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Bycatch of the endangered pallid sturgeon (*Scaphirhynchus albus*) in a commercial fishery for shovelnose sturgeon (*Scaphirhynchus platorynchus*)

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Summary

We quantified the bycatch of pallid sturgeon *Scaphirhynchus albus* in Tennessee's shovelnose sturgeon (*Scaphirhynchus platorynchus)* fishery by accompanying commercial fishers and monitoring their catch on five dates in spring 2007. Fishers were free to keep or discard any sturgeon they collected in their gillnets and trotlines and we were afforded the opportunity to collect meristic and morphometric data and tissue samples from discarded and harvested specimens. Fishers removed 327 live sturgeon from their gear in our presence, of which 93 were harvested; we also obtained the carcasses of 20 sturgeon that a fisher harvested out of our sight while we were on the water with another fisher. Two of the 113 harvested sturgeon were confirmed pallid sturgeon based on microsatellite DNA analyses. Additionally, fishers gave us five, live pallid sturgeon that they had removed from their gear. If the incidental harvest rate of pallid sturgeon (1.8% of all sturgeon harvested) was similar in the previous two commercial seasons, at least 169 adult pallid sturgeon were harvested by commercial fishers in the Tennessee waters of the Mississippi River in 2005–2007. If fishers altered their behavior because of our presence (i.e. if they were more conservative in what they harvested), the pallid sturgeon take was probably higher when they fished unaccompanied by observers. While retrieving a gill net set the previous day, a fisher we were accompanying retrieved a gillnet lost 2 days earlier; this ghost net caught 53 sturgeon whereby one fish was harvested but most fish were dead, including one confirmed pallid sturgeon.

Introduction

There is mounting evidence that the illegal take of federally endangered pallid sturgeon *(Scaphirhynchus albus)* in commercial fisheries targeting shovelnose sturgeon (*Scaphirhynchus platorynchus)* is hampering efforts to recover, and ultimately delist, pallid sturgeon [Colombo et al., 2007; U.S. Fish and Wildlife Service (USFWS), 2007]. The impact of fishing activity and the take of pallid sturgeon on their demographics has been inferred indirectly by noting differences in population structure in reaches of the Mississippi River with commercial shovelnose sturgeon fishing (e.g. Missouri and Illinois waters) and without commercial shovelnose sturgeon fishing (Mississippi and Louisiana waters) (Killgore et al., 2007). Bycatch has long been suspected of adversely impacting sturgeon populations in other waters of North America (ASMFC, 1990; Collins et al., 1996). Pallid sturgeon carcasses are occasionally observed in fish-processing facilities, markets, or in the possession of fishers (Sheehan et al., 1997; USFWS, 2007; Dan Burleson, Special Agent, US Fish and Wildlife Service, pers. comm.). However, the extent of bycatch and harvest of pallid sturgeon in fisheries targeting shovelnose sturgeon is unknown. Such information is vital because populations of late-maturing species such as pallid sturgeon are incapable of sustaining anything other than low levels of exploitation, be it unintentional as bycatch, or due to poaching (Boreman, 1997; Secor et al., 2002).

In locales where the two species are sympatric, distinguishing shovelnose sturgeon from pallid sturgeon based on external characteristics can be difficult (Murphy et al., 2007; Schrey et al., 2007), especially when the specimens are small (i.e. <250 mm standard length; Kuhajda et al., 2007). Possession of a single pallid sturgeon carries a maximum civil penalty of US$25 000 and criminal penalties up to $100 000 and/or 1 year imprisonment. Despite severe penalties and known difficulties in distinguishing the two species based solely on external characteristics, fishing pressure on shovelnose sturgeon (and the bycatch of pallid sturgeon) is not expected to abate because prices for shovelnose (i.e. 'hackleback') sturgeon caviar remain high (~US$40 per 50 g, retail).

The shovelnose sturgeon fishery in the Tennessee waters of the Mississippi River was largely unregulated through 1999. Beginning in 2000, a season was established (1 November through 23 April) and fishers were required to report their monthly sturgeon harvest to the Tennessee Wildlife Resources Agency (TWRA); they were also required to record the fork length (FL) of harvested fish and whether or not roe was taken from each fish (i.e. whether it was a gravid female). About 16% of the sturgeon harvest in the 2001–2002 season (based on measurements provided by fishers) exceeded the maximum observed length for shovelnose sturgeon in the lower Mississippi River (823 mm FL; Morrow et al., 1998); some fishers reported harvesting sturgeon as large as 991 mm FL. The TWRA was concerned that these larger fish could have been pallid sturgeon; therefore, a 762-mm maximum size limit was established before the 2002–2003 season commenced. In 2003, the season was shortened by 15 days (15 November through 23 April) to align the sturgeon season with the statewide paddlefish (*Polyodon spathula*) season.

Tennessee liberalized their sturgeon regulations in 2005 as part of a multi-state (Illinois, Kentucky, Missouri, and Tennessee) sturgeon management plan for the Mississippi River. Although the 15 October–15 May season and 610–813 mm FL harvest slot limit was less restrictive for Tennessee

waters, it offered sturgeon more protection in waters not previously having a size limit or season.

The reported sturgeon harvest from Tennessee waters of the Mississippi River in 2005–2006 (5319 fish) and 2006–2007 (4052 fish) was substantially higher than in each of the previous five seasons (mean: 1358 fish per season). Although this increase was expected, it amplified concerns regarding the sustainability of the shovelnose sturgeon fishery and the incidental or deliberate take of pallid sturgeon. Thus, our objectives were to (i) describe the relative abundance of pallid sturgeon in the commercial catch of shovelnose sturgeon in Tennessee waters, and (ii) estimate the rate at which pallid sturgeon are illegally retained by fishers.

Methods

We followed the general methods of Collins et al. (1996), who described the bycatch of shortnose sturgeon *Acipenser brevirostrum* and Atlantic sturgeon *Acipenser oxyrinchus* in American shad *Alosa sapidissima* and shrimp fisheries along the Atlantic coast of South Carolina and Georgia. On five dates between 19 April and 9 May 2007, we accompanied or intercepted a total of six commercial fishers as they retrieved their gear (i.e. one fisher per day on four dates; two fishers on one date). A typical 'day' for the fishers on the water was only a few hours of retrieving and re-deploying their gear (note: sturgeon could not be legally processed for their roe on the water). We targeted fishers who regularly ranked in the top five commercial sturgeon fishers (based on total reported sturgeon harvest each season) in Tennessee since 2000. Fishers we accompanied used trotlines, standard monofilament gill nets with 76-mm bar-measure webbing, and 'sturgeon nets' consisting of 76-mm monofilament webbing whereby the top and bottom of the net were attached to the lead line (i.e. there was no float line); this design formed a loop of webbing that lay along the substrate when the net was deployed. All observed fishing activity occurred between Mississippi River km 1240 and 1422; the most upriver catches observed were actually collected in Kentucky waters several km above the Tennessee state line (although those fishers launched their boats in Tennessee waters). On three occasions we observed fishers retrieving all of the nets they had deployed the previous day; the number of nets fished per fisher averaged 6.3 (range: 4–8).

On those five dates, and over the course of several hours on each date, we usually had an observer on the fisher's boat. When we were not on their boats, we were drifting close by. When a washtub was filled up with illegal-size shovelnose sturgeon (i.e. under or over the harvest slot size) or legal fish that were thought not to be gravid females (note: most sturgeon were harvested because fishers thought they were gravid females), we would off-load those fish into our boat for processing [FL (mm); weight (g); fin ray sample for aging]. If a fisher handled a fish that he thought might be a pallid sturgeon or a hybrid (note: hybrids were illegal to keep), the fish would be given to us for processing.

If a sturgeon possessed most of the external characteristics of a pallid sturgeon (e.g. offset barbel insertions; ventral squamation absent or nearly so; outer barbels much longer than inner barbels; elongated rostrum), we endeavored to collect morphometric and meristic data needed to calculate a Character Index (CI; Sheehan et al., 1999; Wills et al., 2002), especially if the fish was large (>813 mm FL; note: two of seven large fish were not scored). The CI is a multiple regression character index that requires the following measurements and counts: length of each barbel; head length; mouth-to-inner barbel distance (measured from the midline of the edge of the cartilaginous ridge anterior to the proboscis to the anterior insertion of the right inner barbel); tip of rostrum to anterior insertion of the right outer barbel (i.e. interrostrum length); dorsal fin ray count (note: all fully formed and rudimentary rays were counted with the aid of a dissecting probe); anal fin ray count (following same procedure as dorsal fin ray count). Head length was measured using a flexible tape; all other measurements were made using calipers. The CI scores typically range from about -1.5 to 1.5. Strongly negative scores are indicative of pallid sturgeon and scores from -0.45 to 0.51 suggest possible hybrids according to Sheehan et al. (1999). We also collected a caudal fin clip for possible genetic analysis before releasing fish that we scored. Although we assigned CI scores to 114 sturgeon, we performed genetic analyses on only 18 of 22 fish with a negative CI score.

Genomic DNA was isolated using the DNeasy Tissue Kit (Qiagen, Valencia, CA) and stored at -20°C. Sixteen disomic microsatellite markers developed in *Scaphirhynchus* by McQuown et al. (2000) were scored using an ABI 377 automated DNA analyzer equipped with fragment analysis software (PE Applied Biosystems). The genotype of each sturgeon was compared to a baseline of 94 pallid and 85 shovelnose sturgeon from the Mississippi River that were identified based on genetic and morphological criteria as described in Schrey et al. (2007). The WhichRun software package of Banks and Eichert (2000) was used to calculate the likelihood of generating each sturgeon's genotype in either the pallid or shovelnose gene pools, then calculated the LOD score as the $\log_{10}$ of the ratio of likelihoods of generating a genotype in the pallid gene pool compared to the shovelnose gene pool. An *a priori* minimum of LOD = 2 was set for identifying a fish as a pallid sturgeon, meaning that a genotype had to be at least 100× more likely to have been generated in the pallid gene pool. This criterion was conservative in that it was likely to classify some good pallids as 'intermediates'.

In addition to the sturgeon directly observed being caught and harvested, we obtained the carcasses of 20 sturgeon that were harvested by a fisher out of our sight while we were with another fisher that day. Those 20 fish had already been processed (i.e. the eggs were removed) before we took possession of them, but we were able to collect the same morphometric and meristic data (including fin clips). Finally, we observed the retrieval of a 'ghost net' that the fisher we were accompanying had lost 2 days earlier.

Results

We observed the capture of 327 *Scaphirhynchus* spp. in the overnight sets of gillnets and trotlines whereby fishermen chose to keep 93 of those fish. The harvested sturgeon ranged in size from 578 mm FL (for a fish that was missing the tip of its rostrum) to 782 mm FL. Most (90%) of the sturgeon were captured in gillnets; we observed only 34 sturgeon on trotlines. Water temperatures ranged from 9.2°C to 19.5°C and all sturgeon in both gear types were alive when the gear was retrieved. We were able to assign CI scores to 63 of the 93 harvested fish. One of the 93 sturgeon harvested scored as a pallid sturgeon and two scored in the range between pallid sturgeon and intergrades on the CI scale.

We scored all 20 sturgeon carcasses retrieved from a fisherman whom we did not witness retrieving his gear; none of these fish scored as a pallid sturgeon based on CI scores.

Table 1
Species designation based on microsatellite DNA analysis for 20 *Scaphirhynchus* spp. captured in commercial gear in the lower Mississippi River between river km 1240 and 1422, April–May 2007, character Index (CI) scores, LOD scores (log_{10} of the ratio of the probabilities of generating the genotype of each fish from either a pallid sturgeon or shovelnose sturgeon gene pool), fork length (FL), source of fish, and their fate. All fish were captured in gillnets set by commercial fishers except for two fish caught on trotlines set by Tennessee Wildlife Resources Agency (TWRA) biologists. Ghost net = commercial gillnet that could not be found after soaking for 24 h, but subsequently recovered after ~48 h

Genetic species designation	CI score	LOD score[1]	FL (mm)	Source	Fate
Pallid	−1.77[2]	7.33	925	Overnight gillnet set	Released
Pallid	−1.53[2]	6.48	895	Overnight gillnet set	Released
Pallid	−0.38	6.30	631	TWRA trotline	Released
Pallid	−1.37[2]	4.46	756	Overnight gillnet set	Harvested
Pallid	−0.15	4.41	711	Overnight gillnet set	Released
Pallid	−0.01	4.30	773	Overnight gillnet set	Released
Pallid	−0.65[2]	4.28	845	TWRA trotline	Released
Pallid	−1.34[2]	3.26	834	Ghost Net	Dead in net
Pallid	−0.15	2.95	683	Overnight gillnet set	Harvested
Pallid	−1.66[2]	2.11	791	Overnight gillnet set	Released
Intermediate	−0.77[2]	1.55	732	Overnight gillnet set	Released
Intermediate	−0.41	1.44	721	Overnight gillnet set	Released
Intermediate	−0.07	0.95	743	Ghost net	Dead in net
Intermediate	−1.96[2]	0.92	821	Overnight gillnet set	Released
Intermediate	−0.57[2]	0.83	808	Overnight gillnet set	Released
Intermediate	−0.32	−0.01	780	Ghost net	Dead in net
Intermediate	−0.63[2]	−0.06	743	Overnight gillnet set	Released
Intermediate	−0.29	−0.57	815	Overnight gillnet set	Released
Intermediate	−1.27[2]	−0.63	744	Overnight gillnet set	Released
Shovelnose	−0.10	−4.18	717	Overnight gillnet set	Harvested

[1]LOD score of 2 = fish 100× more likely to have originated from the pallid sturgeon gene pool than the shovelnose sturgeon gene pool.
[2]Individuals designated pallid sturgeon based on their CI scores (Wills et al., 2002).

Adding these 20 fish to the 93 fish we saw fishers harvest equals 113 harvested sturgeon that we handled on those five dates. We scored six of the 53 sturgeon removed from the ghost net, one of which was harvested (for a total of 114 harvested sturgeon); one of the other scored fish from the ghost net was a putative pallid sturgeon based on its CI score.

Genetic analysis of 18 fish with negative CI scores confirmed that pallid sturgeon were regularly encountering commercial gear and that pallid sturgeon were being harvested (Table 1). All but five of the 18 commercially captured fish had genotypes that were more likely to have been generated within the pallid gene pool (i.e. their LOD scores were positive) and ten had LOD scores above our *a priori* criterion of LOD ≥ 2. One confirmed pallid sturgeon was retrieved (dead) from the ghost net and commercial fishers caught seven more confirmed pallid sturgeon in the gear they fished overnight. Fishers harvested two of those seven pallid sturgeon; thus, pallid sturgeon represented 1.8% (two of 114) of all harvested sturgeon. Harvesting two of seven pallid sturgeon meant that fishers were correct in identifying (and not harvesting) pallid sturgeon 71% of the time. The eight pallid sturgeon we observed in the commercial catch represented 2.0% of all (n = 400) sturgeon we handled from all commercial sources on those five dates. The reported harvest in Tennessee of shovelnose sturgeon during the 2005–2006 and 2006–2007 seasons was 9371 fish. If the pallid sturgeon harvest rate we observed (1.8%) was the same in the past two seasons, then commercial fishing activity resulted in the take (kill) of 169 adult (and probably egg-bearing) pallid sturgeon since 2005.

Discussion

Our estimate of the number of mature pallid sturgeon harvested the previous two seasons (n = 169) in the Tennessee waters of the Mississippi River is, for several reasons, probably a minimum estimate. Genetically testing all of the harvested fish we handled may have identified other pallid sturgeons that were retained by fishers. Perhaps the most important reason why we may have underestimated the pallid sturgeon take is that we do not (and cannot) know the behavior of fishers when observers are not present. That is, fishers may be less likely to discard a mature (i.e. potentially egg-bearing) pallid sturgeon when they are unobserved. The waters of the Mississippi River plied by the fishers we accompanied are remote and it is difficult for law enforcement personnel to enforce commercial fishing regulations and the Endangered Species Act (F. Couch, Commercial Fisheries Law Enforcement officer, TWRA, pers. comm.). Similarly, we do not know how many gill nets or trotlines are lost each year, but we observed how effective a ghost net can be in capturing sturgeon, including pallid sturgeon. Ghost nets have long been recognized as a threat to aquatic species, including the white sturgeon *Acipenser transmontanus* in the Columbia River (Kappenman and Parker, 2007); those authors located and retrieved 33 ghost nets containing 121 dead and five live white sturgeon. The threat of ghost nets to pallid sturgeon restoration efforts is unknown, but potentially serious because of the long life span of a ghost net (~7 years on average in the Columbia River) and the ecology of sturgeon species that renders them particularly susceptible to collapsed, lost gillnets [e.g. poor eyesight (Kynard and Horgan, 2001); benthic orientation; reliance on olfactory cues for locating prey (Kappenman and Parker, 2007)].

Encounters between commercial fishing gear and endangered pallid sturgeon were commonplace in the Tennessee (and near-Tennessee) waters of the Mississippi River. In a typical day of handling 50–100 shovelnose sturgeon in their gear, we would expect commercial fishers to handle one or two pallid sturgeon. That 2% encounter rate was confirmed by concurrent sampling by TWRA biologists on 17–18 April 2007, when

they collected 105 *Scaphirhynchus* spp. using trotlines whereby at least two were genetically confirmed pallid sturgeon (Table 1). If commercial fishers were 100% accurate in identifying pallid sturgeon and immediately returning them to the water, law enforcement and conservation concerns would be limited to prohibited activities listed in the Endangered Species Act that do not result in the death of the animal (e.g. wounding or harassing the species). However, we and others have documented pallid sturgeon being taken (i.e. killed) either intentionally or accidentally in the course of pursuing shovelnose sturgeon for their caviar. This finding is inconsistent with long-running, extensive pallid sturgeon recovery efforts throughout the Mississippi River basin and may explain why the age and size structure of pallid sturgeon stocks reflect commercially exploited shovelnose sturgeon populations (Killgore et al., 2007).

Finally, our modest efforts at collecting and utilizing morphometric and meristic data to determine which fish tissues to subject to genetic analysis confirmed what other researchers have noted. Namely, character indices such as the CI of Wills et al. (2002) are incapable of definitively identifying pallid sturgeon in the field, especially in the lower Mississippi River (e.g. Murphy et al., 2007). That said, the fairly simple CI scoring criteria gave us a very useful method for objectively deciding how to allocate scarce genetic testing funds.

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