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ARTICLE

Abundance Estimate for and Habitat Use by Early Juvenile Atlantic Sturgeon within the Delaware River Estuary

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Abstract
The Atlantic Sturgeon *Acipenser oxyrinchus oxyrinchus* historically supported a significant commercial fishery along the eastern coast of North America. However, overfishing led to substantial population declines with contributions from other anthropogenic impacts, including vessel strikes and contaminants that continue to impede recovery. Our work is the first to estimate the abundance of early juvenile (age 0–1), resident Atlantic Sturgeon in the Delaware River estuary. Using the Schumacher and Eschmeyer mark–recapture estimator for multiple censuses, we estimated 3,656 (95% CI = 1,935–33,041) individuals used the Delaware River estuary as a nursery in 2014. We found no significant change in mean length during the course of our study (November–December), and lengths of age 0–1 Atlantic Sturgeon ranged from 220 to 515 mm TL. Further, using a passive acoustic receiver array, we identified significant habitat areas where age-0–1 juveniles spend considerable amounts of time; this included the Marcus Hook area and some habitat use downriver and upriver of Marcus Hook at Cherry Island and the Chester Range. Our results support the idea that a spawning population of Atlantic Sturgeon exists in the Delaware River and that some level of early juvenile recruitment is continuing to persist despite current depressed population levels. Understanding trends in abundance, habitat use, and other population metrics for natal river Atlantic Sturgeon will allow for better conservation and management of the species.

The Atlantic Sturgeon *Acipenser oxyrinchus oxyrinchus* is a long-lived, highly fecund, and late-maturing anadromous subspecies found in coastal waters and major river basins from Labrador, Canada, to Port Canaveral, Florida. From the late 1800s through the late 1900s, overharvest from commercial fishing led to a significant decline of Atlantic Sturgeon throughout its range (McCord et al. 2007). In addition to overfishing, other anthropogenic impacts, including bycatch, habitat degradation, habitat impediments, and vessel strikes, significantly contributed to the population decline and continue to impede population recovery (NOAA 2014). Before 1890, the abundance of adult spawning females in the Delaware River was estimated at 180,000 individuals (Secor and Waldman 1999; Secor 2002; ASSRT 2007), but the estimated number of adult sturgeon in the Delaware River is believed to have declined to fewer than 300 individuals in 2007 (Atlantic Sturgeon Status Review Team 2007). After the 2007 status review of Atlantic Sturgeon, five distinct population segments (DPSs) were listed under the U.S. Endangered Species Act (USOFR 2012), one as threatened (Gulf of Maine DPS) and four as endangered (New York Bight,

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Chesapeake Bay, Carolina, and South Atlantic DPSs), in 2012. Despite the current population status of Atlantic Sturgeon, little is known about the spawning populations of Atlantic Sturgeon within each individual riverine system (USOFR 2010a, 2010b; Wirgin et al. 2015).

In the mid-Atlantic region, spawning migrations occur from late March or April into May (Murawski and Pacheco 1977; Smith 1985; Bain 1997; Smith and Clungston 1997; Caron et al. 2002; Atlantic Sturgeon Status Review Team 2007). Tagging data indicate that Atlantic Sturgeon return to their natal rivers to spawn after extensive mixing in coastal waters (Grunwald et al. 2008). Females do not spawn annually and may spawn at intervals from 2 to 5 years (Vladykov and Greely 1963; Van Eenennaam et al. 1996; Stevenson and Secor 1999), releasing between 400,000 and 8 million eggs (Smith et al. 1982; Van Eenennaam and Doroshov 1998; Dadswell 2006; Atlantic Sturgeon Status Review Team 2007). After hatching, yolk-sac larvae begin migrating downstream to nursery grounds over a 6–12-d period while developing into juveniles and continuing their downriver migrations to brackish water nursery habitat (Kynard and Horgan 2002; Atlantic Sturgeon Status Review Team 2007). Juvenile individuals then remain in their natal riverine systems until they reach 2 years of age. After this point, older juveniles may emigrate and occupy other estuarine systems before returning to natal estuaries as sexually mature adults (McCord et al. 2007). Therefore, the capture of early stage juveniles is considered to be a reliable method to assess distinct riverine populations (McCord et al. 2007).

The Delaware Division of Fish and Wildlife began identifying early juvenile habitat for Atlantic Sturgeon in the Delaware River estuary in 2009 (Fisher 2009). Gill-net sampling of the Marcus Hook Anchorage, located at river kilometer (rkm) 130 (Figure 1) and the reach along Little Tinicum Island (rkm 138) adjacent to the Philadelphia International Airport and Cherry Island Flats (rkm 110) have yielded early stage juveniles in the past (Fisher 2009, 2010). Passive-tracking results indicated a strong preference for the Marcus Hook Anchorage, with movement downriver below rkm 80 and upriver as far as rkm 199 (Stetzar et al. 2015). Active acoustic tracking of Atlantic sturgeon of ages 0–1 indicated a sediment preference of fine to medium sand (Stetzar et al. 2015). Early juvenile Atlantic Sturgeon inhabit waters near Carney's Point, Marcus Hook Bar, Marcus Hook Anchorage, Tinicum Island, and Mantua Creek Anchorage in depths ranging from 8.5 to 15.8 m, with the greatest concentrations at 12.4 m (Fisher 2010; Stetzar et al. 2015). From our sampling efforts in this study within the Delaware River estuary, we were able to estimate the abundance of ages-0–1 Atlantic Sturgeon and examine their habitat use.

STUDY SITE

Delaware Bay is the second largest estuary on the East Coast of the United States (Sharp et al. 1982; Bryant and Pennock 1988). The Delaware River contributes the majority of freshwater input into the estuary and accounts for 58% of the mean annual discharge of 550 m^3/s (Lebo and Sharp 1993; Schieler et al. 2014); one other major tributary, the Schuylkill River, accounts for an additional 14% of the mean annual discharge, and there are minor contributions from other individual sources (Smullen et al. 1983; Lebo and Sharp 1993). Extending for 531 km from Hancock, New York, to the mouth of the Delaware Bay, the Delaware River is the longest undammed river in the United States east of the Mississippi River (DRBC 2013). The estuary provides nursery habitat for many ecologically and economically important fishes (Schieler et al. 2014) and supports significant commercial and recreational fisheries for the surrounding states (Clark and Kahn 2009).

METHODS

Early juvenile Atlantic Sturgeon (ages 0–1) were captured using four anchored gill nets during 14 sampling events from November 3 through December 31, 2014, in the Delaware River estuary (Figure 1). As per the sampling protocol described in *Atlantic Sturgeon Research Techniques* (Damon-Randall et al. 2010) and by National Marine Fisheries Service (NMFS) Atlantic Sturgeon research permit number 16431, the gill nets were 91.5 m long and 2.4 m deep, two consisting of 5.1-cm-stretch mesh and two with 7.6-cm-stretch mesh. The nets were constructed from 0.33-mm-diameter, clear monofilament, and each had a lead line (29.5 kg per 182.9 m) and a foam core rope 1.3 cm in diameter with floats every 4.57 m. Sampling was conducted at least twice a week for a 2-month period and was weather dependent. Anchor nets were set parallel to the current approximately 30 min prior to slack tide and pulled at the onset of the next tide. Sampling was limited to slack tide due to strong tidal currents. When river conditions permitted, anchor nets were set diagonally to the current, which allowed for a longer net set, but nets were still retrieved within the time frame set by NMFS permit number 16431.

The first 11 Atlantic Sturgeon of ages 0–1 caught in 2014 were implanted with acoustic transmitters using established research protocol (i.e., tag weight was less than 2% of the fish body weight; Damon-Randall et al. 2010; Kahn and Mohead 2010) and released as "sentinel fish," to be acoustically tracked at a later date. No sentinel fish were recaptured during the course of our study. Fish of ages 0–1 were distinguished from other age-groups using length-frequency histograms from Shirey et al. (1999), and individuals less than 645 mm TL were classified as less than 2 years of age. Individuals were anesthetized using MS-222 (tricaine methanesulfonate). During surgery, fish were placed in a sling and held at working height by a wooden surgery table frame. An adjustable flow hose was held over the fish's mouth and gill area to aerate and allow the anesthetic to pass over the gills. The incision area was cleaned with povidone iodine (Betadine), and by means of a sterilized scalpel, an incision just large enough for the transmitter to be inserted was made parallel and adjacent to

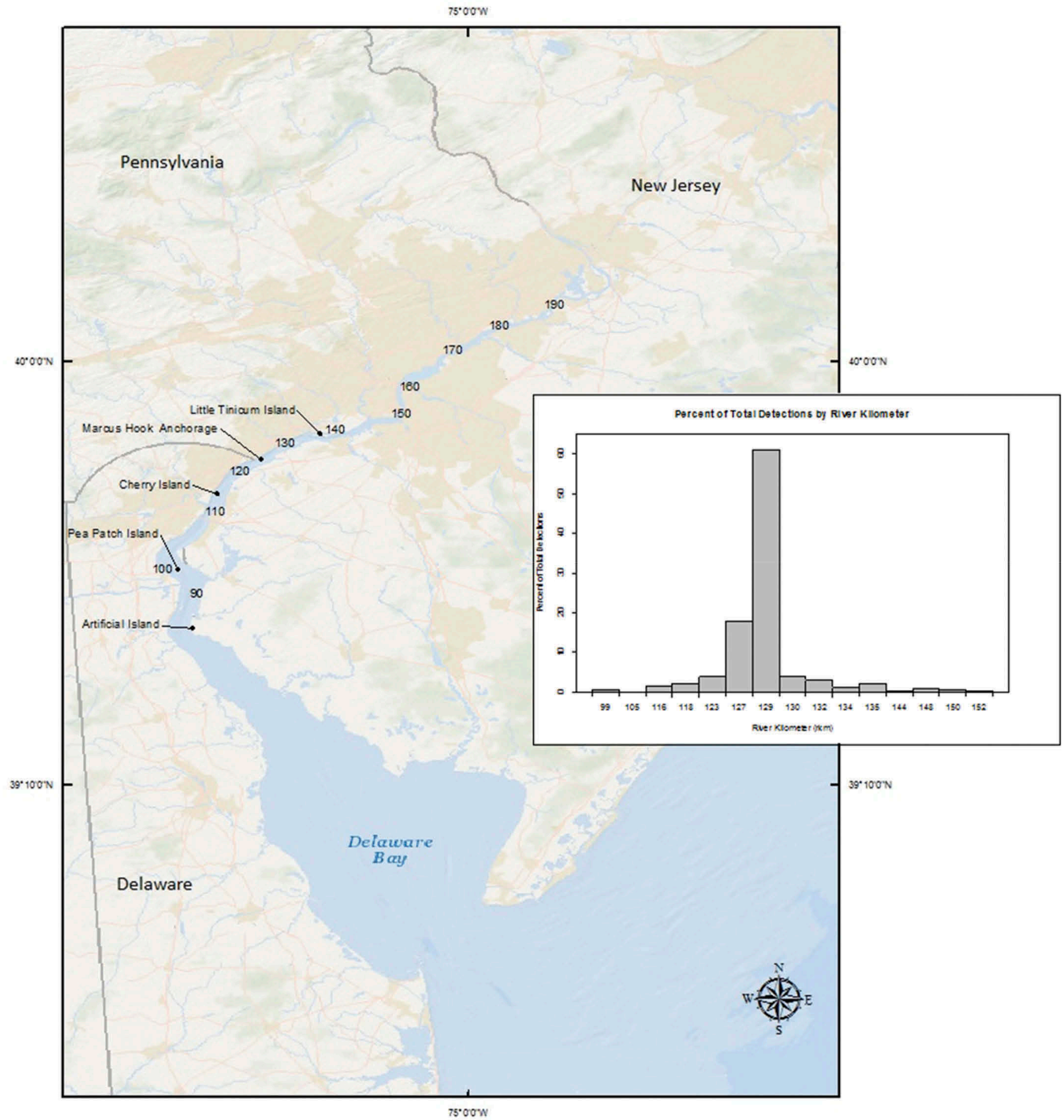

FIGURE 1. The Delaware River estuary showing river kilometers and significant landmarks with an inset of the total percentage of daily modal position by river kilometer for all telemetered (n = 11) Atlantic Sturgeon of ages 0–1.

the ventral midline. The transmitter was also sterilized, then implanted in the ventral peritoneal cavity, and the incision was closed using absorbable sterile sutures. The sturgeon was then placed in a net-pen for observation and released after displaying normal swimming behaviors and exhibiting a strong swim-away response.

Acoustic tagged sentinel fish were manually tracked using a Vemco VR-100 69-kHz hydrophone receiver immediately prior to gill-net deployment to identify areas with potentially greater concentrations of Atlantic Sturgeon, similar to that described by Kynard et al. (2007) in the Potomac River and Fisher (2009) in the Delaware River. Additionally, acoustic-tagged individuals were monitored using a passive receiver array during the course of the study from the point of initial release through March 2015 in conjunction with the Atlantic Cooperative Telemetry network to identify nursery habitat within the Delaware River estuary. The Atlantic Cooperative Telemetry network (http://www.theactnetwork.com/) is a collaborative effort to facilitate data sharing of acoustic-tagged fish between independently owned receiver arrays from Maine to Florida. Daily position was calculated as the daily modal position relative to all tag detections within a 24-h period, while percent habitat use was calculated as a percent of daily modal position throughout the observation period.

All subsequently caught Atlantic Sturgeon of ages 0–1 and greater than 250 mm TL were tagged for future identification with PIT tags using variable tag sizes based on TL. Individuals between 250 and 400 mm TL were marked with 8-mm PIT tags, and Atlantic Sturgeon between 400 and 490 mm TL were marked with 12-mm PIT tags. Individuals larger than 490 mm TL were not tagged with PIT tags, in accordance with the protocol described in NMFS permit number 16431; however, individuals larger than 490 mm TL were not included in the population estimate. Mean TL by date was analyzed using the Mann–Kendall test (Mann 1945; Kendall 1962; Gilbert 1987) to statistically assess whether there was a monotonic upward or downward trend in daily mean length over the course of our study.

Abundance estimates of Atlantic Sturgeon of ages 0–1 and between 250 and 490 mm TL in the Delaware River estuary were generated using a Schumacher and Eschmeyer mark–recapture estimator for multiple censuses (Ricker 1975; Sokal and Rohlf 1995; Zar 1996; Krebs 1998; Kahn et al. 2014) as follows:

$$\hat{N} = \frac{\sum(C_t M_t^2)}{\sum(M_t R_t)},$$

and the variance for $1/\hat{N}$ was estimated from linear regression theory as the variance of the slope of the regression (Sokal and Rohlf 1995; Zar 1996; Krebs 1998),

$$\sigma^2 = \frac{\sum(R_t^2/C_t) - \left[(\sum R_t M_t)^2 / \sum C_t M_t^2\right]}{s-2}.$$

The standard error of the slope of the regression for $1/\hat{N}$ (DeLury 1958) was estimated by

$$\mathrm{SE} = \frac{\sigma^2}{\sum C_t M_t^2},$$

and corresponding 95% CIs were derived from t-values with $m-2$ degrees of freedom (Sokal and Rohlf 1995; Zar 1996; Krebs 1998):

$$\frac{1}{\hat{N}} \pm t_{\propto}\ \mathrm{SE},$$

where $\hat{N}$ is the abundance estimate, C_t is the total number of fish taken per day (both previously marked and unmarked), M_t is the total number of marked fish at large (i.e., individuals that could potentially be captured before a sampling day), R_t is the number of recaptures per day, and m is the number of sampling events. The model assumes no recruitment or mortality during the sampling period. Given the residential life history strategy of juvenile Atlantic Sturgeon (ages 0–1) and the length of our sampling period, we believe these model assumptions were met.

RESULTS

We identified important habitats within the Delaware River estuary, where early juvenile (ages 0–1) Atlantic Sturgeon spend considerable amounts of time based on passive acoustic tag detections. We found local migrations of sentinel, tagged, Atlantic Sturgeon of ages 0–1 ranged from rkm 99 to rkm 152 within the Delaware River from November 2014 through March 2015. However, 79.1% of the total detections (6,515 individual detections out of 8,232 total detections) occurred between rkm 127 and rkm 129 in the Marcus Hook area. Downriver from the Marcus Hook area, we observed 3.9% of the total detections in the Cherry Island range and flats area (rkm 116–118). Upriver from the Marcus Hook area, we observed 8.1% of the total detections from rkm 130 to rkm 134 in the Chester Range (Table 1; Figure 1). Our results indicate that the Marcus Hook area served as an important nursery ground for ages-0–1 Atlantic Sturgeon in 2014, with ancillary habitats immediately upriver or downriver (Figure 1).

The length of Atlantic Sturgeon of ages 0–1 ranged from 220 to 515 mm TL (n = 188; Figure 2), with an average of 336.1 mm TL during the course of our study. Mean lengths were below 325 mm during the first four sampling events, and mean lengths during the final five sampling dates were above 325 mm (Figure 3). However, there was no statistically significant trend in daily mean TL over the course of the study (Kendall–Mann test: τ = 0.253, two-sided P-value = 0.228). Recaptured individuals were between 0 and 8 mm greater in TL than the length at the initial point of capture.

During the 2014 sampling season, 188 Atlantic Sturgeon of ages 0–1 were caught and 181 were marked and released. One fish exceeded the 490-mm-TL limit to be tagged and was not recaptured or included in the population estimate. Two of the fish initially captured were too small to implant with a PIT tag at the initial time of capture and were subsequently released without a

TABLE 1. The number of detections for each of the 11 acoustic-tagged Atlantic Sturgeon per river kilometer in the Delaware River estuary by fish tag identification number (ID). Fish were tracked from the initial time of release at Marcus Hook Anchorage in November 2014 through March 2015.

	River kilometer															
Fish tag ID	99	105	116	118	123	127	129	130	132	134	135	144	148	150	152	Detections
21373						181	441									622
21374						1	1				33					35
21375						50	762					1				813
21376					16	174	105	40	75	4	23	1				438
21377						171	1,818				4	1			1	1,995
21378						12				1	1					14
21379						59	361		2	1						423
21380				9	5	24	35	8	2		1					84
29702			101	138	133	420	1,064	231	149	73	97	21	69	46	29	2,571
29703			2		74	244	297	20	11	9						657
29705	56	8	36	31	92	145	150	37	1	2	20			2		580
Total detections	56	8	139	178	320	1,481	5,034	336	240	90	179	24	69	48	30	8,232

tag and not included in the population estimate. Individual fish were observed traveling in excess of 20 rkm within a 24-h period from passive detection data. No sentinel fish were recaptured during the course of our study. Four fish were recaptured during the survey that were initially captured on November 23, December 4, November 3, and December 3 in 2014 (Table 2). We did not observe any pattern between the time of initial release and the recapture dates of recaptured individuals. The abundance estimate of ages-0–1 Atlantic Sturgeon in the Delaware River estuary was 3,656 individuals (95% CI = 1,935–33,041 individuals) in 2014.

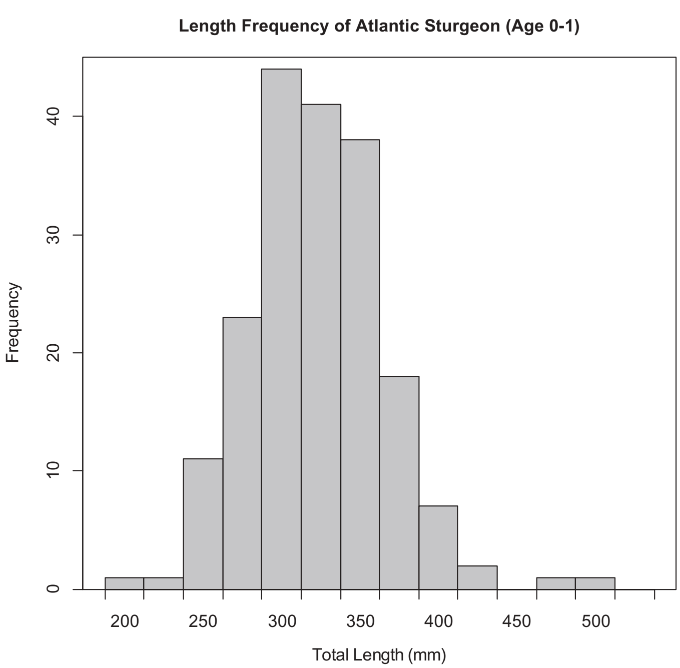

FIGURE 2. Length-frequency distribution of Atlantic Sturgeon of ages 0–1 captured in the Delaware River during the 2014 sampling season (n = 188).

DISCUSSION

The complex life history of Atlantic Sturgeon, including its longevity, spawning behavior, and freshwater residency during early juvenile stages, creates numerous points where anthropogenic impacts can impede population recovery and pose difficulties in estimating population size. Presently, there are only four U.S. subpopulations for which any adult population estimates have been made: Hudson River, New York (~870 spawning adults/year; P. Schuller and D. L. Peterson, paper presented at the 14th American Fisheries Society Southern Division Meeting, 2006); Altamaha River, Georgia (~343 spawning adults/year; Kahnle et al. 2007); Pamunkey River, Virginia (~75 spawning adults/year; Kahn et al. 2014); and the James River, Virginia (3,399 ± 575 [SE] adult spawning males; Balazik et al. 2015). The Hudson and Altamaha rivers are presumed to have the healthiest populations of Atlantic Sturgeon within U.S. waters. Other U.S. spawning populations outside of these areas, including the Delaware River, are thought to have fewer than 300 adults spawning per year (Atlantic Sturgeon Status Review Team 2007), but no abundance estimates have been made for these other river-specific subpopulations. Given the minimal observations of mature adults in the Delaware River estuary based on our own sampling and the ability to generate river-specific population sizes using ages of less than 2 years (McCord et al. 2007), we chose to focus on the number of individuals of ages 0–1 in order to estimate the abundance of natal Atlantic Sturgeon.

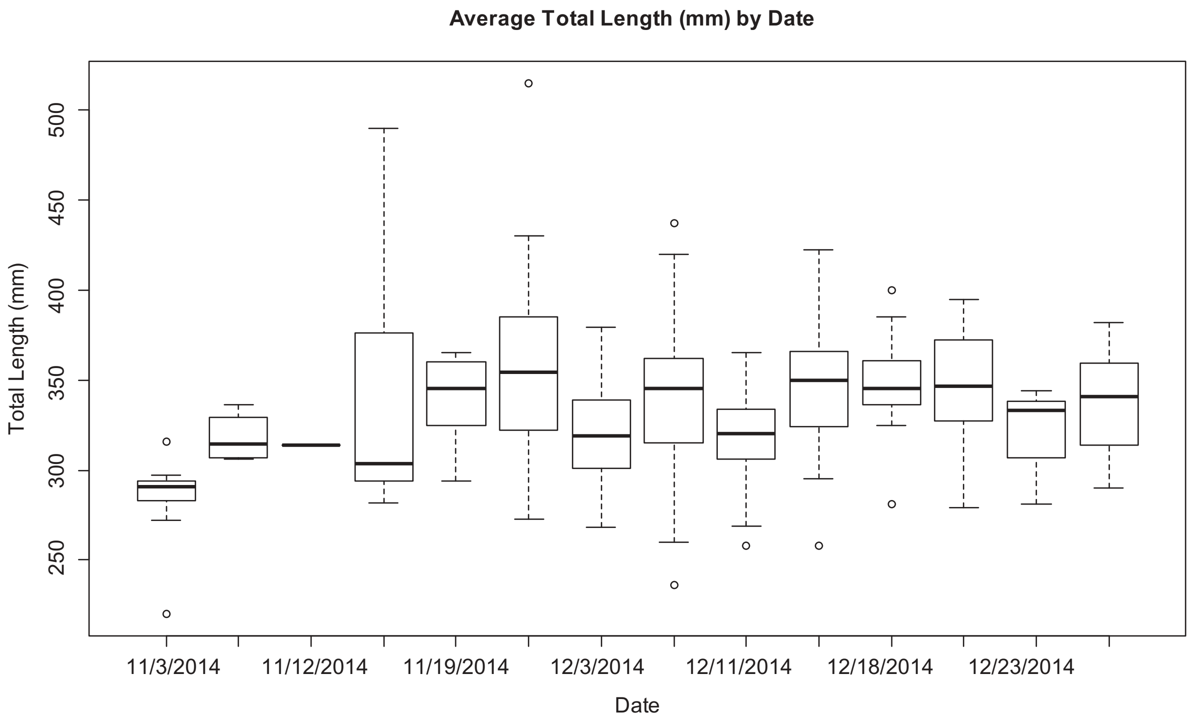

FIGURE 3. Average TL (mm) by date of Atlantic Sturgeon of ages 0–1 (n = 188) captured in the Delaware River during the 2014 sampling season (dates are month/d/year).

Our study was limited by several logistical constraints. The number of times we could gillnet (n = 14) for early juvenile Atlantic Sturgeon was restricted because of limited personnel and adverse weather events, which potentially decreased the accuracy and precision of our abundance estimate. However, the Schumacher–Eschmeyer estimator is considered to be the most robust and useful abundance estimator for multiple censuses on closed populations (Seber 1982; Krebs 1998). Also, gaps in the Delaware River receiver array and weak tag signals may have led to underestimated habitat use. Further, our inability to age individuals led us to assume age at length based on previously aged Delaware River specimens and to pool age-0 and age-1 individuals. Specifically, Shirey et al.'s (1999) minimum size at length for age-2 Atlantic Sturgeon in the Delaware River was based on only two individuals. However, the minimum length at 24 months as observed by Secor et al. (2000) in the Chesapeake Bay was just above 600 mm TL. Therefore, we believe all of the individuals that were caught in this study likely ranged from age 0 to age 1. The possibility exists that the two individuals that were initially captured and less than 250 mm TL were later recaptured after growing past the minimum size of 250 mm TL appropriate for tagging, thereby inducing error in our population estimate. However, given both individuals were less than 237 mm TL and the maximum increase in TL of the recaptured individuals was 8 mm, the possibility of their recapture at a length greater than 250 mm TL is highly unlikely. While we do acknowledge the logistical constraints of our sampling design, our study adequately characterized the abundance of ages-0–1 Atlantic Sturgeon in the Delaware River estuary given our application of the sentinel fish technique (Kynard et al. 2007; Fisher 2009) and our statistical method to estimate abundance (Ricker 1975; Kahn et al. 2014).

We did make several assumptions using the Schumacher and Eschmeyer mark–recapture model. First, similar to Peterson et al. (2008) and Kahn et al. (2014), we assumed that the population (at ages 0–1) was closed. We believe that the application of a closed population model is acceptable for Atlantic Sturgeon of ages 0–1 because at that life history stage, Atlantic Sturgeon are largely considered freshwater residents as emigration from natal estuaries occurs after age 2 (McCord et al. 2007). Further, the habitat use based on our acoustic tags supports our application of a closed model, as the majority (79.1%) of tag detections occurred within a 2-km range of the Marcus Hook Anchorage. Our second assumption was that all individuals had an equal likelihood of being captured. Given the juvenile patterns of riverine residency prior to age 2, and the application of the sentinel fish technique, we believe we met the second assumption of the model. Third, we assumed that enough individuals were marked and recaptured to provide a statistically meaningful estimate of abundance using this model. If an adequate number of individuals are not initially marked (at least half of the population according to Robson and Regier 1964; Roff 1973; Kahn et al.

TABLE 2. The number of individual Atlantic Sturgeon caught (initial captures + recaptures), number recaptured, and number marked from November 3 to December 31, 2014. Three individuals caught were not included in the table or the population estimate because two were too small and one was too large for tagging. No sentinel fish were recaptured during the course of our study.

Date	Number caught (C_t)	Number recaptured (R_t)	Number marked	Marked fish at large (M_t)
Nov 3	8	0	8	0
Nov 5	4	0	4	8
Nov 12	1	0	1	12
Nov 13	6	0	6	13
Nov 19	8	0	8	19
Nov 25	28	0	28	27
Dec 3	14	0	14	55
Dec 4	36	1	36	69
Dec 11	22	0	21	105
Dec 12	17	2	15	126
Dec 18	11	0	11	141
Dec 19	8	1	7	152
Dec 23	3	0	3	159
Dec 31	19	0	19	162
Total	185	4	181	181

2014), even for small population sizes, the mark–recapture model will be biased toward underestimating the population. However, Kahn et al. (2014) suggests considering abundance estimates by their 95% CI range instead of point estimates to satisfy this model assumption. We did so and estimated the abundance of ages-0–1 Atlantic Sturgeon to be between 1,935 and 33,041 individuals using the 95% CI by the Schumacher and Eschmeyer mark–recapture model. Finally, it is possible that systematic errors were propagated in our model as a function of errors due to recruitment and mortality (Ricker 1975). Given our short gill-net sampling period used to estimate abundance (~2 months), we believe that our abundance estimate was minimally affected by recruitment and mortality.

Despite the model assumptions and a limited amount of available Atlantic Sturgeon of ages 0–1, we found evidence of a remnant spawning population in the Delaware River and identified important nursery habitat based on the presence of individuals of ages 0–1. Similarly, Simpson and Fox (2006) suggested the existence of a contemporary spawning population in the Delaware River at much lower levels than historical population abundances (Secor and Waldman 1999). Spawning adults are believed to aggregate at areas with flowing waters (optimal flows of 46–76 cm/s) between the salt front and the fall line of large rivers at depths from 11 to 27 m (Borodin 1925; Leland 1968; Scott and Crossman 1973; Crance 1987; Bain et al. 2000) and deposit adhesive eggs on hard substrate (Gilbert 1989; Smith and Clungston 1997). In the Delaware River estuary, spawning areas have been suggested, based on telemetered adult habitat use, to range from Fox Point to Marcus Hook (rkm 118–129) and from the Marcus Hook area through the Tinicum Range (rkm 127–141) (Simpson and Fox 2006), as well as from Burlington, New Jersey, to Roebling, New Jersey (rkm 189–200) (D. Fox, Delaware State University, personal communication).

Based on our telemetry data, we believe that the Marcus Hook area is a significant juvenile habitat, with important nursery functions for individuals of ages 0–1 occurring down- and upriver of Marcus Hook at Cherry Island and Chester Range. We believe the range of juvenile habitat likely extends beyond the range documented here and based on previous studies extend as far upriver as Trenton, New Jersey (rkm 212; Lazzari et al. 1986), and as far downriver as Artificial Island (rkm 80; Stetzar et al. 2015). Our observations of site preference at the Marcus Hook area (rkm 127–129) with some usage of the Cherry Island Flats generally agree with previously documented habitat use in the Delaware River estuary (Stetzar et al. 2015). A study conducted in the Delaware River estuary during the summers of 1997 and 1998 identified areas with depths between 6 and 9 m from Artificial Island (rkm 82–92) and the Cherry Island Flats (rkm 111) north to the Delaware–Pennsylvania border (rkm 126) as important habitat for larger, subadult, juvenile Atlantic Sturgeon (Shirey et al. 1999). Additionally, previous Delaware Division of Fish and Wildlife habitat surveys have identified the Carney's Point, Tinicum Island Range, Mantua Anchorage, and Roebling area as nursery areas for Atlantic Sturgeon of ages 0–1 (Stetzar et al. 2015). While we did not observe tag detections near several historically visited locations such as Artificial Island, we were limited in the number of individuals we could mark with acoustic tags and by a short tracking period. However, we documented the Marcus Hook area in addition to the Artificial Island, Chester Range, and Cherry Island sites as vital nursery areas for natal Delaware River Atlantic Sturgeon in the current study. The degree of importance for an individual site to natal juvenile residents likely varies by year and ontogenetic stage in response to physical water conditions driven by freshwater discharge and movement of the salt front similar to what has been described for spawning adults (Breece et al. 2013).

The results of this study have significant implications for the management of Atlantic Sturgeon and provide new information on the New York Bight DPS. The abundance of ages-0–1 Atlantic Sturgeon in the Delaware River suggests that the Delaware River spawning subpopulation contributes more to the New York DPS than was formerly considered. Previous population estimates of age-1 Atlantic Sturgeon in the Hudson River estimated the 1976 cohort at 25,647 individuals (Dovel and Berggren 1983) and 4,314 individuals in 1995 (Peterson et al. 2000), which suggested a decline in recruitment through time (Sweka et al. 2006). Our results demonstrate that the abundance of Delaware River Atlantic Sturgeon of ages 0–1 is relatively similar in magnitude to the age-1 sturgeon estimates in the Hudson River suggested by Peterson et al. (2000) for 1995. However, without having an exact age, we are not able to directly compare age-1 estimates at this time between river systems. In order to put our current estimates of abundance for juvenile Atlantic Sturgeon of ages 0–1 in context relative to other regions and to understand if habitat preference for ages-0–1 sturgeon varies annually will require further monitoring efforts and the development of an updated age–length relationship for the Delaware River estuary. Similarly, continued sampling is needed to better understand the annual variability in the production of juvenile Atlantic Sturgeon in order to identify year-class strength and patterns affecting recruitment variability, as well as habitat use in the Delaware River estuary.

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