Population Dynamics of a Migration Limited Shortnose Sturgeon Population

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Abstract: Upstream migration of the Cooper River, South Carolina, population of shortnose sturgeon *(Acipenser brevirostrum)* is severely limited at Pinopolis Dam (river km 77). Shortnose sturgeon congregating and spawning in the tailrace of the dam has been documented but data is lacking on the group's population dynamics. From 1995 through 1999, the population was sampled in the tailrace with 91.4 m long bottom-set gillnets during the spawning season when fish were concentrated in the area. Fish captured during 1996–1998 were tagged for a multiple census mark-recapture population estimate using the modified Schnabel method. Most captured fish were measured and weighed, and the data were fit to a weight-length regression. Pectoral fin rays were removed from a sub-sample of 35 fish for determination of the spawning population's age structure. Length-at-age data were then used to develop a von Bertalanffy growth equation. Population viability was modeled with the MOCPOP 2.0 age-structure model. Overall, 220 adult shortnose sturgeon were captured in the Pinopolis Dam tailrace from 28 January through 30 March when water temperature ranged from 8.0 to 17.8 C. The average catch per gillnet-hour was 6.8 fish. Mark-recapture population estimates ranged from 87 to 301 fish. Observed total lengths ranged from 705 to 1,164 mm ($\bar{x} = 938$ mm, SD = 85.6) and observed weights ranged from 2.68 to 19.36 kg ($\bar{x} = 7.02$ kg, SD = 2.83). Ages ranged from 5 to 18 yr. Estimated annual instantaneous mortality was 0.148. The population model reached equilibrium when annual recruitment was approximately 50 age-1 fish. The population may be depressed to an unsustainable level as a result of poor recruitment that is linked to obstructed migration to favorable spawning habitat.

Key words: shortnose sturgeon, population, age, growth, dam

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Shortnose sturgeon *(Acipenser brevirostrum)* range from the St. John River, New Brunswick, Canada, to the St. Johns River, Florida (Vladykoy and Greeley 1963). In 1967, the species was among the first to be listed under the Endangered Species Act. Causes of population declines included over-harvest, migration blockage due to dams, and habitat degradation (Birstein 1993). Shortnose sturgeon is typically an amphidromous species, migrating between freshwater and mesohaline reaches. Spawning sites occur at the most upstream river reach used (Kynard and Horgan 2002), so a migration blockage could prevent fish from reaching desired habitat. Dams creating population segmentation within a river have also been documented in the Connecticut River, Massachusetts, (Kynard et al. 1999) and possibly for the Santee-Cooper, South Carolina, system (Collins et al. 2003). Nineteen distinct population segments of shortnose sturgeon were identified occurring in 25 river systems (NMFS 1998), and with few exceptions, populations in southern rivers were described as imperiled (Kynard 1997). Most are depressed below levels adequate for their long-term survival (Soule 1989, Thompson 1991). Kynard (1997) identified a significant positive relationship between adult shortnose sturgeon abundance and the distance upriver of spawning location from the head-of-tide. In the Merrimack River, Massachusetts, a dam-restricted northern river, shortnose sturgeon were found to spawn around river km 30. This is just below the head of tide, and the population was characterized as well below the minimum viable population level (Kieffer and Kynard 1996). This relationship may also occur in the Cooper River, South Carolina, population of shortnose sturgeon, where the migration obstruction occurs within the freshwater tidal zone (Cooke et al. 2002, Cooke and Leach 2004).

Until the past decade, shortnose sturgeon in the Cooper River were virtually undocumented. In an environmental impact statement prior to the re-diversion of the Cooper River, the species was not listed as present in the river (USACE 1975). Documentation of the population characteristics only began after recovery of an illegal gillnet in 1992 that contained shortnose sturgeon. Upstream spawning migrations were documented by Cooke et al. (2002) to Pinopolis Dam at river km 77, the first obstruction on the system. Upstream passage of migrating alosine fishes through a navigation lock at the dam has been monitored for more than 25 years, but shortnose sturgeon passage was extremely limited (Cooke et al. 2002, Timko et al. 2003). Subsequent studies of possible spawning by shortnose sturgeon in the Pinopolis Dam tailrace yielded fertilized eggs (Duncan et al. 2004, Cooke and Leach 2004) The site was characterized as atypical of preferred shortnose sturgeon spawning habitat, supporting the hypothesis that a migration blockage imposed spawning at a site that was not historically used (i.e., Kynard et al. 1999). Directed effort has been limited, but no known collections of early life-stage shortnose sturgeon have ever been made in the Cooper River, suggesting that the population may be recruitment limited (Cooke and Leach 2004).

Essential to the species recovery plan is determination of the status of shortnose sturgeon population segments (NMFS 1998). Despite the amount of available information regarding the migration behavior and spawning of Cooper River shortnose sturgeon, there is a paucity of information regarding dynamics of the population segment that spawns in the Pinopolis Dam tailrace. These studies were conducted to estimate the spawning population size, evaluate length, weight and age structure, and model population growth parameters.

Study Site

The Cooper River historically was a short tidal river with a net mean daily flow of 2 m^3/sec (USACE 1975). The river has undergone a series of significant anthropogenic changes. In 1942, Pinopolis Dam was constructed 77 km upriver of the mouth as part of the Santee-Cooper Diversion Project. The project joined Cooper River with the Santee River, South Carolina, the second largest river system in drainage area and volume of flow on the U.S. East Coast (Hughes 1994) and formed two reservoirs. Annual flows to the Cooper River were increased to an average of 442 m^3/sec by the diversion of much of the Santee River flow into Lake Moultrie. As a result of detrimental sedimentation downstream in Charleston Harbor (USACE 1975) much of the flow was re-diverted back to the Santee River via a new dam and canal in 1985, reducing Cooper River flows to a weekly average of 127 m^3/sec (Cooke and Leach 2003). Physical characteristics of the Pinopolis Dam tailrace are detailed in Cooke and Leach (2004).

Methods

Shortnose sturgeon were captured with 91.4 m long x 3.6 m deep bottom-set experimental gillnets. Nets were made of alternating 15.2-m long panels of multifilament nylon 12.7-, 17.8-, and 25.4-cm stretched mesh. Nets were set during late winter and early spring, 1995–1999 in the tailrace from about 20 m to 500 m downstream from the dam. Nets were fished for varying periods of time depending upon water temperature and turbine discharge. Catch per unit effort (CPUE) was expressed as the number of shortnose sturgeon captured per net per hour. Most captured shortnose sturgeon were measured for total length to the nearest mm, and weighed to the nearest 10 g. A weight-length regression was fit using the power function (Ricker 1975):

$$\text{wt.} = \text{a}\,(\text{TL}^{\text{b}}),$$

where wt. = weight (g), TL = total length (mm), and a and b are regression parameters.

Beginning in 1996, most fish were tagged with both external Floy tags and passive integrated transponder (PIT) tags. In 1996, 1997, and 1998, a mark-recapture study was conducted to estimate the population abundance for adult shortnose sturgeon. Since capture and tagging was conducted throughout the recapture period, a multiple census population estimate was used (Ricker 1975), applying the modified Schnabel method (Schnabel 1938, Ricker 1975) where:

$$N = \frac{\sum (CM_{t})}{R + 1}$$

C = total fish captured during *i*th interval, M_t = total marked fish at large at the end of the *t*th interval, and R = total recaptures during the experiment. An experiment was defined as an annual sampling season (e.g. 1996). A Poisson distribution was assumed for computation of confidence intervals.

Age structure was determined for a sub-sample ($N = 35$) of shortnose sturgeon captured during 1997 and 1998. A marginal pectoral fin ray was removed from each sub-sampled fish following the methods of Collins and Smith (1996). Transverse sections of the rays were then made using a dentist's drill and cutting disc, and ages were determined following the methods of Zweiacker (1963). Two readers independently aged each fish. When readings disagreed an intermediate consensus was formed or the sample was disregarded. Using length-at-age information, a von Bertalanffy growth equation was developed (von Bertalanffy 1938, Ricker 1975). Since some year classes (i.e., sub-adults, < age-5) were unavailable for use, the mean lengths at ages1 and 2 were estimated from lengths of cultured shortnose sturgeon stocked into the Savannah River during 1984 through 1992 (Smith et al. 1995). Because sub-adults were not sampled, the assumptions of equal yearly recruitment and constant mortality over time could not be met to estimate annual mortality using a catch curve (Ricker 1975). So, parameters derived from the von Bertalanffy growth equation and observed length-at-capture data were used to estimate the instantaneous rate of mortality:

$$Z = \frac{k(L_\infty - L)}{L - L_c},$$

where k and L_∞ are von Bertalanffy growth parameters, L = mean total length (mm) at capture, and L_c is the total length (mm) of the smallest fish captured (Ricker 1975, Gulland 1983).

Population trends were then modeled using an age structure model, MOCPOP 2.0, (Beamesderfer 1991). Model inputs included the calculated instantaneous rate of mortality, von Bertalanffy growth equation parameters, and an initial age structure that was created by applying the age frequency distribution to the highest population estimate. Simulations were run to 18 years, the age of the oldest fish sampled, and for three levels of annual recruitment to age-1: 25, 50, and 100. For each run, the model output was an estimated annual population (N), depicting a predicted population trend.

Results

Gillnetting yielded a total of 220-shortnose sturgeon captured between the dates 28 January and 30 March when water temperatures ranged from 8.0 to 17.8 C. CPUE averaged 6.8 fish per net-hour, and ranged as high as 46.2 per hour on one individual set. Length was recorded for 186 fish, and weight for 153. Total length ranged from 705 to 1,164 mm ($\bar{x} = 938$ mm, SD = 85.6). Weight ranged from 2.68 to 19.36 kg ($\bar{x} = 7.02$ kg, SD = 2.83). The weight-length relationship, wt. = $4.56e^{-8} \cdot TL^{3.76}$, was significant ($P > F < 0.01$, $R^2 = 0.74$, Fig. 1).

A total of 207 shortnose sturgeon were examined, 157 were tagged and 37 of these were recaptured for the modified Schnabel population estimates. Analysis of data for 1996, 1997, and 1998 resulted in estimates of 87 (95% CL 56–170), 193

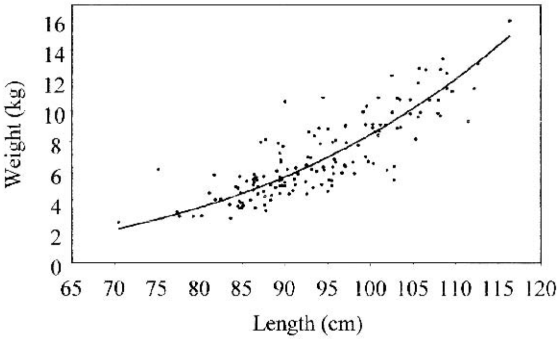

Figure 1. Weight-length regression for 153 shortnose sturgeon captured in the Pinopolis Dam tailrace, Cooper River, South Carolina during 1995–1999 sampling seasons (wt. = $4.56e^{-8}$ x $TL^{3.76}$, $P > F < 0.01$, $R^2 = 0.74$).

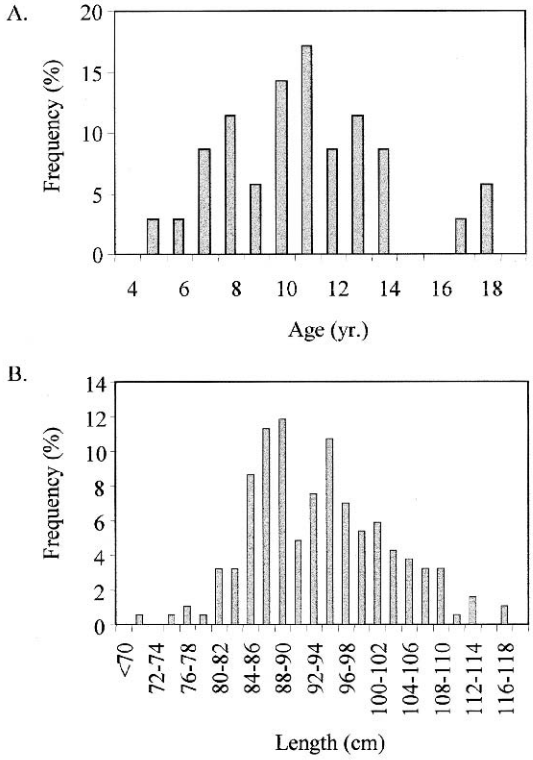

Figure 2. **(A)** Age frequency distribution of 35 shortnose sturgeon captured during 1997 and 1998; (B) Length frequency distribution of 186 shortnose sturgeon captured during 1995–1999 in the Pinopolis Dam tailrace, Cooper River, South Carolina.

Table 1. Cooper River shortnose sturgeon mark-recapture study results and modified Schnabel method population estimates: C = number captured, M = number marked, R = number recaptured, M_t = number at large at end of interval, *N* = estimated population for study period, LCL = lower 95% confidence limit, UCL = upper 95% confidence limit (Poisson).

Year	Date	C	M	R	M_t	CM_t	LCL_{95}	*N*	UCL_{95}
1996	15 Feb	2	2	0	2	4			
	16 Feb	4	4	0	6	24			
	21 Feb	3	2	1	8	24			
	22 Feb	2	2	0	10	20			
	23 Feb	3	3	0	13	39			
	24 Feb	3	2	1	15	45			
	29 Feb	14	11	3	26	364			
	5 Mar	10	7	3	33	330			
	14 Mar	7	5	2	38	266			
	19 Mar	5	1	4	39	195			
	Totals	53	39	14		1,311	56	87	170
1997	28 Jan	10	10	0	10	100			
	14 Feb	5	5	0	15	75			
	19 Feb	5	4	1	19	95			
	24 Feb	7	7	0	26	182			
	26 Feb	30	14	3	40	1,200			
	4 Mar	4	1	3	41	164			
	5 Mar	9	5	4	46	414			
	11 Mar	5	4	1	50	250			
	21 Mar	12	8	4	58	696			
	22 Mar	1	0	1	58	58			
	24 Mar	4	4	0	62	248			
	Totals	92	62	17		3,482	123	193	319
1998	30 Jan	3	3	0	3	9			
	4 Feb	14	12	2	15	210			
	13 Feb	16	16	0	31	496			
	26 Feb	2	1	1	32	64			
	3 Mar	14	13	1	45	630			
	13 Mar	9	8	1	53	477			
	30 Mar	4	3	1	56	224			
	Totals	62	56	6		2,110	150	301	659

(95% CL 123–319), and 301 (95% CL 150–659) adult fish, respectively, residing in the Pinopolis Dam tailrace area during the spawning season (Table 1).

Ages determined from pectoral rays of 35 sub-sampled fish ranged from 5–18 years, mean age was 11 years (SD = 3.2) (Fig. 2). No fish were determined to be less than 5 years old, indicating that only adults were sampled in this population. The length frequency distribution was similar to the age frequency distribution (Fig. 2), suggesting that the age sub-sample was representative of the population. Von Bertalanffy growth parameters were: L_∞ = 1,130 mm, k = 0.18, and t_0 = –1.585. The estimate of instantaneous mortality based upon growth parameters and capture data was 0.148. This was similar to other studies, which cited mortality estimates of 0.08 to 0.15 (Dadswell 1979, Taubert 1980, Dadswell et al. 1984, NMFS 1998).

Based on the largest population estimate, population modeling responses to annual recruitment of 25 age-1 fish showed the population declined to approximately 160. When annual recruitment was 50 age-1 fish, the population remained constant. The population increased with annual recruitment of 100 to 640.

Discussion

Impoundment of the Santee-Cooper system and the subsequent flow alterations that have occurred over the past six decades have probably had profound effects on the endemic shortnose sturgeon population. While historic data are lacking, prior to the 1942 diversion of Santee River flows into the Cooper River, the Cooper River's population was probably small or non-existent. After the diversion, fish from the Santee River may have colonized and become established in the Cooper River. Following the 1985 re-diversion of flows back to the Santee River, the alosine runs of the Cooper River are documented to have drastically declined (Cooke and Eversole 1994). The impact of the increase and reduction of flows to the Cooper River on shortnose sturgeon is unknown, but may have had similar effects. Under current conditions the upstream passage of shortnose sturgeon through the Pinopolis navigation lock has been very low to non-existent (Cooke et al. 2002, Timko et al. 2003), demonstrating that the dam and lock are impediments to shortnose sturgeon passage, preventing access to and from upstream spawning areas. While shortnose sturgeon spawning has been shown to occur in the tailrace (Duncan et al. 2004), it has been suggested that this location was an atypical spawning site and may result in low early life survival (Cooke and Leach 2004). The factors hypothesized to have had negative impacts on early life survival included distance upriver from the saltwater interface; tidal influence; intermittent flow characteristics from a semi-peaking hydroelectric facility; and atypical spawning substrate. This effect may be similar to the imperiled Merrimack River population that has migration and spawning essentially limited to the tidal river by a hydroelectric dam (Kieffer and Kynard 1996).

We hypothesized that the Cooper River shortnose sturgeon population is recruitment limited. Evidence supporting this hypothesis includes obstructed migration to favorable spawning and nursery habitat, lack of juvenile shortnose sturgeon collections from the river, and estimation of a small population. The average population estimate indicated that there were only about 200 adult, spawning-run shortnose sturgeon in the Cooper River. The Ogeechee River, Georgia, is another southern river with low population estimate numbers (Weber et al. 1998). Lack of summer refuges may be a limiting factor for the Ogeechee population. Soule (1989) and Thompson (1991) noted that 500 to 1,000 individuals are required to maintain long-term genetic diversity of a population. It should be noted, Cooper River shortnose sturgeon population estimates only represent the fish participating in the upstream spawning migration so the overall population is surely larger, but questions regarding the viability of the population are still raised.

The increasing trend in the population estimates (i.e., 87, 193, 301) may suggest that the population grew from 1996–1998. However, population estimate confidence intervals overlapped for all three years. These estimates were made over a short period of time relative to the life span and age-at-maturity of the species. Further estimates would need to be conducted and compared to these results to better ascertain the trend.

The MOCPOP modeling results provided a generalized scenario of recruitment required for population recovery. The results indicated that recruitment of approximately 50 age-1 fish were required for population stability. Whether this level of recruitment was realized is unknown. With annual recruitment of 100, the model predicted an asymptote of 640, a number similar to the upper 95% confidence limit for the largest population estimate made. Holyoke Dam fragments the Connecticut River population, and the segment downstream of the dam is dependent on reproduction in the upstream segment for recruitment (Kynard et al. 1999). Santee Cooper's population may also be segmented (Collins et al. 2003) but contribution of upstream spawning to downstream populations is unknown. In the future, early life survival and recruitment studies are recommended to address these questions.

Passage of shortnose sturgeon is of critical concern for recovery efforts (NMFS 1998), and sturgeon passage technology is currently under development (Katopodis 1995, Kynard 1998, Amaral et al. 2002, Kynard et al. 2003). However, several factors must be considered carefully in developing a passage plan including the ability of shortnose sturgeon to navigate the extensive Santee Cooper lake system to preferable spawning habitat, and for both post-spawn adults and young-of-the-year to migrate downstream and pass out of the system. Translocated adult shortnose sturgeon successfully migrated upstream and many entered rivers with favorable spawning habitat (Isely 2002, Cooke and Leach 2004). Ninety-three percent of these survived passing downstream below the dams (Cooke and Leach 2004). These were preliminary studies and emigration survival rates during average and low-water years and for juveniles have not been documented.

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