# Abundance of Juvenile Atlantic Sturgeon in the Ogeechee River, Georgia

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*Abstract:* The Atlantic sturgeon (*Acipenser oxyrinchus*) was once widely abundant, but populations declined because of over-harvest and habitat degradation. The commercial fishery for Atlantic sturgeon was closed in the United States in 1996. Population status and recovery of the species is a primary management need. River-resident juvenile sturgeon provide an opportunity to conduct mark-recapture studies and estimate abundance. The goal of this study was to estimate abundance of juvenile Atlantic sturgeon in the Ogeechee River, Georgia. Mark-recapture data were collected June-August of 2007. Sturgeon were captured using anchored gill and trammel nets set perpendicular to the flow during slack tides. A 0.5- to 1.0-cm section of the leading edge of the pectoral spine was removed from a random sub-sample of 18 juvenile sturgeon for subsequent age determination. Data were analyzed in Program MARK using a Huggins closed capture design model. A set of candidate models were constructed using the covariates of average weekly water temperature, weekly number of nets, and weekly time of net sets in hours. The relative likelihood of each model was evaluated by calculating $AIC_c$. The most plausible model included water temperature and net hours as covariates. The abundance of juvenile Atlantic sturgeon in the Ogeechee River was estimated to be 450 (203–1125) in 2007. The results of this study provide the first estimates of juvenile Atlantic sturgeon abundance in a population at the southern extent of their range. Studies in other river systems can use our methods to estimate juvenile Atlantic sturgeon abundance by river system. Post-harvest population recovery of Atlantic sturgeon should be monitored to evaluate the effectiveness of the closure of the fishery. Annual monitoring of age-1 abundance may indicate trends in Atlantic sturgeon recruitment.

*Key words:* mark-recapture, stock status, recovery, *Acipenser oxyrinchus*, recruitment

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Atlantic sturgeon (*Acipenser oxyrinchus*) are a typical member of the family Acipenseridae: long-lived and late-maturing with protracted spawning periodicity (Bain et al. 2000). Historically, the specie's range included all major coastal rivers from the St. Lawrence River, Canada, to the St. Johns River, Florida. Although once abundant throughout its range, the Atlantic sturgeon has a long history of overexploitation for both meat and caviar that has resulted in its extirpation from many systems (Vladykov and Greeley 1963, Smith and Clugston 1997). Commercial over-harvest began in the late 1800s and led to reduced abundances in many rivers by the 1920s (Atlantic States Marine Fisheries Commission [ASMFC] 1998). Although populations persisted at depressed levels throughout most of the 20th Century, increased demand for caviar during the 1970s spurred a renewal in commercial harvest that continued throughout the 1980s (Rogers et al. 1994, Smith and Clugston 1997). The U. S. commercial fishery has been closed since 1996 because of population declines caused primarily by overexploitation, although dams and habitat degradation have also been a problem on many rivers (ASMFC 1998). Unfortunately, the post-harvest status of many sturgeon populations remains unknown, yet this information is critical in evaluating recovery of populations under the current fishery moratorium.

The saltatory development of the Atlantic sturgeon is characterized by a complex life cycle comprised of discrete life stages, each of which requires different habitats. After hatching, larvae migrate downstream while they transition to the juvenile stage (Kynard and Horgan 2002). This migration continues for at least 12 days until they reach nursery grounds located near the fresh/saltwater interface of large coastal rivers. Once there, age-0 juveniles forage with older river-resident juveniles until they are 2–6 years old. Thereafter, they leave their natal estuaries to search for food in coastal marine habitats as sub-adults (Dovel and Berggren 1983, Kynard and Horgan 2002). Both adults and sub-adults are occasionally found in coastal rivers during the summer months; however, most of their time is spent in marine habitats until they return to spawn in their natal rivers.

As river-resident juveniles, Atlantic sturgeon are largely confined to the tidally-influenced reaches of their natal rivers, making them especially vulnerable to capture in several types of entanglement gear (Bain et al. 1999). As such, mark-recapture of

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river-resident juveniles may provide the most efficient means of estimating annual recruitment. Although adults are similarly vulnerable during spawning runs, estimation of adult abundance is difficult because of their protracted and variable spawning periodicity. Likewise, sub-adult abundance is difficult to estimate because they are dispersed in marine and estuarine habitats. Consequently, monitoring annual abundance of river-resident juveniles may provide the best measure of population recovery in many river systems (Peterson et al. 2000).

At present, the range of the Atlantic sturgeon is divided into five discrete population segments (DPS) based on the distinct genetic and behavioral characteristics of each: Gulf of Maine, New York Bight, Chesapeake Bay, Carolina, and South Atlantic (Atlantic Sturgeon Status Review Team [ASSRT] 2007). The ultimate goal of identifying these DPS was to preserve genetic diversity of the species. Within each DPS, however, the populations of individual rivers are considered as distinct management units (ASSRT 2007), thus providing managers with a framework to develop recovery plans that address the specific needs of each population on a case-by-case basis. Although the Atlantic States Marine Fish Commission has recently completed a comprehensive status review for the Atlantic sturgeon, the group concluded that a full assessment of the South Atlantic DPS was precluded by a lack of current population data from the eight rivers within this region: ACE Basin and Broad/ Coosawhatchie (South Carolina), Savannah, Ogeechee, Altamaha, Satilla, and St. Mary's (Georgia), and St. Johns (Florida) (ASSRT 2007). To properly evaluate, restore, and manage populations within the South Atlantic DPS, current data on abundance and stock status of each extant population are needed.

The Ogeechee River is one of several coastal rivers in Georgia known to harbor a genetically-discrete population of Atlantic sturgeon (Grunwald et al. 2008), but a targeted assessment of this population has not been previously attempted. Although several previous sampling efforts have documented presence of river-resident juveniles in the Ogeechee River, population status is unknown because abundance data are lacking (ASSRT 2007). The objective of this study was to estimate abundance of juvenile Atlantic sturgeon in the Ogeechee River, Georgia.

## Methods

The study was conducted entirely within the tidally-influenced portion of the Ogeechee River, near Savannah, Georgia, from June-August, 2007 (Figure 1). The Ogeechee River flows for 425 river kilometers (rkm) without any large reservoirs or hydroelectric dams (Ogeechee River Basin Plan [ORBP] 2001). Its largest tributary, the Canoochee River, runs for 84 rkm and enters the mainstem at rkm 55. A 6th-order river, the Ogeechee is classified

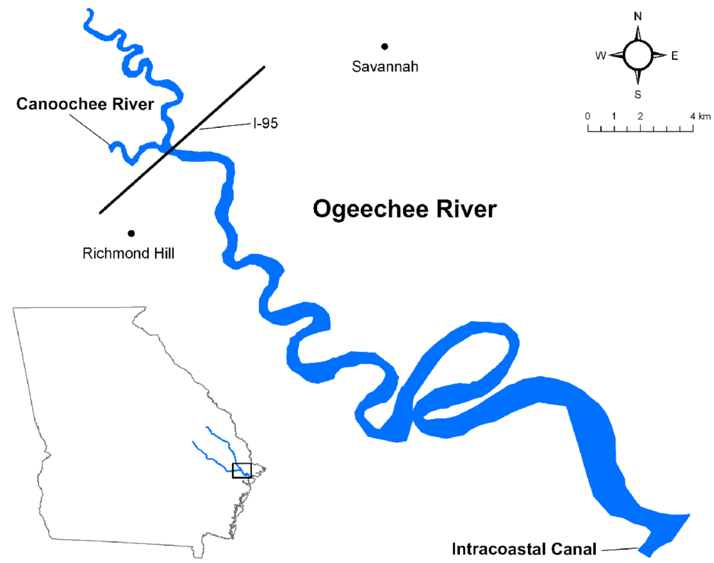


**Figure 1.** Sampling area for mark-recapture estimates of juvenile Atlantic sturgeon in the Ogeechee River, Georgia. Specific netting locations were selected at random throughout the lower Ogeechee from the confluence of the Canoochee River, downstream to the Intracoastal Canal.

as a "blackwater" system because of its tannic, nutrient-poor waters (Meyer et al. 1997). The river originates on the Piedmont plateau in central Georgia and flows southeasterly through a largely undeveloped coastal plain watershed of approximately 14,000 $km^2$ (ORBP 2001). Tidal amplitudes on the Ogeechee River vary from 1.6 to 2.7 m and mean annual discharge is 66.8 $m^3$ sec/L (Meyer et al. 1997). Maximum discharge occurs in spring and winter; however, tropical storms frequently cause brief periods of flooding during the late summer and fall (Meyer et al. 1997).

Sampling sites were distributed randomly throughout the lower 65 rkm of the Ogeechee River and the lower 5 rkm of the Canoochee River. Juvenile Atlantic sturgeon were captured using trammel and gill nets measuring 61 × 2.5 m. Gill nets were constructed of 10.2-, 12.7-, and 15.2-cm monofilament mesh (stretch measure); trammel nets were constructed from a 7.6-cm mesh inner panel and two 30.5-cm mesh outer panels. Nets were deployed perpendicular to the current, anchored to the bottom, and set for 25–90 min during slack tides. After all nets had been set, water temperatures were measured using a YSI multi-meter.

As nets were retrieved, juvenile Atlantic sturgeon were removed and placed in a floating net pen, where they were allowed to recover for 10–15 min prior to data collection. Each fish was then measured (mm; TL) and checked for a passive integrated transponder (PIT) tag using a portable PIT tag reader. If a tag was not detected, then one was injected beneath the fourth dorsal scute. A 0.5- to 1.0-cm section of the leading edge of the pectoral spine was removed from a random sub-sample of 18 individuals for subsequent age determination. All fish were released in good condition.

Ages of juvenile sturgeon were determined based on modal distributions of length-frequency histograms as described by Peterson et al. (2000) and McCord et al. (2007). The accuracy of these age assignments was verified from fin spine samples using methods described by Cuerrier (1951). Pectoral fin spine sections were air-dried for at least one month, cross-sectioned using a Buehler Isomet low-speed saw, and viewed under a dissecting scope to count growth annuli.

Mark-recapture data were analyzed using a Huggins closed capture model to estimate capture and recapture probabilities and abundance (Huggins 1989). This model was chosen because juvenile Atlantic sturgeon are limited to tidally-influenced habitats during the summer months (Moser and Ross 1995, Bain 1997). As such, cohorts of these river-resident juveniles were considered as closed populations over the sampling period of our study. Individual capture histories for the model were constructed by using each sampling week during the summer as an individual sampling period (recaptures within a week were not counted) with mean weekly sampling effort and water temperature included as covariates. Sampling effort was characterized in the model two ways: total weekly number of nets set and total weekly number of net-hours. Program MARK (Version 5.1) was used to evaluate the relative weight of each model and subsequently, for estimation. Candidate models with differing combinations of parameters for capture and recapture probabilities were constructed to quantify influences of environmental predictor variables. Capture and recapture probabilities were modeled as constant, time varying, or functions of covariates. Because previous studies have shown that recapture probability of juvenile Atlantic sturgeon is not affected by previous capture (Schueller and Peterson 2010), capture and recapture probabilities were considered equal in this study. All covariates were standardized to a mean of zero and standard deviation of one.

To identify the most plausible model, the relative likelihood of each model was evaluated using an information theoretic approach (Burnham and Anderson 2002), by calculating Akaike's information criterion (Akaike 1973) with a small sample size adjustment ($AIC_c$; Hurvich and Tsai 1989). The most plausible model of capture and recapture probabilities was then used to estimate abundance of juvenile Atlantic sturgeon.

## Results

From 1 June to 31 August 2007, we deployed a total of 390 net sets and captured a total of 58 juvenile Atlantic sturgeon, including four recaptures (Table 1). The total fishing effort was 278 net-h with a weekly mean of 21.4 net-h. Mean weekly catch-per-unit-effort (CPUE) was 0.23 fish/net-h over the entire sampling period but varied from 0.00–0.53 fish/net-h. Sizes of captured juveniles varied from 242–1015 mm TL; however, length-frequency analysis revealed a distinct modal distribution of juvenile age classes (Figure 2). Age-determinations from the random sample of pectoral fin spines confirmed that age-1 juveniles measured 242–361 mm TL and age-2 and age-3 juveniles measured 606–1015 mm TL. Subsequent assignment of ages from length-frequency histograms showed that age-1 juveniles accounted for 24% of all river-resident juveniles captured (Table 2).

Huggins closed capture models revealed that the top two models accounted for 99% of the relative $AIC_c$ weight, with average temperature and weekly net-h as predictors of capture/ recap-

**Table 1.** A summary of effort, catch (including recaptures), and catch-per-unit-effort (CPUE) of juvenile Atlantic sturgeon age-1 to age-3 in relation to mean water temperature in the Ogeechee River, Georgia, 2007.

| Month | *n* nets | Total net hours | *n* sturgeon captured | CPUE (fish / net hour) (range) | Mean water temperature (C) (range) |
|---|---|---|---|---|---|
| June | 125 | 125 | 30 | 0.2400 (0.1026–0.5294) | 26.92 (25.80–29.31) |
| July | 148 | 83 | 18 | 0.2169 (0.1500–0.2667) | 29.06 (27.87–29.52) |
| August | 117 | 70 | 18 | 0.2571 (0.0000–0.4667) | 29.77 (28.50–31.13) |

**Table 2.** Age-specific catch proportion of juvenile Atlantic sturgeon in the Ogeechee River, Georgia, 2007.

| Year | Age class | *n* captured | Proportion of population |
|---|---|---|---|
| 2007 | 1 | 13 | 0.24 |
| | 2–3 | 41 | 0.76 |

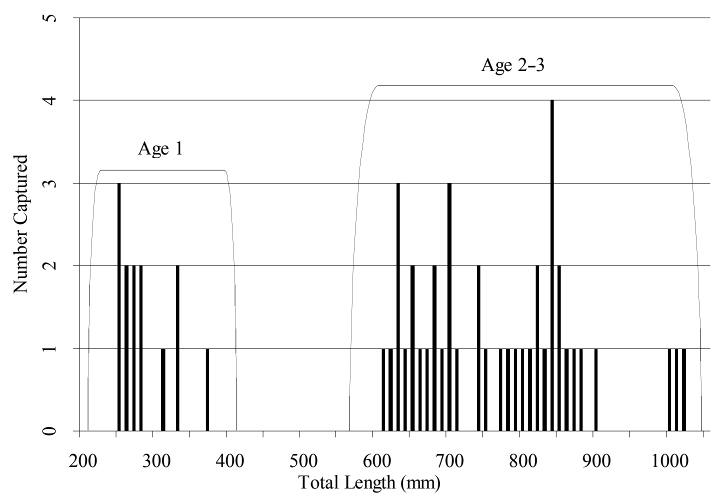


**Figure 2.** Length-frequency histogram of juvenile Atlantic sturgeon captured in the Ogeechee River, Georgia, June to August 2007. Modal age assignments were verified from counts of annuli on cross sections of pectoral fin spines.

**Table 3.** Results of Huggins closed-capture models and corresponding abundance estimates of juvenile Atlantic sturgeon in the Ogeechee River, Georgia, 2007.

| Capture/recapture probability | AICc | Delta AICc | AICc weight | Model likelihood | *n* parameters | Deviance | Abundance estimate | 95% Confidence limits | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Lower | Upper |
| Temperature + net hours | 336.139 | 0.00 | 0.62347 | 1.0000 | 3 | 423.578 | 450.89 | 203.82 | 1125.38 |
| Temperature * net hours | 337.182 | 1.04 | 0.37002 | 0.5935 | 4 | 422.601 | 449.01 | 203.10 | 1120.52 |
| Time varying | 345.628 | 9.49 | 0.00542 | 0.0087 | 12 | 414.698 | 443.51 | 200.97 | 1106.31 |
| Net hours | 349.337 | 13.20 | 0.00085 | 0.0014 | 2 | 438.792 | 461.74 | 207.97 | 1153.68 |
| *n* nets | 353.654 | 17.52 | 0.00010 | 0.0002 | 2 | 443.108 | 464.27 | 208.94 | 1160.28 |
| Temperature + *n* nets | 353.775 | 17.64 | 0.00009 | 0.0001 | 3 | 441.215 | 463.23 | 208.54 | 1157.58 |
| Temperature * *n* nets | 355.760 | 19.62 | 0.00003 | 0.0000 | 4 | 441.179 | 463.10 | 208.49 | 1157.25 |
| Constant | 359.116 | 22.98 | 0.00001 | 0.0000 | 1 | 450.581 | 468.93 | 210.72 | 1172.49 |
| Temperature | 359.726 | 23.59 | 0.00000 | 0.0000 | 2 | 449.181 | 468.16 | 210.43 | 1170.43 |

ture probabilities (Table 3). The most plausible model carried an $AIC_c$ weight of 0.62347. All models produced similar estimates of abundance, confidence intervals, and standard errors, so only the top model is presented. The most plausible model estimated total juvenile Atlantic sturgeon abundance at 450 individuals (95% CL 203–1125) (Table 3).

## Discussion

The results of this study provide the first quantified abundance estimates of juvenile Atlantic sturgeon for any river system within the South Atlantic DPS. Our estimate of 450 (203–1125) juveniles indicates that the Ogeechee River still contains a population of Atlantic sturgeon. For comparison, a Peterson mark-recapture study of juvenile Atlantic sturgeon in the Hudson River estimated 4314 age-1 sturgeon in 1994 (Peterson et al. 2000). A four-year study of the Altamaha River population of Atlantic sturgeon estimated total juvenile abundance was roughly 1000–2000 for the years 2004–2007 (Schueller and Peterson 2010). Although the small number of recaptures we observed resulted in a relatively wide confidence interval, additional sampling likely would have improved the precision of the estimate. Nonetheless, our findings show that targeted sampling of river-resident juveniles can provide a quantified estimate of juvenile abundance, even for small populations.

Although no age-0 juveniles were captured during this study, targeted sampling for these younger juveniles could provide a useful means of monitoring recruitment. Previous studies on the Altamaha River, however, suggest that age-0 Atlantic sturgeon are less vulnerable to entanglement gear and are more spatially dispersed compared to older river-resident juveniles, which are typically confined to tidally influenced estuarine habitats during their first three years of life (Moser and Ross 1995, Bain 1997, Hatin et al. 2007, Schueller and Peterson 2009). Consequently, we suggest that targeted sampling of age-1 juveniles may provide the best opportunity to quantify annual recruitment of Atlantic sturgeon. While spawning run assessments are also needed to better understand age structure and long-term population trends, short-term assessments based on spawning runs are confounded by the presence of non-spawning adults. A more precise estimate of recruitment trends could be attained using a mark-recapture model applied to individual age cohorts resulting in age-specific abundance estimates. These methods have been used successfully on both the Hudson (Peterson et al. 2000) and Altamaha rivers (Schueller and Peterson 2010), although those populations are much larger than that of the Ogeechee. Regardless of which method is used, annual estimation of age-1 juveniles should become standard practice for monitoring recovery of Atlantic sturgeon as part of a comprehensive recovery strategy for the species.

Model results showed that the inclusion of time-varying covariates yielded the best models for estimating capture and recapture probabilities, and hence, juvenile abundance. Specifically, the inclusion of sampling effort as a predictor variable resulted in the most plausible models. Of the two measures of sampling effort, the number of weekly net-hours produced a higher $AIC_c$ weight than those incorporating numbers of weekly net sets—probably because soak time of individual net sets varied greatly depending on flow and tidal cycle. Consequently, future assessments should incorporate total soak time and mean water temperature as covariates.

The results of this study show that mark-recapture of river-resident juveniles can provide quantified estimates of juvenile abundance—an important first step in monitoring recovery of Atlantic sturgeon under the current ASMFC fishery moratorium. Future studies are needed, however, to update recruitment information, monitor trends in spawner abundance, and to fill information gaps regarding latitudinal variation in life history and population dynamics (Peterson et al. 2008).

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