410	5(3), 2(4)	1(2)	-	2(3)
420	4(3), 1(4)	1(4)	-	1(3)
430	6(3), 1(4)	1(3)	1(4), 1(5)	1(3), 1(5)
440	7(3)	2(3)	-	2(4)
450	7(3), 2(4)	3(3), 1(5)	1(3), 1(4)	2(3)
460	4(3), 2(4)	3(3), 2(4)	2(4), 1(5), 1(6)	-
470	5(3), 5(4)	1(3)	-	-
480	6(4), 1(5)	1(3), 2(4), 1(5)	-	-
490	1(3), 9(4)	2(4), 1(5)	2(4), 2(5)	2(3)
500	9(4), 1(5)	1(3), 2(4), 1(5)	1(3), 1(4), 2(5)	3(3), 2(5)
510	10(4)	1(4)	1(3), 1(5)	2(4), 1(5)

Appendix A. Continued (see page 56 for heading).

Length group (mm)	Pool 13	14	16	18
520	6(4), 3(5), 1(7)	1(6)	4(4), 2(5), 3(6)	2(3), 5(4), 1(5), 1(6)
530	6(4), 4(5)	1(4), 2(5), 1(7)	3(4), 5(5), 2(6)	5(4), 3(5), 1(6), 1(7)
540	9(4), 5(5)	3(4), 2(5), 2(6)	3(4), 4(5), 1(6), 1(7), 1(8)	2(3), 5(4), 2(5), 1(6)
550	3(4), 5(5), 2(6)	1(3), 4(4), 2(5)	3(5), 1(7)	2(4), 4(5), 1(6)
560	1(4), 7(5), 2(6)	2(4), 1(5), 1(6)	1(5), 2(6), 2(7), 2(8), 2(9)	1(4), 2(5), 6(6), 1(7), 1(8)
570	1(4), 4(5), 4(6), 1(7)	2(4), 3(5)	1(4), 2(5), 4(6), 1(7), 1(8)	1(4), 3(5), 3(6), 3(7)
580	1(4), 3(5), 6(6)	1(4), 5(5), 1(6)	1(5), 4(6), 2(7), 1(9), 1(10)	5(5), 5(6)
590	1(4), 2(5), 5(6), 2(7)	1(4), 10(5)	4(6), 4(7), 1(8), 1(10)	2(5), 5(6), 2(7), 1(9)
600	3(5), 2(6), 3(7), 2(8)	6(5), 3(6), 1(7)	2(5), 1(6), 3(8), 3(9), 1(10)	2(5), 4(6), 3(7), 1(9)
610	2(5), 9(6), 1(7), 1(8), 1(11)	4(5), 2(6), 1(7)	2(6), 2(7), 7(8), 1(9), 1(10)	2(5), 4(6), 2(7), 2(8)
620	2(5), 4(6), 4(7)	1(5), 4(6), 2(7)	3(7), 3(8), 1(9)	2(5), 4(7), 3(8), 1(9)
630	2(6), 4(7), 1(8), 1(9), 1(10), 1(11)	2(5), 5(6), 2(7)	5(7), 2(8), 2(9), 1(11)	1(5), 1(6), 6(7), 2(8)
640	3(6), 4(7), 2(8), 1(10)	1(4), 1(5), 1(6), 4(7), 1(8)	1(7), 2(8), 1(9), 2(10), 2(11), 1(14)	1(6), 4(7), 5(8)
650	1(6), 4(7), 3(8), 2(10)	2(6), 1(7), 1(8), 1(11)	1(7), 1(8), 2(9), 1(10), 2(11)	1(5), 4(7), 1(8), 2(9),2(11)
660	1(7), 4(8), 2(10), 2(11), 1(13)	2(6), 1(7)	2(7), 1(8), 3(9), 1(10), 1(11)	1(7), 3(8), 5(9), 1(12)
670	1(6), 1(7), 4(8), 1(9), 2(10), 1(11)	1(5), 2(7), 1(8)	1(11), 1(12), 1(14)	1(7), 2(8), 5(9), 1(10),1(11)
680	3(7), 4(10), 1(11), 1(13)	1(7), 1(8), 1(9)	1(7), 1(10), 1(12), 1(14)	1(6), 3(9), 3(10), 2(11)
690	-	2(6), 1(7), 1(12)	1(11)	1(6), 1(7), 2(8), 2(11), 2(12), 1(13), 1(15)
700	1(7), 1(8), 1(9), 2(10), 2(11)	-	1(9), 1(10), 1(14)	1(11), 1(12)
710	2(10), 2(12)	1(7), 2(13)	-	1(8), 1(9), 3(10), 1(11)
720	2(10), 1(11)	-	-	2(12), 1(13), 1(14), 1(15)
730	2(10), 1(12), 1(13)	1(8), 1(10)	-	-
740	1(8), 1(16)	1(11)	-	1(13)
750	2(13)	-	-	1(8), 1(10), 1(16)
760	1(10)	1(8), 1(10), 1(11)	-	-
770	1(13)	-	-	-
780	1(10)	-	-	1(15)
790	-	-	-	
800	-	1(14)	-	
810	-	-	-	-

Appendix A. Continued (see page 56 for heading).

	Pool			
Length group (mm)	13	14	16	18
820	-	-	-	-
830	-	-	-	1(14)
840	-	-	-	-
850	-	-	-	1(14)

APPENDIX B. MEAN BACK-CALCULATED LENGTH AT AGE OF SHOVELNOSE STURGEON

Mean back-calculated length at age by year-class for shovelnose sturgeon from the upper Mississippi River. Standard errors are shown in parentheses.

Year - class	Age	N	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
											Pool 4								
2001	6	10	133.5 (5.4)	307.0 (12.0)	440.3 (15.3)	525.1 (5.6)	580.3 (7.9)	621.5 (9.7)	-	-	-	-	-	-	-	-	-	-	-
2000	7	11	126.8 (8.1)	317.7 (16.1)	425.5 (13.4)	502.8 (8.4)	566.0 (7.1)	611.9 (5.5)	638.1 (4.5)	-	-	-	-	-	-	-	-	-	-
1999	8	27	139.9 (7.2)	291.8 (11.2)	404.4 (10.9)	486.6 (9.5)	544.1 (8.1)	589.9 (6.4)	630.8 (5.3)	657.8 (5.4)	-	-	-	-	-	-	-	-	-
1998	9	28	135.3 (6.9)	292.9 (12.5)	410.0 (8.6)	489.2 (7.2)	545.0 (6.0)	588.3 (5.1)	622.6 (5.3)	657.2 (5.8)	684.4 (5.9)	-	-	-	-	-	-	-	-
1997	10	15	131.6 (7.8)	279.5 (10.3)	402.2 (12.1)	491.9 (11.8)	551.6 (9.3)	597.6 (7.4)	632.6 (7.3)	662.7 (7.0)	686.4 (7.2)	703.7 (7.3)	-	-	-	-	-	-	-
1996	11	10	127.5 (10.6)	281.7 (21.4)	382.1 (21.1)	454.2 (21.0)	513.2 (20.4)	562.7 (16.8)	595.1 (13.8)	628.5 (12.6)	663.0 (11.9)	692.6 (12.0)	715.5 (12.0)	-	-	-	-	-	-
1995	12	5	130.2 (17.2)	266 (33.7)	370.2 (24.8)	422.8 (24.2)	473.3 (19.8)	532.6 (14.2)	576.8 (12.9)	615.9 (14.1)	645.8 (14.8)	674.5 (14.6)	699.1 (14.4)	719.6 (16.5)	-	-	-	-	-
1994	13	5	145.0 (10.6)	293.4 (20.1)	369.1 (31.4)	414.5 (33.8)	456.4 (32.8)	507.7 (24.3)	546.1 (24.8)	584.0 (25.2)	624.6 (24.1)	656.9 (21.0)	696.4 (21.0)	724.3 (20.7)	746.1 (19.1)	-	-	-	-
1993	14	1	84.6	228.6	338.6	415.5	473.8	515.5	529.8	562.8	594.7	628.8	654.0	680.4	695.8	714.5	-	-	-
1991	16	2	84.4 (17.5)	204.9 (9.6)	318.3 (24.0)	385.1 (19.4)	436.8 (5.1)	481.7 (3.6)	516.4 (5.3)	545.2 (12.8)	573.7 (17.1)	606.7 (10.0)	642.9 (2.9)	669.6 (7.3)	694.5 (11)	711.6 (8.2)	724.4 (7)	739.9 (8.4)	-
											Pool 7								
2002	5	13	127.3 (6.2)	313.6 (10.9)	444.7 (6.2)	518.8 (6.6)	571.3 (6.2)	-	-	-	-	-	-	-	-	-	-	-	-
2001	6	38	129.8 (4.5)	312.6 (6.1)	442.5 (4.6)	513.1 (4.0)	564.8 (3.7)	595.1 (3.8)	-	-	-	-	-	-	-	-	-	-	-
2000	7	28	134.5 (5.9)	310.0 (7.3)	427 (5.6)	505.3 (4.4)	547.7 (4.7)	591.3 (5.1)	616.4 (5.0)	-	-	-	-	-	-	-	-	-	-
1999	8	16	129 (7.2)	301.0 (15.0)	421.9 (13.3)	500.8 (9.5)	553.7 (8.0)	586.5 (8.0)	619.2 (8.0)	638.7 (7.8)	-	-	-	-	-	-	-	-	-
1998	9	8	175.9 (18.5)	369.5 (20.9)	459 (15.6)	504 (9.6)	544.6 (10.7)	579.9 (10.0)	611.3 (7.8)	639.9 (9.1)	659.5 (7.9)	-	-	-	-	-	-	-	-
1997	10	13	138.6 (9.5)	309.5 (17.1)	401.0 (21.0)	472.6 (18.9)	523.6 (16.9)	568.3 (13.9)	608.5 (10.4)	636.7 (9.8)	664.7 (8.9)	683.1 (9.3)	-	-	-	-	-	-	-
1996	11	9	135.8 (10.0)	335.1 (13.9)	431.4 (12.7)	497.0 (11.0)	533.6 (13.8)	566.2 (14.8)	596.8 (14.1)	627.7 (13.1)	651.4 (12.2)	669.5 (10.6)	685.8 (9.4)	-	-	-	-	-	-
1995	12	10	149.8 (13.0)	286.4 (17.0)	384.1 (20.2)	460.1 (17.7)	511.2 (16.4)	546.1 (15.3)	583.5 (12.8)	615.9 (13.3)	643.9 (13.9)	666.7 (14.6)	688.9 (15.6)	707.9 (16.2)	-	-	-	-	-
1994	13	4	147.4 (13.9)	294.6 (25.3)	383.2 (25.3)	434.1 (31.5)	472 (22.2)	515.7 (14.7)	550.9 (18.3)	588.5 (15.8)	619.4 (13.6)	648.3 (10.9)	680.4 (15.5)	699.1 (13.7)	715.3 (15.9)	-	-	-	-
1993	14	2	116.5 (19.2)	255.7 (3.5)	341.4 (10.7)	391 (24.5)	439.2 (22.2)	507 (2.5)	560.8 (4.2)	601.2 (7.5)	631 (2.1)	656.5 (6.0)	670.9 (3.9)	693.7 (8.1)	706.4 (8.8)	718.6 (7.8)	-	-	-

Appendix B. Continued (see page 62 for heading).

Year - class	Age	N	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Pool 9																			
1990	17	2	121.8 (28.3)	216.9 (64.5)	304.6 (55.3)	381.8 (64.4)	430.2 (62)	486.2 (52.2)	520.2 (57.3)	551.3 (46.9)	579.1 (43.5)	604.3 (46.8)	633.1 (31.7)	661 (34.2)	682.6 (29.3)	700.8 (33.6)	728.1 (37.8)	754.7 (36.7)	775.0 (34)
2002	4	3	187.1 (28.3)	379.1 (23.6)	474.3 (15.0)	536.0 (9.8)	-	-	-	-	-	-	-	-	-	-	-	-	-
2001	5	18	143.3 (10.4)	317.2 (11.3)	448.9 (8.2)	518.5 (7.5)	565.0 (7.8)	-	-	-	-	-	-	-	-	-	-	-	-
2000	6	35	131.7 (5.7)	305.8 (6.8)	436.0 (5.0)	510.6 (4.5)	554.4 (4)	586.1 (4.5)	-	-	-	-	-	-	-	-	-	-	-
1999	7	33	124.5 (5.1)	290 (8.5)	426.6 (6.9)	505.4 (6)	555.1 (5.7)	590.9 (5.3)	619.8 (5)	-	-	-	-	-	-	-	-	-	-
1998	8	20	139 (6.6)	304.3 (14.1)	400.0 (13.4)	492.9 (10.6)	547.8 (9.3)	593.4 (8.1)	623.7 (7.1)	649.3 (6.8)	-	-	-	-	-	-	-	-	-
1997	9	10	143.9 (11.4)	314.2 (14.9)	406.1 (13.0)	478.1 (10.8)	533.0 (11.3)	570.6 (11.1)	607.2 (11.7)	644 (6.6)	668 (6.5)	-	-	-	-	-	-	-	-
1996	10	17	132.1 (7.4)	296.2 (13.9)	404.4 (15.1)	478.1 (14.9)	528.2 (13.7)	565.9 (12.2)	603.8 (10.0)	644.9 (7.4)	674.9 (5.9)	699.8 (6.1)	-	-	-	-	-	-	-
1995	11	19	151.2 (9.6)	322.2 (15)	417.7 (14.2)	491.6 (12.3)	539.4 (11.3)	579.9 (12.5)	613.2 (11.9)	647.7 (10.0)	675.2 (9.8)	702.6 (8.8)	725.8 (8.7)	-	-	-	-	-	-
1994	12	8	130.8 (10.9)	310.6 (21.1)	421.0 (12.9)	480.2 (12.2)	536.0 (11.7)	568.3 (11.9)	601.8 (9.8)	629.4 (8.7)	658.3 (9.4)	683.9 (8.3)	702.3 (8.1)	720.1 (6.8)	-	-	-	-	-
1993	13	13	137.3 (8.7)	337.3 (18.4)	431.4 (18.5)	484.8 (18.4)	526.6 (14.8)	558.7 (13.1)	585.6 (11.8)	613.1 (11.6)	639.6 (10.7)	668.6 (10.1)	691 (9.4)	710.7 (9.0)	728.3 (8.8)	-	-	-	-
1992	14	6	99 (11.2)	209.8 (22.6)	333.8 (20.2)	410.6 (26.8)	468 (26.1)	510.7 (24.3)	545.6 (22.5)	577.9 (20.1)	608.8 (18.9)	634.8 (19.4)	657.8 (20.2)	678.9 (16.3)	699.7 (15.6)	716.0 (14.2)	-	-	-
1991	15	5	119.7 (8.6)	331.4 (20.4)	417.6 (33.5)	470.6 (37.8)	504.2 (42.3)	529.9 (41.3)	550.6 (40.3)	580.0 (36.0)	602.3 (34.8)	620.5 (35.4)	649.1 (25.8)	674.1 (22.6)	689.7 (18.6)	706.3 (19.4)	718.8 (19)	-	-
1990	16	3	121.0 (11.3)	217.3 (20.1)	325.3 (24.6)	419.6 (23.9)	487.8 (16.4)	529.7 (16.9)	575.5 (15.2)	603.5 (6.8)	632.4 (0.5)	654.5 (4.7)	684.2 (10.0)	703 (11.2)	715.9 (12.0)	727 (10.9)	752.1 (10.7)	771 (8.3)	-
1989	17	1	144.7	346.9	413.9	476.8	500.9	537.1	580.0	590.7	616.1	661.7	672.4	701.9	723.3	742.0	759.5	776.9	795.6
Pool 11																			
2004	3	6	186.8 (12.9)	351.9 (6.1)	431.4 (8.3)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	4	12	191.8 (15.0)	363.9 (14.4)	451.3 (11.2)	504.3 (8.5)	-	-	-	-	-	-	-	-	-	-	-	-	-
2002	5	42	150.3 (4.3)	334.4 (6.6)	436.2 (5.5)	495.7 (5.1)	536.6 (4.9)	-	-	-	-	-	-	-	-	-	-	-	-
2001	6	57	153.9 (3.8)	346.7 (5.8)	448.8 (4.4)	511.3 (3.9)	555.2 (3.9)	584.5 (4.4)	-	-	-	-	-	-	-	-	-	-	-
2000	7	23	143.8 (6.4)	306.1 (8.3)	424.6 (8.6)	511.6 (8.0)	561.9 (8.4)	596.8 (8.4)	621.1 (8.2)	-	-	-	-	-	-	-	-	-	-
1999	8	20	148.3 (6.9)	320.8 (9.6)	429.3 (8.3)	506.8 (8.1)	557.5 (7.6)	598.2 (7.3)	626.4 (6.5)	645.7 (6.2)	-	-	-	-	-	-	-	-	-

Appendix B. Continued (see page 62 for heading).

Year - class	Age	N	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1998	9	11	140.7 (6.0)	308.9 (15.1)	406.4 (19.3)	474.7 (20.2)	533.3 (15.7)	576.3 (15.0)	611 (14.9)	643.4 (14.6)	665.3 (15.0)	-	-	-	-	-	-	-	-
1997	10	14	135.9 (9.4)	275.2 (13.2)	359.5 (14.1)	427.5 (11.6)	494.1 (12.2)	552.1 (10.4)	595.8 (10.0)	633.8 (8.7)	660.2 (9.0)	682.3 (9.2)	-	-	-	-	-	-	-
1996	11	10	152.0 (8.1)	311.0 (10.4)	382.6 (14.3)	445.9 (17.5)	482.8 (17.5)	525.3 (15.5)	557.4 (15.4)	594.3 (15.6)	623.7 (14.3)	650.0 (12.5)	673.2 (9.7)	-	-	-	-	-	-
1995	12	12	153.1 (11.9)	278.8 (10.1)	366.6 (16.5)	433.8 (17.1)	488.3 (13.9)	525.2 (12.9)	557.4 (11.6)	593.1 (9.4)	622.4 (7.6)	647.3 (7.8)	675.9 (5.7)	701.0 (7.1)	-	-	-	-	-
1994	13	9	138.5 (8.4)	311.1 (23.7)	396.2 (24.8)	461.5 (18.1)	512.0 (14.8)	558.9 (11.8)	593.1 (11.3)	622.1 (12.9)	654.4 (11.9)	680.6 (12.0)	701.4 (13.0)	721.8 (12.1)	736.5 (12)	-	-	-	-
1993	14	6	124.7 (8.6)	266.6 (16.4)	364.3 (10.1)	436.9 (14.1)	488.8 (17.6)	523.5 (19.0)	560.4 (17.2)	595.3 (11.5)	624.4 (9.7)	654.8 (6.0)	684.3 (7.8)	704.7 (8.6)	725.4 (9.2)	741.2 (10.1)	-	-	-
1992	15	4	143.7 (11.2)	296.2 (31.0)	380.1 (14.1)	431.8 (9.1)	478.3 (9.0)	508.1 (10.7)	539.9 (9.2)	576.7 (6.7)	602.9 (9.8)	633.0 (7.0)	668.5 (3.4)	701.1 (4.1)	733.6 (6.5)	761.9 (3.6)	793.5 (3.0)	-	-
1991	16	3	136.9 (19.2)	255.7 (23.6)	350.6 (20.5)	411.5 (27.6)	456.0 (29.1)	485.9 (31.1)	545.8 (34.2)	590.6 (40.0)	621.6 (41.6)	651.1 (44.8)	690.4 (42.2)	711.9 (41.2)	731.8 (36.4)	749.8 (35.0)	774.4 (35.3)	790.1 (35.1)	-
Pool 13																			
2005	1	2	251.5 (31.6)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	2	21	171.4 (7.7)	353.0 (5.4)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	3	44	149.6 (6.0)	321.6 (5.9)	425.1 (3.6)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2002	4	75	158.8 (3.5)	334.9 (4.1)	436.8 (4.0)	496.8 (3.9)	-	-	-	-	-	-	-	-	-	-	-	-	-
2001	5	42	150.1 (5.7)	326.4 (8.5)	441.3 (7.7)	507.6 (6.9)	551.2 (5.0)	-	-	-	-	-	-	-	-	-	-	-	-
2000	6	41	137.1 (4.5)	297.7 (7.5)	427.4 (6.6)	502.1 (5.4)	556.0 (4.6)	592.5 (4.5)	-	-	-	-	-	-	-	-	-	-	-
1999	7	30	130.2 (5.6)	290.5 (11.7)	401.7 (11.8)	495.6 (9.4)	550.7 (8.3)	595.4 (7.5)	625.0 (6.8)	-	-	-	-	-	-	-	-	-	-
1998	8	19	132.4 (5.8)	264.2 (10.3)	366.5 (10.6)	450.3 (10.3)	530.2 (6.4)	583.4 (5.2)	620.4 (6.0)	648.6 (7.6)	-	-	-	-	-	-	-	-	-
1997	9	3	164.4 (39.4)	297.4 (16.2)	412.6 (37.5)	478.4 (25.3)	519 (23.8)	555.6 (22)	600.6 (13.2)	640 (20.6)	660.1 (18.2)	-	-	-	-	-	-	-	-
1996	10	22	134.1 (8.6)	290.1 (13.1)	390.4 (13.5)	455.5 (13.6)	508.8 (11.5)	553.6 (12.0)	599.1 (10.9)	635.4 (9.8)	664.9 (9.0)	686.9 (8.4)	-	-	-	-	-	-	-
1995	11	9	114.8 (13.7)	217.5 (26.5)	300.5 (34.8)	403.0 (43.4)	452.5 (46.6)	492.3 (45.4)	526.4 (44.7)	557.2 (45.4)	589.1 (41.1)	625.7 (34.7)	654.0 (23.6)	-	-	-	-	-	-
1994	12	3	147.9 (27.3)	277.2 (21.6)	370.6 (26.0)	436.9 (30.4)	495.6 (30.0)	533.1 (26.9)	563.5 (23.7)	603.3 (24.1)	623.4 (21.0)	654.2 (10.5)	679.9 (3.6)	708.0 (1.7)	-	-	-	-	-
1993	13	6	123.9 (7.1)	301.3 (10.4)	391.8 (12.0)	439.3 (14.4)	472.6 (9.9)	503.1 (7.8)	537.9 (10.9)	569.6 (11.2)	600.4 (12.6)	647.9 (13.9)	680.0 (14.6)	705.8 (16.7)	722.2 (17.3)	-	-	-	-

Appendix B. Continued (see page 62 for heading).

Year - class	Age	N	Age																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1990	16	1	111.4	170.6	238.8	284.3	348.0	475.3	575.4	600.4	623.2	648.2	673.2	689.1	693.7	707.3	723.3	741.5	-
Pool 14																			
2004	2	13	174.4 (8.3)	317.5 (8.4)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	3	14	157.0 (11.3)	370.7 (14.6)	449.4 (11.8)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2002	4	26	162.2 (7.6)	339.3 (10.4)	447.3 (10.5)	513.3 (10.6)	-	-	-	-	-	-	-	-	-	-	-	-	-
2001	5	44	156.1 (7.2)	333.8 (10.2)	448.3 (8.9)	523.7 (6.6)	571.7 (6.3)	-	-	-	-	-	-	-	-	-	-	-	-
2000	6	26	149.7 (7.9)	317.8 (13.8)	440.4 (11.0)	515.3 (10.3)	573.0 (10.2)	609.9 (8.7)	-	-	-	-	-	-	-	-	-	-	-
1999	7	18	125.3 (8.8)	280.8 (13.9)	407.0 (12)	500.6 (10.6)	557.4 (8.9)	602.1 (8.5)	633.4 (9.3)	-	-	-	-	-	-	-	-	-	-
1998	8	6	131.1 (19.5)	253.5 (24.2)	389.9 (27.2)	471.8 (26.1)	550.5 (13.5)	609.7 (13.9)	658.6 (17.9)	687.2 (19.3)	-	-	-	-	-	-	-	-	-
1997	9	1	64.3	153.8	223.7	317.4	437.7	510.4	549.6	606.9	681.0	-	-	-	-	-	-	-	-
1996	10	2	123.6 (39.0)	351.8 (0.9)	448.4 (26.7)	512.7 (48.1)	564.4 (43.8)	616.9 (18.2)	655.7 (10.2)	686.0 (6.7)	715.1 (0.6)	740.4 (13.1)	-	-	-	-	-	-	-
1995	11	3	117.8 (9.9)	220.7 (25.1)	316.1 (27.4)	398.6 (38.5)	461.9 (27.3)	509.9 (35.7)	567.8 (30.7)	630.9 (38.5)	661 (38.1)	686.5 (36.2)	710.9 (33.6)	-	-	-	-	-	-
1994	12	1	136.5	214.4	289.7	335.6	376.4	412.2	497.7	535.9	607.4	649.5	668.7	689.1	-	-	-	-	-
1993	13	2	133.1 (16.6)	232.2 (39.8)	340.7 (22.9)	416.2 (23.8)	471.2 (26.9)	493.6 (34)	525.3 (32.8)	569.3 (17.4)	597.6 (26.7)	625.5 (30.5)	664.5 (18.9)	689.4 (8.3)	709.3 (1.6)	-	-	-	-
1992	14	1	141.4	400.9	449.0	488.3	523.3	551.0	610.8	657.4	714.3	743.4	762.4	772.6	787.1	797.3	-	-	-
Pool 16																			
2004	3	3	162.5 (5.8)	342.4 (10.1)	451.5 (7.6)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	4	18	158.4 (6.5)	332.8 (9.4)	437.6 (9.2)	500.8 (8.8)	-	-	-	-	-	-	-	-	-	-	-	-	-
2002	5	27	155.4 (7.2)	304.2 (8.6)	402.5 (8.0)	478.2 (8.0)	524.2 (7.4)	-	-	-	-	-	-	-	-	-	-	-	-
2001	6	24	157.1 (6.2)	300.7 (6.4)	394.7 (9.3)	467.5 (8.2)	515.6 (7.4)	555.7 (6.9)	-	-	-	-	-	-	-	-	-	-	-
2000	7	26	155.3 (6.4)	285.9 (9.5)	372.6 (8.3)	447.6 (8.0)	508.0 (7.7)	561.6 (7.5)	600.3 (7.6)	-	-	-	-	-	-	-	-	-	-
1999	8	24	138.2 (6.2)	273.1 (8.8)	355.4 (8.9)	422.9 (8.8)	487.4 (7.8)	530.9 (6.4)	573.2 (6.3)	603.5 (6.0)	-	-	-	-	-	-	-	-	-
1998	9	17	154.8 (7.7)	270.1 (8.7)	353.4 (10.8)	417.3 (10.1)	465.3 (10.3)	518.1 (10.7)	558.8 (9.1)	593.4 (8.7)	619.6 (9.1)	-	-	-	-	-	-	-	-

Appendix B. Continued (see page 62 for heading).

Year - class	Age	N	Age																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1997	10	10	145.5 (9.1)	247.2 (14.0)	326.4 (13.7)	394.5 (14.2)	455.1 (13.6)	499.5 (13.3)	540.4 (15.5)	578.6 (14.0)	608.3 (13.5)	629.9 (13.0)	-	-	-	-	-	-	-
1996	11	8	152.7 (14.9)	272.8 (13.7)	342.1 (10.3)	408.2 (12.9)	447.8 (13.2)	486.9 (14.4)	521.1 (12.8)	562.6 (11)	598.5 (7.2)	627.8 (8)	651 (7.9)	-	-	-	-	-	-
1995	12	2	92.7 (23)	194.2 (68.5)	250.2 (80.1)	304.8 (79.7)	371.2 (71.1)	418.4 (69.7)	469.5 (50)	526.9 (25.1)	575.7 (22.1)	605.8 (16.2)	651.7 (13.6)	668.8 (7.4)	-	-	-	-	-
1993	14	4	135.4 (10.9)	236.7 (9.2)	307.5 (17.0)	357 (18.2)	397.4 (14.9)	445.5 (7.4)	476.2 (4.5)	508.5 (3.6)	543.8 (7.8)	578.8 (7.9)	604.3 (9.6)	628.6 (8.4)	657 (7.8)	685.6 (6.1)	-	-	-
											Pool 18								
2005	2	5	170.0 (11.1)	307.4 (8.1)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2004	3	16	166.4 (13.9)	380.8 (11.4)	460.2 (10.8)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	4	23	173.5 (7.7)	329.2 (13.8)	445.4 (8.0)	511.8 (6.4)	-	-	-	-	-	-	-	-	-	-	-	-	-
2002	5	35	156.7 (6.6)	316.4 (9.1)	427.2 (9.7)	500.9 (8.5)	549.4 (8.7)	-	-	-	-	-	-	-	-	-	-	-	-
2001	6	35	152.2 (5.2)	316.6 (9.3)	421.4 (7.9)	491.1 (6.4)	544.4 (6.3)	580.8 (5.8)	-	-	-	-	-	-	-	-	-	-	-
2000	7	33	159.6 (7.0)	309.0 (11.2)	405 (10.5)	474.8 (8.8)	531 (7.9)	578.2 (6.6)	613.7 (6.1)	-	-	-	-	-	-	-	-	-	-
1999	8	23	154.4 (6.6)	278.1 (10.7)	388.1 (9.2)	460.2 (8.6)	521.5 (8.7)	574.8 (9.0)	611.5 (9.4)	642.5 (8.4)	-	-	-	-	-	-	-	-	-
1998	9	19	147.6 (6.9)	279.5 (10.4)	368 (10.4)	451.5 (10.1)	511.0 (9.7)	555.7 (7.7)	593.6 (6.6)	628.6 (5.7)	653.3 (6.2)	-	-	-	-	-	-	-	-
1997	10	8	144.4 (10.1)	276.3 (23.1)	369.6 (26.6)	435.8 (23.7)	500.7 (21.7)	550.5 (19.4)	597.5 (16.4)	639.3 (11.6)	668.0 (10.7)	693.3 (9.2)	-	-	-	-	-	-	-
1996	11	9	157.7 (7.5)	272.8 (12.1)	349.4 (11.3)	405.8 (10.2)	448.6 (9.8)	498 (10.6)	535.6 (7.0)	583.4 (10.1)	617.9 (9.2)	652.5 (8.3)	674.2 (7.1)	-	-	-	-	-	-
1995	12	6	168.9 (17.1)	285.7 (20.0)	367.2 (19.2)	421.0 (14.7)	475.9 (16.8)	513.3 (17.5)	545.3 (16.6)	579.6 (12.4)	614.0 (10.7)	649.4 (9.8)	680.2 (9.1)	697.1 (9.4)	-	-	-	-	-
1994	13	3	162.6 (38.3)	271.2 (41.6)	320.3 (43.0)	375.1 (36.7)	441.4 (33.1)	503.0 (35.0)	550.1 (33.2)	584.2 (29.6)	617.6 (26.8)	647.6 (18.2)	673 (20.1)	695.8 (17.5)	713.9 (16.0)	-	-	-	-
1993	14	3	160.7 (20.4)	269.2 (11)	382.1 (52.5)	438.6 (49.1)	487.5 (45.9)	555.8 (53.1)	595.7 (57.7)	628.0 (53.7)	661.1 (50.2)	698.7 (56.6)	740.2 (51.5)	764.6 (46.5)	783.9 (42.5)	796.1 (40.7)	-	-	-
1992	15	3	135 (15.0)	279.2 (27.6)	363.1 (26.4)	422.8 (20.2)	472.8 (23.7)	530.1 (30.3)	564.3 (23.8)	596.0 (25.4)	625 (23.1)	644.8 (24.2)	664.6 (26.3)	680.5 (28.3)	702.5 (30.1)	715 (29.1)	726.6 (28.5)	-	-
1991	16	1	188.0	319.2	416.7	478.2	513.1	528.2	540.9	558.3	585.0	618.7	639.6	665.1	689.5	717.4	732.5	751.0	-

APPENDIX C. RELATIVE WEIGHT OF SHOVELNOSE STURGEON

Mean, standard error, median, minimum, and maximum relative weights of shovelnose sturgeon from the upper Mississippi River.

Pool	*N*	Mean	Standard error	Median	Minimum	Maximum
4	122	91.7	0.007	91.9	67	110
7	155	91.7	0.006	91.7	74	115
9	203	94.2	0.007	93.8	63	122
11	290	91.2	0.006	90.1	72	132
13	198	86.6	0.006	85.1	69	108
14	162	91.0	0.008	90.0	56	129
16	210	89.6	0.007	89.9	62	126
18	315	96.3	0.006	95.9	50	130