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Harvest of Mississippi River sturgeon drives abundance and reproductive success: a harbinger of collapse?

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Summary

Within harvested populations, relationships between harvest intensity and reproductive responses are typically unclear, rendering regulatory decisions difficult. Harvest of the commercially important shovelnose sturgeon (*Scaphirhynchus platorynchus*) is increasing in the upper Mississippi River; standardized seasonal sampling revealed that adult abundance is declining. Relative density of annual cohorts varied negatively with historical harvest intensity ($r^2 = 0.84$), suggesting that removal of mature adults is reducing the contribution of cohorts to population density. The results of simulation modeling suggest that this currently unregulated fishery is experiencing both growth and recruitment overfishing. Further, the current proposed multi-state minimum length regulation was insufficient to maintain a sustainable stock. Only a more conservative minimum length limit (685 mm) produced yields that were sustainable at the current level of mortality and provided room for the fishery to grow. The annual mortality rate of the sympatric, federally endangered pallid sturgeon (*S. albus*) was similar to that of the shovelnose sturgeon population, raising concerns that harvest-induced mortality is affecting this congener's vital rates.

Introduction

The majority of fisheries worldwide are fully exploited, overharvested, or recovering (Botsford et al., 1997). Although harvest typically is implicated as the reason for the decline of exploited fish populations, habitat degradation either through fishing activities (Vitousek et al., 1997) or natural environmental change (Houde, 1987) may also contribute. Harvested populations likely collapse due to the removal of reproductively viable adults. This causes a reduction in reproductive ability and thus sustainability (Beverton and Holt, 1957; Ricker, 1975; Quinn and Deriso, 1999). Fish are often highly fecund and improved reproductive success may compensate for declining densities. Thus, distinct relationships between adult abundance and reproductive success are often weak or non-existent in populations until populations become very small (Koslow et al., 1987; Koslow, 1992). For species with specific spawning requirements, either access to or the availability of reproductive areas may interact with reductions in mature adults to hasten population declines (Birnstein, 1993). Although these concepts are widely accepted in fisheries ecology, robust field patterns are typically absent because of unclear patterns or high variation in assessment data (Myers, 2001).

Populations of sturgeon are threatened across the globe due to a combination of unregulated harvest and habitat loss (Williams et al., 1987; Birnstein, 1993; Boreman, 1997; Pikitch et al., 2005). The recent ban of importation of beluga sturgeon (*Huso huso*) eggs (caviar) into the United States by the US Department of the Interior (Pala, 2005) is testament to current concerns about declines. The commercial fishery for shovelnose sturgeon (*Scaphirhynchus platorynchus*), still allowed by several states in the Mississippi and Missouri river drainages of the US, may bear increased burden as market pressure for domestic roe increases (Keenlyne, 1997; Quist et al., 2002; Secor et al., 2002). Recreational harvest also occurs but is comparatively minor and likely not driven by market forces. Although still considered abundant in the center of its range, shovelnose sturgeon has declined or been extirpated in many drainages at the peripheries (Keenlyne, 1997). Of particular concern is that its larger and more fecund congener, the US federally endangered pallid sturgeon (*S. albus*), occurs sympatrically with this species throughout much of its range. Although illegal to harvest, the species is often difficult to distinguish visually from the shovelnose sturgeon and is likely harvested incidentally or is negatively affected by handling when captured as bycatch; poaching also occurs (Herzog, 2002; Secor et al., 2002).

Understanding how commercial harvest affects populations is essential for effective management of sustainable stocks and requires knowledge of the population age structure. To estimate the age structure of a population, an accurate measure of age is needed. For sturgeon the only currently acceptable ageing method uses the pectoral fin ray. This method has been validated in the lake sturgeon (Rossiter et al., 1995) and white sturgeon (Brennan and Cailliet, 1989). For the shovelnose sturgeon, this method has been shown to be the most precise (Jackson, 2004) and annulus formation has been validated (Whiteman et al., 2004). Once the age structure of a population is determined the mortality and growth rate can be determined.

A simple regression of the log-transformed frequency of each age group plotted against age (i.e. catch curve) provides an estimate of instantaneous mortality (Z) (Ricker, 1975). If harvest is at a level that cannot be compensated for by a reduction in the natural mortality of the population, mortality will increase. Further, the residuals in the catch curve may provide an estimate of year-class strength (Maceina, 1997; Sammons et al., 2002).

Because sturgeon are long-lived (> 20 years), reproduce late (age 5 or older), and are harvested primarily for eggs

(Keenlyne, 1997; Herzog, 2002; Pikitch et al., 2005), they are sensitive to the impact of harvest (Fabrizio and Richards, 1996) and the limited reproductive habitat on population dynamics, providing a model system for quantifying harvest effects on populations. One approach used to determine the influence of commercial exploitation is simulation modeling. Models such as the Beverton-Holt yield-per-recruit model have been effective at estimating the theoretic yield of populations as a function of alternative management strategies (Maceina et al., 1998; Quist et al., 2002). To assess the potential for harvest to remove adults before they have met their reproductive potential, the spawning potential ratio (SPR) can be calculated (Goodyear, 1993; Slipke et al., 2002). The SPR estimates the potential proportion of eggs a recruit will produce in an exploited population compared to that of an unexploited one. In an unexploited population the proportion is equal to one, and declines toward zero with increased fishing mortality. For many marine fisheries a SPR of 30% is considered the critical value below which the population reaches recruitment overfishing (Goodyear, 1993).

We present suggestive evidence of harvest-induced reproductive dynamics and potential population decline of one of the last commercially-viable sturgeon species, raising concerns about the impact of increasing domestic harvest. Further, using simulation modeling, we assessed how current and proposed management strategies may affect the population yield and reproductive potential of the MMR shovelnose sturgeon population.

Methods

Commercial harvest

We reviewed the historical data for shovelnose sturgeon flesh harvested in the upper Mississippi River (above confluence of the Ohio River) compiled by the states of Missouri and Illinois. We used these data because these states border the river reach in which our sampling occurred, although harvest also occurs in other states. To determine whether shovelnose sturgeon harvest was related to Russian caviar harvest, yield of Russian sturgeon was estimated from Pikitch et al. (2005).

Adult density

To provide an index of adult shovelnose sturgeon density in the unimpounded portion of the upper Mississippi River between Cairo, Illinois and St Louis, Missouri, we used catch as a function of effort based on winter standardized sampling conducted during January–February 1995 through 2001. Shovelnose sturgeon were sampled from randomly selected historically productive wing-dike, channel-training structures on the unimpounded river, each year using 51 mm bar monofilament mesh gill nets that were 46 m long and 3 m deep. Effort was standardized as fish per net night and a mean for each year was calculated.

Population demographics

Shovelnose sturgeon were captured from randomly selected sites in the MMR using 51 mm bar mesh during 2002 and 2003. All shovelnose sturgeon were measured to the nearest mm fork length and weighed to the nearest gram. For age analysis, a 25 mm section of the right pectoral fin was removed from an area proximal to the origin of the ray. Because pallid sturgeon are rare, numerous methods were employed to sample them. We employed baited trot lines, 51 mm and 76 mm gill nets, a Missouri trawl, and commercial fishers. Any capture pallid was weighed, measured and numerous morphometric and meristic measurements were made for species identification (Wills et al., 2002). A 25 mm section of the right pectoral fin was removed from all pallid sturgeon for age analysis as well.

Age, growth, and mortality

Fin rays were sectioned using a Buhler Isomet® slow speed saw. Three 600-um sections were mounted to glass slides and aged to the nearest annulus at 7–45× magnification under a stereomicroscope. Annuli were determined to be the light bands when transmitted light was used; areas of growth showed up as dark bands with transmitted light. Fish were aged by two readers independently. Disagreements were resolved by reaching a consensus. If a consensus could not be reached, the spine was discarded. Pallid sturgeon fin rays were processed in the same fashion as the shovelnose sturgeon.

Mortality rates were quantified for both the pallid and shovelnose sturgeon using analysis of catch curves. To reduce the amount of bias created by an influential observation in the catch curve, we used weighted regression, which deflates the importance of rare old fish (Slipke and Maceina, 2000). The declining slope of the catch curve reflects instantaneous mortality (Z). This estimate of Z was used to determine the total annual mortality (A) from the equation $A = 1-e^{-Z}$. For pallid and shovelnose sturgeon, catch curves were generated by summing the number of fish caught per age-class across years. This method mitigates the bias created by variability in recruitment inherent in the catch curve (Ricker, 1975).

Shovelnose sturgeon growth was assessed using a von Bertalanffy model, using the length at capture as a measure of length at age. The von Bertalanffy model assumes the form $L_t = L_\infty(1-e^{-K(t-t_0)})$, where, L_t is the length at time t, L_∞ is the theoretic maximum length, K is the growth constant, t is time of concern and t_0 is the age at which length is zero. These parameters can be used to compare growth among populations.

Year-class strength

The residuals generated from each catch curve regression provided an index of cohort strength (Maceina, 1997; Sammons et al., 2002). Points that fall above the regression line indicate strong annual cohorts (i.e. a generation with high recruitment to the population) and points that fall below the line indicate weaker than average year classes (Maceina, 1997; Sammons et al., 2002). These residuals can then be used to determine those factors that contribute to year-class strength. Because previous research suggested that harvest was more important to cohort abundance than were abiotic factors (e.g. discharge) in shovelnose sturgeon (Jackson, 2004), we used harvest as the sole independent variable. Harvest for the upper Mississippi River was determined from the commercial reports submitted by Illinois and Missouri commercial fishers. To determine if the relative strength of the different year-classes (i.e. strong and weak) was maintained among samples we used pairwise correlations between years.

Simulation modeling

The commercially exploited shovelnose sturgeon population of the MMR was modeled using the Beverton-Holt equilibrium yield model (Ricker, 1975) in the yield per recruit function in Fishery Analysis and Simulation Tools (FAST) software (Slipke and Maceina, 2000). The FAST yield per recruit model is actually a modification of the original Beverton-Holt model (Ricker, 1975; Slipke et al., 2002), but it is similar to the yield model of other programs (Quist et al., 2002). The Beverton-Holt yield per recruit estimates yield using the following formula (Slipke and Maceina, 2000):

$$Y = \frac{FN_t \, e^{Zr} \, W_\infty}{K} [\beta(X, P, Q)] - [\beta(X_1, P, Q)], \tag{1}$$

where F = instantaneous fishing mortality; N_t = the number of recruits entering the fishery at some time t; Z = instantaneous mortality rate; r = time to recruitment ($t_r - t_0$); W_∞ = maximum theoretic weight estimated from L_∞ and the weight length regression; K = the Brody growth constant from the von Bertalanffy model; β = the incomplete beta function; $X = e^{-Kr}$; $X_1 = e^{-K(\text{Max Age} - t_0)}$, Max Age is the maximum age from the sample; $P = Z/K$; Q = slope of the weight length regression + 1.

Several parameters are needed to run the simulation models using FAST. Information regarding the growth, longevity, and weight length regression was calculated from the data collected during this study (Table 1). For the minimum length limits we used 550, 610, and 685 mm coinciding with the current (no limit), proposed (IL, KY, MO, TN), and conservative length limits, respectively (Table 1).

To generate an estimate of conditional natural mortality (natural mortality rate when no fishing mortality occurs), a mortality estimate similar to the unexploited shovelnose sturgeon population in the Missouri River was used (3–7%; Quist et al., 2002). To estimate how yield was affected by harvest we modeled the populations over varying conditional fishing mortality. The lowest minimum conditional fishing mortality was 0%, coinciding with an unexploited fishery, and the population was modeled to a high of 90% fishing mortality (Table 1). For the yield per recruit models, the inflection point in the conditional fishing mortality yield plot was considered above which growth overfishing occurs. The 10% rule ($F_{0.1}$ = fishing mortality that leads to a slope 10% of the slope at F = 0; King, 1995) was used to determine the level of mortality that maintained a sustainable fishery (Hilborn and Walters, 1992; Haddon, 2001; King, 1995). The 10% rule is more conservative than F_{max} and has been shown robust to maintain sustainability (Hilborn and Walters, 1992; Haddon, 2001; King, 1995).

Table 1
Selected population demographics and parameters used to simulate effect of harvest on shovelnose sturgeon (*Scaphirhynchus platorynchus*) in MMR

Parameter	IN and IL
Von Bertalanffy growth parameters	
L_∞	792 mm
K	0.16
t_0	−1.54
Conditional natural mortality	0.05, 0.10
Conditional fishing mortality	0.0–0.90
Log (weight): log(length) coefficients	$a = -10.98$; $b = 2.85$
Age at sexual maturity	5.5
Fecundity: length relationship	$m = 2.77$; $b = -3.174$
Percent of females spawning	
5.5–6 year olds[a]	50%
7–18 year olds[a]	25%
Maximum age	18.2
Minimum length limits	550; 610; 685 mm

[a] From Colombo (2004).

The effect of harvest on the reproductive potential of the population was estimated by simulating the spawning potential ratio (SPR). The SPR has been used extensively in marine systems (Goodyear, 1993) and has recently been used to determine the point of recruitment overfishing in freshwater systems (Quist et al., 2002; Slipke et al., 2002). The SPR estimates the number of eggs produced in an exploited fishery compared to an unexploited one by estimating the fecundity potential of the recruits using the formula (Goodyear, 1993):

$$P = \sum_{i=1}^{n} E_i \prod_{j=0}^{t=1} S_{ij} \tag{2}$$

where n = number of ages in an unfished population; E_i = the mean fecundity of females of age i; $S_{ij} = e^{-(F_{ij} + M_{ij})}$, the density-independent annual survival probabilities of females age i when age j; F_{ij} = instantaneous fishing mortality rate of females age i when age j; and M_{ij} = instantaneous natural mortality rate of females age i when age j.

Calculation of SPR requires information on age at sexual maturation, an estimate of length to fecundity, and percentage of females spawning annually, all derived from Colombo (2004) (Table 1). We used a threshold level of 40% SPR to produce a sustainable fishery. A critical level of 30% (i.e. allowing fish to meet 30% of their maximum expected reproductive potential) was set as the minimum level of SPR necessary to avoid recruitment overfishing (Goodyear, 1993).

Results

Commercial harvest

Harvest of shovelnose sturgeon in the Mississippi River reached historically high levels during 2001 (Fig. 1). Harvest of shovelnose sturgeon was related to decreasing harvest from the Russian sturgeon species caviar fisheries (Fig. 2).

Adult density

Standardized winter catch rates of shovelnose sturgeon in gill nets during 1997 through 2001 declined exponentially as basin-wide harvest increased (Fig. 3). Pallid sturgeon catch rates were too low to estimate their abundance using a standardized scheme. Although standardized sampling suggests an impact of harvest on adult shovelnose sturgeon numbers, a separate approach is necessary to evaluate historical effects on reproduction.

Mortality and growth

Annual percent mortality rates for shovelnose sturgeon were estimated by quantifying the rate of decline in annual cohorts through time with independently derived annual samples. Rates were 42% for 2000 (ln frequency = 9.73–0.568 × age, $r^2 = 0.92$, $P < 0.001$), 31% for 2002 (ln frequency = 5.90–0.374 × age, $r^2 = 0.94$, $P < 0.001$), 35% for 2003 (ln frequency = 7.77–0.452 × age, $r^2 = 0.86$, $P < 0.004$), and pooled 37% (ln frequency = 9.14–0.47 × age, $r^2 = 0.92$, $P < 0.001$). By pooling cohort abundances across sampling

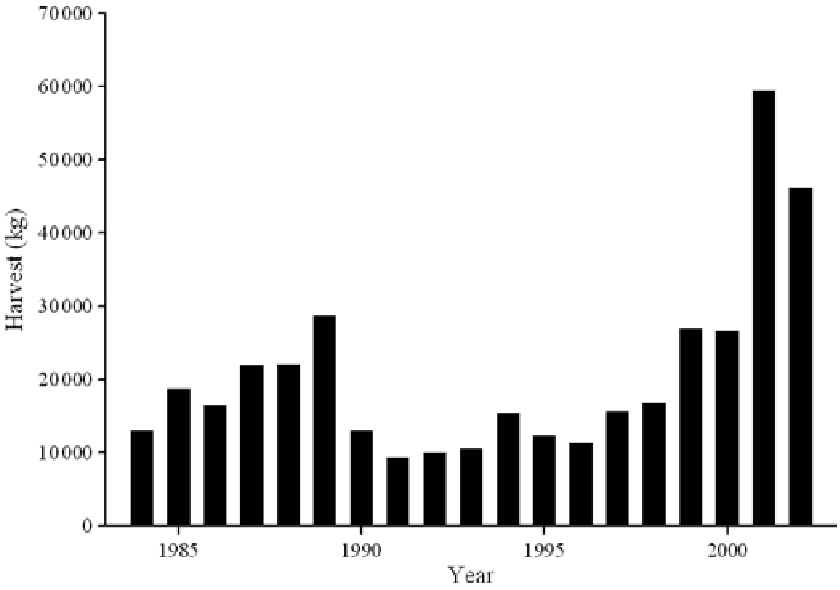

Fig. 1. Harvest of shovelnose sturgeon (*Scaphirhynchus platorynchus*) flesh by Illinois and Missouri fishers in the upper Mississippi River system (i.e. entire border of the state) from 1984 to 2002

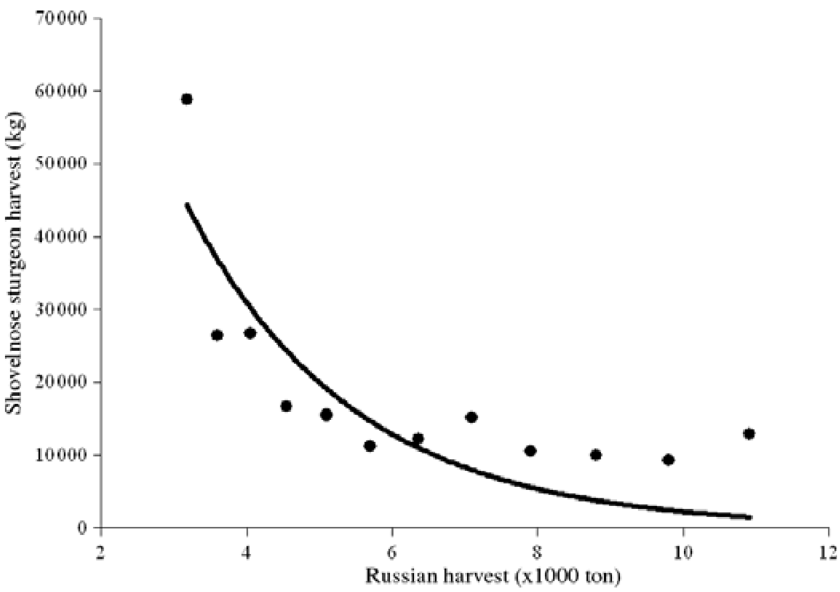

Fig. 2. Relationship between harvest of Russian sturgeon species and harvest of shovelnose sturgeon in the Upper Mississippi River from 1990 through 2002. *Ln* (shovelnose) = 11.68–1.12 Ln (Russian), $r^2 = 0.68$, $P < 0.001$

years, we quantified pallid sturgeon annual mortality to be 37% (ln frequency = 7.08–0.465 × age, $r^2 = 0.95$, $P < 0.001$).

The Brody growth constant of the shovelnose sturgeon population in the MMR was similar to that of other sturgeon populations (Table 1; Morrow et al., 1998; Quist et al., 2002). However, the theoretic maximum length was higher (Table 1); this may be attributable to the reduced density due to commercial exploitation leading to a higher L_∞ (Beverton, 1992; Lorenzen, 1996; Shin and Rochet, 1998).

Year-class strength

Analyzing residual deviations from the average regression line of age vs relative abundance in an unbiased population sample may reflect the relative success of annual cohorts (Maceina, 1997; Sammons et al., 2002). There was a high degree of correlation among the different samples (2000–2002: $r = 0.89$, 2000–2003: $r = 0.83$, 2002–2003: $r = 0.97$) suggesting the different samples provided a similar picture of year class strength. Positive deviations occurred during years of low harvest and negative deviations during high harvest (Fig. 4, 2000: year-class strength = 0.702–5 × 10^{-5} × harvest, $r^2 = 0.72$, $P < 0.05$; 2002: year-class strength = 1.003–7 × 10^{-5} × harvest, $r^2 = 0.73$, $P < 0.05$; 2003: year class strength = 0.917–6 × 10^{-5} × harvest, $r^2 = 0.74$, $P < 0.05$), suggesting a negative impact of harvest on the ultimate success (i.e. recruitment to adulthood) of annual cohorts. Furthermore, from these equations the level of harvest that allowed for an average year class was determined to be 14536 (±380) kg.

Simulation modeling

Under the lower estimate of natural mortality ($cm = 5\%$), with harvest being limited only by age at maturity and gear selectivity, the population reached F_{max} at a conditional fishing mortality of 26% (Fig. 5), well below the current level of annual mortality. The level of annual mortality that could be sustained ($F_{0.1}$) with no management was 16% (Fig. 5). Using the proposed minimum length limit of 610 mm, the population reached F_{max} at 35% fishing mortality (Fig. 5); the population was sustainable at a fishing mortality of 20% (Fig. 5). With a

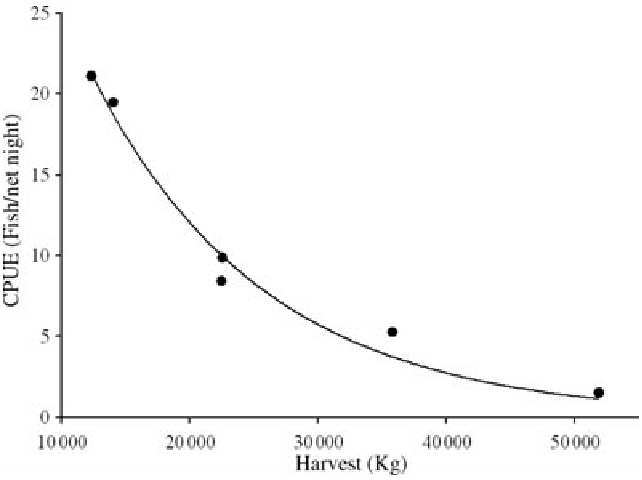

Fig. 3. Adult abundance of shovelnose sturgeon (*Scaphirhynchus platorynchus*) as a function of Mississippi River shovelnose sturgeon harvest by Illinois and Missouri commercial fishers. CPUE $= 53.062e^{(-0.0001\text{Harvest})}$, $r^2 = 0.981$, P $= 0.0001$

685 mm minimum length limit, F_{max} was not reached until fishing mortality reached 67% (Fig. 5) and the population remained sustainable until mortality reached 33% (Fig. 5). At a higher estimate for conditional natural mortality (*cm* = 10%) yield per recruit for all management options was approximately 36% lower at F_{max} than at natural mortality of 5% (Fig. 5). However, there was an increase in the level of fishing mortality before F_{max} was reached.

With no minimum length limit and a conditional mortality rate of 5% the spawning potential ratio of the population fell below 40% at a fishing mortality of 15% (Fig. 6) and below 30% at 20% annual mortality (Fig. 6). At the same level of natural mortality with the proposed minimum length limit (610 mm), the population fell below the 40% threshold in SPR at a fishing mortality rate of 21% (Fig. 6) and below the critical 30% threshold at 30% fishing mortality (Fig. 6). With the more conservative length limit (685 mm), the threshold SPR of 40% was not reached until conditional fishing mortality reached 69% (Fig. 6) and the critical threshold SPR was not reached over the entire range of mortalities for which the population was modeled (Fig. 6). Similar results were seen with the higher natural mortality rate (10%), the exception being that the threshold SPR (40%) was not reached under the conservative length limit (Fig. 6). When the results of the yield per recruit modeling are compared to the SPR modeling it becomes apparent that these populations experience a reduction in SPR below the critical threshold (30%) at mortalities similar to those of F_{max}. This suggests that the more conservative $F_{0.1}$ be used as a target for management rather than F_{max}.

Discussion

In our view, these results provide compelling, albeit correlative, support for a harvest effect on the population of shovelnose sturgeon in the MMR. Harvest is directly impacting adult abundances and indirectly affecting reproductive success, ultimately influencing the contribution of cohorts to population size. Given that sturgeon do not become fully vulnerable to standardized sampling gear and commercial harvest until age 6 or greater, a considerable lag exists between the impact of the fishery on cohort abundance and the apparent response of the population documented by both

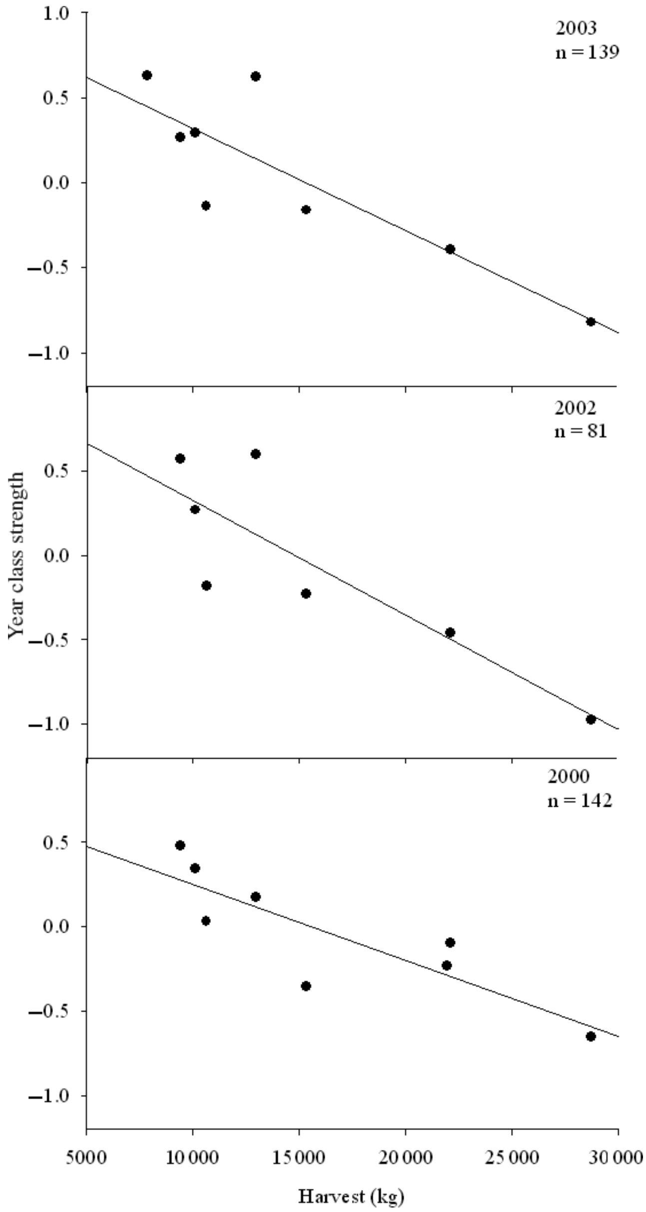

Fig. 4. Relationship between Mississippi River harvest by Illinois and Missouri commercial fishers and year-class strength as derived from residuals from catch-curves for shovelnose sturgeon (*Scaphirhynchus platorynchus*) sampled during 2003 ($r^2 = 0.73$, $P < 0.05$), 2002 ($r^2 = 0.74$, $P < 0.05$) and 2000 ($r^2 = 0.72$, $P < 0.05$). 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

biologists and fishers. These lags may be responsible for the apparently sudden decline in many fish populations after years of sustained but high harvest (Fromentin and Fonteneau, 2001). The apparent decline in standing stock that we documented coupled with a succession of weak year classes may well cause a large decline in future catch rates. Although we cannot tease apart the contribution of harvest to observed annual mortality rates, it is probable that these rates are largely driven by harvest, given that sturgeon mature late in life and are long-lived (Birnstein, 1993; Billard and Lecointre, 2001; Secor et al., 2002). Annual mortality rates of shovelnose sturgeon in the unharvested middle Missouri River (3%; Quist et al., 2002), harvested lower Missouri River (20%; Quist et al., 2002), and historically harvested lower Mississippi River

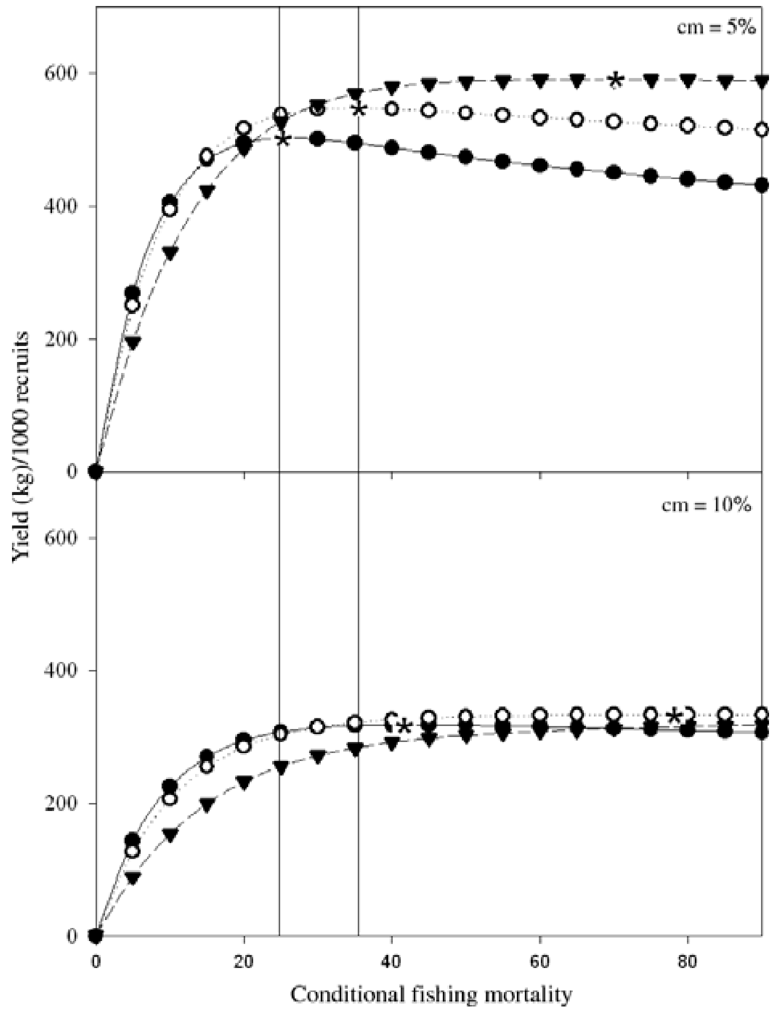

Fig. 5. Simulated yield per 1000 recruits for shovelnose sturgeon (*Scaphirhynchus platorynchus*) population in middle Mississippi River under three different length limits: no limit (-550 mm), dark circles; proposed (610 -mm), open circles; conservative (685 mm), dark triangles; and two different conditional natural mortalities (*cm*), 5% top graph and 10% bottom graph. Vertical lines denote range of current level of harvest. Asterisks – denote F_{max}

(20%; Morrow et al., 1998) were considerably lower than found in this study (37%). This suggests that harvest has caused an increase in the mortality rate of the population.

The strong association between harvest and annual cohort size is likely related to removal of mature, ovigerous females from the upper Mississippi River fishery as they are staging to spawn. Similar reproductive aggregations and strong spawning migrations are found in other taxa that have experienced collapse, including Pacific salmon (Nehlsen et al., 1997) and Atlantic cod (Fogarty et al., 2001). Although strong anecdotal evidence exists for the location of spawning aggregations in the upper Mississippi River, the actual location or locations of successful spawning contributing to annual cohorts is unknown. If spawning habitat is limited or adult movement through impoundments of the upper river is impeded, then harvest effects are likely to be exacerbated on remaining viable areas.

Modeling suggested at the current level of harvest with no regulations that the population is theoretically experiencing both growth and recruitment overfishing. With the proposed state limitation change to a 610 mm minimum length limit, there is still a propensity for the population to become overfished at similar mortality rates to what it is currently experiencing. Further recruitment overfishing would also be occurring. With a more conservative minimum length limit (i.e. 685 mm) the population theoretically could withstand an increase in harvest. Modeling also suggested with a higher natural morality rate that the stock could withstand a higher level of fishing mortality before reaching either $F_{0.1}$ or F_{max}. However, the yield per recruit at all levels of fishing mortality is lower when modeled with a lower natural mortality rate.

The population reproductive potential of shovelnose sturgeon in the MMR is strongly affected by harvest. This suggests that the population has the propensity to experience recruitment overfishing with moderate increases in harvest. Similar results were seen with other populations of shovelnose sturgeon (Quist et al., 2002) and white sturgeon (Boreman, 1997). This is primarily due to the life history of sturgeon (i.e. late maturation and intermittent spawning). As this is one of the last harvestable sturgeon populations it is advisable to be conservative in management practices so that in the face of increased demand the population remains sustainable.

Annual mortality rates of pallid sturgeon were similar to those of its congener. During an intensive four-year sampling effort in which many individuals were recaptured, no pallid sturgeon sampled by our crews was beyond 15 years of age. In the northern Missouri River, pallid sturgeon reach 60 years of age with very low annual mortality (Krentz et al., 2001). Although little is known about the age of maturity in pallid sturgeon, our initial analysis of these data suggests that females do not become mature until 9 years of age. Thus, harvest of large, mature individuals, whether intentional or not, may be contributing to the mortality rates we have quantified. Given the rarity of this species and the lack of

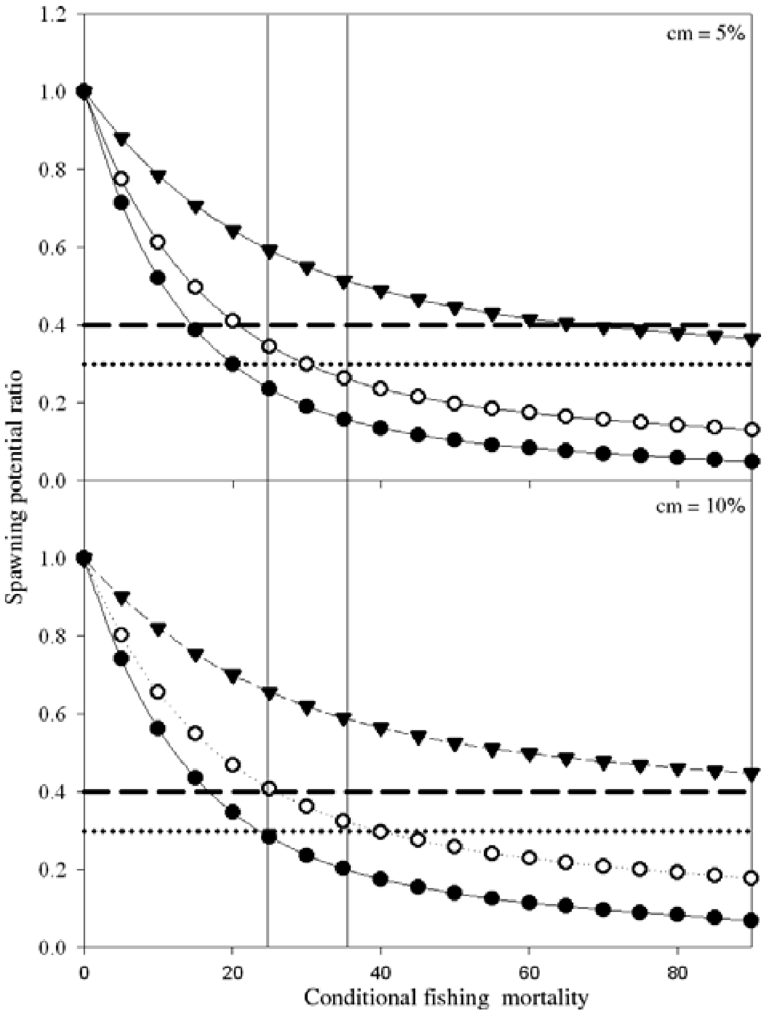

Fig. 6. Simulated spawning potential ratio for shovelnose sturgeon (*Scaphirhynchus platorynchus*) population in middle Mississippi River under three different length limits: no limit (550 - mm), dark circles; proposed (610 mm), open circles; conservative (685 mm), dark triangles; and two different conditional natural mortalities (*cm*), 5% top graph and 10% bottom graph. Horizontal dashed line represents threshold SPR of 40%; horizontal dotted line represents critical SPR of 30%. Vertical lines denote range of current level of harvest

apparent reproduction in most of its range, the potential relationship between harvest and reproduction for shovelnose sturgeon may also hold for this species, hastening its decline. Other sources of mortality beyond senescence are likely rare for adults. However, entrainment by barges may contribute to mortality in the river, reducing juvenile and adult survival (Killgore et al., 2001; Gutreuter et al., 2003).

Although fisheries ecology has often failed to isolate clear patterns between fishing activities and population dynamics, these strong patterns from a notoriously variable river ecosystem provide suggestive evidence that harvest of adults is directly affecting production of future generations. Although harvest has been largely unregulated in the past, some size-dependent and seasonal regulations have been proposed by the states in 2005 to reduce the potential impact of harvest on shovelnose sturgeon. However, the interaction between spawning habitat availability and harvest is far from understood. Given that the proposed regulations do not restrict the number of individuals harvested, the recently increasing trend in domestic harvest may cause shovelnose sturgeon to become commercially extinct and perhaps extirpated within the center of its range. Further, current recovery efforts underway for the endangered pallid sturgeon may be jeopardized.

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