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Abstract—The Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) is an anadromous species that historically occurred in the Atlantic Ocean along the North American coast from maritime Canada to the St. Johns River, Florida. A century of overharvesting and habitat loss has resulted in range-wide population declines, and in 2012 the species was listed under the U.S. Endangered Species Act. The extirpation of several individual populations—especially in the southeastern United States—was an important consideration in the final determination to list the species as endangered. Although historical data confirm the presence of Atlantic sturgeon in the St. Johns River, no recent evidence of a viable population exists for that river system. The primary objective of our study was to document the presence or absence of Atlantic sturgeon in the St. Johns River. During 2014–2015, we conducted nearly 200 hours of directed sampling with gill nets of different mesh sizes in the St. Johns River estuary but found no evidence of an extant population within the St. Johns River system. We did document the seasonal presence of several adult and subadult individuals that had been acoustically tagged by researchers working in other coastal systems, and that finding indicates that nonnatal individuals still use this estuary.

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Seasonal occurrence of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the St. Johns River, Florida

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The Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) is an anadromous species characterized by a long life span and late age at maturity. Historically, this species occurred in the rivers and estuaries of the Atlantic Ocean along the North American coast from the St. Lawrence River, Canada, to the St. Johns River, Florida, United States (ASSRT, 2007). Commercial fisheries of both the United States and Canada exploited populations of Atlantic sturgeon throughout much of the 19th and 20th centuries (Smith and Clugston, 1997); however, most of these fisheries collapsed during the early 20th century because of gross overharvesting, industrial development, and damming and pollution of Atlantic coast rivers (Smith and Clugston, 1997; ASSRT, 1998; Secor, 2002; ASSRT, 2007).

In response to the rapid population declines of Atlantic sturgeon that resulted from commercial overexploitation, federal management agencies in the United States and Canada implemented several regulatory protections for this species during the late 20th century. Commercial fisheries for Atlantic sturgeon were closed in U.S. waters with the issuance of a 1998 federal moratorium, and in 2012 the species was listed under the U.S. Endangered Species Act. Under this listing, distinct population segments (DPSs) were designated for 5 regions within U.S. waters: Gulf of Maine, New York Bight, Chesapeake Bay, North and South Carolina, and the southeastern United States (ASSRT, 2007). All DPSs were listed as endangered except the Gulf of Maine DPS, which was listed as threatened (Federal Register, 2012a, 2012b).

Although several northern populations of Atlantic sturgeon have had at least some level of recovery in recent decades, many populations within the DPS for the southeastern United States remain severely depressed or possibly extirpated (ASSRT, 1998; ASSRT, 2007). Despite federal protections, many of these populations continue to suffer from degraded habitats in natal river systems, and from incidental bycatch in commercial fisheries that target other coastal or estuarine species (ASSRT, 1998; Collins et al., 2000; ASSRT, 2007). The implementation of modern environmental regulations has helped reduce point sources of pollution in many river systems in the southeastern United States, but nonpoint sources continue to degrade water quality, particularly in the lower rivers and estuarine habitats that were historically inhabited by juvenile Atlantic sturgeon (ASSRT, 2007).

As an anadromous fish, Atlantic sturgeon adults typically reside in marine environments but migrate into freshwater rivers to spawn (Vladykov and Greeley, 1963). In northern populations, spawning occurs in the spring (Bain, 1997), whereas the results of recent studies indicate that at least some central and southern populations spawn in the fall (Hager et al., 2014; Smith et al., 2015; Ingram and Peterson, 2016). During the first several years of life, the young fish, known as river-resident juveniles (RRJs), occupy estuarine habitats near the freshwater–saltwater interface. The period of river residency varies depending on latitude, but in southern populations the RRJs typically remain in their natal system for 2–4 years before transitioning to nearshore marine habitats as marine-migratory juveniles (MMJs) (Bain, 1997). Consequently, the presence of RRJs within a river system is considered strong evidence of an extant population, especially in depressed populations in which adult spawners may be rare (Schueller and Peterson, 2010).

The St. Johns River in Florida is considered the southernmost river system historically occupied by Atlantic sturgeon (ASMFC[1]; ASSRT, 2007). Throughout the 20th century, sturgeon were commonly reported as bycatch in commercial fisheries that operate on the St. Johns River (Cox and Moody[2]); however, reports of small juveniles are rare and spawning has never been confirmed there (McLane, 1955; Gilbert, 1992a). Furthermore, the construction of Rodman Dam (now called Kirkpatrick Dam) in 1968 blocked adults from accessing some of the best potential spawning habitats in the Ocklawaha tributary (Gilbert, 1992a; ASMFC[1]; ASSRT, 2007). The current status of Atlantic sturgeon, however, remains unknown within the St. Johns River system. The most recent survey of this population, conducted from 2002 to 2003 by the Florida Fish and Wildlife Commission, yielded zero Atlantic sturgeon despite hundreds of hours of directed sampling effort (Holder et al.[3]). The results of that study indicate that Atlantic sturgeon likely have been extirpated from St. Johns River, although rare but recurring captures of adult and subadult individuals by local anglers indicate that a small population could be present or that migrants from other systems are regularly occupying the estuary.

Extirpation of any fish population is difficult to establish conclusively, but it is especially difficult with sturgeons because of their cryptic nature, complex migratory life history, and periodic reproductive strategy. Given the uncertain status of Atlantic sturgeon within the St. Johns River, the objectives of this study were 1) to document seasonal occurrence of Atlantic sturgeon in the lower estuary and 2) to sample for RRJs as evidence of an extant population of Atlantic sturgeon in the St. Johns River.

Materials and methods

Study site

The St. Johns River is a large, blackwater river in northeast Florida, characterized by tannic waters and a very low mean gradient (~2.0 cm/km) (Whitney et al., 2004). It flows for 500 km to the Atlantic Ocean, draining several subbasins and associated tributaries that have in total a combined watershed area of approximately 22,900 km^2. Nontidal flow at the mouth averages 420 cm/s, but the rate may exceed 4220 cm/s after heavy rains. Much of the St. Johns River basin is urbanized and developed, and the river itself has been modified by dam construction and dredging (EPB[4]).

Sampling of sturgeon

All sampling was conducted in the lower St. Johns River estuary below the head of tide, between river kilometer (rkm) 25 and rkm 115. Sampling occurred during summer months because this season is the most effective time to capture RRJ Atlantic sturgeon (Schueller and Peterson, 2010; Bahr and Peterson, 2016). Specific netting locations within this zone (Fig. 1) were selected by using navigational charts and preliminary sonar surveys to find areas with depths of at least 2.5 m and

[1] ASMFC (Atlantic States Marine Fisheries Commission). 1998. Amendment 1 to the interstate fishery management plan for Atlantic sturgeon. Fish. Manage. Rep. 31, 42 p. ASMFC, Washington, DC. [Available from website.]

[2] Cox, D. T., and H. L. Moody. 1981. St. Johns River fisheries resources. Completion report. Study I. Ecological aspects of the fishery. Florida Game Fresh Water Fish Comm., Tallahassee, FL. [Available from Florida Fish Wildl. Conserv. Comm., Farris Bryant Bldg., 620 S. Meridian St., Tallahassee, FL 32399-1600.]

[3] Holder, J. C., R. E. Lundy, A. R. Hyle, and L. West. 2005. Completion report: St. Johns River fisheries resources, Lower St. Johns River resource development. Florida Fish Wildl. Conserv. Comm., Tallahassee, FL. [Available from Florida Fish Wildl. Conserv. Comm., Farris Bryant Bldg., 620 S. Meridian St., Tallahassee, FL 32399-1600.]

[4] EPB (Environmental Protection Board). 2014. State of the river report for the lower St. Johns River basin, Florida: water quality, fisheries, aquatic life, and contaminants 2014. State River Rep. 7, 301 p. EPB, City of Jacksonville; Univ. North Florida; and Jacksonville Univ., Jacksonville, FL. [Available from website.]

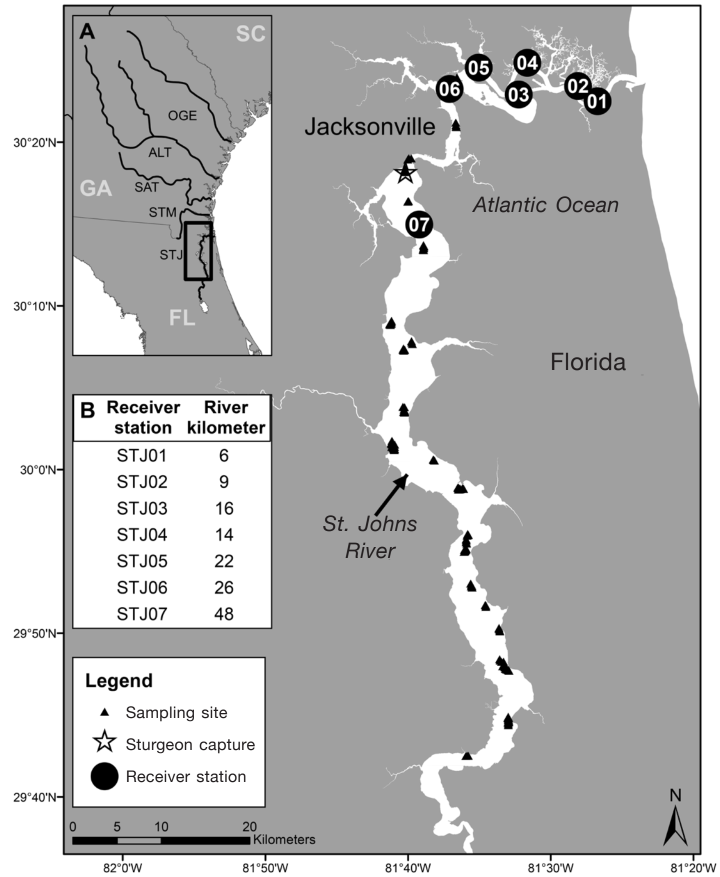

Figure 1

Map of sites where sampling was conducted during 2014–2015, the location where an Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) was captured in July 2015 (☆), and the stations (01–07) where acoustic receivers were deployed in the St. Johns River (STJ) in Florida. Inset A depicts the rivers of the southeastern United States, including several rivers nearby the St. Johns River with documented populations of Atlantic sturgeon: Ogeechee (OGE), Altamaha (ALT), and Satilla (SAT) in Georgia and St. Marys (STM) along the border of Georgia and Florida. Approximate river kilometers (rkm) of the locations of the receivers from the mouth of the estuary are listed in inset B.

obstruction-free bottoms. On sampling days, crews set 5–12 anchored gill and trammel nets perpendicular to the channel and soaked them for approximately 30–90 min, depending on conditions. Gill nets 91.4 m in length and 3.1 m deep, were composed of panels of 7.6-, 10.2-, and 15.3-cm monofilament mesh (stretch measure). Trammel nets were of similar dimensions and material and were composed of one 7.6-cm inner panel and three 30.5-cm outer panels. As nets were retrieved, entangled sturgeons were quickly removed and placed in a floating net pen.

Once all nets had been recovered, each captured sturgeon was measured to the nearest millimeter (total length [TL] and fork length [FL]) and was inspected for tags. If no tag was present, a passive integrated transponder tag was injected under the 4th dorsal scute and a small tissue sample was taken from the dorsal fin for genetic analysis. The fish was then placed on a custom-made, v-shaped surgical board that held the fish in lateral recumbency. A small bilge pump (473.2 L/h) was used to maintain a gentle flow of river water over the gills. A sterile scalpel was then used to make a 1-cm incision along the midline of the ventrum for insertion of a 69-kHz Vemco V7-4x[5] sonic transmitter (Vemco, Bedford, Canada). The incision was closed by using a 2/0 absorbable monocryl suture (Monoswif L943, CP Medical, Inc., Norcross, GA) as a simple suture with interrupted stiches as described by Boone et al. (2013). Once the incision was closed, the fish was allowed to recover and returned to the river at its original capture site.

Fish ages were estimated by using a length-frequency histogram based on Schueller and Peterson (2010); individuals with TL<550 mm were considered to be age-1 RRJs.

Acoustic telemetry

A passive array of 7 stationary acoustic receivers (Vemco VR2W) were distributed in June 2014 throughout the St. Johns River estuary to monitor the spatial and temporal movements of acoustically tagged Atlantic sturgeon. The submerged acoustic receivers were attached to channel markers and other stationary structures by using aluminum u-channel or stainless steel cables and hardware. All acoustic receivers were affixed in an upright position, 2–3 m below the surface to ensure that they remained completely submerged throughout the tidal cycle. Range testing conducted at receiver locations indicated an average tag detection radius of approximately 400 m (range: 200–800 m). Once the receivers were deployed, data from these acoustic receivers were downloaded every 3–5 months throughout the duration of this study.

Water-quality

To monitor variations in water quality throughout the sampling period, we collected measurements of water temperature (degrees Celsius), dissolved oxygen (milligrams per liter), and salinity at each fish sampling site during June–July in 2015 and 2016. These measurements were obtained at the surface and at 0.5 m from the bottom at each netting site by using a portable YSI Pro2030 multiprobe (YSI, Inc., Yellow Springs, OH).

[5] Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1

Sampling effort by net type within the St. Johns River, Florida, during the summers of 2014 and 2015 in our study of the seasonal occurrence of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*).

	Gill nets		Trammel nets		Annual totals	
Year	No. of sets	Soak time (h)	No. of sets	Soak time (h)	No. of sets	Soak time (h)
2014	30	24	1	1	31	25
2015	105	127	14	22	119	149
Combined totals	135	151	15	23	150	174

Results

Sampling of sturgeon

Initial sampling was conducted from 25 June through 2 July 2014 to identify suitable sampling sites within the estuary where anchored nets could be safely fished without impeding commercial or recreational vessels. During this period, we set 31 nets for a total of 24.3 h of soak time (Table 1). Between 23 June and 10 July 2015, we set 119 nets for a total of 149.4 h of soak time. Only one MMJ Atlantic sturgeon (786 mm FL, 920 mm TL) was captured during this study, and subsequent genetic analysis assigned this individual to the population of the Altamaha River, Georgia, with 98% probability (Wirgin[6]).

Acoustic telemetry

The single Atlantic sturgeon captured at rkm 40 in July 2015 was was tagged with an acoustic tag, but it was never detected on the acoustic array. The array did, however, detect 8 previously tagged Atlantic sturgeon that had been captured and released by other researchers working outside St. Johns River (Table 2, Fig. 1). At the time of tagging, these individuals were either MMJs (n=3) or adults (n=5). We examined data recorded by the acoustic receivers from June 2014 through June 2016. All detections of Atlantic sturgeon obtained during the period of this study occurred in winter or early spring (Figs. 2 and 3)—a temporal pattern that was consistent in both 2014 and 2015. Most of these migrant Atlantic sturgeon (n=5, 62.5%) were never detected upriver from receiver STJ02 (rkm 9), and only one individual (12.5%) was detected as far upstream as receiver STJ06 (rkm 48).

Water quality

During the summer sampling period, mean daily water temperatures in the St. Johns River estuary were comparable to those obtained in other nearby rivers where populations of Atlantic sturgeon have been well documented (Table 3, Fig. 4). Dissolved oxygen levels in the St. Johns River were also well within the range of those observed in other rivers of the southeastern United States with extant populations of Atlantic sturgeon (Table 3, Fig. 5).

[6] Wirgin, I. 2017. Personal commun. Sch. Med., New York Univ., 57 Old Forge Rd., 2nd Fl., Tuxedo, NY 10987.

Discussion

After expending 174 net hours of sampling effort dispersed over 150 individual net-sets, we could not confirm the presence of a juvenile cohort of Atlantic sturgeon within the St. Johns River estuary. Our sampling efforts included many of the same sampling sites used in previous surveys of sturgeon in the St. Johns River (Holder et al.[3]), and these sites were primarily established on the basis of incidental captures of sturgeon in commercial and recreational fisheries that target other species. Although salinities at specific sampling sites varied depending on tidal cycle and seasonal precipitation, the range of salinities that we observed within our sampling area was similar to those documented in other nearby rivers (e.g., Altamaha and Satilla rivers in Georgia) where several RRJ cohorts have been documented in recent years (Schueller and Peterson, 2010; Bahr and Peterson, 2016; Fritts et al., 2016). Likewise, water temperatures and levels of dissolved oxygen at sampling sites in this study were well within the known tolerances of juvenile Atlantic sturgeon and, again, were comparable to those in other nearby rivers with extant populations of Atlantic sturgeon. Genetic analysis of the tissue sample obtained from the single Atlantic sturgeon captured indicates that this fish was almost certainly a subadult migrant from the Altamaha River.

During 2 summers of sampling in the St. Johns River, we captured no RRJ Atlantic sturgeon. Concurrent sampling was conducted in several nearby estuaries, including the Ogeechee and Altamaha rivers in Georgia and St. Marys River on the border of Georgia and Florida; the same methods and gear successfully captured RRJ Atlantic sturgeon in those rivers (senior author and D. Peterson, unpubl. data). Furthermore, the catch rate for Atlantic sturgeon (at all life stages)

Table 2

Details for tagged Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) detected by acoustic receivers in the St. Johns River (STJ), Florida, from June 2014 through June 2016. Each fish was assigned to a distinct population segment (DPS) based on genetic analyses provided by the U.S. Geological Survey Leetown Science Center, which maintains a comprehensive genetic database for all known populations of Atlantic sturgeon.

Life stage when tagged	Total length (mm) when tagged	Tagging location	Tagging year	Tagging organization	Number of days detected in the STJ	Region of origin of DPS
Subadult	1380	Coastal NY/NJ	2011	Stony Brook University	1	Southeastern United States
Adult	2290	Coastal Mid-Atlantic	2012	Delaware State University[a]	1	Southeastern United States
Adult	2040	Altamaha River, GA	2012	University of Georgia	2	Southeastern United States[d]
Adult	1466	Altamaha River, GA	2013	University of Georgia	2	Not available
Adult	1870	Altamaha River, GA	2013	University of Georgia	2	Not available
Subadult	893	Cape Fear River, NC	2013	NC DMF[b]	4	Southeastern United States
Adult	1093	Santee Bay, SC	2014	SC DNR[c]	1	Southeastern United States
Adult	1490	Cooper River, SC	2015	SC DNR[c]	1	Not available

[a] Fox, D. 2017. Personal commun. Dep. Agric. Nat. Resour., Coll. Agric. Relat. Sci., Delaware State Univ, Agric. Annex Rm. 123, 1200 N. DuPont Hwy., Dover, DE 19901.

[b] Loeffler, M. 2017. Personal commun. North Carolina Div. Mar. Fish., 3441 Arendell St., Morehead City, NC 28557.

[c] Post, W. 2017. Personal commun. South Carolina Dep. Nat. Resour., P.O. Box 12559, Charleston, SC 29422-2559.

[d] Stock assignment was based on telemetry data from Ingram and Peterson (2016) that indicated that this fish made a putative spawning run in the Altamaha River, Georgia, in 2014.

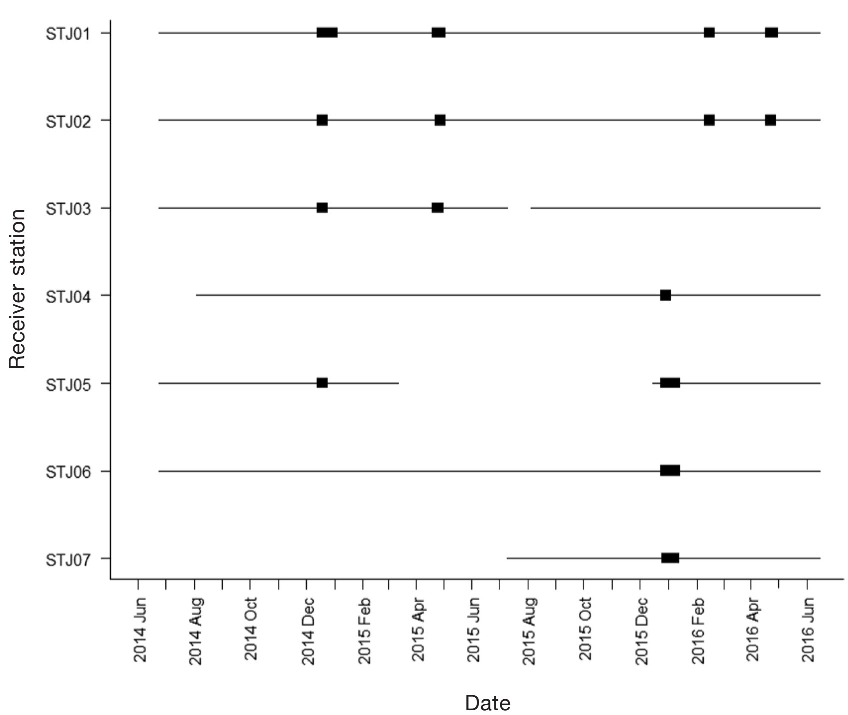

Figure 2

Temporal distribution of acoustic receivers (horizontal lines) and days with detection of individual tagged Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) (black rectangles) in the St. Johns River estuary in Florida from June 2014 through June 2016.

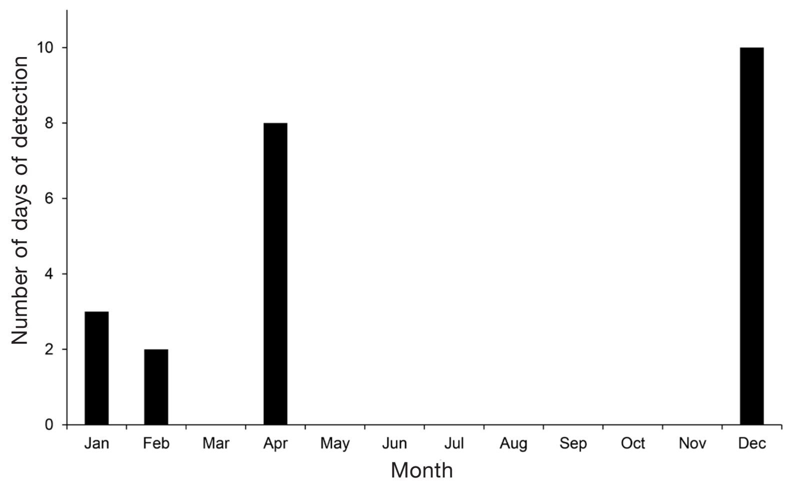

Figure 3

Number of days of detection per month of tagged Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) by acoustic receivers in the St. Johns River in Florida during 2014–2016. The number of days of detection (one detection per individual per day) were combined by month across all years of the study.

Table 3

Water temperatures and dissolved oxygen levels in the Altamaha and Satilla rivers in Georgia and the St. Johns River in Florida during June–July 2015.

	Temperature (ºC)		Dissolved oxygen (mg/L)	
River	Mean	Standard deviation	Mean	Standard deviation
Altamaha	30.30	0.73	5.70	0.47
Satilla	29.96	0.67	3.39	0.61
St. Johns	29.50	0.47	4.70	0.82

Table 4

Concurrent sampling efforts in 2015 with the use of similar entanglement gear and the resulting catch of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) measured as the number of individual fish caught per hour, in several rivers in the southeastern United States.

River	Soak time (h) of nets	Number of individuals captured	Catch (individuals/h)
Ogeechee	175	154	0.880
Altamaha	50	76	1.520
Satilla	176	76	0.432
St. Marys	122	10	0.082
St. Johns	149	1	0.007

for our study in the St. Johns River was far below the rates typically observed for sampling for studies in other rivers of the southeastern United States where populations have been documented (Table 4). Even in St. Marys River, which hosts the smallest known extant population of Atlantic sturgeon (ASSRT, 2007; senior author and D. Peterson, unpubl. data), catch rates were an order of magnitude greater than those we observed in our study of the St. Johns River. In rivers with extant populations of Atlantic sturgeon, the methods employed in our study generally produce dozens to hundreds of RRJ sturgeon annually (Schueller and Peterson, 2010; Bahr and Peterson, 2016; senior author and D. Peterson, unpubl. data). The complete absence of RRJs captured over the 2 consecutive summers of sampling in the St. Johns River indicates that a natal RRJ cohort was not likely present in either year of the study.

The observed absence of RRJs during this study, though not conclusive, indicates that a viable population of Atlantic sturgeon is not currently present within the St. Johns River, as was suggested by Holder et al.[3]. Although a historical status of this population has never been confirmed, Gilbert (1992b) suggests that access to potential spawning habitat for a natal population likely was eliminated by the construction of the Kirkpatrick Dam in 1968. Still, we emphasize caution in designating Atlantic sturgeon as extirpated

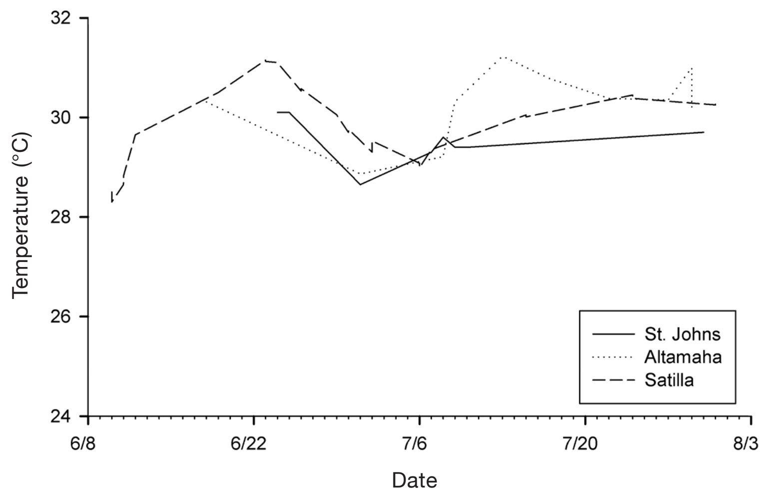

Figure 4

Mean daily water temperature (°C) measured at sampling sites in the St. Johns River in Florida and in the Altamaha and Satilla rivers in Georgia during June–July 2015.

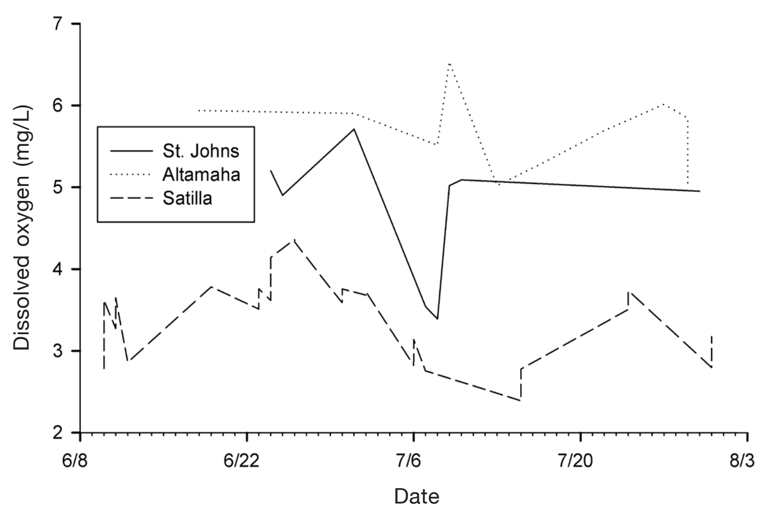

Figure 5

Mean daily levels of dissolved oxygen (mg/L) measured at sampling sites in the St. Johns River in Florida and in the Altamaha and Satilla rivers in Georgia during June–July 2015.

from the St. Johns River—the absence of evidence is, by no means, conclusive evidence of absence. Atlantic sturgeon are long-lived, intermittent spawners, and several previous studies have shown that remnant populations can be extremely difficult to detect even with intensive sampling efforts. For example, populations of Atlantic sturgeon were, until recently, thought to be extirpated from the St. Marys River, an adjacent river located only 34 km north of the St. Johns River (Blair et al.[7]). Recent sampling in that river system, however, has documented the presence of an RRJ cohort in that system, confirming the pres-

[7] Blair, S., M. Ezell, H. Hall, and J. November. 2009. St. Marys River watershed. Prepared for the St. Marys River Management Committee in collaboration with the University of Florida Conservation Clinic and the University of Georgia Environmental Law Practicum. [Available from website.]

ence of an extant population (senior author and D. Peterson, unpubl. data). Despite the limited sample size obtained there, preliminary genetic analyses of tissue samples from those juveniles indicate that they represent a unique population within the DPS for the southeastern United States, one likely produced from a remnant population of subadults that survived the era of commercial fishing (Wirgin[6]).

Although the St. Johns River channel has been dammed and dramatically altered, the river still potentially could support a population of Atlantic sturgeon. Water temperatures and levels of dissolved oxygen measured during this study were quite comparable to those in nearby rivers with extant populations. Consequently, we emphasize that additional assessments are needed in the future (every 2–3 years) to definitively ascertain the status of Atlantic sturgeon within the St. Johns River system. If neither RRJs nor spawning adults can be captured in future studies, the use of modern environmental DNA (eDNA) methods could be used to help establish the presence of spawning adults within the upper reaches of the St. Johns River. A similar approach was used recently by Pfleger et al. (2016) to document the presence of the Alabama sturgeon (*Scaphirhynchus suttkusi*) in the Mobile River basin, Alabama.

The data collected in this study confirm the seasonal presence of both adult and MMJ Atlantic sturgeon in the lower St. Johns River estuary during the late winter and early spring months. The seasonal presence of adult and MMJ individuals was detected on all acoustic receivers within our array. All 8 migrants originally had been tagged in either the mid-Atlantic or southeastern United States, indicating that the St. Johns River may still provide important wintering habitat for nonresident Atlantic sturgeon. Similar movement patterns have been documented in several other river systems of the southeastern United States (senior author and D. Peterson, unpubl. data); however, more information is needed to better understand the seasonal importance of nonspawning migrations. Regardless, the results of this study indicate that adult fish are most abundant in the St. Johns River estuary during the late winter and early spring. As range-wide recovery of Atlantic sturgeon continues, seasonal abundance within the lower St. Johns River will likely increase even in the absence of a natal population. Consequently, we emphasize the need for future studies with sample sizes larger than those in our study because the use of larger sample sizes will help to better define seasonal patterns of habitat use by migrating Atlantic sturgeon within the St. Johns River estuary.

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