SEASONAL OCCURRENCE AND MOVEMENTS OF ATLANTIC STURGEON

(*ACIPENSER OXYRINCHUS OXYRINCHUS*) IN GEORGIA AND FLORIDA

by

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(Under the Direction of Douglas L. Peterson)

ABSTRACT

The Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) is a federally endangered anadromous fish that historically occurred along the Atlantic coast of North American from Canada to Florida. Through the 20th century, overharvest and dam construction resulted in range-wide population declines. Despite two decades of federal protection, many populations have not recovered, and information about the status of many populations is lacking, especially in the Southeastern United States. Recruitment may be a bottleneck for recovery, but habitat use by early juveniles is not well understood. The objectives of this study were to 1) assess the status of Atlantic Sturgeon populations in the St. Johns River in Florida and the St. Marys River in Georgia, at the southern margin of the species' range, and 2) describe seasonal movement by juvenile Atlantic Sturgeon in the Ogeechee, Altamaha, and Satilla Rivers in Georgia. Sturgeon were captured using monofilament gill and trammel nets, and some individuals were tagged with surgically-implanted acoustic transmitters. Fish movements were monitored using an array of passive acoustic receivers distributed throughout the lower river and estuary of each system. We found no evidence of an extant population of Atlantic Sturgeon within the St. Johns River system, but did document the presence of young juveniles in the St. Marys River. Those fish represent a small, but genetically distinct population in a river where the species had previously been thought extirpated. Our results also indicated that both rivers continue to provide seasonally important habitat for migrating adults from other populations. Tagged age-1 river-resident juvenile sturgeon in the Ogeechee, Altamaha, and Satilla Rivers exhibited similar patterns of seasonal habitat use – during the summer, fish were concentrated in upriver portions of nursery habitat, but during the winter they dispersed downriver and used more polyhaline habitat. Also during the winter of age-2, at least 30% of tagged fish outmigrated from their natal river. These results provide important information for management agencies regarding the status of Atlantic Sturgeon in the two southernmost rivers in their range, as well as helping to fill knowledge gaps about juvenile habitat use and outmigration.

INDEX WORDS: Atlantic Sturgeon, Acipenser oxyrinchus oxyrinchus, Anadromous fish, Endangered species, Habitat use, Acoustic telemetry, St. Johns River, St. Marys River, Altamaha River, Ogeechee River, Satilla River

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CHAPTER 1

ATLANTIC STURGEON (*ACIPENSER OXYRINCHUS OXYRINCHUS*) IN GEORGIA

Species Description

Sturgeons are considered “living fossils,” as they have existed largely unchanged for at least 200 million years (Bemis et al. 1997). The sturgeon family, Acipenseridae, comprises four genera and 27 extant species with an holarctic distribution. All members of the family are characterized by large, heavy, almost cylindrical bodies. They have a single dorsal fin located far back on the body, an anal fin opposite, and a heterocercal tail. Sturgeons possess a cartilaginous skeleton and, while they lack scales, they have patches of denticles on their skin, and are armored with five rows of bony scutes along the dorsal ridge, flanks, and ventral margins (Scott and Crossman 1973; Birstein 1993). The underside of a sturgeon’s rostrum features four barbels and numerous ampullae that assist with prey detection (Zhang et al. 2012). Although a few species are found only in fresh water, the majority are anadromous. Most sturgeons are benthic, and all are long-lived with a late age at maturity. Many extant populations are currently at risk because of historical overfishing and other anthropogenic activities (Birstein 1993).

Nine species of sturgeon (belonging to two genera) are native to North America (Bemis and Kynard 1997). The Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus* Mitchill 1815) is found along the East coast of the continent, with a range extending from the St. Lawrence River, Canada, to the St. Johns River, Florida. The Gulf Sturgeon subspecies *Acipenser oxyrinchus* *desotoi* is found in the Gulf of Mexico from Louisiana to Florida (Scott and Crossman 1973; Gilbert 1989). Atlantic Sturgeon coloration is variable and changes throughout life, but they generally have a dark brown dorsum and a white or light-colored ventral surface. Although there is little sexual dimorphism, females are typically larger than males. Adult Atlantic Sturgeon can reach lengths of over 3 m – the largest documented specimen measured 4.27 m and weighed over 360 kg (Vladykov and Greely 1963). Like other Acipenerids, Atlantic Sturgeon have long lifespans, and may reach at least 60 years of age (Mangin and Beauleiu 1963 as cited in van den Avyle 1984), although in the southern part of their range they are not known to exceed 30 years of age (Scott and Crossman 1973; van den Avyle 1984; Gilbert 1989; Birstein 1993; Vescei and Peterson 2000).

Natural History

The life cycle of Atlantic Sturgeon is complex and consists of multiple stages, each with differing habitat requirements and behavioral patterns. Atlantic Sturgeon are anadromous, spending their adult lives in marine waters but returning to their natal river to spawn. Gilbert (1989) reported that spawning occurs over a relatively short period of approximately 3-5 days, in deep water with strong currents and hard substrate. A spawning female can produce 800,000 to 2.4 million eggs, each about 2.5-2.6 mm in diameter. The eggs are typically broadcast into the water where they quickly become adhesive, facilitating their adherence to any clean hard substrate (Scott and Crossman 1973; Murawski and Pacheco 1977). Recent studies have found that Atlantic Sturgeon exhibit clinal variation with regard to spawning season. In northern rivers (e.g. the Hudson River in NY), spawning occurs in the spring (Bain 1997). In some mid-Atlantic rivers, sturgeon may spawn in both fall and spring (Balazik and Musick 2014), but some rivers have fall spawning only (Hagar et al. 2014; Smith et al. 2015). In southern rivers (e.g. the Altamaha River in GA), Atlantic Sturgeon appear to spawn only in the fall (Ingram and Peterson 2016). Following spawning, adults rapidly move downriver and return to sea.

No studies have been conducted on larval Atlantic Sturgeon in Georgia rivers; however, their habits are likely similar to those described elsewhere. Upon hatching, the "prolarvae" (free embryos) are about 7 mm in length, and have no functional mouth or gills and only rudimentary fins (Smith et al. 1980). During the first few days of life, prolarvae remain hidden within the interstitial spaces of the substrate (Ross and Bennett 1997). About eight days after hatching, the young fish transform into true larvae – complete with all structures need to capture planktonic prey. At this point, they become photopositive, which facilitates their downstream migration toward the estuary (Kynard and Horgan 2002). Because they are intolerant of salinity, however, the larvae are thought to settle well above the head of tide where they continue to feed on zooplankton (van Eenennaam et al. 1996). Bain (1997) reported that the transition from larvae to juvenile occurred at lengths of about 30 mm, at which point the young fish resume their downstream migration until they reach their estuarine nursery areas. In the Connecticut River, young-of-year (age-0) juveniles migrated 38-84 km from the spawning grounds to the estuary in as little as 6-12 days (Kynard and Horgan 2002). In the Hudson River, young juveniles were found to overwinter in brackish water, though the timing of this transition to saline habitats is uncertain (Bain 1997). Evidence suggests Atlantic Sturgeon experience limited predation during these early life stages (Kynard and Horgan 2002).

Most early life history studies of Atlantic Sturgeon have focused on the species' ecology and ontogeny in northern rivers, and although their life cycle is thought to be similar in southern rivers, comparable studies in southern river systems are lacking. From age-1 to as late as age-4, river-resident juveniles (RRJs) occupy habitats below the head of tide, near the fresh/saltwater interface (Bain 1997). The diet of RRJs consists of benthic plants and animals, including insect larvae, bivalves, isopods and amphipods, which they extract from the muddy substrate (Scott and Crossman 1973). Like all other sturgeon species, Atlantic Sturgeon are able to protrude their mouth parts, allowing them to capture their benthic prey with suction feeding (Miller 2005). The presence of RRJs within a river system provides strong evidence of an extant population, especially in rivers where adult spawners may be rare (Schueller and Peterson 2010).

Juvenile Atlantic Sturgeon grow quickly and may start to outmigrate from their natal estuary into coastal marine habitats as early as age-2. Once they leave their natal river, fish transition into the marine migratory juvenile (MMJ) phase (Bain 1997). As MMJs the young fish may return to natal or non-natal estuarine or riverine habitats for prolonged periods during the summer months (Dovel and Berggren 1983; Bain 1997), although the reasons for this behavior are unclear.

Atlantic Sturgeon require approximately 10 years to grow to an average adult size of about 150 cm (Bain 1997); females continue to grow steadily after maturation, but growth in males typically slows. Although age at maturity varies latitudinally, females typically mature at 7-20 years and spawn every 3-5 years. Males typically mature at 5-13, and spawn every 1-4 years (Smith et al. 1982; Smith 1985; Van Eenennaam et al. 1996).

As adults, Atlantic Sturgeon inhabit large areas of the coastal ocean - some may even leave the continental shelf (Scott and Crossman 1973; Bain 1997). Consequently, adults from different populations frequently mix together offshore. For example, Waldmen et al. (2013) found that adults captured in Long Island Sound comprised a mix of individuals originating from the adjacent Hudson and Connecticut Rivers, as well as other fish from the Delaware River, James River, and even some from rivers in the southeastern United States (U.S.). During their time at sea, adults feed on a variety of invertebrates, including molluscs, crustaceans, isopods, amphipods, and polychaetes. They will also opportunistically consume small fishes, such as capelin (*Mallotus villosus*) (Johnson et al. 1997; Vescei and Peterson 2000; Miller 2005). As adults, Atlantic Sturgeon have very few natural predators, although they may be parasitized by lampreys (Scott and Crossman 1973) and by several species of marine invertebrates.

Status and Management

Atlantic Sturgeon were intensively exploited for their meat and caviar throughout much of the Twentieth Century (Scott and Crossman 1973; Smith and Clugston 1997). Their annual spawning runs provided a predictable harvest for fishermen using nets, trawls, traps, and even harpoons (Smith and Clugston 1997), and by 1900, many sturgeon fisheries began to collapse from overfishing (Fig. 1.1). Prior to their collapse, sturgeon fisheries were overseen by the Atlantic States Marine Fisheries Commission, but managed by individual states – most of which imposed few if any restrictions on harvest. Early regulations on commercial fishing were not sufficient to reverse widespread population declines, and in 1996, the National Marine Fisheries Service (NMFS) enacted an emergency moratorium to halt further harvest in U.S. waters. In 1998, the emergency action was replaced by a 40 year closure of the fishery, and in 2012 the species was listed as endangered under the U.S. Endangered Species Act (Taub 1990; ASMFC 1998; ASSRT 2007; Spear 2007; Federal Register 2012). Although the species has now been protected from harvest for nearly two decades, anthropogenic sources of mortality remain an ongoing problem. Ship strikes and bycatch in both riverine and coastal commercial fisheries have been identified as important impediments to species recovery, and though limited in scope, poaching has also been documented in several states (Taub 1990; ASMFC 1998; Collins et al. 1996; Smith and Clugston 1997; Collins et al. 2000; Stein et al. 2004; ASMFC 2007).

In addition to fishing pressure, Atlantic Sturgeon have also been heavily impacted by habitat degradation. During the 20th century, many rivers were dammed to generate hydroelectric power. Dams negatively affect many Atlantic Sturgeon populations by eliminating access to upstream spawning grounds and by altering seasonal patterns of flow and temperature downstream (ASSRT 2007). Declines in water quality in rivers and the coastal ocean also pose a threat to Atlantic Sturgeon. Industry, agriculture, silviculture, and other anthropogenic activities introduce pollutants, increase run-off and erosion, and increase nutrient loading in rivers. These changes can have major impacts on spawning areas and on the freshwater habitats available to sturgeon in coastal regions, which are already limited by natural processes and the species' environmental tolerances (Niklitschek and Secor 2005). Furthermore, their long lifespan and benthic ecology makes Atlantic Sturgeon especially likely to bioaccumulate heavy and trace metals and persistent organic pollutants, which can have sublethal effects on both survival and reproduction (ASSRT 2007).

Under the Endangered Species Act listing, populations of Atlantic Sturgeon within the U.S. have been divided into five independently-managed distinct population segments (DPSs), based on geographic, genetic and ecological factors (ASSRT 2007) (Fig. 1.2). Every DPS contains several rivers, each hosting a genetically distinct population (Wirgin et al. 2000; Grunwald et al. 2008; Peterson et al. 2008). Atlantic Sturgeon spawning populations are currently supported in fewer than 20 rivers. Recent population studies suggest that the Hudson River in New York and the Altamaha and Savannah Rivers in Georgia are home to robust populations of Atlantic Sturgeon (Bain 1997; Schueller and Peterson 2010; Bahr and Peterson 2016), but comparable assessments are lacking for most other populations, especially within the South Atlantic DPS (ASSRT 2007). Habitat use of Atlantic Sturgeon is also poorly understood within the southern margin of the range, although the life cycle in southern populations is known to be ecologically different from that in northern rivers (Collins et al. 2000).

Although Atlantic Sturgeon have been protected from harvest for decades, few rivers have fully recovered, especially in the South Atlantic DPS. Historically, Atlantic Sturgeon could be found in five rivers in Georgia and one in Florida (ASSRT 2007) (Fig. 1.3). The Savannah River, on the South Carolina-Georgia border, hosts a robust sturgeon population, despite numerous anthropogenic disturbances (Bahr and Peterson 2016). In addition to a dam that restricts access to some historic sturgeon spawning habitat, the Savannah River population has also endured extensive channel modification and continuous shipping activity associated with the port of Savannah. Although adult fish must pass through the lower Savannah during the upstream spawning migrations, the major habitat modifications to the lower reaches of the river are of particular concern to RRJ sturgeon that reside in this area until they outmigrate as MMJ. (ASSRT 1998; Collins et al. 2010). Despite the impediments, Atlantic Sturgeon in the Savannah River consistently produce yearly cohorts of >500 age-1 RRJ (Bahr and Peterson 2016). In comparison, the next population to the south in the Ogeechee River is relatively small and exhibits only intermittent recruitment (Farrae et al. 2009). The Altamaha River is one of the longest undammed rivers on the U.S. Atlantic coast, and hosts the largest known population of Atlantic Sturgeon in the southeast (ASSRT 2007). This population exhibits consistent annual recruitment of juvenile cohorts typically >1200 individuals, and that number has steadily increased from approximately 1300 fish in 2007 (Schueller and Peterson 2010) to more than

6000 fish in 2010 (Peterson Lab unpubl. data). The Altamaha River population also has adult spawning runs of well over 300 individuals (Peterson et al. 2008). The Satilla River hosts a small remnant adult population (Fritts et al. 2016), with infrequent recruitment and small juvenile cohorts (Fritts and Peterson 2011). The St. Marys River, which forms the border between coastal Georgia and Florida, historically hosted a population of Atlantic Sturgeon large enough to support a small commercial fishery through the early1990s. (Weber et al. 1995; ASSRT 2007). Few researchers have conducted targeted sampling for Atlantic Sturgeon on the St. Marys and hence, the status of the population there remains unclear. Surveys by Fritts and Peterson (2011) observed no RRJs (and therefore no recruitment) in the St. Marys, and Blair et al. (2009) suggest that sturgeon have likely been extirpated from the river. The St. Johns River, in northern Florida, is the southernmost river historically occupied by Atlantic Sturgeon. Throughout the 20th century, Atlantic Sturgeon were commonly reported as bycatch in commercial fisheries operating there (Cox and Moody 1981). However reports of small juveniles are rare and spawning has never been confirmed (McLane 1955, Gilbert 1992a). Furthermore, the construction of Rodman Dam (now Kirkpatrick Dam) in 1968 blocked access to the Ocklawaha tributary where much of the best potential Atlantic Sturgeon spawning habitat was found (Gilbert 1992a; ASMFC 1998; ASSRT 2007). The current status of Atlantic Sturgeon remains unknown within the St. Johns system, but directed sturgeon surveys by Holder et al. (2005) suggest that population has likely been extirpated.

The National Marine Fisheries Service's most recent Atlantic Sturgeon status review (ASSRT 2007) identified a number of key research needs to aid species recovery, including population abundance estimates, genetic analyses, recruitment monitoring (especially in southern rivers), and identification of spawning and nursery grounds. Although NMFS designated critical habitat for Atlantic Sturgeon in 2016 (Federal Register 2017), a better understanding of riverine and estuarine habitat use will help identify potential environmental and anthropogenic stressors (ASMFC 1998; ASSRT 2007). Little is known about how habitat affects annual recruitment despite the fact that recruitment rate is a key factor in sturgeon recovery (Secor et al. 2002). In addition, seasonal patterns of habitat use by RRJs, and the timing of outmigration by MMJs, are not well understood for Atlantic Sturgeon.

To better define the status of each population of Atlantic Sturgeon, we must first confirm that populations still persist in the specific river systems that comprise the species' historical range. The presence of RRJs within the estuary is a strong indicator of an extant population because it confirms that successful reproduction is occurring (Schueller and Peterson 2010). Likewise, quantified estimates of recruitment across multiple years can also provide a measure of population trends. Because RRJs are the only life stage at which an entire year class can be feasibly quantified, annual recruitment estimates provide managers with the best current metric for assessing population status. Finally, by developing a better understanding of the nursery habitats used by RRJs, and the key environmental factors that affect year class formation, future studies may be better able to identify specific factors that limit recruitment within each population. Ultimately, this information will be critical to a broader understanding of how best to develop and implement population-specific recovery strategies.

References

Altamaha Council. 2011. Altamaha Regional Water Plan. Atlanta, Georgia. <http://www.altamahacouncil.org>.

ASMFC (Atlantic States Marine Fisheries Commission). 2007. Estimation of Atlantic Sturgeon bycatch in coastal Atlantic commercial fisheries of New England and the Mid-Atlantic. Special Report to the Atlantic Sturgeon Management Board. Arlington, VA.

ASSRT (Atlantic Sturgeon Status Review Team). 1998. Status review of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), 126 p. Report prepared for Natl. Mar. Fish. Serv., Silver Springs, MD.

ASSRT 2007. Status review of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), 174 p. Report to Northeast Reg. Off., Natl. Mar. Fish. Serv., Gloucester, MA.

Bahr, D. L., and D. L. Peterson. 2016. Recruitment of juvenile Atlantic Sturgeon in the Savannah River, Georgia. Trans. Am. Fish. Soc. 145:1171–1178.

Bain, M. B. 1997. Atlantic and Shortnose Sturgeons of the Hudson River: common and divergent life history attributes. Environ. Biol. Fish. 48:347–358.

Bemis, W.E., E.K. Findeis, and L. Grande. 1997. An overview of Acipenseriformes. Environ. Biol. Fish. 48: 25-71.

Bemis, W.E., and B. Kynard. 1997. Sturgeon rivers: an introduction to acipenseriform biogeography and life history. Environ. Biol. Fish 48: 347-358.

Benke, A.C., and C.E. Cushing, eds. 2010. Field guide to rivers of North America. Academic Press, Burlington, MA. 459 p.

Birstein, V.J. 1993. Sturgeons and paddlefishes: threatened fishes in need of conservation. Conserv. Biol. 7:773–787.

Boone, S. S., S. J. Divers, A. C. Camus, D. L. Peterson, C. A. Jennings, J. L. Shelton, and S. M. Hernandez. 2013. Pathologic and physiologic effects associated with long-term intracoelomic transmitters in captive Siberian sturgeon. North Am. J. Fish. Manage. 33:869–877.

Cai, W., and Y. Wang. 1998. The chemistry, fluxes, and sources of carbon dioxide in the estuarine waters of the Satilla and Altamaha Rivers, Georgia. Limnol.Oceanogr. 43: 657-668.

Coastal Georgia Council. 2011. Coastal Georgia Regional Water Plan. Atlanta, Georgia. <http://www.coastalgeorgiacouncil.org/>.

Collins, M. R., S. G. Rogers, T. I. J. Smith, and M. L. Moser. 2000. Primary factors affecting sturgeon populations in the southeastern United States: fishing mortality and degradation of essential habitats. Bull. Mar. Sci. 66:917–928.

Collins, M.R., S.G. Rogers, and T.I.J. Smith. 1996. Bycatch of sturgeons along the southern Atlantic coast of the USA. North Am. J. Fish. Manage. 16: 24-29.

Cooke, D.W., S.D. Leach, and J.J. Isely, 2002. Behavior and Lack of Upstream Passage of Shortnose Sturgeon at a Hydroelectric Facility and Navigation Lock Complex. Am. Fish. Soc. Sym. 28: 101-110.

Crossman, J.A., K.L. Hammell, and M.K. Litvak. 2013. Experimental examination of surgical procedures for implanting sonic transmitters in juvenile Shortnose Sturgeon and Atlantic Sturgeon. North Am. J. Fish. Manage. 33: 549-556.

Dadswell, M.J. 1979. Biology and population characteristics of Shortnose Sturgeon, *Acipenser brevirostrum* LaSurur 1818 (Osteichthes: Acipenseridae), in the Saint John Estuary, New Brunswick, Canada. Can. J. Zool. 57: 2186-2210.

Dovel, W.L., and J.T. Berggren. 1983. Atlantic Sturgeon of the Hudson Estuary, New York. New York Fish and Game Journal 30: 140-172.

EPD (Environmental Protection Division). 2002. Satilla River Basin Management Plan. Georgia Department of Natural Resources, Environmental Protection Division. Atlanta, GA.

EPD. 2001. Ogeechee River Basin Management Plan. Georgia Department of Natural Resources, Environmental Protection Division. Atlanta, GA.

Farrae, D.J., P.M. Schueller, D.L. Peterson. 2009. Abundance of juvenile Atlantic Sturgeon in the Ogeechee River, Georgia. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 63:172-176

Federal Register. 2012. Endangered and threatened wildlife and plants; threatened and endangered status for distinct population segments of Atlantic Sturgeon in the northeast region. Fed. Register 82:39160-39274.

Federal Register. 2017. Endangered and Threatened Species; Designation of Critical Habitat for the Endangered New York Bight, Chesapeake Bay, Carolina and South Atlantic Distinct Population Segments of Atlantic Sturgeon and the Threatened Gulf of Maine Distinct Population Segment of Atlantic Sturgeon. Fed. Register 77:5880–5912.

Fritts, M. W., C. Grunwald, I. Wirgin, T. L. King, and D. L. Peterson. 2016. Status and genetic character of Atlantic Sturgeon in the Satilla River, Georgia. Trans. Am. Fish. Soc. 145:69–82.

Fritts, M.W. and Peterson. 2011. Status of imperiled sturgeon species in the Satilla and Saint Marys Rivers, Georgia. Final Report to the Natl. Mar. Fish. Serv., Silver Spring, Maryland.

Gilbert, C.R. 1989. Species profile: Life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic)—Atlantic and Shortnose Sturgeons. U.S. Fish and Wildlife Service biological report 82(11.122), U.S. Army Corps of Engineers TR-EL-82-4. 28p

Grunwald, C.J., L. Maceda, J. Waldman, J. Stabile, and I. Wirgin. 2008. Conservation of Atlantic Sturgeon *Acipenser oxyrinchus oxyrinchus*: delineation of stock structure and distinct population segments. Conserv. Genet. 9:1111-1124.

Hook, J.D. 2010. Sturgeon habitat quantified by side-scan sonar imagery. Masters thesis, Warnell School of Forestry and Natural Resources, University of Georgia. Athens, GA. 70pp.

Huggins, R.M. 1989. On the statistical analysis of capture experiments. Biometrika 76:133-140.

Ingram, E. C., and D. L. Peterson. 2016. Annual spawning migrations of adult Atlantic Sturgeon in the Altamaha River, Georgia. Mar. Coast. Fish. 8:595–606.

Johnson, J.H., D.S. Dropkin , B.E. Warkentine , J.W. Rachlin, and W.D. Andrews. 1997. Food Habits of Atlantic Sturgeon off the Central New Jersey Coast. Trans. Am. Fish. Soc. 126:166-170

Kynard, B. and Horgan, M. 2002. Ontogenetic behavior and migration of Atlantic Sturgeon, *Acipenser oxyrinchus*, and Shortnose Sturgeon, *A. brevirostrum*, with notes on social behavior. Environ. Biol. Fish. 63:137-150.

Miller, M.J. 2005. The ecology and functional morphology of feeding of North American sturgeon and paddlefish. In *Sturgeons and paddlefish of North America*, pp. 87-102. Springer Netherlands.

Moser, M.L., M. Bain, M.R. Collins, N. Haley, B. Kynard, J.C. O'Herron II, G. Rogers, T.S. Squiers. 2000. A Protocol for use of Shortnose and Atlantic Sturgeons. NOAA Technical Memorandum NMFS-OPR-18.

Murawski, S.A. and A.L. Pacheco. 1977. Biological and fisheries data on Atlantic Sturgeon, *Acipenser oxyrinchus* (Mitchill). U.S. Department of Commerce Natl. Mar. Fish. Serv. Northeast Fisheries Center Technical Service Report. 69pp.

Niklitschek, E.J., and D.H. Secor. 2005. Modeling spatial and temporal variation of suitable nursery habitats for Atlantic Sturgeon in the Chesapeake Bay. Estuar. Coast. Shelf Sci. 64:135-148.

Parker, E., and B. Kynard. 2014. Latitudinal variation in ontogenetic behaviour of Shortnose Sturgeon, *Acipenser brevirostrum* Lesueur, 1818: an artificial stream study. J. Appl. Ichthy. 30:1115-1124.

Peterson, D.L., P.Schueller, and R. DeVries. 2008. Annual run size and genetic characteristics of Atlantic Sturgeon in the Altamaha River, Georgia. Trans. Am. Fish. Soc. 137:393-401.

Raabe, J.K., B. Gardner, J.E. Hightower. 2014. A Spatial capture-recapture model to estimate fish survival and location from linear continuous monitoring arrays. Can. J. Fish. Aquat. Sci. 71:120-130.

Ross, R.M., and R.M. Bennett. 1997. Comparative behavior and dietary effects in early life phases of American sturgeons. Fish. Manage. Ecol. 4:17-30.

Schlenger, A.J., E.W. North, Z. Schlag, Y. Li, D.H. Secor, K.A. Smith, E.J. Niklitschek. 2013. Modeling the influence of hypoxia on the potential habitat of Atlantic Sturgeon *Acipenser oxyrinchus*: a comparison of two methods. Mar. Ecol. Prog. Ser. 483:257-272.

Schueller, P. and D. L. Peterson. 2010. Abundance and recruitment of juvenile Atlantic Sturgeon in the Altamaha River, Georgia. Trans. Am. Fish. Soc. 139:1526–1535.

Scott, W.B., and E.J. Crossman. 1973. Freshwater fishes of Canada. Bulletin of the Fisheries Research Board of Canada 184. 966 p.

Secor, D.H. 2002. Atlantic Sturgeon fisheries and stock abundances during the late nineteenth century. Am. Fish. Soc. Symp. 28:89-100.

Secor, D.H., P.J. Anders, W. Van Winkle, and D.A. Dixon. 2002. Can we study sturgeons to extinction? What we do and don't know about the conservation of North American sturgeons. Am. Fish. Soc. Symp. 28:3-10.

Smith, T.I.J. 1985. The fishery, biology and management of Atlantic Sturgeon, *Acipenser oxyrinchus*, in North America. Environ. Biol. Fish. 14:61-72.

Smith, T.I.J., D.E. Marchette, and R.A. Smiley. 1982. Life history, ecology, culture and management of the Atlantic Sturgeon, *Acipenser oxyrinchus oxyrinchus* Mitchill, in South Carolina. South Carolina Wildlife and Marine Resource Commission technical report AFS-9. 75 p.

Smith, T.I.J., E.K. Dingley and D.E. Marchette. 1980. Induced spawning and culture of the Atlantic Sturgeon, *Acipenser oxyrinchus* (Mitchill). Prog. Fish Cult. 42:147-151.

Smith, T. I. J., and J. P. Clugston. 1997. Status and management of Atlantic Sturgeon, *Acipenser oxyrinchus*, in North America. Environ. Biol. Fish. 48:335–346.

Spear, B.K. 2009. U.S. Management of Atlantic Sturgeon. Am. Fish. Soc. Symp. 57:339-346.

Toub, S.H. 1990. Fishery management plan for Atlantic Sturgeon (*Acipenser oxyrinchus*). Fisheries Management Report No. 17 of Atlantic States Marine Fisheries Commission. 73 p.

van den Avyle, M.J. 1984. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (south Atlantic)—Atlantic Sturgeon. U.S. Fish and Wildlife Service biological report 81(11.25), U.S. Army Corps of Engineers TR EL-82-4. 17 p.

van Eenennaam, J.P., S.I. Doroshov, G.P. Moberg, J.G. Watson, D.S. Moore and J. Linares. 1996. Reproductive conditions of the Atlantic Sturgeon (*Acipenser oxyrinchus*) in the Hudson River. Estuaries, 19:769-777.

Vecsei, P. and Peterson, D. 2000. Threatened fishes of the world: *Acipenser oxyrinchus* Mitchill, 1815 (Acipenseridae). Environ. Biol. Fish. 59:98.

Vladykov, V. D., and J. R. Greeley. 1963. Order Acipenseroidei. In Fishes of the western North Atlantic, part 3 (Y. H. Olsen, ed.), p. 24–60. Sears Foundation for Marine Research, Yale University, New Haven, CT.

Waldman, J.R., T. King, T. Savoy, L. Maceda, C. Grunwald, I. Wirgin. 2013. Stock origins of subadult and adult Atlantic Sturgeon, *Acipenser oxyrinchus*, in a non-natal estuary, Long Island Sound. Estuaries Coast. 36:257-267.

Weber, W., C.A. Jennings, and S. Gordon Rogers. 1998. Population size and movement patterns of Shortnose Sturgeon in the Ogeechee River system, Georgia. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 52:18-28.

Weber, W., G. Rogers, J. Music, R. Michaels, S. Shipman, and J. Richardson. 1995. Status and restoration of Atlantic and Shortnose Sturgeons in Georgia. Report to Natl. Mar. Fish. Serv., Southeast Regional Office. 31 p.

Williot, P., G. Arlati, M. Chebanov, T. Gulyas, R. Kasimov, F. Kirschbaum, N. Patriche, L.P. Pavloskaya, L. Poliakova, M. Pourkazemi, Y. Kim, P. Zhuang, I.M. Zholdasova. 2002. Status and management of Eurasian sturgeon: an overview. Int. Rev. Hydrobiol. 87:483-506.

Wirgin, I., J.R. Waldman, J. Rosko, R. Gross, M.R. Collins, S.G. Rogers, and J. Stabile. 2000. Genetic structure of Atlantic Sturgeon populations based on mitochondrial DNA control region sequences. Trans. Am. Fish. Soc. 129:476-486.

Zhang, X., J. Song, C. Fan, H. Guo, X. Wang, and H. Blackmann. 2012. Use of electrosense in the feeding behavior of sturgeons. Integr. Zool. 7: 74-82.

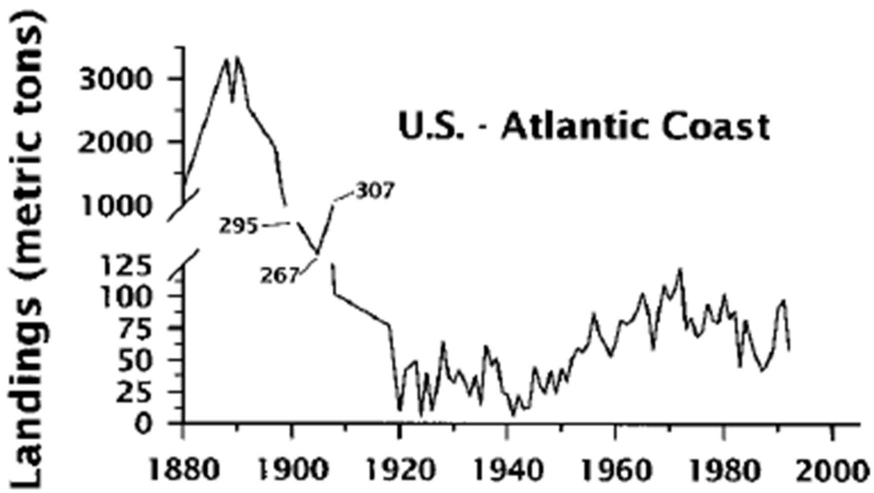

Figure 1.1: Reported landings of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), based on National Marine Fisheries Service data (which may include Shortnose Sturgeon prior to 1972). *Modified from Smith and Clugston (1997).*

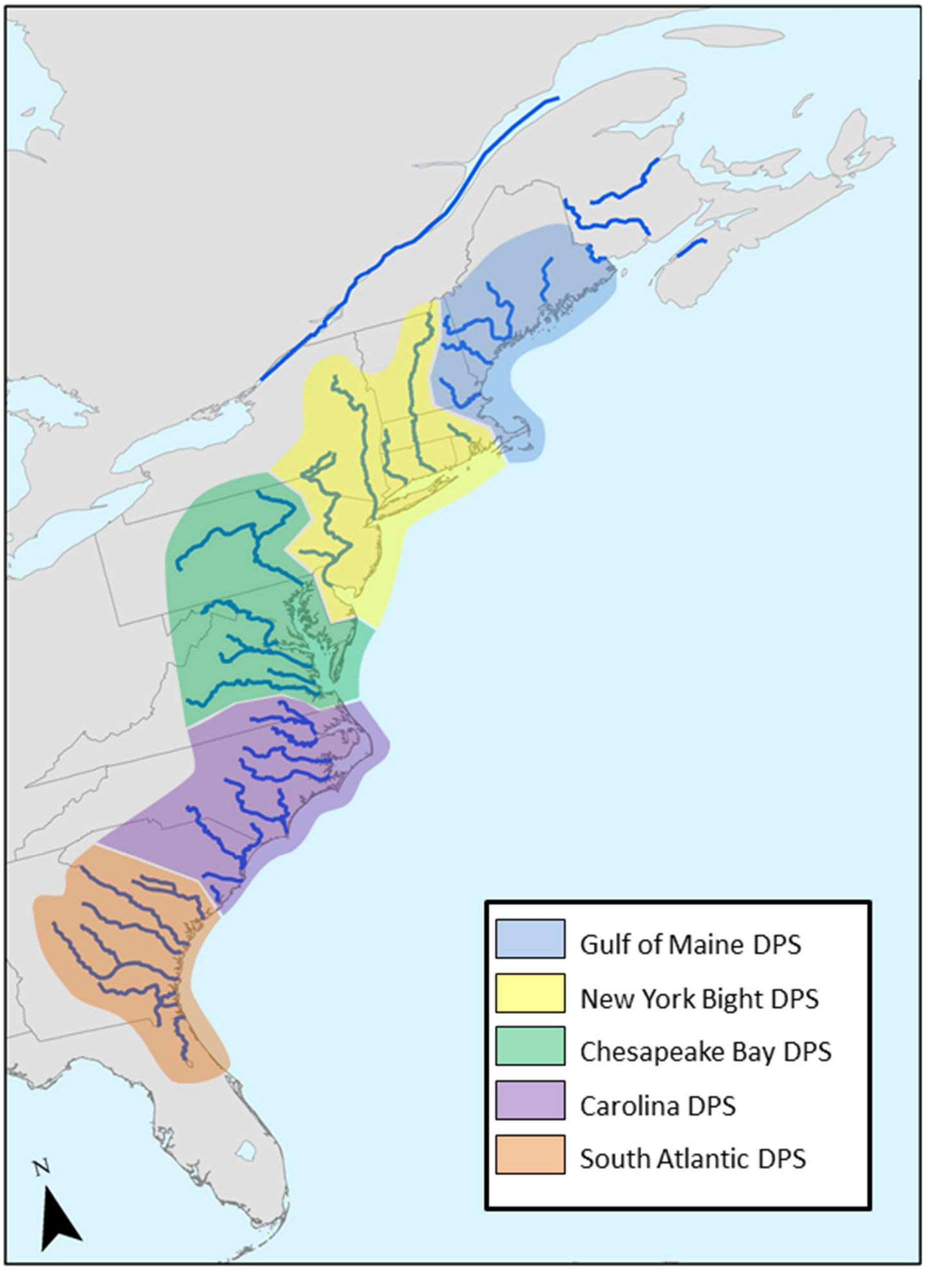

Figure 1.2: The five distinct population segments (DPSs) for Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the United States.

Figure 1.3: The sturgeon rivers of Georgia and Florida, USA.

CHAPTER 2

SEASONAL OCCURRENCE OF ATLANTIC STURGEON (*ACIPENSER OXYRINCHUS OXYRINCHUS*) IN THE ST. JOHNS RIVER, FLORIDA[1]

[1] Fox, A.G., E.S. Stowe, K.J. Dunton, and D.L. Peterson. Accepted by *Fishery Bulletin*. Reprinted here with permission of publisher. May 2018.

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 overharvest 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.

Introduction

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 five 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 1998; 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 1981); 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 1998; 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. 2005). 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.

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 total a combined watershed area of approximately 22,900 km2. 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 2014).

Sampling of sturgeon

All sampling was conducted in the lower St. Johns River estuary below the head of the 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. 2.1) were selected by using navigational charts and preliminary sonar surveys to find areas with depths of at least 2.5 m and 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 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 seven 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).

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 2.1). 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, I. 2017. Personal commun. Sch. Med., New York Univ., 57 Old Forge Rd., Tuxedo NY 10987).

Acoustic telemetry

The single Atlantic Sturgeon captured at rkm 40 in July 2015 was tagged with an acoustic tag, but it was never detected on the acoustic array. The array did, however, detect eight previously tagged Atlantic Sturgeon that had been captured and released by other researchers working outside St. Johns River (Table 2.2, Fig. 2.1). 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. 2.2 and 2.3)—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 2.3, Fig. 2.4). 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 2.3, Fig. 2.5).

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. Sampling efforts included many of the same sampling sites used in previous surveys of sturgeon in the St. Johns River (Holder et al. 2005), 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 observed within the 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 two 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 (Fox and Peterson, unpubl. data). Furthermore, the catch rate for Atlantic Sturgeon (at all life stages) for 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 2.4). Even in St. Marys River, which hosts the smallest known extant population of Atlantic Sturgeon (ASSRT 2007; Fox and Peterson, unpubl. data), catch rates were an order of magnitude greater than those observed in the St. Johns River. In rivers with extant populations of Atlantic Sturgeon, the methods employed in this study generally produce dozens to hundreds of RRJ sturgeon annually (Schueller and Peterson 2010; Bahr and Peterson 2016; Fox and Peterson, unpubl. data). The complete absence of RRJs captured over the two 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. (2005). 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 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. 2009). Recent sampling in that river system, however, has documented the presence of an RRJ cohort in that system, confirming the presence of an extant population (Fox and 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, I. 2017. Personal commun. Sch. Med., New York Univ., 57 Old Forge Rd., Tuxedo NY 10987).

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 the 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 (Fox and 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 this 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.

Acknowledgments

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References

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.

ASSRT (Atlantic Sturgeon Status Review Team). 1998. Status review of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), 126 p. Report prepared for Natl. Mar. Fish. Serv., Silver Springs, MD.

ASSRT 2007. Status review of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), 174 p. Report to Northeast Reg. Off., Natl. Mar. Fish. Serv., Gloucester, MA.

Bahr, D. L., and D. L. Peterson. 2016. Recruitment of juvenile Atlantic Sturgeon in the Savannah River, Georgia. Trans. Am. Fish. Soc. 145:1171–1178.

Bain, M. B. 1997. Atlantic and Shortnose Sturgeons of the Hudson River: common and divergent life history attributes. Environ. Biol. Fish. 48:347–358.

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 Law Practicum.

Boone, S. S., S. J. Divers, A. C. Camus, D. L. Peterson, C. A. Jennings, J. L. Shelton, and S. M. Hernandez. 2013. Pathologic and physiologic effects associated with long-term intracoelomic transmitters in captive Siberian sturgeon. North Am. J. Fish. Manage. 33:869–877.

Collins, M. R., S. G. Rogers, T. I. J. Smith, and M. L. Moser. 2000. Primary factors affecting sturgeon populations in the southeastern United States: fishing mortality and degradation of essential habitats. Bull. Mar. Sci. 66:917–928.

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.

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.

Federal Register. 2012a. Endangered and threatened wildlife and plants; threatened and endangered status for distinct population segments of Atlantic Sturgeon in the northeast region. Fed. Register 77:5880–5912.

Federal Register. 2012b. Endangered and threatened wildlife and plants; final listing determinations for two distinct population segments of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the southeast. Fed. Register 77:5914–5982.

Fritts, M. W., C. Grunwald, I. Wirgin, T. L. King, and D. L. Peterson. 2016. Status and genetic character of Atlantic Sturgeon in the Satilla River, Georgia. Trans. Am. Fish. Soc. 145:69–82.

Gilbert, C. R. 1992a. Atlantic Sturgeon, *Acipenser oxyrinchus*. In Rare and endangered biota of Florida. Vol. 2: fishes (C. R. Gilbert, ed.), p. 31–39. Univ. Press Florida, Gainesville, FL.

Gilbert, C. R. 1992b. Shortnose Sturgeon, *Acipenser brevirostrum*. In Rare and endangered biota of Florida. Vol. 2: fishes (C. R. Gilbert, ed.), p. 15–22. Univ. Press Florida, Gainesville, FL.

Hager, C., J. Kahn, C. Watterson, J. Russo, and K. Hartman. 2014. Evidence of Atlantic Sturgeon spawning in the York River system. Trans. Am. Fish. Soc. 143:1217–1219.

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.

Ingram, E. C., and D. L. Peterson. 2016. Annual spawning migrations of adult Atlantic Sturgeon in the Altamaha River, Georgia. Mar. Coast. Fish. 8:595–606.

McLane, W. M. 1955. Fishes of the St. Johns River system. Ph. D. diss., 361 p. Univ. Florida, Gainesville, FL.

Pfleger, M. O., S. J. Rider., C. E. Johnston, and A. M. Janosik. 2016. Saving the doomed: using eDNA to aid in detection of rare sturgeon for conservation (Acipenseridae). Global Ecol. Conserv. 8:99–107.

Schueller, P. and D. L. Peterson. 2010. Abundance and recruitment of juvenile Atlantic Sturgeon in the Altamaha River, Georgia. Trans. Am. Fish. Soc. 139:1526–1535.

Secor, D. H. 2002. Atlantic Sturgeon fisheries and stock abundances during the late nineteenth century. Am. Fish. Soc. Symp. 28:89–98.

Smith, T. I. J., and J. P. Clugston. 1997. Status and management of Atlantic Sturgeon, *Acipenser oxyrinchus*, in North America. Environ. Biol. Fish. 48:335–346.

Smith, J. A., H. J. Flowers, and J. E. Hightower. 2015. Fall spawning of Atlantic Sturgeon in the Roanoke River, North Carolina. Trans. Am. Fish. Soc. 144:48–54.

Vladykov, V. D., and J. R. Greeley. 1963. Order Acipenseroidei. In Fishes of the western North Atlantic, part 3 (Y. H. Olsen, ed.), p. 24–60. Sears Foundation for Marine Research, Yale University, New Haven, CT.

Whitney, E., D. B. Means, and A. Rudloe. 2004. Priceless Florida: Natural ecosystems and native species, 423 p. Pineapple Press, Inc., Sarasota, FL.

Table 2.1: Sampling effort by net type within the St. Johns River, Florida, USA during the summers of 2014 and 2015.

	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*

Table 2.2: Details for tagged Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) detected by acoustic receivers in the St. Johns River (STJ), Florida, USA from June 2014-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.

Table 2.2.

Life stage when tagged	Total length (mm) when tagged	Tagging location	Tagging year	Tagging organization	Number of days detected in the STJ	DPS of origin
Subadult	1380	Coastal NY/NJ	2011	Stony Brook University	1	South Atlantic
Adult	2290	**Coastal** Mid-Atlantic	2012	Delaware State University[a]	1	South Atlantic
Adult	2040	Altamaha River, GA	2012	University of Georgia	2	South Atlantic[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	South Atlantic
Adult	1093	Santee Bay, SC	2014	SC DNR[c]	1	South Atlantic
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.

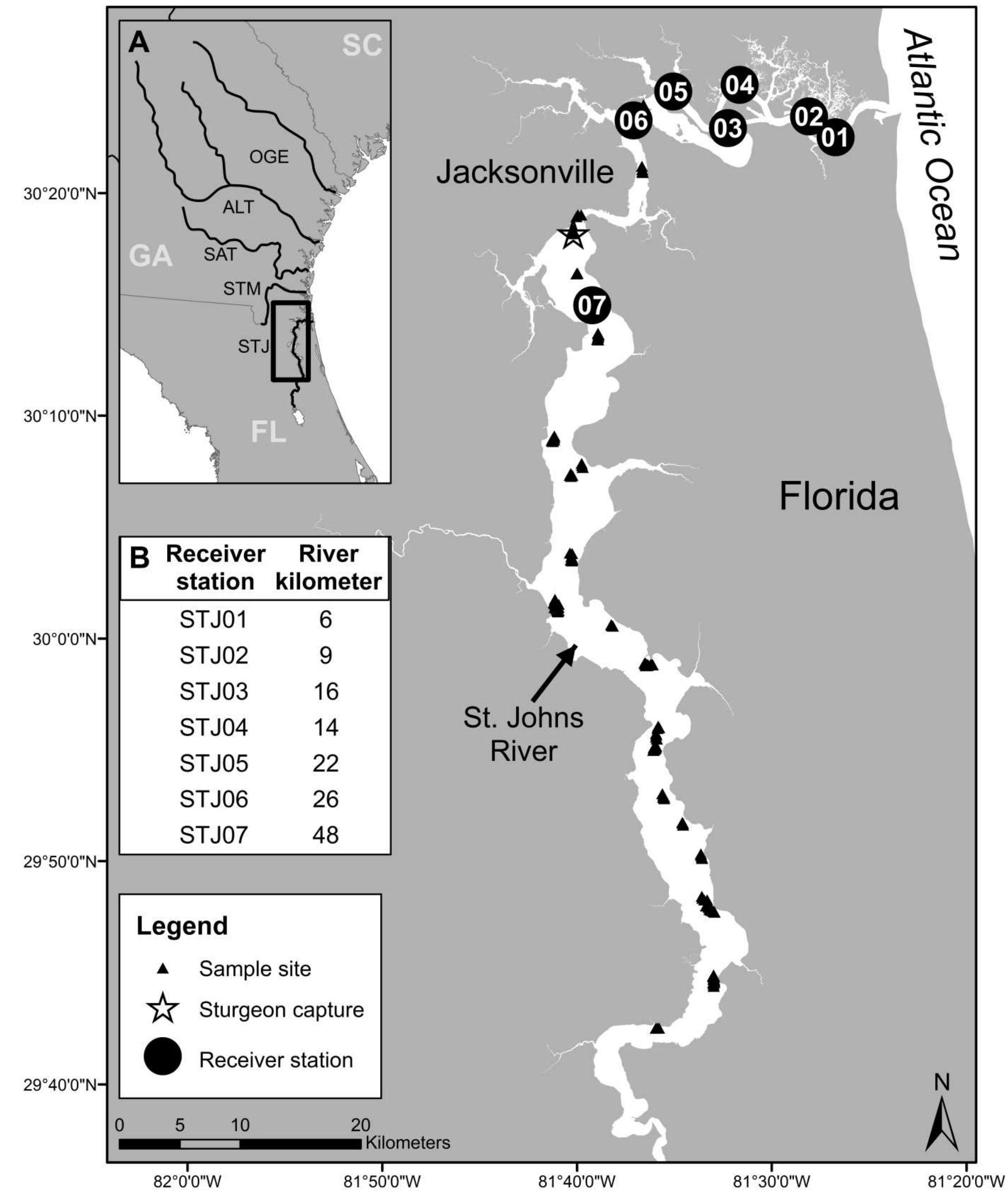
[d] Stock assignment was based on telemetry data from Ingram and Peterson (2016) that indicated that this fish made a putative spawning run in the Altamaha River, Georgia, in 2014.

Table 2.3: Water temperatures and dissolved oxygen levels in the Altamaha and Satilla Rivers in Georgia, USA and the St. Johns River, Florida during June-July 2015.

	Temperature (°C)		**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 2.4: 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	Net hours	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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B
Receiver station
River kilometer
STJ01 6
STJ02 9
STJ03 16
STJ04 14
STJ05 22
STJ06 26
STJ07 48
Legend
Sample site
Sturgeon capture
Receiver station
0 5 10 20 Kilometers
N
30°20'0"N
30°10'0"N
30°0'0"N
29°50'0"N
29°40'0"N
82°0'0"W
81°50'0"W
81°40'0"W
81°30'0"W
81°20'0"W

Figure 2.1.

Figure 2.1: 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), Florida, USA. 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

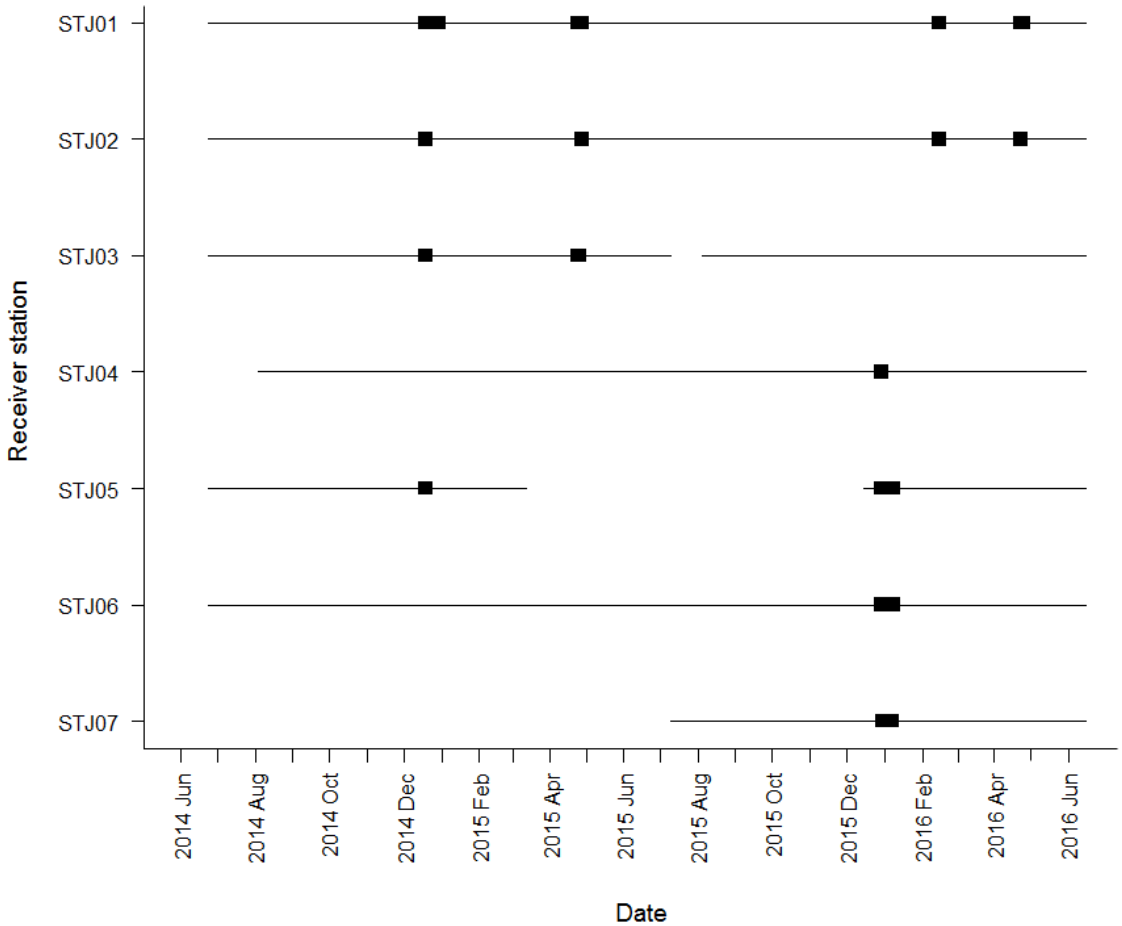

Figure 2.2: Temporal distribution of acoustic receivers (horizontal lines) and days with detection of individual tagged Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) (black rectangles) in the St. Johns River estuary Florida, USA from June 2014-June 2016.

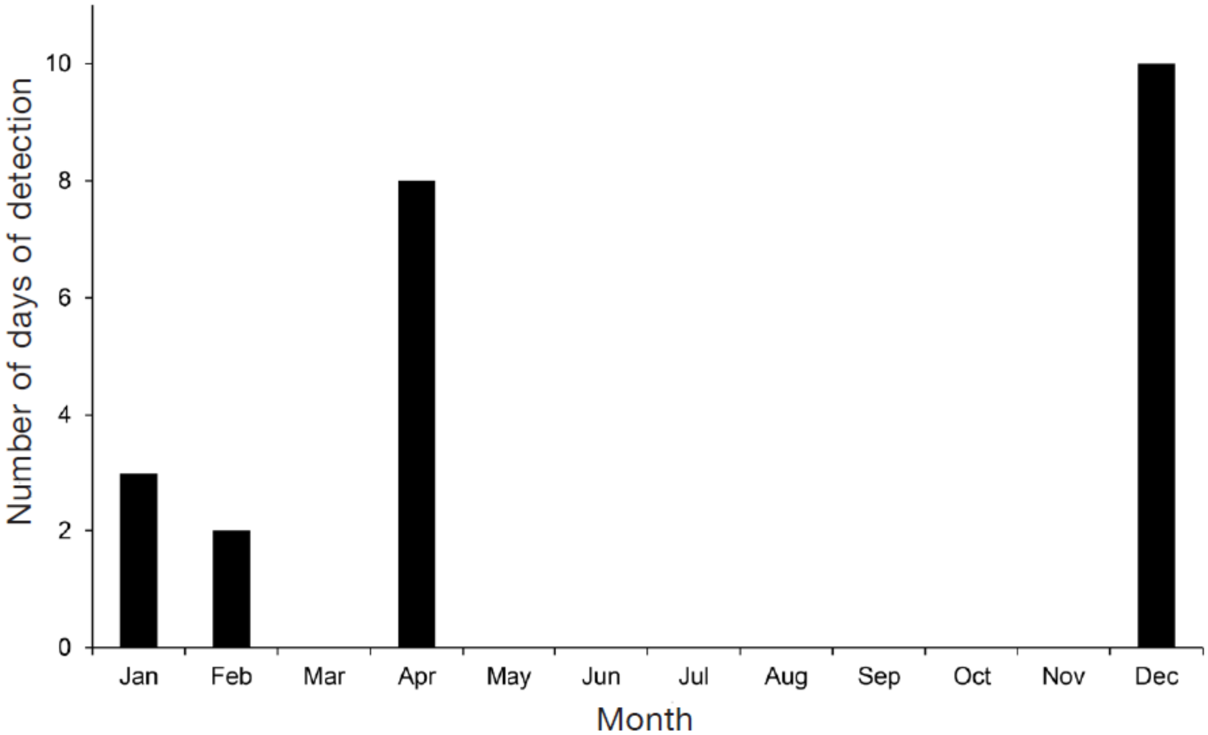

Figure 2.3: Number of days of detection per month of tagged Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) by acoustic receivers in the St. Johns River, Florida, USA during 2014-2016. The number of days of detection (one detection per individual per day) were combined by month across all years of the study.

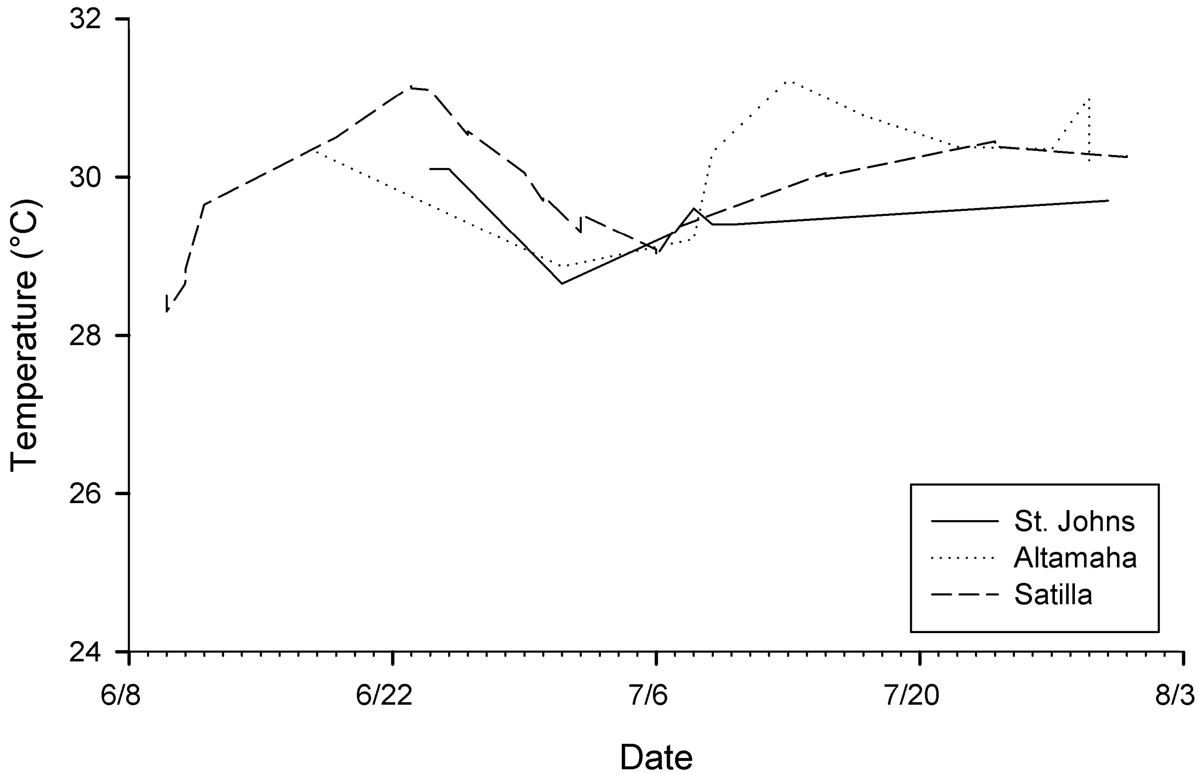

Figure 2.4: Mean daily water temperatures measured at sampling sites in the St. Johns River, Florida, USA and in the Altamaha and Satilla rivers in Georgia during June-July 2015.

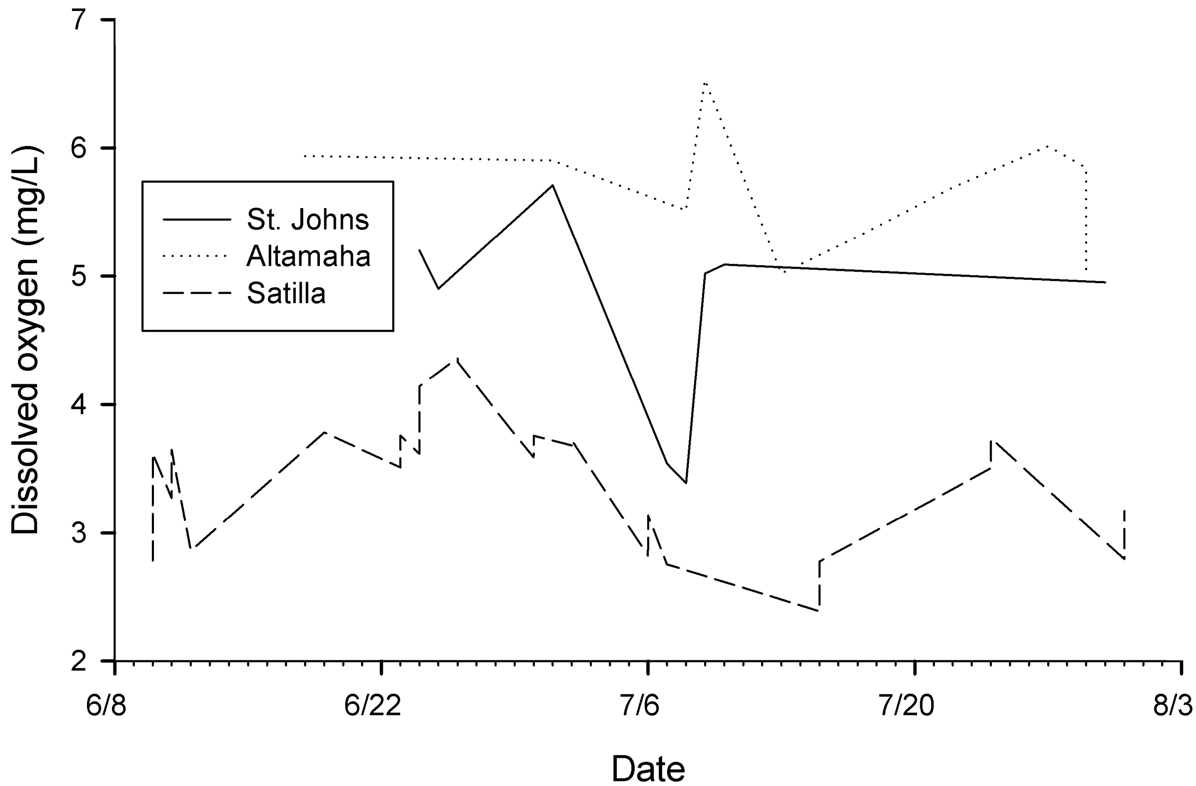

Figure 2.5: Mean daily levels of dissolved oxygen (mg/L) measured at sampling sites in the St. Johns River, Florida, USA and in the Altamaha and Satilla rivers in Georgia during June-July 2015.

CHAPTER 3

SEASONAL OCCURRENCE OF ATLANTIC STURGEON (*ACIPENSER OXYRINCHUS OXYRINCHUS*) IN THE ST. MARYS RIVER, GEORGIA[2]

[2] Fox, A.G., I.I. Wirgin, and D.L. Peterson. Submitted to *Marine and Coastal Fisheries,* April 2018.

Abstract

The Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) is an anadromous species that historically occurred along the Atlantic coast of North America from maritime Canada to the St. Johns River, Florida. Decades of overharvest and habitat loss 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 was identified as an important consideration in the final determination to list the species as endangered. In the St. Marys River, Georgia, USA, the 2nd-southernmost river within their historical range, Atlantic Sturgeon were thought to have been extirpated for several decades. The objectives of this study were to document the seasonal occurrence of Atlantic Sturgeon in the St. Marys River, and to document any evidence of an extant population in the river. During the summers of 2014-2016, we set >500 nets and captured a total of 25 Atlantic Sturgeon, including eight river-resident juveniles. These fish represent a distinct population of Atlantic Sturgeon in the St. Marys River. Using acoustic telemetry, we monitored the movements and habitat use of 14 individuals in the St. Marys estuary. Acoustically tagged juveniles resided mainly within the St. Marys River mainstem, but the receiver array did detect a number of adult migrants using Cumberland Sound on a seasonal basis. These results indicate that Atlantic Sturgeon persist in the St. Marys River, and that the estuary also provides seasonally important habitat for migrating adults from other populations.

Introduction

The Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) is an anadromous fish that historically occurred in the rivers and estuaries along the Atlantic coast of North America, from the Saint Lawrence River, Canada, south to the St. Johns River, Florida, United States (US). Throughout their range, Atlantic Sturgeon populations collapsed during the early 20th century because of commercial overharvest, industrial development, pollution, and the construction of dams on many of its Atlantic coast spawning rivers. (Bemis and Kynard 1997; Smith and Clugston 1997; ASSRT 1998; Secor 2002; ASSRT 2007).

As a result of the major declines in Atlantic Sturgeon populations, federal management agencies in the U.S. implemented several protections during the late 20th century. The commercial Atlantic Sturgeon fishery was closed in all state waters in 1998, and the species was listed under the U.S. Endangered Species Act in 2012. This listing designated five distinct population segments (DPS) in U.S. waters: Gulf of Maine, New York Bight, Chesapeake Bay, Carolina, and South Atlantic. All DPS populations were listed as endangered except for the Gulf of Maine DPS, which was listed as threatened (ASSRT 2007; Federal Register 2012a, 2012b).

Within the South Atlantic DPS, many Atlantic Sturgeon populations have shown little sign of recovery, and several may be extirpated (ASSRT 1998; ASSRT 2007). Despite federal protections from harvest, recovery of many populations has been impeded by degraded habitats in spawning rivers, loss of spawning habitat due to dams, and incidental bycatch in commercial fisheries targeting other coastal or estuarine species (ASSRT 1998; Collins et al. 2000; ASSRT 2007). Although modern environmental regulations have helped reduce the pollution affecting many of these river systems, non-point sources continue to degrade water quality, particularly in estuarine habitats that are critically important to juvenile sturgeon (ASSRT 2007).

As an anadromous species, Atlantic Sturgeon adults typically reside in marine environments but migrate into their natal freshwater rivers to spawn (Vladykov and Greeley 1963). Recent studies have shown that the timing of spawning varies by latitude, with northern populations spawning in the spring (Bain 1997) and at least some central and southern populations spawning only or primarily in the fall (Hager et al. 2014; Flowers and Hightower 2015; Ingram and Peterson 2016). Young, river-resident juveniles (RRJ; total length [TL] <550 mm) typically reside in estuarine habitats near the freshwater-saltwater interface for their first 2-4 years before transitioning to nearshore marine habitats as marine migratory juveniles (MMJ; TL 550-1200 mm) (Bain 1997). Hence, the presence of RRJ within a particular river system is widely recognized as strong evidence of an extant population, especially in rivers where adult spawners may be rare (Schueller and Peterson 2010; Fox et al., 2018).

The St. Marys River, in southeastern Georgia (Figure 1), is the second-southernmost river in the Atlantic Sturgeon's range, and historically hosted a spawning population (ASSRT 2007). During the 1980s and 1990s, the river supported a small commercial fishery for Atlantic Sturgeon (Weber et al. 1995). The population has not been well-studied, and the most recent surveys suggest that the population may have been extirpated. Targeted sampling conducted by Fritts and Peterson (2011) documented the presence of MMJ, but not RRJ. Genetic analyses of tissue samples obtained from the MMJ captured in that study suggested that the fish originated from within the SA DPS but, because a genetic baseline was never established for the St. Marys River, the authors were unable to determine if the fish were native to the system or merely migrants from some other nearby population.

Establishing the extirpation of any fish population is difficult, but doing so for Atlantic Sturgeon populations is especially problematic because of their cryptic nature, complex migratory life history, and protracted spawning periodicity. Given the uncertain status of Atlantic Sturgeon populations within the St. Marys River, the objectives of this study were to: 1) conduct an extensive survey to determine the presence or absence of RRJ Atlantic Sturgeon within the St. Marys estuary; and 2) quantify seasonal habitat use by resident and/or non-resident individuals. Because loss of individual populations is an important criterion for listing under the ESA, the results of this study will help clarify the current status of the St. Marys River population.

Methods

Study site

The St. Marys River forms much of the southeastern boundary between coastal Georgia and northeastern Florida (Fig. 3.1). Its watershed encompasses approximately 3,366 km^2, and lies entirely within the coastal plain of Georgia. As a typical blackwater river in the southeastern United States, the St. Marys River is characterized by a tea-colored appearance and a relatively low, but highly variable, discharge (Dame et al. 2000; Blair et al. 2009). There are no major impoundments on the St. Marys River system, and a total of 274 river kilometers (RKM) of free-flowing habitats are accessible to sturgeons and other anadromous fishes. Point sources of pollution in the St. Marys River include several wastewater treatment facilities and a now-defunct paper mill. The river also collects nutrient-laden runoff from silvicultural sites and urban areas (EPD).

Sturgeon sampling

All sampling was conducted below the head of tide in the St. Marys River estuary from May-July, 2013-2016. Sturgeon were captured with anchored gill and trammel nets that have been proven effective for catching juvenile sturgeon in Georgia (Schueller and Peterson 2010; Bahr and Peterson 2016; Fox et al. 2018). Nets were deployed within the channel between RKM 0-60 (Fig. 3.1), and were soaked for approximately 30 to 90-min periods around the slack tides. As nets were retrieved, entangled sturgeon were quickly removed and placed in a floating net pen tethered to the research vessel. Once all nets had been recovered, each captured sturgeon was measured to the nearest mm TL and inspected for tags. If no tag was present, a passive integrated transponder (PIT) tag was injected under the 4^{th} dorsal scute and a small tissue sample was taken from the dorsal fin for subsequent genetic analysis. The first eight juvenile sturgeon captured each year were fitted with acoustic transmitters, which were surgically implanted into the body cavity. Surgical methods used for this procedure were similar to those described by Boone et al. (2013). Captured fish were removed from the floating net pen and placed into lateral recumbency on a v-shaped surgical board; a small pump maintained a gentle stream of fresh river water flowing 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 69kHz Vemco acoustic transmitter (Vemco, Nova Scotia, Canada). In 2013, we deployed V16-4x transmitters, and in 2014-15, we deployed V7-4x transmitters. The incision was closed using a 2/0 absorbable monocryl suture (Monoswift™ L943) in a single interrupted pattern. Once the incision was closed, the fish was returned to the river at its original capture site.

Acoustic telemetry

A passive array of 14 stationary acoustic receivers (Vemco VR-2W) was distributed throughout the lower St. Marys River system, including connecting waters of the Intracoastal Waterway (ICW) and Cumberland Sound (Fig. 3.1). Within the array, receivers 1-4 collectively formed an "acoustic gate" at the south entrance to Cumberland Sound, through which the fish had to pass as they moved between the Sound and the Atlantic Ocean. Receivers 7-8 formed a similar gate at the north end of Cumberland Sound. Receiver 5 was used to detect the presence of tagged individuals within the interior portion of Cumberland Sound. Receiver 6 formed the third and final gate between Cumberland Sound and the mainstem St. Marys River, while receivers 9-14 monitored the movements of tagged fish in the river reach upstream of the Sound. The submerged receivers were mounted in an upright position, typically 2-3 m below the surface, and were attached to floating navigational buoys, channel markers, and other stationary structures using stainless steel cable or aluminum u-channel. Range testing at receivers revealed a tag detection radius of approximately 400 m. Receivers were monitored over 25 consecutive months (~139 weeks), from 23 May 2014-7 December 2016. Data were downloaded from receivers at approximately 3-month intervals throughout the duration of the study, except when environmental conditions precluded safe access to the receivers.

Results

Sturgeon sampling

From 12 April 2013 - 7 July 2016, we deployed a total of 533 nets for a total of 557 hours of soak time yielding a total of 25 Atlantic Sturgeon, all either RRJ or MMJ (Table 3.1). Over the three years of the study a total of 14 Atlantic Sturgeon were successfully tagged with acoustic transmitters (Table 3.2). All tagged fish were released in excellent condition, and 85.7% (n=12) were detected at least twice by the receiver array. Based on TL at capture, eight of the 14 tagged Atlantic Sturgeon were likely natal RRJ. Four of the individuals captured in 2015 were classified as age-2, based on length frequency analysis after Schueller and Peterson (2010). This suggests that they were likely part of the same cohort as the RRJ tagged in the 2014.

Acoustic telemetry

During the entirety of this study, the stationary acoustic array recorded a total of 46,548 detections of transmittered Atlantic Sturgeon (Fig. 3.2). Of these, 45,062 detections were from fish tagged as part of this study (Table 3.2); the remaining 1,486 detections were from 20 individual Atlantic Sturgeon tagged by researchers working in other Atlantic coast river systems (Fig. 3.3). Eight of these individuals were tagged in other Georgia rivers, three in South Carolina, six in North Carolina, one in Virginia, and two in Delaware.

Although the array was serviced by field crews at regular intervals throughout the entire study, several receivers either failed or were lost during the intervening periods causing gaps in receiver coverage during various periods throughout the study. Over the course of the entire study, mean weekly coverage at each receiver station was 74% (range of 40-100%). In total, the array was active for 1413 receiver-weeks, including a total of 754 receiver-weeks during the six warmest months of the year (May-October), and 659 receiver-weeks during the six coolest months of the year (November-April).

Acoustically tagged Atlantic Sturgeon were detected at all receiver stations within the St. Marys River estuary, including those in the river mainstem and Cumberland Sound. Of the 14 fish tagged in this study, most remained entirely within the river mainstem; only three were ever detected below the river gate-receiver (receiver 6). One individual that was tagged in 2013 (before the array was fully in place) left the study area and was later detected by the author's receiver array in the nearby Altamaha River. The other two individuals were last detected by gate-receivers at the South entrance to Cumberland Sound in the cool season. All migrant Atlantic Sturgeon (n=20) detected during this study were detected by at least one of the Cumberland Sound gates during the time that they used the St. Marys River estuary. Ninety-five percent of individuals (n=19) were first detected by gate receivers at either the north or south entrances to Cumberland Sound; however, one individual apparently went undetected by the gate receivers and was first detected by an interior receiver. Interestingly, all three age-2 MMJ (originally tagged by the author in other Georgia rivers) were first detected at the Cumberland North gate, while 16 of the 17 adult or subadult migrants were first detected by the Cumberland South Gate. The Cumberland Sound gate receivers also recorded the final detection for 85% of migrant individuals (n=17).

Spatial and temporal analyses of telemetry data showed that juvenile Atlantic Sturgeon tagged during this study exhibited a pattern of seasonal habitat use within the lower St. Marys River (Fig. 3.4). During the warm season, juveniles were detected exclusively within the St. Marys River, and migrant individuals were mainly detected in Cumberland Sound (Fig. 3.5a). In the summers of all three study years, both RRJ and MMJ tended to congregate in the upstream reaches of the study area from RKM 25-35. During the cool season, juveniles were detected mainly within the St. Marys River, but both RRJ and MMJ became increasingly dispersed throughout downstream habitats near the river mouth and Cumberland Sound. Migrant individuals detected in the winter exclusively used Cumberland Sound (Fig. 3.5b). Two of 14

(14.3%) fish tagged in this study eventually left the St. Marys River and were subsequently detected by acoustic receivers in the Altamaha and Ogeechee Rivers (Fox and Peterson 2018).

Discussion

Population status

The RRJ captured during the 2014 field season represent the first documented evidence of successful Atlantic Sturgeon reproduction within the St. Marys River. Despite much uncertainty regarding the status of this population, the results of 2014 sampling provide strong evidence that the St. Marys population has not been extirpated, as was previously suggested (ASSRT 2007; Fritts and Peterson 2011). Genetic analyses of tissue samples obtained from juveniles captured in this study suggest that the RRJ captured in 2014 and several of the MMJ captured in 2015 were closely related. This aligns with the results of the length-frequency analysis; these individuals were likely all from the same cohort spawned in 2013. Despite the lack of a genetic baseline for the St. Marys population, comparisons of the genetic samples from juveniles captured in this study with those from other populations along the Atlantic Coast indicate that the juveniles captured in this study likely represent a remnant St. Marys River population of Atlantic Sturgeon that is distinct, but closely related to other populations within the South Atlantic DPS (Fox and Peterson 2017). Future studies are needed to increase the number of juvenile genetics samples across several years, which will help better define demographic parameters as well as genetic structure of the St. Marys River population.

Habitat use

Receiver coverage throughout the St. Marys River mainstem was consistent throughout most of the study (Fig. 3.2) with the notable exception of receiver 9, located at RKM 14.1. Although this receiver was lost in August 2015, it was not a gate receiver, so its absence had no effect on the array's ability to detect tagged fish entering or leaving the St. Marys mainstem. The receiver array in Cumberland Sound, however, did experience several receiver failures that created operational gaps in the array, particularly within the northern and interior portions of Cumberland Sound. Despite these operational gaps the gate-receivers performed well throughout the study. Of the 14 acoustically tagged sturgeon that were tracked during this study only one (7.1%) of these evaded detection by the gate-receiver located between the mainstem and Cumberland Sound. Likewise, the gate-receivers at the north and south entrances of Cumberland Sound detected 19 of the 20 (95%) migrant Atlantic Sturgeon as they entered the St. Marys System; the only other individual was detected by both interior and gate-receivers as it moved through the system. Although it is possible that a small number of acoustically tagged migrants could have gone completely undetected during the operational gaps in the receiver array, the consistent detection of migrants documented at multiple interior and gate receivers suggests that this was not likely. Likewise, gaps in receiver coverage did not appear to bias seasonal comparisons of habitat use by natal and migratory Atlantic Sturgeon. Although there were more non-operational receivers during the cool season (659 receiver-weeks during the cool season vs. 754 receiver-weeks in the warm season), migrant Atlantic Sturgeon were only detected during the cool season.

Seasonal movements and habitat use of juvenile Atlantic Sturgeon documented in this study (Fig. 3.4) were quite similar to those documented in other South Atlantic rivers (Fox and Peterson 2018). The acoustically tagged RRJ and MMJ were detected almost exclusively within the St. Marys River mainstem - mostly upstream of the St. Marys municipal waterfront. During the summer months, both juvenile life stages clustered farther upriver, probably to escape the combined effects of high temperatures and salinities typical in the lower river during this period (Niklitschek and Secor 2005). In cooler months, however, most of these juveniles moved downstream, becoming much more widely dispersed throughout the lower river and upper estuary, although only a few were ever detected in Cumberland Sound. As has been documented in other southeastern populations, RRJ in this study did not begin leaving the St. Marys River system until the winter after they had been tagged, at which point they had likely transitioned to the MMJ stage (Fox and Peterson 2018). Those individuals tagged as RRJ or MMJ that did not leave the St. Marys River during the winter typically returned to the same riverine reach that they had occupied during the previous summer, specifically the 15 RKM reach located directly upstream of the I-95 bridge.

Throughout the course of the study, a total of 20 migrant Atlantic Sturgeon were detected within the lower St. Marys River and Cumberland Sound (Fig. 3.2). The number and seasonal pattern of these detections suggest that the St. Marys River estuary may be an important seasonal habitat for the species as a whole, particularly for non-spawning, migratory life stages. Most migrant individuals (n=17) were detected only in Cumberland Sound (Figs. 3.5a and 3.5b) and only a few (n=3) ever entered the lower reaches of the St. Marys River mainstem. Interestingly, no migrant Atlantic Sturgeon were detected during the warmest months of the year. Most migrants were never detected in the river reaches used by RRJ, denoting a distinct difference in habitat use by migratory and river-resident life stages. Similar patterns in seasonal habitat use have been documented in several other southeastern river systems, including the Altamaha, Ogeechee, and St. Johns Rivers (Fox and Peterson 2018; Fox et al. *in press*).

The results of this study show that the St. Marys River remains an important riverine and estuarine habitat for both natal and migrant Atlantic Sturgeon. More importantly, however, these findings demonstrate that remnant Atlantic Sturgeon populations can survive, undetected, for several years or even decades after a major population decline. The persistence of the St. Marys population has important ramifications for populations in other river systems where the species is currently thought to be extirpated. Despite three years of directed sampling conducted in this study and three previous years of sampling by Fritts and Peterson (2011), RRJ were only detected in one year. Consequently, we emphasize the need for long-term studies with directed sampling for RRJ to definitively determine the status of Atlantic Sturgeon, particularly for rivers where historical populations are thought to be extirpated.

Acknowledgements

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References

ASSRT (Atlantic Sturgeon Status Review Team). 1998. Status review of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), 126 p. Report prepared for Natl. Mar. Fish. Serv., Silver Springs, MD.

ASSRT 2007. Status review of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), 174 p. Report to Northeast Reg. Off., Natl. Mar. Fish. Serv., Gloucester, MA.

Bain, M. B. 1997. Atlantic and Shortnose Sturgeons of the Hudson River: common and divergent life history attributes. Environ. Biol. Fish. 48:347–358.

Blair, S., M. Ezell, H. Hall, and J. November. 2009. St. Marys River Watershed. Prepared for The St. Marys River Management Committee.

Boone, S. S., S. J. Divers, A. C. Camus, D. L. Peterson, C. A. Jennings, J. L. Shelton, and S. M. Hernandez. 2013. Pathologic and physiologic effects associated with long-term intracoelomic transmitters in captive Siberian sturgeon. North Am. J. Fish. Manage. 33:869–877.

Collins, M. R., S. G. Rogers, T. I. J. Smith, and M. L. Moser. 2000. Primary factors affecting sturgeon populations in the southeastern United States: fishing mortality and degradation of essential habitats. Bull. Mar. Sci. 66:917–928.

Dame, R., M. Alber, D. Allen, M. Mallin, C. Montague, A. Lewitus, A. Chalmers, R. Gardner, C. Gilman, B. Kjerfve, J. Pinckney, and N. Smith. 2000. Estuaries of the South Atlantic Coast of North America: Their Geographical Signatures. Estuaries 23:793-819.

Federal Register. 2012a. Endangered and threatened wildlife and plants; threatened and endangered status for distinct population segments of Atlantic Sturgeon in the northeast region. Fed. Register 77:5880–5912.

Federal Register. 2012b. Endangered and threatened wildlife and plants; final listing determinations for two distinct population segments of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the southeast. Fed. Register 77:5914–5982.

Flowers, H. J., and J. E. Hightower. 2015. Fall Spawning of Atlantic Sturgeon in the Roanoke River, North Carolina. Trans. Am. Fish. Soc. 144:48-54.

Fox, A. G., and D. L. Peterson. 2017. Occurrence and Movements of Atlantic and Shortnose Sturgeon in Cumberland Sound and the St. Marys River, Georgia. Final report to the United States Army Corps of Engineers and the United States Navy.

Fox. A. G., and D. L. Peterson. 2018. Quantifying annual recruitment and nursery habitats of Atlantic Sturgeon in Georgia, July-December 2017. Report to the Natl. Mar. Fish. Serv..

Fox, A. G., E. S. Stowe, K. J. Dunton, and D. L. Peterson. 2018. Seasonal Occurrence of Atlantic Sturgeon in the St. Johns River, Florida. Fish. Bull.116: 219-227.

Fritts, M. W, and D. L. Peterson. 2011. Status of imperiled sturgeon species in the Satilla and Saint Marys Rivers, Georgia. Final Report to the Natl. Mar. Fish. Serv., Silver Spring, Maryland.

EPD (Environmental Protection Division). 2002. Satilla River Basin Management Plan. Georgia Department of Natural Resources, Environmental Protection Division. Atlanta, GA.

Hager, C., J. Kahn, C. Watterson, J. Russo, and K. Hartman. 2014. Evidence of Atlantic Sturgeon Spawning in the York River System. Trans. Am. Fish. Soc. 143:1217–1219.

Ingram, E. C., and D. L. Peterson. 2016. Annual spawning migrations of adult Atlantic Sturgeon in the Altamaha River, Georgia. Mar. Coast. Fish. 8:595–606.

Niklitschek, E. J., and D. H. Secor. 2005. Modeling spatial and temporal variation of suitable nursery habitats for Atlantic Sturgeon in the Chesapeake Bay. Estuar. Coast. Shelf Sci. 64:123-148.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Bulletin of the Fisheries Research Board of Canada 184.

Secor, D. H. 2002. Atlantic Sturgeon fisheries and stock abundances during the late nineteenth century. Am. Fish. Soc. Symp 28:89-100.

Smith, T. I. J., and J. P. Clugston. 1997. Status and management of Atlantic Sturgeon*, Acipenser oxyrinchus*, in North America. Environ. Biol. Fish. 48:335–346.

Vladykov, V. D., and J. R. Greeley. 1963. Order Acipenseroidei. In Fishes of the western North Atlantic, part 3 (Y. H. Olsen, ed.), p. 24–60. Sears Foundation for Marine Research, Yale University, New Haven, CT.

Weber, W., G. Rogers, J. Music, R. Michaels, S. Shipman, and J. Richardson. 1995. Status and restoration of Atlantic and Shortnose Sturgeons in Georgia. Report to Natl. Mar. Fish. Serv., Southeast Regional Office.

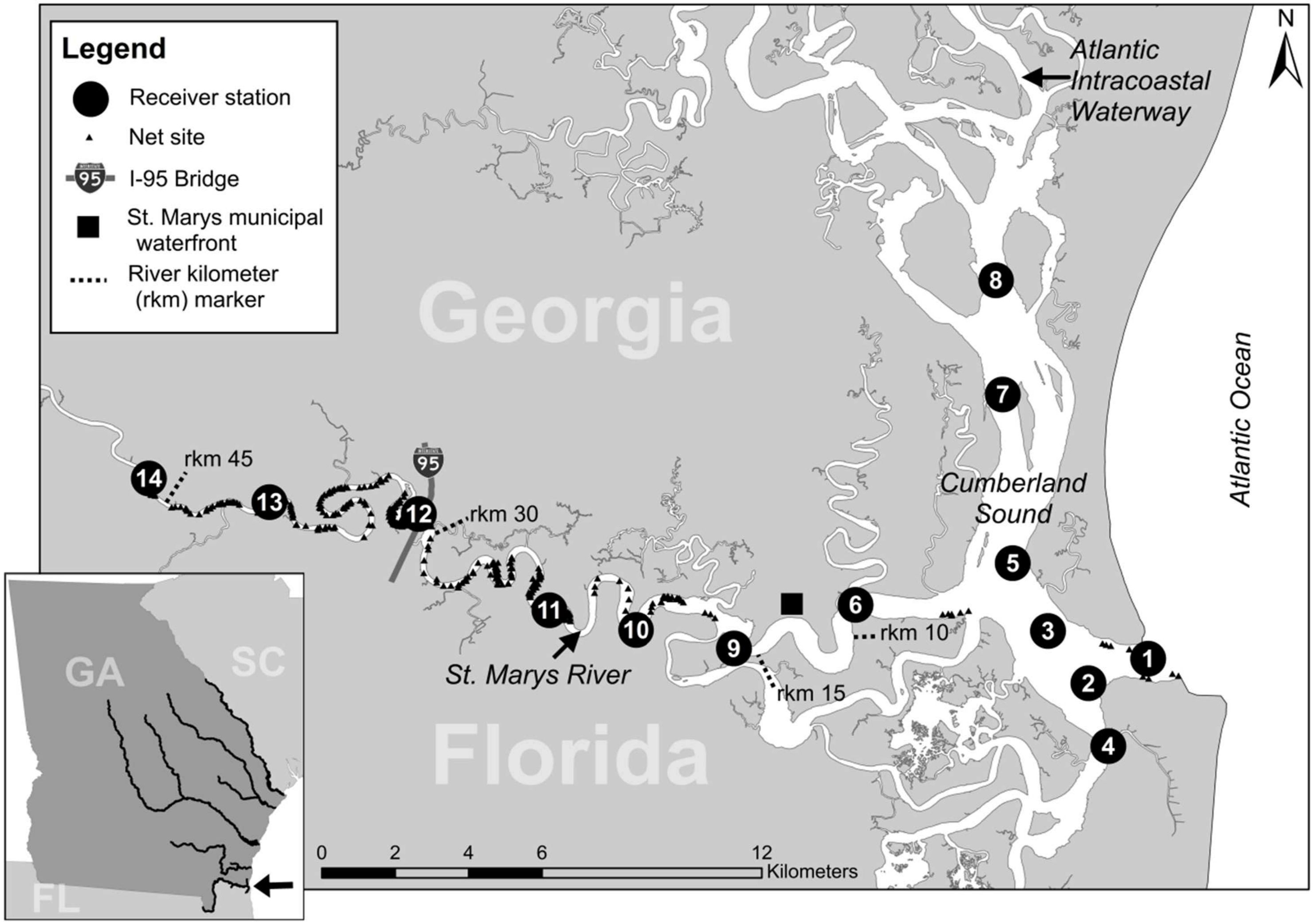
Table 3.1: Annual sampling effort and catch of Atlantic Sturgeon in the lower St. Marys River, Georgia, USA during the summers of 2013-2016. Total catch, total number of unique individuals, and number of unique age-1 and age-2 river-resident juveniles (RRJs) is also reported for each year.

	Effort		Catch			
Year	**Sets**	**Soak (h)**	**Total catch**	**Individuals captured**	**Age-1 RRJ**	**Age-2 RRJ**
2013	178	192	1	1	0	0
2014	85	102	10	9	8	0
2015	122	105	9	6	0	5
2016	148	159	5	4	0	0
Total	*533*	*558*	*25*	*20*	*9*	*8*

Table 3.2: Acoustic telemetry data for Atlantic Sturgeon tagged in the St. Marys River, Georgia, USA, 2013-2016. Fish tagged in this study were either river-resident juveniles (RRJs) or marine migratory juveniles (MMJs). Life stage and age classification was based on length (Schueller and Peterson 2010). St. Marys River detections of each fish are separated by year (X = detected, 0 = not detected). ATS-01 was never detected in the St. Marys River, but was subsequently detected by a receiver array in the Altamaha River, Georgia (unpubl. data, Fox). ATS-04 was never detected. NA=not available

Table 3.2.

Life stage	Fish ID	TL (mm)	Age	Tagging year	Year(s) Detected 2014	2015	2016
RRJ	ATS-02	336	1	2014	X	X	0
	ATS-03	376	1	2014	X	X	0
	ATS-04	325	1	2014	0	0	0
	ATS-05	393	1	2014	X	X	0
	ATS-07	374	1	2014	X	X	0
	ATS-08	374	1	2014	X	X	0
	ATS-09	405	1	2014	X	X	0
	ATS-10	684	2	2015	NA	X	X
	ATS-11	655	2	2015	NA	X	X
	ATS-13	576	2	2015	NA	X	X
	ATS-14	651	2	2015	NA	X	X
MMJ	ATS-01	1093	NA	2013	0	0	0
	ATS-06	932	NA	2014	X	X	0
	ATS-12	735	NA	2015	NA	X	X


Legend
Receiver station
Net site
I-95 Bridge
St. Marys municipal waterfront
River kilometer (rkm) marker
Georgia
Florida
Atlantic Intracoastal Waterway
Atlantic Ocean
Cumberland Sound
St. Marys River
rkm 45
rkm 30
rkm 15
rkm 10
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0 2 4 6 12 Kilometers
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Figure 3.1.

Figure 3.1: Study site in the St. Marys River, Georgia, USA. Black circles indicate the locations of acoustic receiver stations (numbered). Black triangles represent the locations of net sets, 2013-2016. The black square indicates the location of the City of St. Marys municipal waterfront.

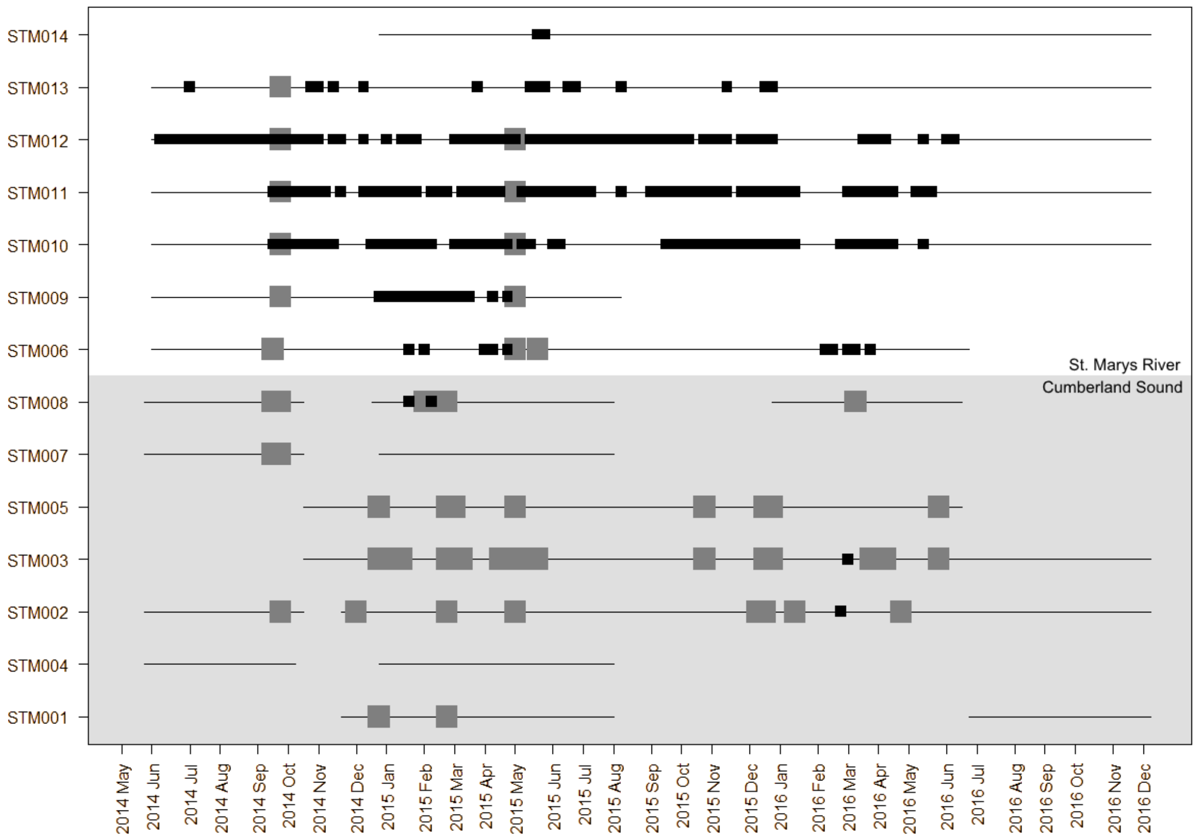


Figure 3.2: Weekly receiver coverage (—) and Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) detections in the St. Marys River estuary, Georgia, USA from June 2014-December 2016. Natal sturgeon (■) were tagged in the St. Marys during this study; migrant sturgeon (■) were originally tagged in other river systems. Receivers (on the y-axis) are arranged by river kilometer from the river mouth. The shaded background indicates detections/coverage within Cumberland Sound, and white background indicates St. Marys River mainstem.

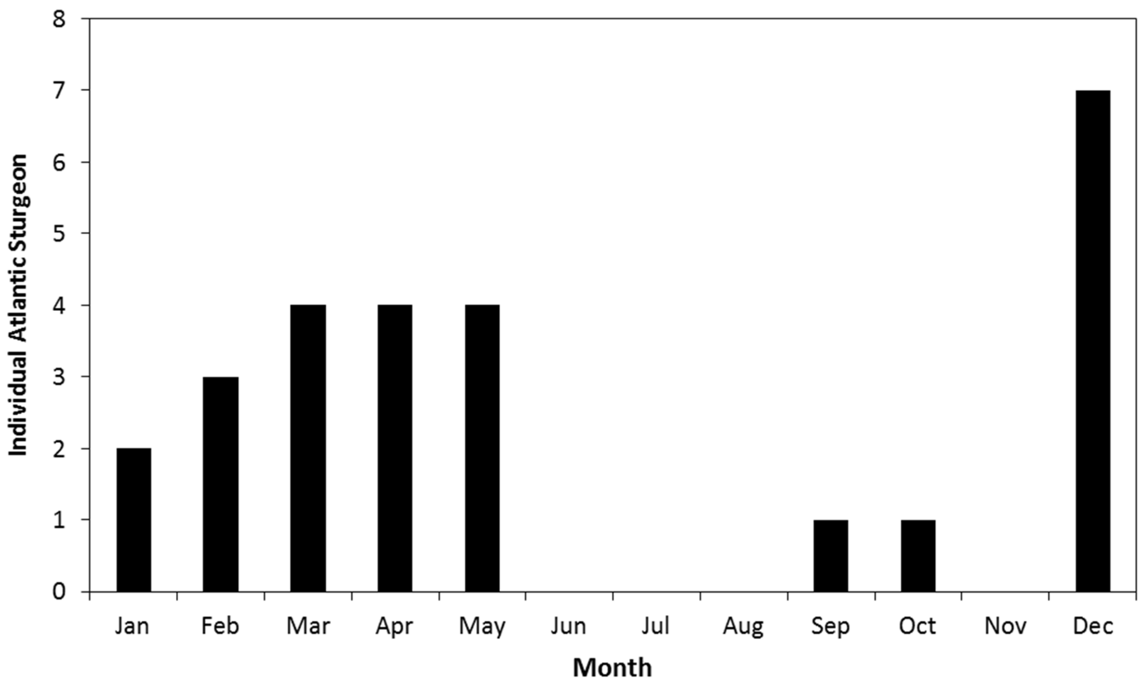


Figure 3.3: Seasonal detections of non-natal Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the St. Marys River and estuary, Georgia, USA from May 2014-December 2016. Black bars represent the total number of unique individuals detected by the acoustic array for each month of the study across all years of the study. Although the receiver array actually had more coverage during warm months (May-October), nearly all migrant sturgeon detections occurred during cool month.

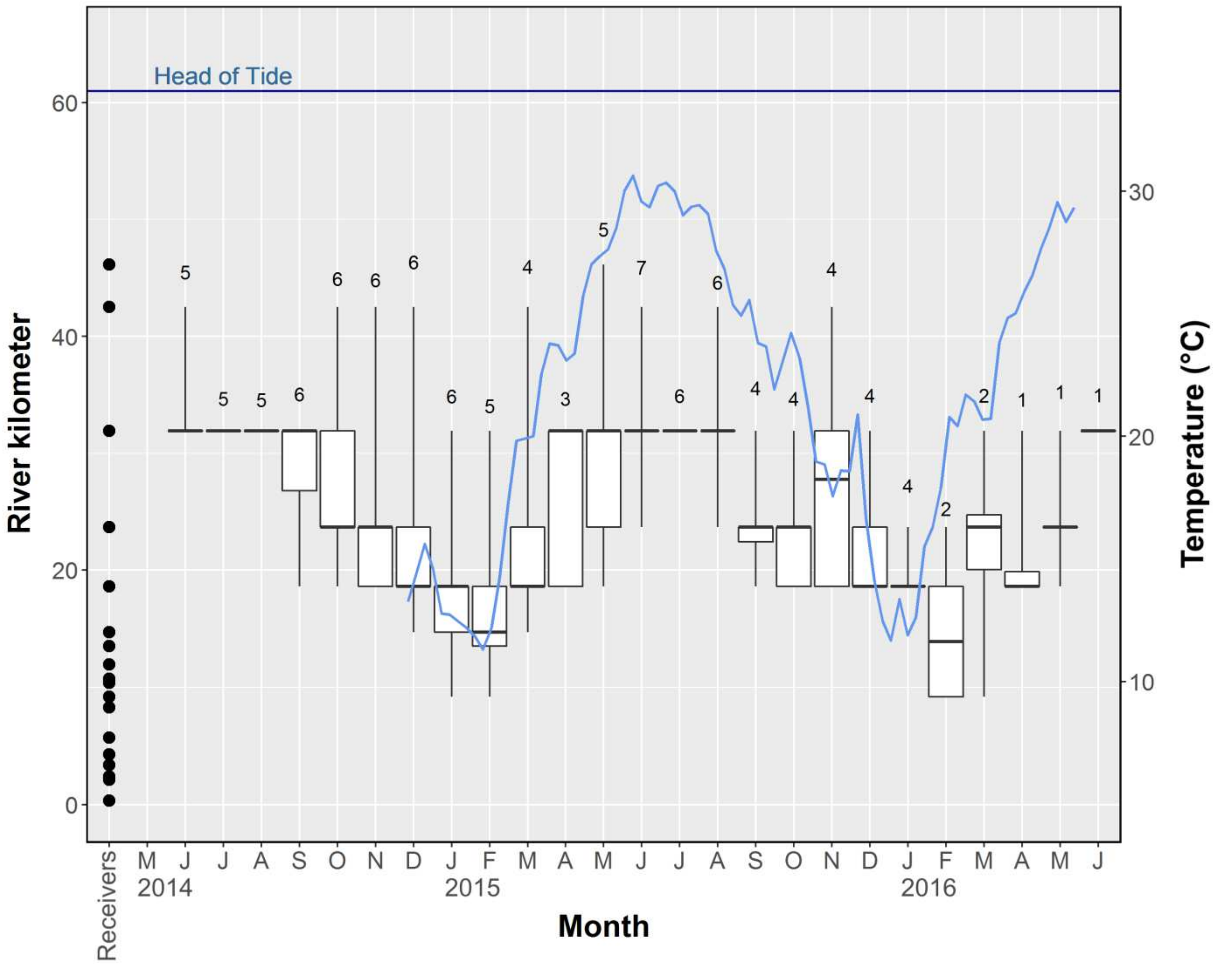
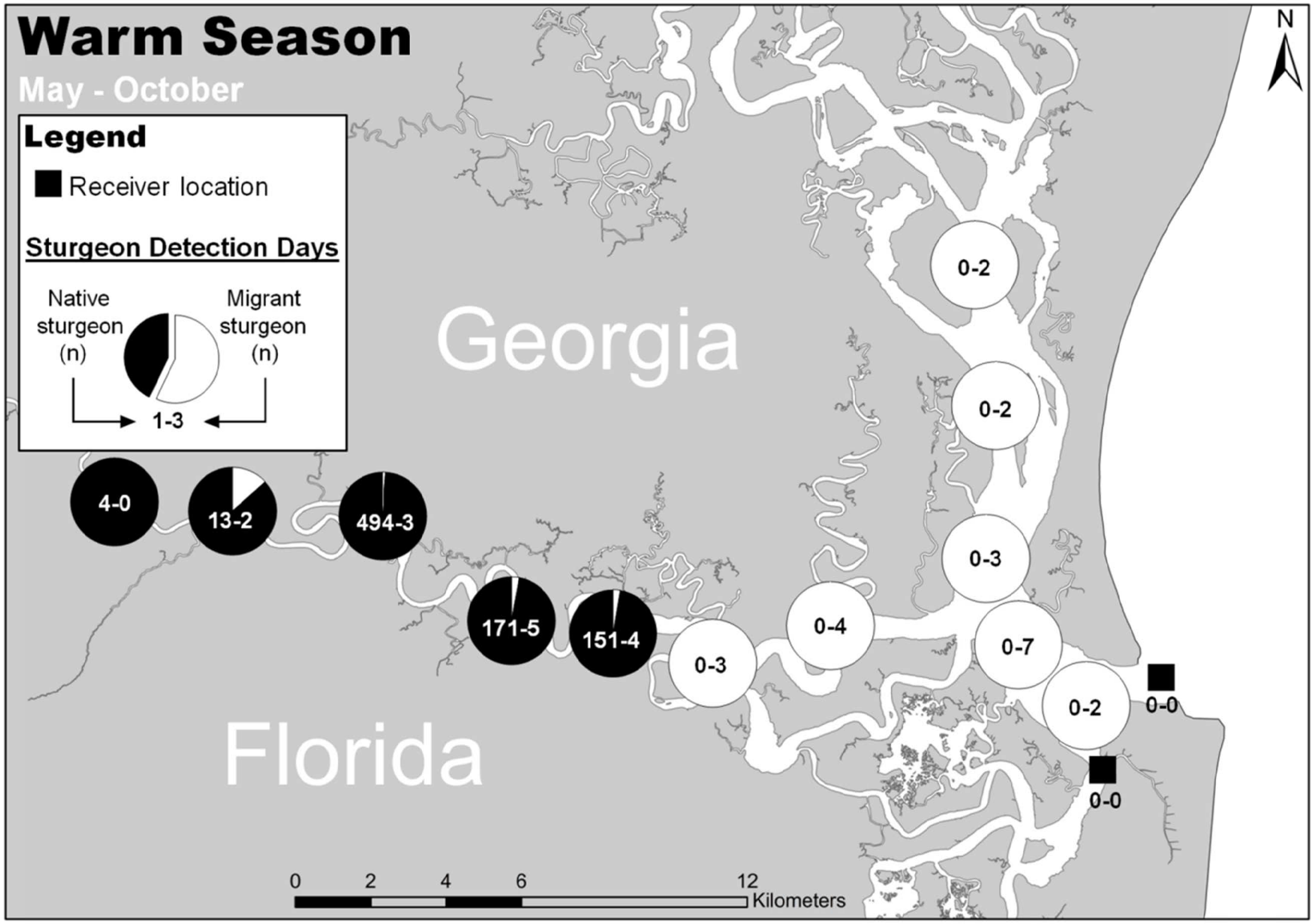


Figure 3.4: Habitat use by river-resident juvenile Atlantic Sturgeon (age-1 and -2) tagged in the St. Marys River, Georgia, USA. Boxplot ends represent 25th and 75th percentiles of all tag detections. Thick line within box is median river kilometer (rkm) position of all fish. Error bars [whiskers] represent minimum and maximum rkm detections. The number over each box indicates the number of individuals detected that month. Dots along the main Y-axis represent the rkm positions of receivers in the acoustic array. The blue line indicates water temperature along the secondary y-axis. Data are from 4 May 2014-17 June 2016.



Warm Season
May - October
Legend
Receiver location
Sturgeon Detection Days
Native sturgeon (n)
Migrant sturgeon (n)
1-3
Georgia
Florida
4-0
13-2
494-3
171-5
151-4
0-3
0-4
0-2
0-2
0-3
0-7
0-2
0-0
0-0
N
0
2
4
6
12
Kilometers

Figure 3.5a.

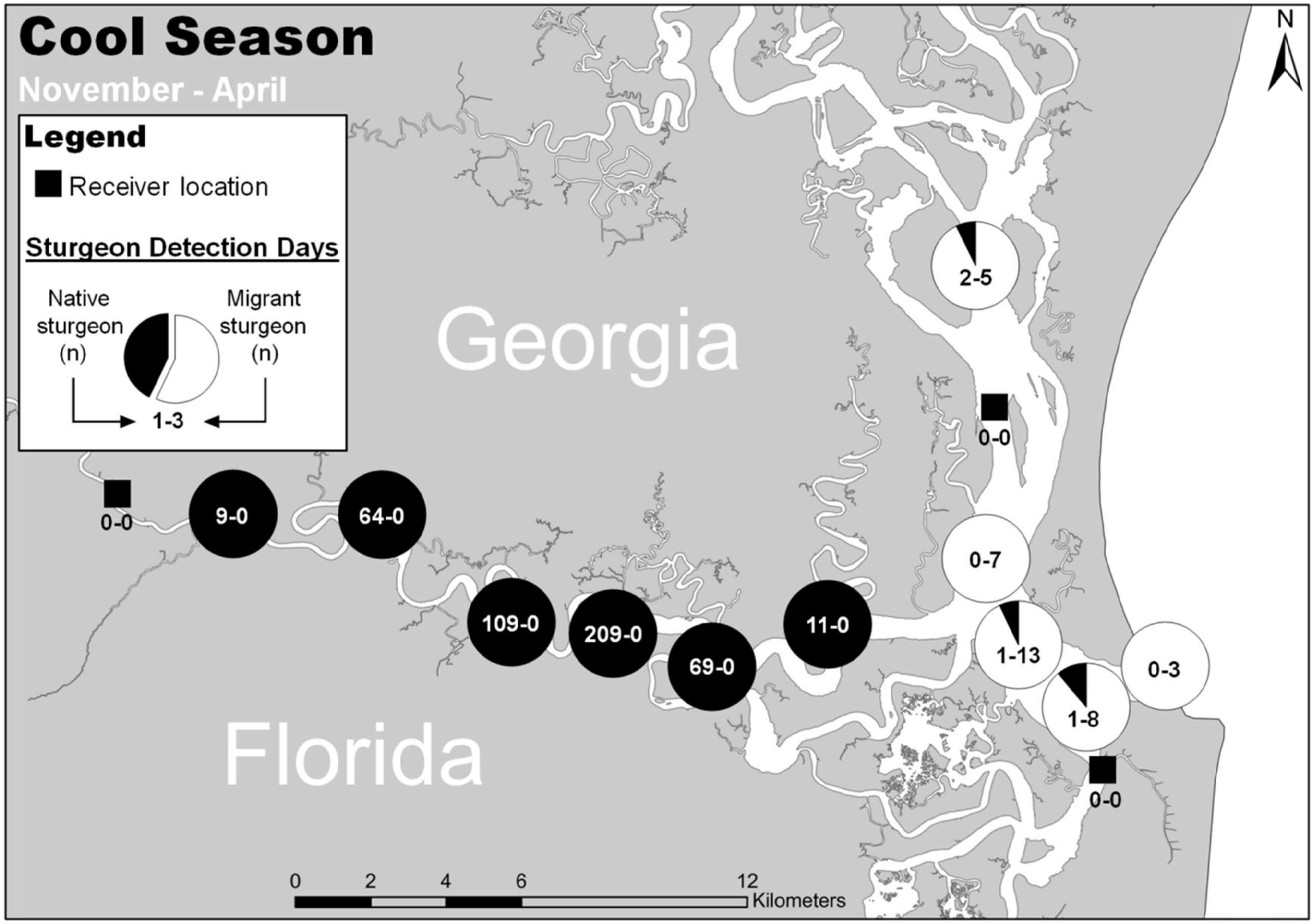

Cool Season
November - April
Legend
Receiver location
Sturgeon Detection Days
Native sturgeon (n)
Migrant sturgeon (n)
1-3
Georgia
Florida
0-0
9-0
64-0
109-0
209-0
69-0
11-0
2-5
0-0
0-7
1-13
1-8
0-3
0-0
0
2
4
6
12
Kilometers
N

Figure 3.5b.

Figure 3.5: Seasonal trends in occupancy of Atlantic Sturgeon in the St. Marys River estuary, Georgia, USA 2014-2016. Figure 3.5a shows occupancy during the warm season (May-October), and figure 3.5b shows occupancy during the cool season (November-April). Each receiver is represented by a pie chart illustrating the proportions of native and migrant Atlantic Sturgeon detection days (one detection per fish per receiver per day, totaled across the three study years) at that site. Native sturgeon (●) were within the St. Marys River during this study; migrant sturgeon (○) were originally captured and tagged in other river systems or coastal areas. Receivers with no sturgeon detections are represented by a black square. Numerals within each pie chart indicate the total number of native and migrant detection days for that particular receiver location.

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CHAPTER 4

HABITAT USE AND OUTMIGRATION BY JUVENILE ATLANTIC STURGEON (*ACIPENSER OXYRINCHUS OXYRINCHUS*) IN GEORGIA[3]

[3] Fox, A.G., and D.L. Peterson. To be submitted to *Marine and Coastal Fisheries*.

Abstract

The Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) is a federally endangered anadromous fish found along the east coast of North America. Despite two decades of Federal Protection, many populations have not recovered and many biologists now believe that poor recruitment may be responsible. Unfortunately, the lifecycle and habitat use of river-resident juveniles (RRJs) is not well understood. The objectives of this study were to quantify seasonal habitat use by RRJ Atlantic Sturgeon, examine patterns in RRJ outmigration, and describe annual variation in RRJ seasonal habitat use and outmigration in three populations along the Georgia Coast. During the summers of 2014-2016 we collected age-1 RRJ Atlantic Sturgeon in the Ogeechee, Altamaha, and Satilla Rivers. A total of 92 fish were implanted with acoustic transmitters, 72 of which were included in analysis. Movements of fish were monitored using an array of stationary receivers deployed below the heads of tide in each river system. During the summer months the fish congregated in freshwater reaches relatively close to the head of tide, but during the winter months they moved downriver and became more broadly distributed. 30.4% of fish were detected outside their natal river, a confirmation that they had outmigrated. 36.7% of tagged fish remained in their natal river the summer after tagging as age-2 RRJs, and the fate of the remaining 32.9% of fish was not known. All fish that outmigrated did so between December and March, and these individuals were detected in estuaries as far as 300 km from their natal river. The results of this study support several of the assumptions that underpin recent studies used that quantify Atlantic Sturgeon recruitment, currently the only quantified measure of species recovery.

Introduction

The Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) is a large anadromous fish that historically occurred along the east coast of North America from maritime Canada to northern Florida. As an anadromous species, adults live in marine waters but periodically return to their natal rivers to spawn. Recent studies have documented important clinal variations in spawning times among northern and southern populations. At the northern end of the range (e.g., the Hudson River in NY), spawning occurs in the spring (Bain 1997). In mid-Atlantic rivers, some populations may spawn in both fall and spring (Balazik and Musick 2014), but others exhibit fall spawning only (Hagar et al. 2014; Smith et al. 2015). In southern rivers (i.e. the Altamaha River in GA), spawning only occurs in the fall (Ingram and Peterson 2016). Preferred spawning habitat is typically found in areas with strong currents and rocky substrate (Gilbert 1989). After hatching, larval sturgeon migrate downstream toward the estuary where they eventually settle as (Kynard and Horgan 2002, Bain 1997) river-resident juveniles (RRJs). During this life stage the young fish remain in their natal estuary, typically below the head of tide. They grow quickly, and by age-2 to -4 some individuals transition to the marine migratory juvenile (MMJ) life stage and leave their natal river for nearshore coastal marine habitats, however; the factors that affect the age of this transition have not been well studied. As the MMJs grow and mature in the marine environment, they may occasionally return to natal or non-natal estuarine or riverine habitats for prolonged periods during the summer months (Dovel and Berggren 1983; Bain 1997).

During the early 20th century Atlantic Sturgeon populations collapsed from a combination of anthropogenic factors including commercial overharvest, pollution, and the damming of many Atlantic coast spawning rivers (Bemis and Kynard 1997; Smith and Clugston 1997; ASSRT

1998; Secor 2002; ASSRT 2007). As a result, the commercial fishery was closed in United States waters in 1998, and the species was eventually listed as endangered in 2012. Under the listing, US populations were divided into five distinct population segments (DPS): Gulf of Maine, New York Bight, Chesapeake Bay, Carolina, and South Atlantic. All DPSs were listed as endangered except for the Gulf of Maine DPS, which was listed as threatened (ASSRT 2007; Federal Register 2012a, 2012b). Despite federal protections, spawning populations are currently supported in fewer than 20 rivers, compared to 35-38 historically (ASSRT 2007). Recovery of many populations has been impeded by degraded spawning habitats and incidental bycatch in commercial fisheries (ASSRT 2007; Collins et al. 2000; ASSRT 1998). Within the South Atlantic DPS, many populations have shown little sign of recovery, and several may be extirpated (ASSRT 1998; ASSRT 2007; Fox et al. 2018; Fox and Peterson - Chapter 3).

To aid species recovery, the National Marine Fisheries Service (NMFS) recently identified a number of key research needs including quantified status assessments for each population (ASSRT 2007). Unfortunately, the complex migratory life history of Atlantic Sturgeon precludes comprehensive population estimates, and because the adults only spawn intermittently, spawning run estimates are similarly lacking. Consequently, several previous researchers have argued that annual assessment of RRJs should be a focus of range wide population assessments, because that life stage represents the only period in the species' life cycle when an entire cohort can be effectively sampled within a well-defined location (Bain et al. 1999; Peterson et al. 2000; Schueller and Peterson 2010). By estimating abundance of age-1 cohorts, several previous studies have quantified annual recruitment for several populations including the Hudson River in NY (Peterson et al. 2000), the Delaware River (Hale et al. 2016), and the Altamaha (Schueller and Peterson 2010), Savannah (Bahr and Peterson 2016), and

Satilla Rivers in GA (Fritts et al. 2016). These studies all used similar methods to conduct mark-recapture estimates of age-1 RRJ within estuarine nursery habitats during the summer months. A key assumption of these studies was that the age-1 cohort was closed during the assessment period; however, this assumption has not been well tested. Regardless, these recruitment estimates represent one of the few quantitative measures of Atlantic Sturgeon recovery since the species was listed in 2012.

A second key research need identified by NMFS is the identification of Atlantic Sturgeon nursery habitats within each spawning river (ASSRT 2007). In 2016, NMFS designated critical habitat for the species to include all mainstem reaches from the river mouth to either the fall line or the lowermost barrier within each of these river systems (Federal Register 2017). Understanding which specific reaches are used by RRJs, however, is essential for future assessments of annual recruitment and for ongoing efforts to protect or restore juvenile habitats in populations where recruitment appears to be an important limiting factor. A better understanding of how RRJs use riverine and estuarine habitats can also help identify potential environmental stressors and anthropogenic threats to species recovery (ASMFC 1998; ASSRT 2007). This study addresses two of the key research needs identified by NMFS. The objectives of this study were to 1) quantify seasonal habitat use by RRJ Atlantic Sturgeon, 2) examine patterns in RRJ outmigration, and 3) describe annual variation in RRJ seasonal habitat use and outmigration in three separate populations along the Georgia Coast.

Methods

Study Sites

This study was conducted in three adjacent rivers along the Georgia coast: the Ogeechee, the Altamaha, and the Satilla River (Fig. 4.1). The Altamaha River hosts the largest known population of Atlantic Sturgeon in the southeast (ASSRT 2007). The population exhibits consistent annual recruitment with juvenile cohorts typically consisting of at least several hundred to several thousand individuals (Schueller and Peterson 2010). In contrast, the Ogeechee River, located 60 km to the north, is home to a relatively small population that exhibits only intermittent recruitment (Farrae et al. 2009). The Satilla River, approximately 40 km south of the Altamaha, hosts a small remnant population with infrequent recruitment and low RRJ abundances (Fritts et al. 2016).

The Ogeechee River (Fig. 4.2) features one the longest unimpounded river reaches in the eastern United States (Benke and Cushing 2010). From its origin near the edge of north Georgia's Piedmont province, the Ogeechee flows approximately 390 km in a southeasterly direction through the coastal plain before draining into Ossabaw Sound and the Atlantic Ocean immediately to the south of Skidaway Island, GA. The watershed consists of approximately 14,300 km^2, and is relatively undeveloped: above the head of tide, 39% of the basin is forested and only 1% features urban development (Coastal Georgia Council 2011, EPD 2001). The only major tributary, the Canoochee River, converges with the Ogeechee approximately 55 km from the Atlantic Ocean. Because of its tannic, nutrient-poor water, the Ogeechee is classified as a blackwater river, although its pH is closer to neutral (mean 6.5) than other comparable blackwater systems (Meyer et al. 1997). The only dam on the Ogeechee system is located near the headwaters, just below the fall line. Consequently, Atlantic sturgeon and other migratory fishes have access to approximately 97% of historic spawning habitat in this river (ASSRT 2007). Hook (2010) located a number of potential spawning grounds in the Ogeechee between 84 and 219 km from the ocean, based on depth and bottom composition. During the summer months, low flows and hypoxic conditions can degrade estuarine habitats used by juvenile Atlantic Sturgeon (ASSRT 2007, Farrae et al. 2013). The head of tide in the Ogeechee River is typically located at or near river kilometer (rkm) 61 (Sheldon and Alber 2005).

The Altamaha River (Fig. 4.3) is one of the longest undammed rivers in eastern North America. The Altamaha system comprises the Oconee and Ocmulgee Rivers, which form the mainstem Altamaha at their confluence. Both major tributaries originate in the Piedmont province of north Georgia, and are undammed below the fall line. From the point of the confluence, the mainstem Altamaha River flows 205 km in a southeasterly direction through the coastal plain, draining into Altamaha Sound and the Atlantic Ocean near Darien, GA. The watershed drains over 36,000km^2, and is relatively undeveloped. Above the head of tide, 41% of the watershed is covered by forest, and only 6% is subject to urban development, although there are several major industrial sites located along the river (Altamaha Council 2011). There is minimal development around the lower river and estuary. As a “brownwater” Piedmont river, the Altamaha has a more neutral pH than the blackwater Ogeechee and Satilla Rivers (Cai and Wang 1998). The head of tide in the Altamaha River is at rkm 54 (Sheldon and Alber 2005). The Altamaha features the largest and least-altered migratory route for spawning Atlantic Sturgeon within the southern portion of their range, with over 750 km of free-flowing river habitats (including both major tributaries). This likely encompasses 100% of the historical habitat used by Atlantic Sturgeon in this river system, including many isolated rocky shoals suitable for spawning (ASSRT 2007).

The Satilla River (Fig. 4.4) is a blackwater river situated entirely within the coastal plain of Georgia. It flows approximately 320 km in a west/southwesterly direction before draining into St. Andrew Sound and the Atlantic Ocean. The river is unimpounded, and Atlantic Sturgeon are able to access 100% of their historic habitat (ASSRT 2007). The Satilla watershed drains approximately 10,200km^2, with less than 2% urban development (EPD 2002). Fritts and Peterson (2011) reported widespread hypoxic conditions (mean 3.20 mg/L) throughout the lower Satilla River during summer months. The head of tide in the Satilla River is typically located at or near rkm 50 (Sheldon and Alber 2005).

Sturgeon Sampling

Sampling in each of the three river systems was conducted below the heads of tide in each system from May through July, 2014-2016. Atlantic Sturgeon were captured with anchored gill and trammel nets designed to capture juveniles as described by several previous authors (Fox et al. 2018; Bahr and Peterson 2016; Schueller and Peterson 2010). Nets were deployed within the main channels at slack tides and were soaked for 30 to 90-min periods. As nets were retrieved, captured Atlantic Sturgeon were placed in floating net pens tethered to the research vessel. Once all nets had been recovered, each fish was measured to the nearest mm FL and inspected for tags. If no tag was present, a passive integrated transponder (PIT) tag was injected under the 4th dorsal scute. In each year of the study, up to 14 age-1 RRJs (FL <500 mm) were randomly selected for surgical implantation of an acoustic transmitter (age was estimated based on length, after Schueller and Peterson 2010, and a random subsample of pectoral fin ray sections were collected to validate ages). Surgical methods used for transmitter implantation were similar to those described by Boone et al. (2013). Captured fish were placed into lateral recumbency on a v-shaped surgical board, and a small pump maintained a gentle stream of fresh river water flowing 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 69kHz Vemco V7-4x acoustic transmitter (Vemco, Nova Scotia, Canada). The manufacturer estimated that battery life of these transmitters was 426 days. The incision was closed using a 2/0 absorbable monocryl suture (Monoswift™ L943) in a single interrupted pattern. Once the incision was closed, the fish was allowed to fully recover in a net pen before being returned to the river at its original capture site.

Acoustic Telemetry

To monitor fish movement, we deployed a total of 42 stationary acoustic receivers (Vemco VR2W) throughout the three individual study rivers. Nine receivers were deployed in the Ogeechee River array, 24 in the Altamaha River array, and nine in the Satilla River array (Figs. 2-4). The Ogeechee River array extended from rkm 14.7-64.0, effectively monitoring movements of tagged fish throughout 81% of the area below the head of tide. The Altamaha array extended from rkm 3.2-43.4, and covered 74% of the area below the head of tide. In the Satilla River, the array extended from rkm 10.2-50.2, covering 80% of the habitat below the head of tide. Within each array, submerged receivers were mounted in an upright position, typically 2-3 m below the surface, and were attached to channel markers and trees using stainless steel cable or aluminum u-channel. Range testing at receivers revealed a tag detection radius of approximately 400 m (range 200–800 m). Receivers were monitored over 38 consecutive months (~167 weeks), from 4 May 2014 through 10 July 2017. Data were downloaded from receivers at approximately 3-4 month intervals.

Water Quality Monitoring

Data on water temperature and flow were obtained from a variety of sources located as close to the study sites as possible. Ogeechee River flow data were obtained from United States Geological Survey (USGS) streamgage 02202600, and temperature data came from a monitoring station run by the Phinizy Center for Water Sciences at river kilometer (rkm) 50. Altamaha River flow data were obtained from USGS streamgage 02226000, located at approximately rkm 90, and temperature data were from a University of Georgia monitoring station located at rkm 23 (Di Iorio 2017). Satilla River flow data and temperature data from May 2014 through October 2014 were obtained from USGS streamgage 02228000 located at approximately rkm 140; temperature data for the remainder of the study came from streamgage 02226500 located at approximately rkm 250. Additional measurements of water temperature, salinity, and dissolved oxygen were obtained from a portable YSI Pro2030 multiprobe (YSI, Inc., Yellow Springs, OH) while nets were soaked at each sampling site.

Data Analysis

Raw telemetry data were transformed into "detection days," defined as one detection per individual per receiver per day. Based on these detection days we then calculated the median rkm position of each fish on a daily, weekly, and monthly basis. We also calculated the minimum, 25th percentile, 75th percentile, and maximum rkm positions of all fish within each river for each month of the study.

To examine the relationship between fish position and environmental parameters, we constructed a linear regression model in which median daily rkm position of each tagged fish was the response variable and water temperature and flow were explanatory variables. The model treated river as a fixed effect, and individual, study year, and month as random effects. Prior to running this model, we used a Pearson's test to check for correlation between water temperature, flow, and Julian date. Differences in RRJ outmigration rates among study rivers were evaluated using ANOVA tests. Differences in sizes of transmittered RRJs that outmigrated versus those that did not were also evaluated using t-tests. Data for both of these analyses were tested for normality and homogeneity of variance using a Shapiro-Wilk test.

Results

Sturgeon Sampling

Netting was conducted in the Ogeechee, Altamaha, and Satilla Rivers between May and August 2014-2016. Over the three years of the study, we set a total 1570 nets, for a total of 1186 hours of sampling effort (Table 4.1). Across all three rivers, we captured 990 Atlantic Sturgeon, 606 of which were RRJ (Table 4.1; Fig. 4.5). In the Ogeechee River, we captured 264 Atlantic Sturgeon; annual catch varied from 66-104 individuals (RRJ catch range: 48-94). Mean FL for fish caught in the Ogeechee was 449.4 mm ± 309.6 mm (Std. Dev). The total catch of Atlantic Sturgeon in the Altamaha River was 540 individuals; total annual catch varied from 72-353 (RRJ catch: 32-220), and mean FL was 468.0 ± 152.0mm. We captured a total of 186 Atlantic Sturgeon in the Satilla River; annual catch varied from 37-81 (RRJ catch: 18-58), and mean FL was 481.2 ± 150.4 mm.

Transmitters were surgically implanted into a total of 92 age-1 Atlantic Sturgeon: 25 in the Ogeechee, 35 in the Altamaha, and 32 in the Satilla (Tables 4.2 and 4.3). Four of the tagged fish (4.3%) were never detected, and hence, were removed from subsequent analyses. Another nine fish (9.7%) that were last detected ≤7 days after tagging, were also censored. The remaining 79 transmitters comprised 17 individuals tagged in the Ogeechee, 32 in the Altamaha, and 30 in the Satilla River. A total of 349,087 detections of these fish were recorded on the receiver arrays or obtained from similar arrays deployed by other researchers working in nearby areas. Overall, the mean number of detections per fish was 4419 (range: 16-80,325) and the mean number of days these individuals were tracked (days between tagging date and last detection) was 298 (range 20-432). The mean number of days each fish was tracked was similar across all three rivers: 306 days (range: 20-415) in the Ogeechee, 294 days in the Altamaha (range: 21-432), and 298 days in the Satilla (range: 63-431).

Habitat Use

Over the course of this study, transmittered RRJs were detected on every receiver in each of the three river arrays. Telemetry data indicated a similar pattern of juvenile habitat use in all three rivers: during the summer months the fish congregated in freshwater reaches relatively close to the head of tide, but during the winter months they moved downriver and became more broadly distributed (Figs. 4.6a,b,c). In all three rivers, the mean percentage of habitat used by the 25^{th}-75^{th} percentile of tagged fish generally decreased from their maximum values in January-February to their minimum values in July-August (Fig. 4.7).

There was a weak correlation between water temperature and flow (r^2= -0.184, p<0.001), and both parameters were also weakly correlated with Julian date (temperature: r^2= -0.081, p<0.00; flow: r^2= -0.238, p<0.001). Because the correlation was so low between these variables, we were able to include both temperature and flow in our regression model . Model outputs (Table 4.6) indicated that water temperature had a significant positive relationship with rkm position of tagged fish, and flow had a smaller, but still significant, negative relationship with rkm position. The marginal R^2 for this model was 0.583, and the conditional R^2 was 0.806. The model results showed that as temperature increased, tagged fish moved upriver, and as flow increased, they moved downriver.

Outmigration

Of the 79 RRJs included in the analysis, 24 individuals (30.4%) were detected at least once on an acoustic receiver outside of their natal river (Table 4.4) – confirmation that these juveniles had outmigrated from their natal river as MMJs. These fish were detected by receiver arrays in other study rivers or by other researchers' receiver arrays in coastal Georgia and South Carolina. A greater proportion of transmittered juveniles outmigrated from the Altamaha River (50.0%) than from the Ogeechee (11.8%) or Satilla Rivers (20.0%), but the difference was not significant when compared among all years of the study (p=0.782, F=0.256, df=2; tests for normality and homogeneity of variance of data showed that both assumptions were met). The overall rate of outmigration for all rivers was significantly different among study years (p=0.039, F=5.812, df=2); 2014 had a significantly higher rate of outmigration than 2015 (p=0.035), but there were no significant differences between 2014 and 2016 (p=0.165) or between 2015 and 2016 (p=0.472).

As tagged RRJs outmigrated, some individuals were able to pass undetected by the acoustic receiver(s) located at or near the mouth of their natal river. In the Ogeechee River, 100% of outmigrating individuals were detected by the lowermost receivers in that system, but only 76.4% of Altamaha River fish and only 50% of Satilla River fish were detected as they outmigrated. However, there was no significant difference in probability of outmigration detection among the three rivers (p=0.16, F=5.786, df=2). All fish that outmigrated were last detected in their natal river during the winter months at age-2; nine fish outmigrated in December, five outmigrated in January, February, and March (Fig. 4.8). No outmigration was observed between April and November in any river system in any year of the study.

Overall, tagged fish that transitioned to MMJs at age-2 were significantly larger (p=0.011, t=2.366, df=48) at the time of tagging (361.8 mm FL ±45.80 mm, Std. Dev) than those that remained as age-2 RRJs (336.6 mm ± 34.0 mm) (Table 4.5). Within each study river, however, only the Ogeechee had significantly larger tagged fish that outmigrated, compared to those that remained as age-2 RRJs (p=0.004, t=2.228, df=10). There was no significant difference in length between tagged fish that outmigrated and those that did not in either the Altamaha (p=0.09, t=2.080, df=21) or the Satilla Rivers (p=0.06, t=2.120, df=16).

Twenty-nine of the 79 transmittered juveniles (36.7%) remained in their natal rivers as age-2 RRJs for at least 1 full year after they were tagged. A greater proportion of fish remained as age-2 RRJs in the Ogeechee River (58.8%) than in the Altamaha (21.9%) or Satilla (40%), but these differences were not significant (p=0.628, F=0.504, df=2). Twenty-six individuals (32.9%) were neither confirmed as outmigrants nor as age-2 RRJs - these fish either died, experienced transmitter failure, or their fate was simply unclear because they were not detected by a receiver outside their natal river, nor were they detected in their natal river during the summer subsequent to tagging. Nine of these individuals were last detected near the mouth of their natal river between December and March, and an additional nine were last detected in their natal river in December-March.

Discussion

Habitat Use

Several previous studies have shown that habitat selection by RRJ Atlantic Sturgeon is likely associated with several water quality parameters including temperature, salinity, dissolved oxygen, and flow (Secor and Gunderson 1997; Bain et al. 2000; ASSRT 2007; Niklitschek and Secor 2010; Allen et al. 2014; Moberg and DeLucia 2016). Throughout this study RRJs in all three rivers exhibited a similar pattern of seasonal habitat use. In the warmest months of the year (May-July), RRJ sturgeon distribution was concentrated farther upriver, closer the head of tide, while in the coldest months (Dec-Feb), RRJs were more widely distributed throughout the lower reaches of the estuary. Modeling of telemetry data indicated that temperature was an important predictor of habitat use, with fish typically moving upstream as water temperatures increased. A likely explanation is that for juvenile Atlantic Sturgeon living in high-temperature water, increased in salinity causes elevated metabolic rate and decreased growth (Niklitschek and Secor 2009II). In the Chesapeake Bay, Niklitschek and Secor (2005) found that elevated water temperatures reduce juvenile tolerance for hypoxia and salinity, thereby decreasing the amount of suitable nursery habitat available to RRJs during summer months. The results of this study showed that as temperatures increased during the summer, RRJs in all three Georgia rivers moved upstream into fresher water and, subsequently, used less of the brackish water habitat available to them in the lower estuary (Fig. 4.7). In all three study rivers, the median monthly position of RRJs sturgeon in June and July occurred in reaches where the salinity range was 0-10 ppt, compared to salinities > 20 ppt in the lower estuary where fish were commonly found during winter months.

Although seasonal habitat use by RRJ Atlantic Sturgeon has not been previously described in the southern portion of the range, the movement patterns observed in Georgia are similar to those described for RRJs in the Hudson River, NY. From April-October, Hudson River RRJs demonstrated preferences for water temperatures of 24-28 °C, and salinities of 0-5 ppt, but during the winter RRJs moved downstream into river reaches where salinity was 3-18 ppt (Bain et al. 2000). Throughout their range, RRJ Atlantic Sturgeon habitat appears to be the most constrained during the warmest months, although further studies are needed to determine if this seasonal restriction in habitat use could be an important factor limiting species recovery.

Outmigration

Across all three rivers in this study, 25% of tagged RRJ Atlantic Sturgeon were detected outside of their natal river (Table 4.4). In all three rivers these fish were last detected in their natal rivers in December-March. Given that Ingram and Peterson (2016) found that spawning occurs from October-December in the Altamaha River, the results of this study suggest that RRJs began their initial transition to MMJs during the winter and early spring months immediately after reaching age-2. During the winter, all of the tagged RRJ dispersed downstream, likely as declining water temperature allowed them to tolerate more saline water. The detection of 24 tagged individuals (45% of fish with known fates) outside of their natal river confirms that many of these fish continued that downstream movement into marine waters as they transitioned to the MMJ life stage. As water temperatures began to increase in the spring, the remaining 55% of fish with known fates moved back upriver toward the head of tide as age-2 RRJs.

Across all rivers in this study, tagged RRJs that outmigrated were significantly larger than those that did not (small within-river sample sizes may explain why this difference in size was not apparent at the river level). Although further studies are needed to better understand the factors affecting RRJ outmigration, the results of this study suggest that juvenile growth may be one such factor. In a laboratory experiment, Niklitschek and Secor (2009I) found that age-1 juveniles are more tolerant of salinity than age-0 juveniles. In this study, RRJs that were larger at age-1 were significantly more likely to outmigrate than their smaller counterparts. Likewise, our results also showed that smaller RRJs within each river system were more likely to return back upstream to freshwater reaches in the spring as water temperatures increased.

In addition to the 30.3% of RRJs that transitioned to MMJs and the 36.7% that remained in their natal river as age-2 RRJs, the status of 32.9% of tagged fish was unknown (Table 4.4). Although some of these fish could have died or experienced transmitter failures, at least some of these individuals probably outmigrated without being detected. Across all three rivers, 29.2% of tagged fish that were confirmed as MMJs were not detected by receivers near the mouth of their natal river as they left their natal river. The spatial and physical complexities of each river likely enabled some fish to pass undetected by the receivers closest to the mouth. In the Ogeechee River, where 100% of known MMJs were detected as they outmigrated, only two channels were available to outmigrating RRJs, and the channel width in both of these was less than the detection range of the receivers. In the Satilla River, however, the river mouth was considerably wider than the receiver detection range, and outmigrating RRJs could have passed undetected through gaps in receiver coverage. Although receivers were placed along the deepest part of the channel, 50% of confirmed outmigrants in the Satilla left the river without being detected. The Altamaha River estuary was the most spatially complex within the study, with multiple distributaries and braided channels. However, these branches were generally much narrower than the lower Satilla and well within the detection range of the receivers, resulting in a 76.4% outmigration detection rate.

Estimates of age-1 outmigration presented in this study should be viewed as conservative estimates. Based on the timing and location of their last natal detection, several of the tagged RRJs with unknown fates may have also outmigrated, but were never detected outside of their natal river. Given that all of the confirmed MMJs left their natal river between December and March and that nine of the RRJs with unknown fates (11.4% of fish included in analysis) were last detected in their natal river at a receiver close to the mouth during this same time period, these individuals likely outmigrated but were never detected elsewhere. Another nine individuals were last detected in their natal river between December and March, but not at a receiver near the mouth. Because some known MMJs were able to leave undetected by these lowest receivers, these fish most likely outmigrated as well.

Outmigrating MMJs showed no consistent pattern of directional movement after leaving their natal estuaries. Some fish appeared to use the Atlantic Intracoastal Waterway to travel to an adjacent river, while others moved directly offshore. Several MMJs even returned to their natal river after spending time in other river systems. MMJs tagged in this study were detected in several South Carolina rivers >300 km away. Although the dispersal patterns of MMJ appeared to be random in this study, further studies with larger sample sizes could help managers understand broad patterns of habitat connectivity among different populations. As Atlantic Sturgeon populations continue to recover, these patterns may become increasingly important in protecting MMJ habitats during their critical transition to marine environments.

The results of this study support several of the important assumptions that underpin recent studies that have used mark-recapture of RRJ cohorts to quantify Atlantic Sturgeon recruitment (Schueller and Peterson 2010; Bahr and Peterson 2016; Fritts et al. 2016; Hale et al. 2016). This method requires intensive sampling of age-1 RRJ cohorts within their nursery habitats during the summer months, under the assumption they are closed to emigration during sampling. The results of this study indicate that during the summer months, RRJs in Georgia rivers occupy a relatively small area of nursery habitat located between the head of tide and the mouth of their natal river. Telemetry data from this study showed that no RRJs left their natal estuary before reaching age-2 in their third winter - a strong indicator that the age-1 cohorts are, in fact, closed to emigration during the summer months. Telemetry data also showed that by their third summer, up to 50% of age-2 individuals had left their natal river as MMJ. These results support the findings of Schueller and Peterson (2010) that mark-recapture estimates of RRJs older than age-1 may substantially underestimate the number of fish in those cohorts. Consequently, we suggest that using mark-recapture to estimate age-1 RRJ cohorts is currently the best available method for assessing annual recruitment of Atlantic Sturgeon – at least within the southern portion of the range. Similar studies of juvenile habitat use and outmigration are needed in other parts of the range to account for clinal variations in ecology of the species.

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References

Allen, P. J., Z. A. Mitchell, R. J. DeVries, D. L. Aboagye, M. A. Ciaramella, S. W. Ramee, H. A. Stewart, and R. B. Shartau. 2014. Salinity effects on Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus* Mitchill, 1815) growth and osmoregulation. J. Appl. Ichthy. 30:1229-1236.

Altamaha Council. 2011. Altamaha Regional Water Plan. Atlanta, Georgia. <http://www.altamahacouncil.org>.

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.

ASSRT (Atlantic Sturgeon Status Review Team). 1998. Status review of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), 126 p. Report prepared for Natl. Mar. Fish. Serv., Silver Springs, MD.

ASSRT 2007. Status review of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), 174 p. Report to Northeast Reg. Off., Natl. Mar. Fish. Serv., Gloucester, MA.

Bahr, D. L., and D. L. Peterson. 2016. Recruitment of juvenile Atlantic Sturgeon in the Savannah River, Georgia. Trans. Am. Fish. Soc. 145:1171–1178.

Bain, M. B. 1997. Atlantic and Shortnose Sturgeons of the Hudson River: common and divergent life history attributes. Environ. Biol. Fish. 48:347–358.

Bain, M. B., D. L. Peterson, K. K. Arend, and N. Haley. 1999. Atlantic Sturgeon population monitoring for the Hudson River estuary: sampling design and gear recommendations. Final Report to the Hudson River Fisheries Unit, Bureau of Marine Resources, NY Department of Environmental Conservation, New Paltz, NY and the Hudson River Foundation, New York, NY. New York Cooperative Fish and Wildlife Research Unit, Cornell University, Ithaca, NY. 34p.

Bain, M.B., N. Haley, D. Peterson, J.R. Waldman, and K. Arend. 2000. Harvest and habits of Atlantic sturgeon *Acipenser oxyrinchus* Mitchill 1815 in the Hudson River estuary: lessons for sturgeon conservation. Boleti Instituto Espanol de Oceanografia 16:43-54.

Balazik, M. T., and J. A. Musick. 2014. Dual annual spawning races in Atlantic Sturgeon. PLoS One 10: e0128234.

Bemis, W.E., and B. Kynard. 1997. Sturgeon rivers: an introduction to acipenseriform biogeography and life history. Environ. Biol. Fish 48: 347-358.

Boone, S. S., S. J. Divers, A. C. Camus, D. L. Peterson, C. A. Jennings, J. L. Shelton, and S. M. Hernandez. 2013. Pathologic and physiologic effects associated with long-term intracoelomic transmitters in captive Siberian sturgeon. North Am. J. Fish. Manage. 33:869–877.

Cai, W., and Y. Wang. 1998. The chemistry, fluxes, and sources of carbon dioxide in the estuarine waters of the Satilla and Altamaha Rivers, Georgia. Limnol.Oceanogr. 43:657-668.

Coastal Georgia Council. 2011. Coastal Georgia Regional Water Plan. Atlanta, Georgia. <http://www.coastalgeorgiacouncil.org/>.

Collins, M. R., S. G. Rogers, T. I. J. Smith, and M. L. Moser. 2000. Primary factors affecting sturgeon populations in the southeastern United States: fishing mortality and degradation of essential habitats. Bull. Mar. Sci. 66:917–928.

Di Iorio, Daniela. 2017. Long-term Hydrographic Mooring Data from the Georgia Coastal Ecosystems LTER Salinity Monitoring Program - Primary 30 Minute Observational Data. Georgia Coastal Ecosystems LTER Project, University of Georgia, Long Term Ecological Research Network. <http://gce-lter.marsci.uga.edu/public/app/dataset_details.asp?accession=PHY-GCES-1610>.

Dovel, W.L., and J.T. Berggren. 1983. Atlantic Sturgeon of the Hudson Estuary, New York. New York Fish and Game Journal 30: 140-172.

EPD (Environmental Protection Division). 2001. Ogeechee River Basin Management Plan. Georgia Department of Natural Resources, Environmental Protection Division. Atlanta, GA.

EPD. 2002. Satilla River Basin Management Plan. Georgia Department of Natural Resources, Environmental Protection Division. Atlanta, GA.

Farrae, D.J., P.M. Schueller, D.L. Peterson. 2009. Abundance of juvenile Atlantic Sturgeon in the Ogeechee River, Georgia. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 63:172-176

Farrae, D. J., S. E. Albeke, K. Pacifici, N. P. Nibbelink, D. L. Peterson. 2013. Assessing the influence of habitat quality on movements of the endangered shortnose sturgeon. Environ. Biol. Fish 97: 691-699.

Federal Register. 2012a. Endangered and threatened wildlife and plants; threatened and endangered status for distinct population segments of Atlantic Sturgeon in the northeast region. Fed. Register 77:5880–5912.

Federal Register. 2012b. Endangered and threatened wildlife and plants; final listing determinations for two distinct population segments of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the southeast. Fed. Register 77:5914–5982.

Federal Register. 2017. Endangered and Threatened Species; Designation of Critical Habitat for the Endangered New York Bight, Chesapeake Bay, Carolina and South Atlantic Distinct Population Segments of Atlantic Sturgeon and the Threatened Gulf of Maine Distinct Population Segment of Atlantic Sturgeon. Fed. Register 77:5880–5912.

Fox, A. G., E. S. Stowe, K. J. Dunton, and D. L. Peterson. 2018. Seasonal occurrence of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the St. Johns River, Florida. Fish. Bull. 116:219-227.

Fritts, M. W., C. Grunwald, I. Wirgin, T. L. King, and D. L. Peterson. 2016. Status and genetic character of Atlantic Sturgeon in the Satilla River, Georgia. Trans. Am. Fish. Soc. 145:69-82.

Fritts, M.W. and Peterson. 2011. Status of imperiled sturgeon species in the Satilla and Saint Marys Rivers, Georgia. Final Report to the Natl. Mar. Fish. Serv., Silver Spring, Maryland.

Gilbert, C.R. 1989. Species profile: Life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic)—Atlantic and Shortnose Sturgeons. U.S. Fish and Wildlife Service biological report 82(11.122), U.S. Army Corps of Engineers TR-EL-82-4. 28p

Hagar, C. J. Kahn, C. Watterson, J. Russon, and K. Hartman. 2014. Evidence of Atlantic Sturgeon spawning in the York River system. Trans. Am. Fish. Soc. 143:1217-1219.

Hale, E.A., I.A Park, M.T. Fisher, R.A. Wong, M.J. Stangl, and J.H. Clark. 2016. Abundance estimate for and habitat use by early juvenile Atlantic Sturgeon within the Delaware River estuary. Trans. Am. Fish. Soc 145:1193:1201.

Hook, J.D. 2010. Sturgeon habitat quantified by side-scan sonar imagery. Masters thesis, Warnell School of Forestry and Natural Resources, University of Georgia. Athens, GA. 70pp.

Ingram, E. C., and D. L. Peterson. 2016. Annual spawning migrations of adult Atlantic Sturgeon in the Altamaha River, Georgia. Mar. Coast. Fish. 8:595–606.

Kynard, B. and Horgan, M. 2002. Ontogenetic behavior and migration of Atlantic Sturgeon, *Acipenser oxyrinchus*, and Shortnose Sturgeon, *A. brevirostrum*, with notes on social behavior. Environ. Biol. Fish. 63:137-150.

Meyer, J. L., A. C. Benke, R. T. Edwards, and J. B. Wallace. 1997. Organic matter dynamics in the Ogeechee River, a blackwater river in Georgia, USA. J. North Am. Benthological Soc. 16:82-87.

Moberg, T., and M. DeLucia. 2016. Potential impacts of dissolved oxygen, salinity and flow on the successful recruitment of Atlantic Sturgeon in the Delaware River. The Nature Conservancy. Harrisburg, PA. 37p.

Niklitschek, E. J., and D. H. Secor. 2005. Modeling spatial and temporal variation of suitable nursery habitats for Atlantic Sturgeon in the Chesapeake Bay. Estuar. Coast. Shelf Sci. 64:135-148.

Niklitschek, E. J., and D. H. Secor. 2009I. Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic Sturgeon in estuarine waters: I. Laboratory results. J. Mar. Biol. Ecol. 381:S150-S160.

Niklitschek, E. J., and D. H. Secor. 2009II. Dissolved oxygen, temperature and salinity effects on the ecophysiology and survival of juvenile Atlantic Sturgeon in estuarine waters: II. Model development and testing. J. Mar. Biol. Ecol. 381:S161-S172.

Peterson, D. L., M. B. Bain, and N. Haley. 2000. Evidence of declining recruitment of Atlantic Sturgeon in the Hudson River. North Am. J. Fish. Manage. 20: 231-238

Schueller, P. and D. L. Peterson. 2010. Abundance and recruitment of juvenile Atlantic Sturgeon in the Altamaha River, Georgia. Trans. Am. Fish. Soc. 139:1526–1535.

Secor, D.H. 2002. Atlantic sturgeon fisheries and stock abundances during the late nineteenth century. Am. Fish. Soc. Symp 28: 89-100.

Secor, D. H., and T. E. Gunserson. 1997. Effects of hypoxia and temperature on survival, growth, and respiration of juvenile Atlantic Sturgeon, *Acipenser oxyrinchus*. Fish Bull. 96:603-613.

Sheldon, J. E., and M. Alber. 2005. Comparing transport times through salinity zones in the Ogeechee and Altamaha River estuaries using Squeezebox. In *Proceedings of the 2005 Georgia Water Resources Conference*, ed. Kathryn J. Hatcher. Athens, Georgia: Institute of Ecology, University of Georgia.

Smith, T. I. J., and J. P. Clugston. 1997. Status and management of Atlantic Sturgeon, *Acipenser oxyrinchus*, in North America. Environ. Biol. Fish. 48:335–346.

Smith, J. A., H. J. Flowers, and J. E. Hightower. 2015. Fall spawning of Atlantic Sturgeon in the Roanoke River, North Carolina. Trans. Am. Fish. Soc. 144: 48-54.

Table 4.1: Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) sampling effort and catch in the Ogeechee, Altamaha, and Satilla Rivers, GA, USA 2014-2016. Fish with a fork length <500 mm were considered to be river-resident juveniles (RRJs).

Table 4.1.

River	**2014**				**2015**				**2016**			
	Net Sets	**Net hours**	**Total catch**	**RRJ catch**	**Net Sets**	**Net hours**	**Total catch**	**RRJ catch**	**Net Sets**	**Net hours**	**Total catch**	**RRJ catch**
Ogeechee	197	137	66	48	263	175	104	71	241	156	94	53
Altamaha	88	85	115	64	49	43	72	32	160	155	353	220
Satilla	159	93	37	18	185	176	68	58	228	166	81	42
Total	*444*	*315*	*218*	*130*	*497*	*394*	*244*	*161*	*629*	*477*	*528*	*315*

Table 4.2: Number of acoustically tagged age-1 Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), and the number subsequently detected in the Ogeechee, Altamaha, and Satilla Rivers, Georgia, USA 2014-2016.

	No. juveniles tagged (detected)		
River	**2014**	**2015**	**2016**
Ogeechee	2 (1)	11 (8)	12 (8)
Altamaha	10 (8)	11 (11)	14 (13)
Satilla	8 (7)	11 (11)	13 (12)
Total	*20 (16)*	*33 (30)*	*39 (33)*

Table 4.3: Individual Atlantic Sturgeon (Acipenser oxyrinchus oxyrinchus) acoustically tagged in the Ogeechee, Altamaha, and Satilla Rivers, Georgia, in summer 2014-2016. Individuals marked with a * were not detected or were last detected < 7 days after tagging, and were removed from analysis. Some fish were detected in non-natal locations by receiver arrays in Georgia located in the St. Marys River, offshore of Jekyll Island, offshore of St. Simons Island, and in Ossabaw Sound, and by receiver arrays in South Carolina located in the Edisto River, offshore of Folly Beach, Charleston Harbor, the Cooper River, the North and South Santee Rivers, Winyah Bay, the Great Pee Dee River, the Sampit River, the Waccamaw River, and the Little River jetties. FL = fork length.

Table 4.3.

Fish ID	River	Date tagged	FL	No. detections	Days tracked	Non-natal locations detected
OGE-01*	Ogeechee	7/14/2014	469	41	3	
OGE-02	Ogeechee	7/29/2014	448	4,480	191	Ossabaw Sound[a]
OGE-03	Ogeechee	5/15/2015	310	212	112	
OGE-04	Ogeechee	5/19/2015	317	16	313	
OGE-05*	Ogeechee	5/27/2015	300	0	0	
OGE-06	Ogeechee	5/27/2015	312	805	297	
OGE-07	Ogeechee	5/27/2015	317	816	334	
OGE-08	Ogeechee	5/28/2015	309	972	326	
OGE-09*	Ogeechee	5/29/2015	299	1	3	
OGE-10	Ogeechee	6/1/2015	320	658	318	
OGE-11	Ogeechee	6/1/2015	316	388	7	
OGE-12	Ogeechee	6/3/2015	310	530	411	
OGE-13	Ogeechee	8/2/2015	316	3,582	415	
OGE-14	Ogeechee	6/7/2016	311	15,156	390	
OGE-15	Ogeechee	6/7/2016	356	2,938	352	
OGE-16*	Ogeechee	6/7/2016	357	65	2	
OGE-17	Ogeechee	6/9/2016	347	968	389	
OGE-18*	Ogeechee	6/15/2016	330	0	0	
OGE-19	Ogeechee	6/22/2016	334	35,634	277	
OGE-20	Ogeechee	6/24/2016	379	926	340	

OGE-21	Ogeechee	6/24/2016	371	3,375	338	Edisto R.[b]
OGE-22	Ogeechee	6/24/2016	328	1,310	353	
OGE-23*	Ogeechee	7/1/2016	329	0	0	
OGE-24	Ogeechee	7/1/2016	336	2,655	20	
OGE-25*	Ogeechee	7/6/2016	290	71	6	
ALT-01	Altamaha	5/21/2014	323	7,463	74	
ALT-02	Altamaha	5/21/2014	300	522	410	
ALT-03	Altamaha	5/21/2014	309	2,359	127	
ALT-04*	Altamaha	5/28/2014	327	1	1	
ALT-05*	Altamaha	5/28/2014	375	137	6	
ALT-06	Altamaha	5/28/2014	315	178	286	Satilla R.
ALT-07	Altamaha	6/2/2014	329	3,386	326	Satilla R.
ALT-08	Altamaha	6/2/2014	344	1,698	304	Satilla R.
ALT-09	Altamaha	6/2/2014	354	4,644	229	Ossabaw Sound[a]
ALT-10	Altamaha	6/2/2014	328	138	309	Ossabaw Sound[a]
ALT-11	Altamaha	5/8/2015	307	914	259	
ALT-12	Altamaha	5/8/2015	311	561	42	
ALT-13	Altamaha	5/8/2015	328	830	308	
ALT-14	Altamaha	5/11/2015	294	3,073	308	Satilla R.
ALT-15	Altamaha	5/11/2015	296	610	249	
ALT-16	Altamaha	5/11/2015	326	443	21	
ALT-17	Altamaha	5/11/2015	314	3,915	430	
ALT-18	Altamaha	5/11/2015	315	3,214	373	

ALT-19	Altamaha	5/13/2015	300	1,201	320	
ALT-20	Altamaha	5/13/2015	300	4,762	432	
ALT-21	Altamaha	7/29/2015	379	5,873	327	Ogeechee R.
ALT-22	Altamaha	5/4/2016	315	2,995	263	St. Simons Is.[a]
ALT-23	Altamaha	5/4/2016	311	1,734	83	
ALT-24	Altamaha	5/9/2016	365	595	346	
ALT-25	Altamaha	5/9/2016	360	7,645	431	St. Simons Is.[a], Winyah Bay[b], Gr. Pee Dee R.[b], Waccamaw R.[b]
ALT-26	Altamaha	5/9/2016	315	21,850	311	St. Simons Is.[a], Charleston harbor[b], S. Santee R., Little R.[b]
ALT-27	Altamaha	5/9/2016	341	17,739	427	Folly Beach[b], Little R.[b], Cooper R.[b]
ALT-28	Altamaha	5/9/2016	349	2,618	392	Waccamaw R.[b], Gr. Pee Dee R.[b], Winyah Bay[b], Sampit R.[b]
ALT-29	Altamaha	5/9/2016	357	494	333	Charleston Harbor[b], Little R.[b]
ALT-30*	Altamaha	5/11/2016	328	1	4	
ALT-31	Altamaha	5/11/2016	332	4,738	416	St Simons Is.[a], Jekyll Is.[a], Satilla R.

ALT-32	Altamaha	6/23/2016	431	431	130	
ALT-33	Altamaha	6/23/2016	361	2,433	382	St. Simons Is.[a]
ALT-34	Altamaha	6/27/2016	345	9,064	379	
ALT-35	Altamaha	6/27/2016	403	8,106	370	Ogeechee R.
SAT-01	Satilla	6/19/2014	468	333	276	
SAT-02	Satilla	6/19/2014	421	52	195	
SAT-03	Satilla	6/20/2014	404	1,279	320	Jekyll Is.[a], Charleston harbor[b], S. Santee R.[b]
SAT-04	Satilla	6/25/2014	425	1,150	287	Jekyll Is.[a], N. Santee R.[b]
SAT-05	Satilla	6/27/2014	412	1,065	165	
SAT-06	Satilla	7/14/2014	392	1,660	249	
SAT-07*	Satilla	7/25/2014	424	80	7	
SAT-08	Satilla	7/30/2014	459	720	239	St. Marys R[c], Altamaha R.
SAT-09	Satilla	5/13/2015	333	261	242	
SAT-10	Satilla	5/13/2015	310	616	349	St. Marys R.[c]
SAT-11	Satilla	6/5/2015	308	2,056	372	
SAT-12	Satilla	6/5/2015	336	847	219	
SAT-13	Satilla	6/8/2015	344	2,119	364	
SAT-14	Satilla	6/8/2015	318	942	342	
SAT-15	Satilla	6/9/2015	290	512	431	
SAT-16	Satilla	6/9/2015	325	163	281	

SAT-17	Satilla	6/9/2015	306	5,619	63	
SAT-18	Satilla	6/9/2015	327	700	294	
SAT-19	Satilla	7/31/2015	319	4,114	308	
SAT-20	Satilla	5/23/2016	355	1,323	396	Ogeechee R.
SAT-21	Satilla	5/25/2016	372	1,376	407	
SAT-22	Satilla	5/31/2016	431	253	276	
SAT-23	Satilla	6/7/2016	343	1,904	395	
SAT-24	Satilla	6/7/2016	375	1,763	359	
SAT-25	Satilla	6/10/2016	450	267	267	
SAT-26	Satilla	6/13/2016	328	878	288	
SAT-27	Satilla	6/13/2016	381	1,255	302	
SAT-28	Satilla	6/15/2016	436	1,426	216	Altamaha R.
SAT-29	Satilla	6/20/2016	446	80,325	383	
SAT-30	Satilla	6/22/2016	362	32,712	332	
SAT-31	Satilla	6/22/2016	361	538	327	
SAT-32*	Satilla	7/14/2016	419	0	0	

[a]Detections courtesy of C. Kalinowsky, GA Dept. of Natural Resources, Coastal Resources Division.

[b]Detections courtesy of W. Post, SC Dept. of Natural Resources.

[c]Detections from University of Georgia receiver array maintained by authors.

Table 4.4: Status of acoustically tagged Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) tagged in the Ogeechee, Altamaha, and Satilla Rivers, GA. Sturgeon were tagged as river-resident juveniles (RRJ) during the summer of age-1. Age-2 RRJ remained in their natal river the summer subsequent to being tagged. Marine migratory juveniles (MMJ) were detected outside of their natal river before the summer of age-2. Outmigration detection probability based on whether a confirmed outmigrant sturgeon was detected by the acoustic receivers closest to the mouth of its natal river before being detected by a non-natal river receiver

River	Confirmed age-2 RRJ (%)	Confirmed age-2 MMJ (%)	Unknown status (%)	Outmigration detection probability
Ogeechee	10 (58.8)	2 (11.8)	5 (29.4)	100.0%
Altamaha	7 (21.9)	16 (50.0)	9 (28.1)	75.0%
Satilla	12 (40.0)	6 (20.0)	12 (40.0)	50.0%
Total	*29 (36.7)*	*24 (30.4)*	*26 (32.9)*	*70.1%*

Table 4.5: Mean fork lengths (FL) of acoustically tagged Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the Ogeechee, Altamaha, and Satilla Rivers, Georgia, 2014-2016. Lengths are from time of tagging as age-1 river-resident juveniles during the summer months.

	Remained in natal river				Outmigrated from natal river			
River	**n**	**Mean FL (mm)**	**Std. dev. (mm)**	**Range (mm)**	**n**	**Mean FL (mm)**	**Std. dev. (mm)**	**Range (mm)**
Ogeechee	10	329.3	23.6	309-379	2	409.5	24.4	371-448
Altamaha	7	321.4	24.4	300-365	16	342.3	27.3	294-403
Satilla	12	351.6	41.5	290-446	6	398.2	55.7	310-459
Total	*29*	*336.6*	*34.0*	*290-3446*	*24*	*361.8*	*45.8*	*294-459*

Table 4.6: Linear regression model of daily rkm position of each tagged fish versus combined effects of water temperature and flow (explanatory variables). River was treated as a fixed effect; individual, study year, and month were random effects. Regression output includes slope, standard error, 95% confidence interval (CI), degrees of freedom (df), t value, and p value (Pr(>|t|)). The marginal R^2 for the model was 0.583, and the conditional R^2 was 0.806.

Fixed effect	Estimate	Standard error	95% CI	df	t value	Pr (>|t|)
Temperature	0.237	0.042	0.155-0.320	583.2	5.370	p<0.001
Flow	4.46×10^{-5}	1.80×10^{-5}	9.320×10^{-6}-7.988×10^{-5}	4941	-2.478	p=0.013
Altamaha	13.420	1.970	9.560-17.281	14.45	6.813	p<0.001
Ogeechee	23.830	1.451	20.986-26.674	58.0	16.426	p<0.001
Satilla	15.260	1.411	12.494-18.026	59.65	10.819	p<0.001

Figure 4.1: Study sites: the Ogeechee, Altamaha, and Satilla Rivers, Georgia, USA

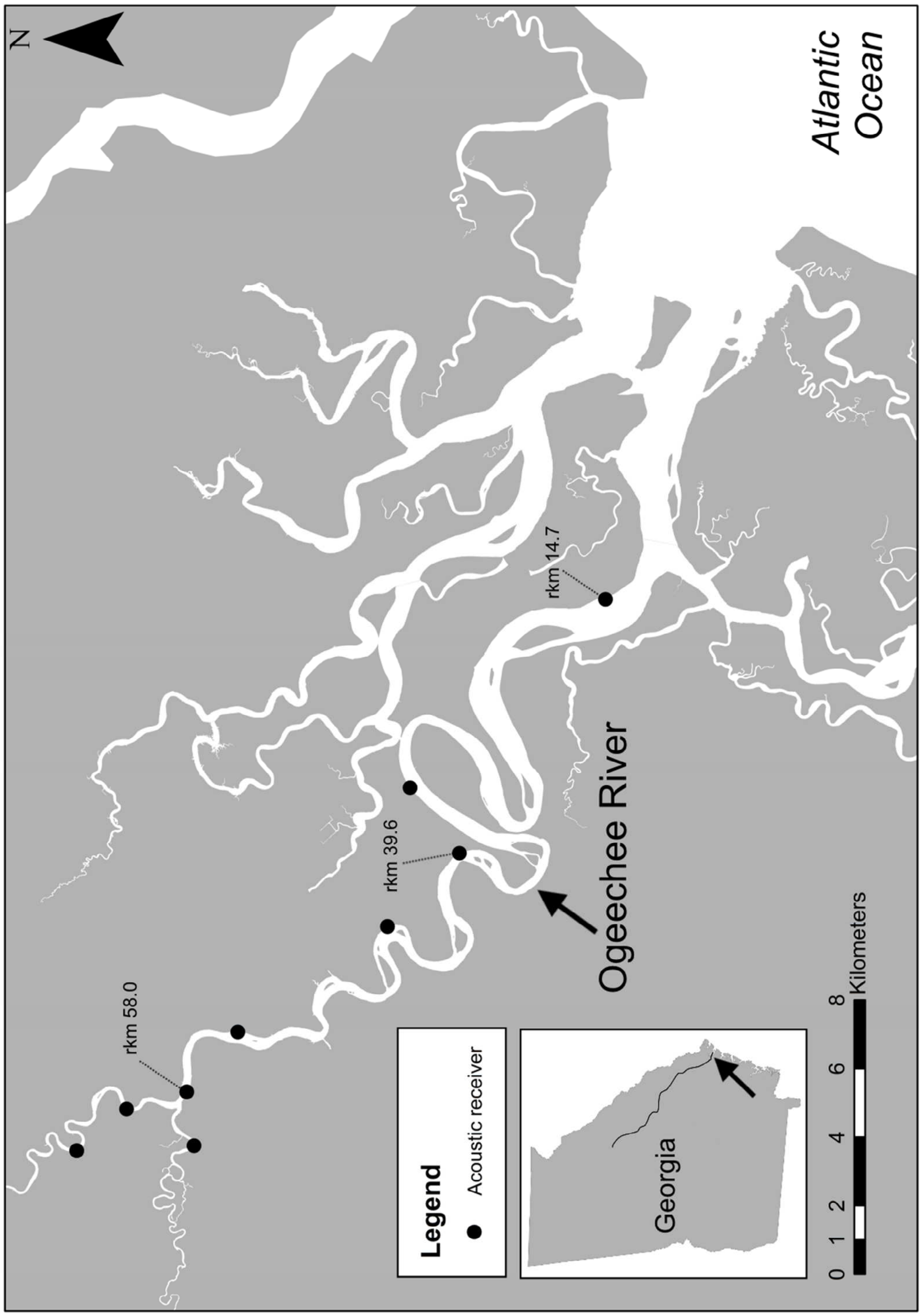


Figure 4.2.

Figure 4.2: Map of Ogeechee River, Georgia, USA. Black dots represent acoustic receiver stations. River kilometer (rkm) location of several receiver stations is included for reference.

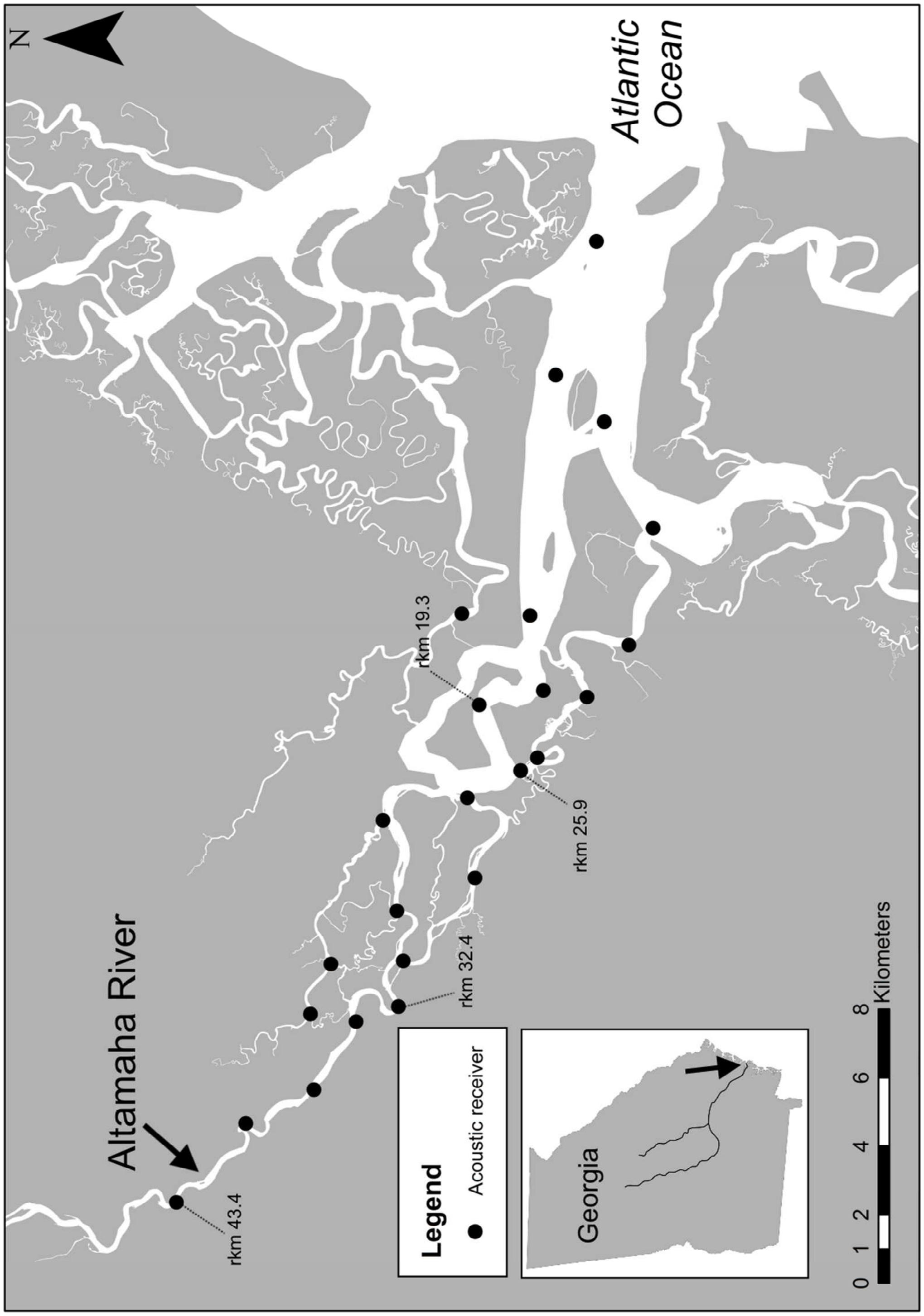


Figure 4.3.

Figure 4.3: Map of Altamaha River, Georgia, USA. Black dots represent acoustic receiver stations. River kilometer (rkm) location of several receiver stations is included for reference.

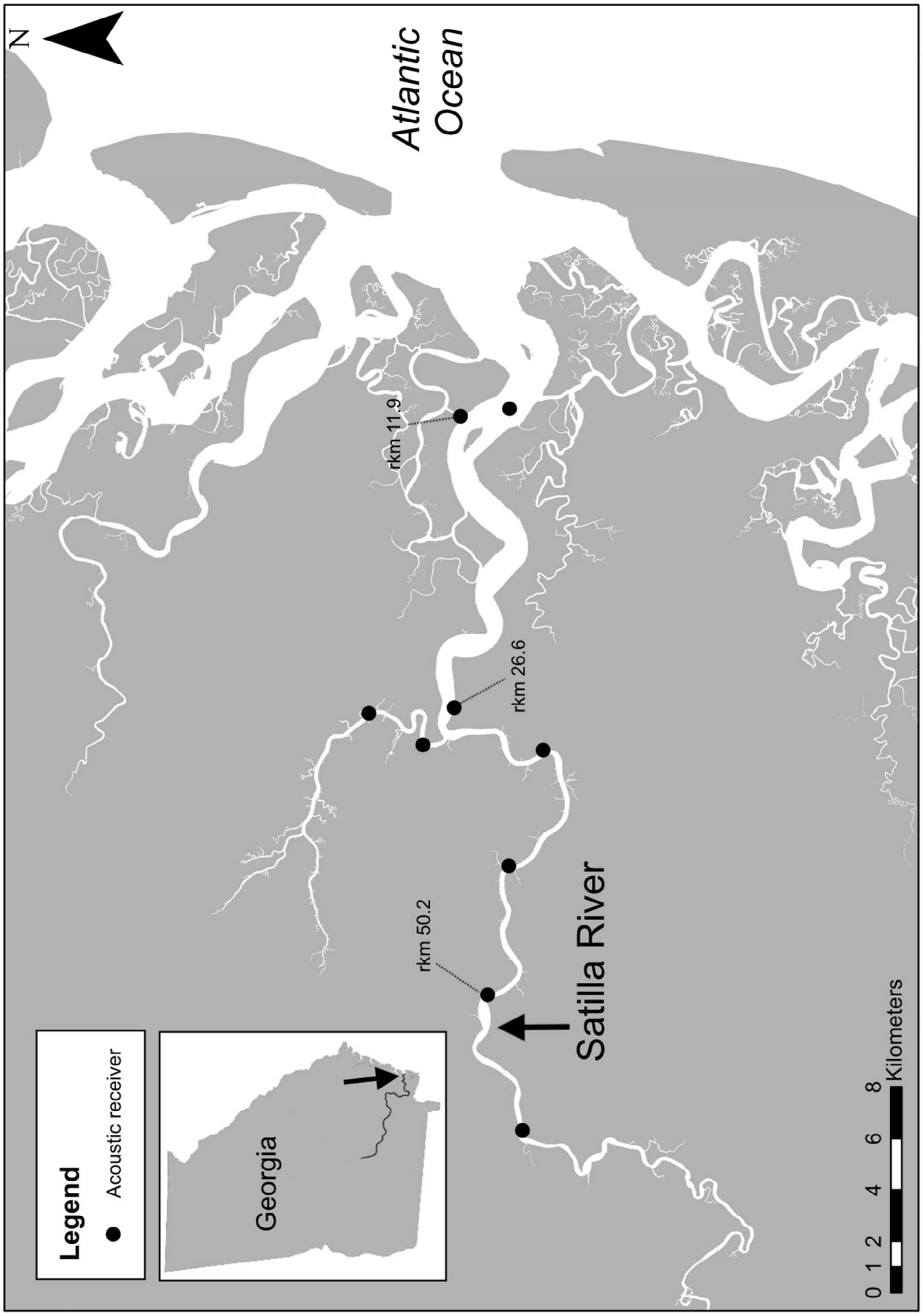
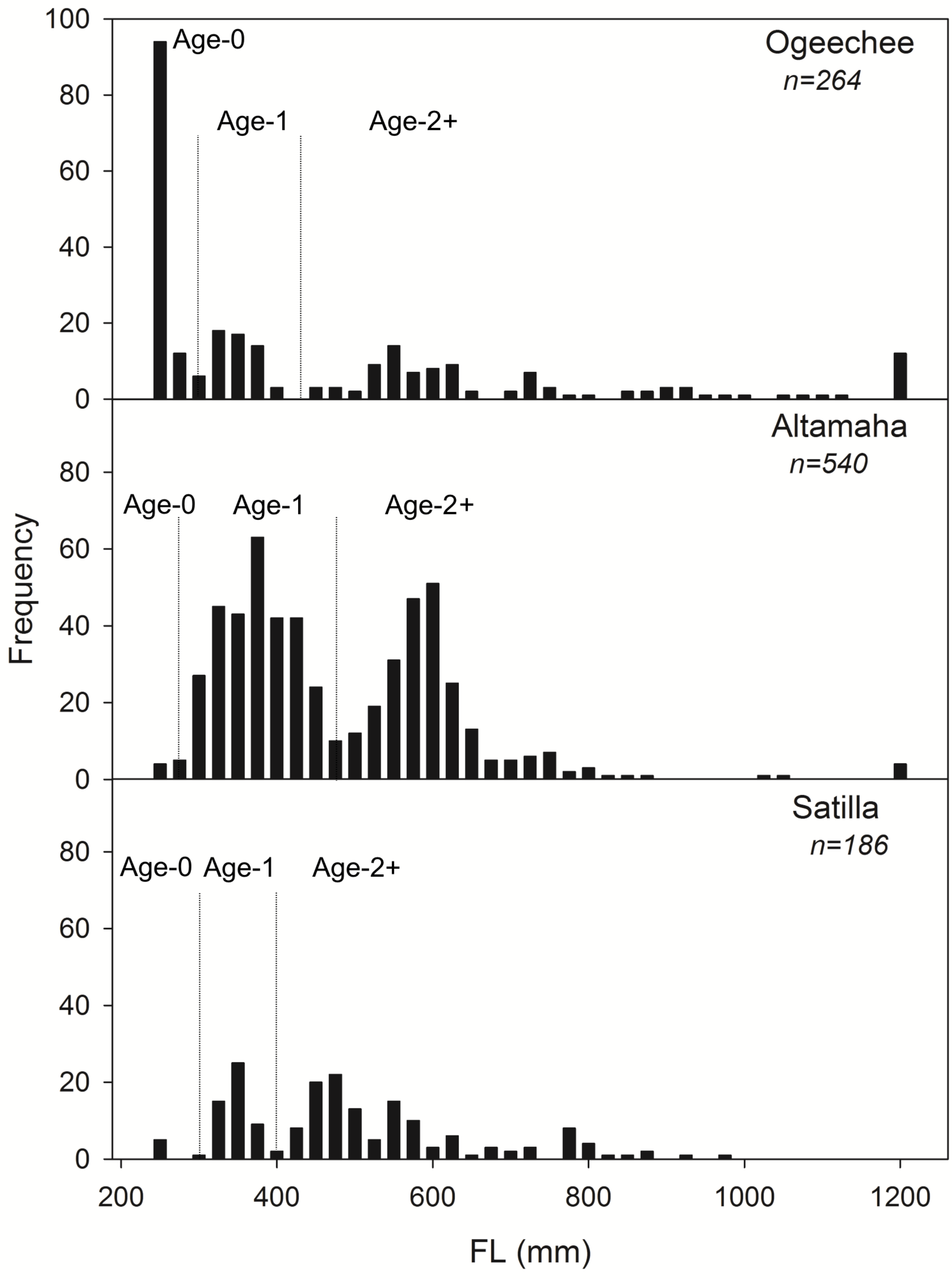


Figure 4.4.

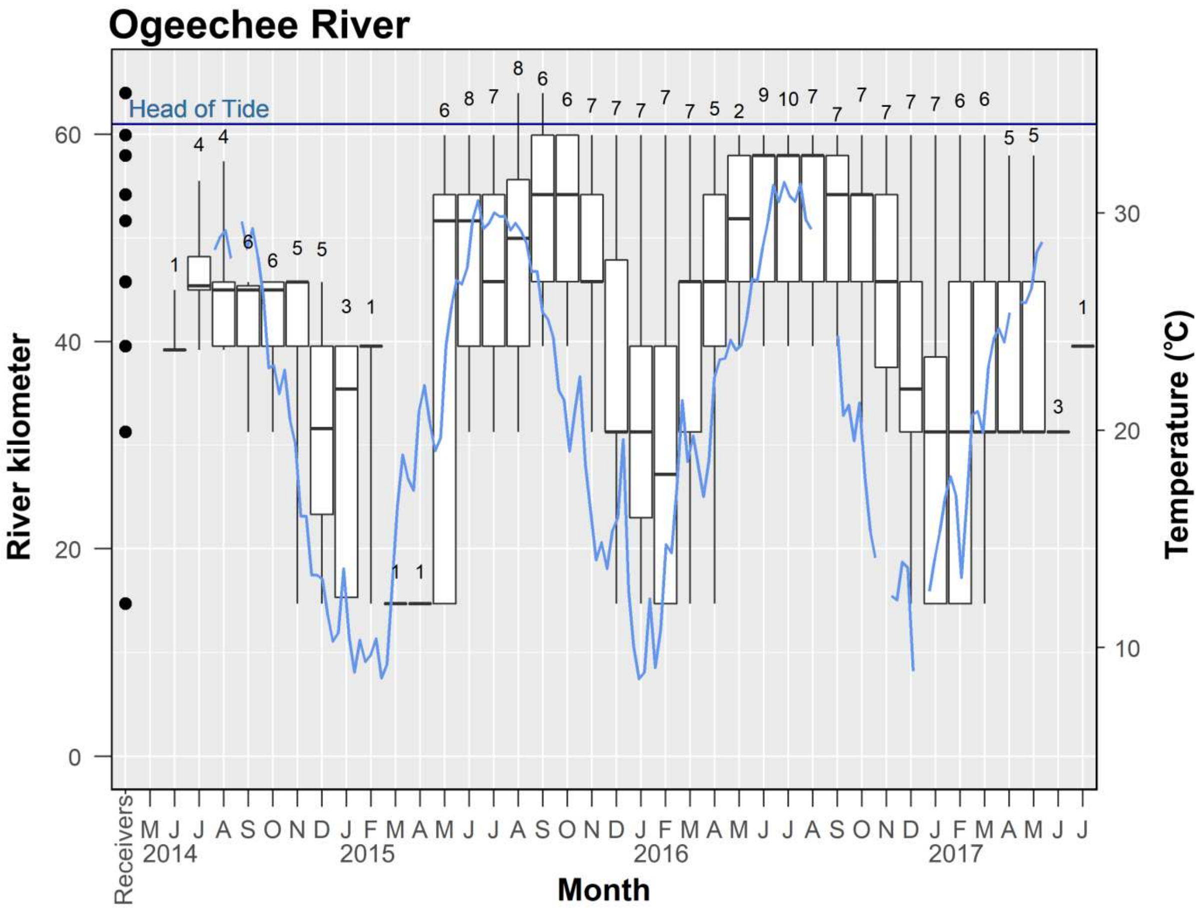
Figure 4.4: Map of Satilla River, Georgia, USA. Black dots represent acoustic receiver stations. River kilometer (rkm) location of several receiver stations is included for reference.



Ogeechee
n=264
Age-0
Age-1
Age-2+
Altamaha
n=540
Age-0
Age-1
Age-2+
Satilla
n=186
Age-0
Age-1
Age-2+
Frequency
FL (mm)
0
20
40
60
80
100
200
400
600
800
1000
1200

Figure 4.5.

Figure 4.5: Length-frequency histograms for Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) captured in the Ogeechee, Altamaha, and Satilla Rivers, Georgia, USA in 2014-2016. Age assignments are based on Schueller and Peterson (2010), and validated by aging with randomly selected fin rays



Ogeechee River
Head of Tide
River kilometer
Temperature (°C)
Month
Receivers
M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J
2014
2015
2016
2017
0
20
40
60
10
20
30

Figure 4.6a.

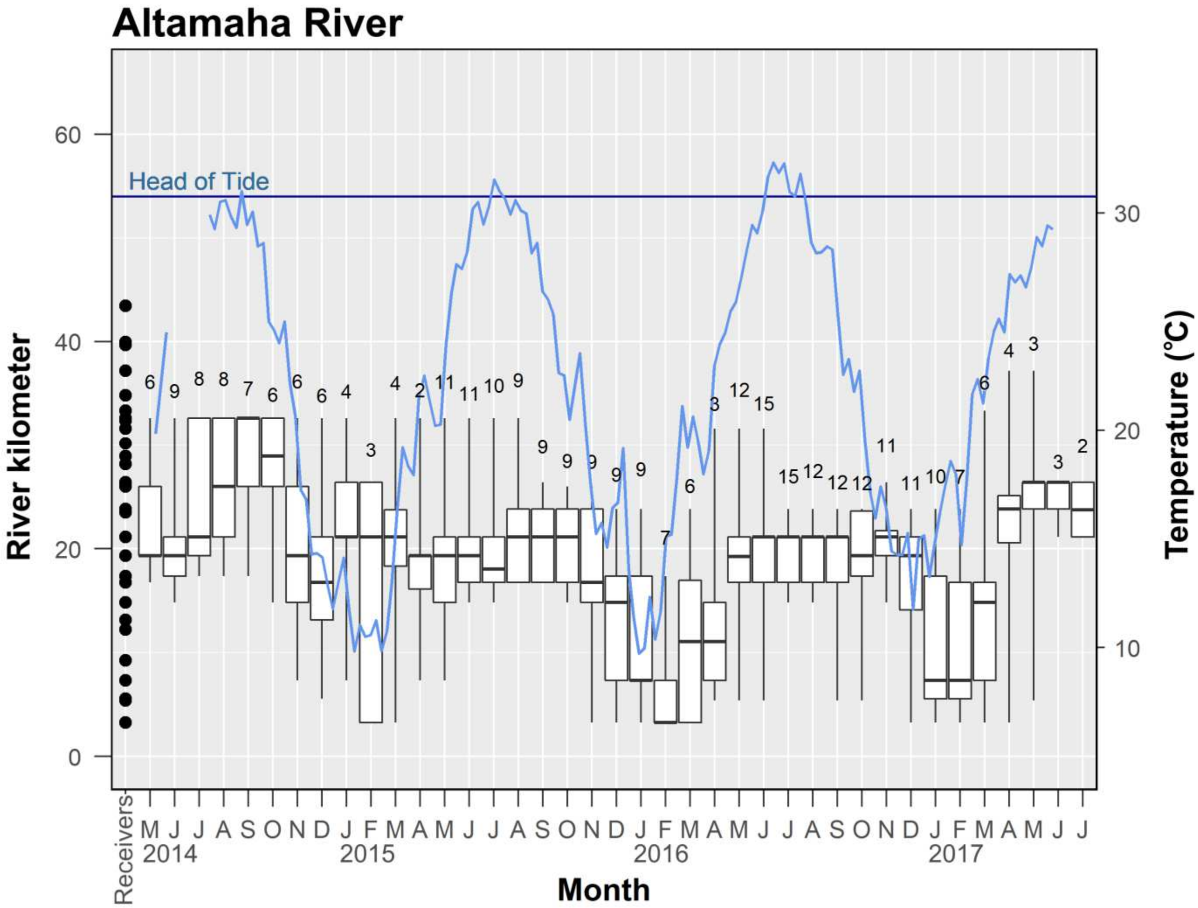

Altamaha River
Head of Tide
River kilometer
Temperature (°C)
Month
Receivers
M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J
2014
2015
2016
2017

Figure 4.6b.

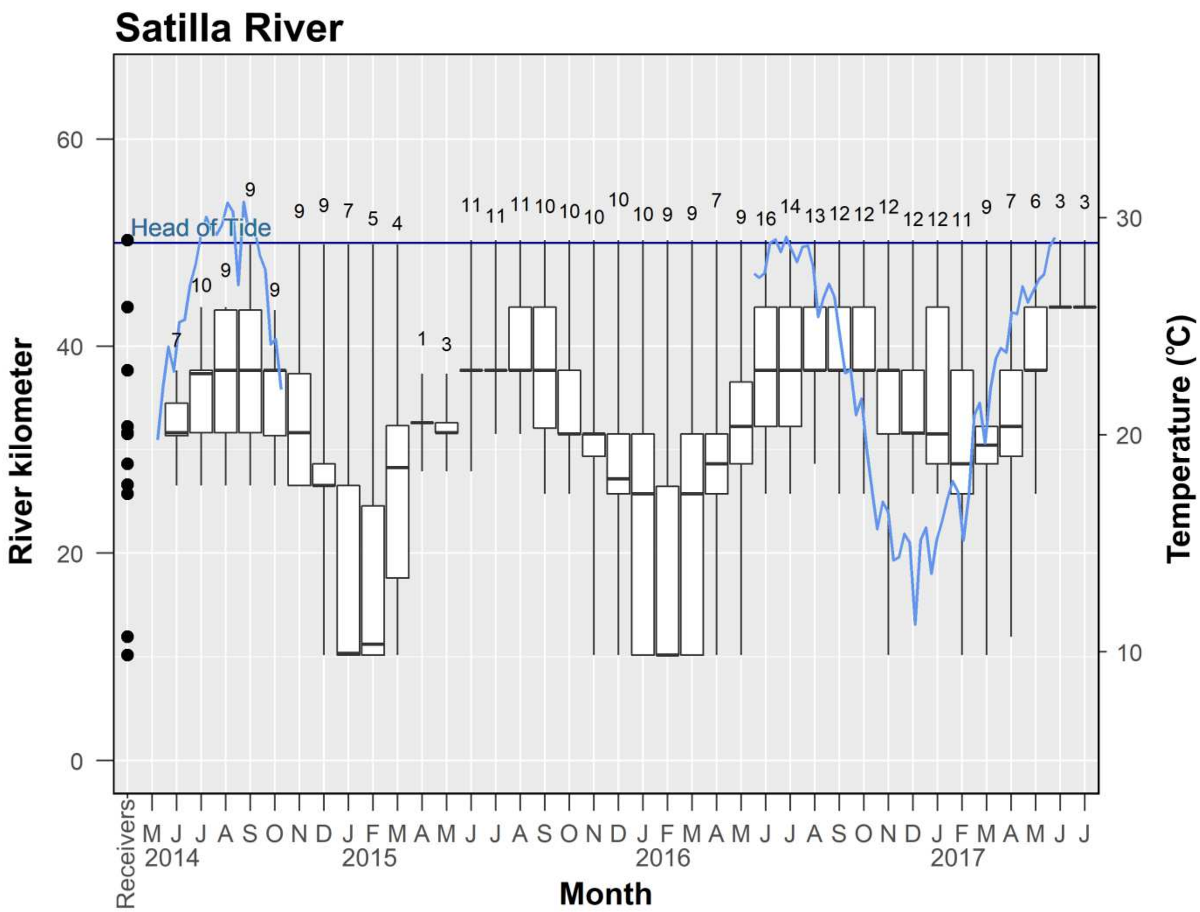

Satilla River
Head of Tide
River kilometer
Temperature (°C)
Receivers
M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J
2014
2015
2016
2017
Month
0
20
40
60
10
20
30

Figure 4.6c

Figure 4.6: Habitat use by age-1 juvenile Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) tagged in the Ogeechee River (Fig. 4.6a), Altamaha River (Fig. 4.6b), and Satilla River (Fig. 4.6c), GA, USA. Boxplot ends represent 25th and 75th percentiles of all tag detections. Line within box is median river kilometer (rkm) position of all fish. Error bars [whiskers] represent minimum and maximum rkm detections. The number over each box indicates the number of individuals detected that month. Dots along the main Y-axis represent the rkm positions of receivers in the acoustic array. The blue line indicates water temperature.

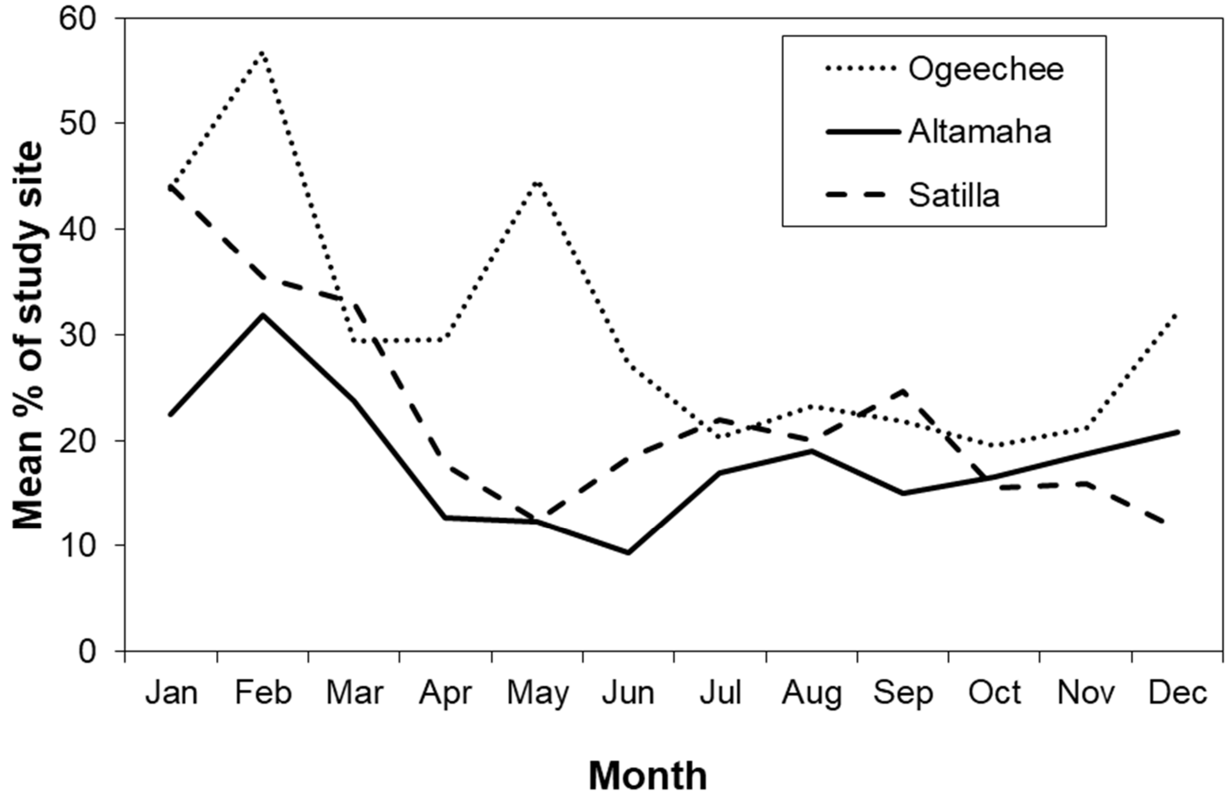


Figure 4.7: Mean percentage of study site used by the 25th-75th percentile of age-1 Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) per month (months combined) in the Ogeechee, Altamaha, and Satilla Rivers, Georgia, USA, 2014-2017.

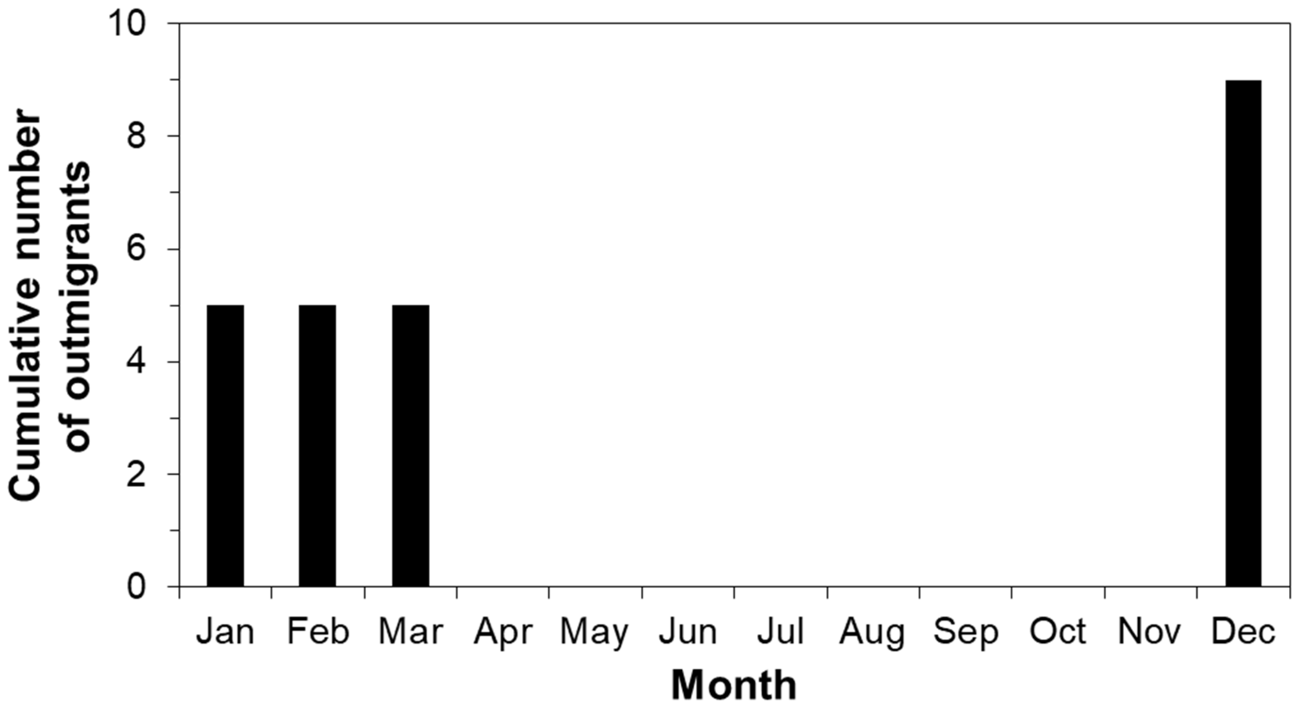


Figure 4.8: Number of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) outmigrating from their natal river, by month. Outmigration was denoted by the last acoustic detection in the natal river of an acoustically tagged fish that was later detected in a non-natal system. Fish were originally tagged in the Ogeechee, Altamaha, and Satilla Rivers, Georgia, USA. Counts are cumulative for each month across all study years (2014-2017).

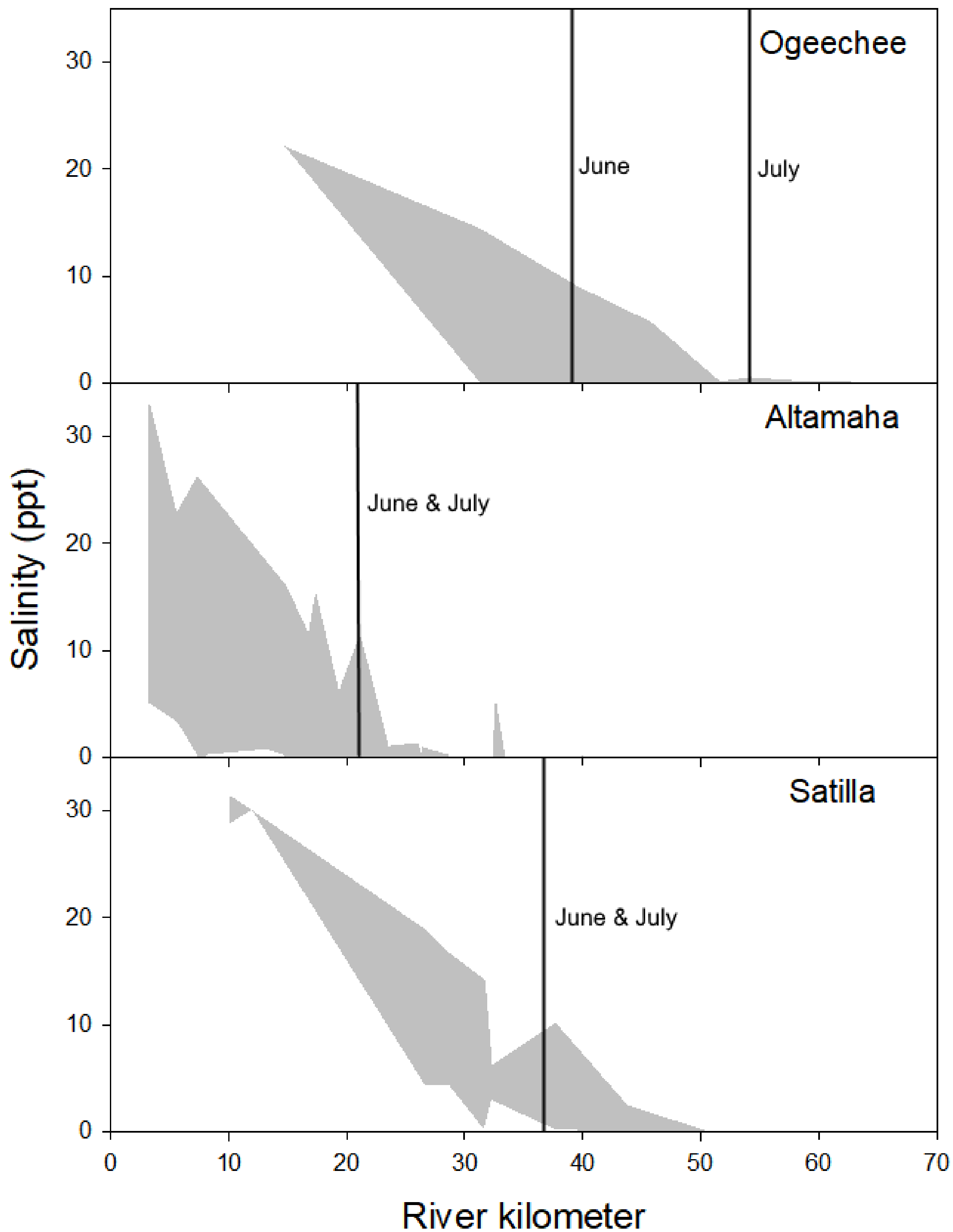

Ogeechee
June
July
Altamaha
June & July
Satilla
June & July
Salinity (ppt)
River kilometer
0
10
20
30
0
10
20
30
40
50
60
70

Figure 4.9.

Figure 4.9: Observed salinity ranges in the Ogeechee, Altamaha, and Satilla Rivers, Georgia, USA during June and July 2015-2016. Shaded area represents the range (minimum to maximum) of recorded salinities (on the Y-axis) at each receiver station (plotted by river kilometer on the X-axis). Median monthly positions of age-1 Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) for each month are indicated with vertical lines.

CHAPTER 5

CONCLUSIONS

This study addressed several key research objectives identified by the National Marine Fisheries Service (NMFS) regarding the endangered Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) at the southern margin of the species' range (ASSRT 2007). First, we conducted status assessments for the two southernmost rivers in the species' historic range: the St. Johns River in Florida and the St. Marys River in Georgia, in order to determine if Atlantic Sturgeon had been extirpated from those systems. Second, we investigated the seasonal patterns of habitat use by river-resident juveniles (RRJs) in the southern part of the species' range, and compared the recovering Altamaha River to the still-impaired Ogeechee and Satilla Rivers. We also looked at the timing and drivers and timing of outmigration as RRJs left their natal rivers. Although NMFS designated critical habitat for Atlantic Sturgeon in 2016 (Federal Register 2017), our results provide a better understanding of riverine and estuarine habitat use that may help management agencies identify environmental and anthropogenic stressors that are impairing recovery.

The first step in defining the status of each Atlantic Sturgeon population is to confirm that the species is still present in each river. The presence of RRJs within the estuary is a strong indicator of an extant population, as it confirms that reproduction is successfully occurring in that system (Schueller and Peterson 2010). Because RRJs are the only life stage at which an entire year class can be quantified, annual recruitment estimates provide managers with the best current metric for assessing population status. The St. Johns River is considered to be the southernmost river in the historic range of the Atlantic Sturgeon, and the present status of the population there was unclear (ASSRT 1998; ASSRT 2007). Our sampling there produced no evidence of RRJ sturgeon. This lack of successful reproduction suggests that the St. Johns River population of Atlantic Sturgeon has likely been extirpated from that river system. The loss of this population is an indication of range contraction. Sampling in the St. Marys River, Georgia, the second-southernmost river in the species' range, did produce evidence of RRJ Atlantic Sturgeon, although only one small cohort was observed. The RRJs we captured were genetically distinct from other South Atlantic sturgeon populations, and the capture of these juveniles provided proof that a remnant Atlantic Sturgeon population persists in the St. Marys. Until this rediscovery, the species was thought to have been extirpated from the St. Marys River (Blair et al. 2009). Telemetry data from both the St. Johns and St. Marys River estuaries revealed that both estuaries remain important habitat for the species, as migrant adult and subadult Atlantic Sturgeon originating from other rivers regularly use both rivers.

My analysis of juvenile Atlantic Sturgeon habitat use in the Ogeechee, Altamaha, and Satilla Rivers is the first of its kind from the southern portion of the species' range. Telemetry data revealed a consistent pattern of seasonal habitat use, in which RRJ sturgeon become concentrated in a relatively small area of nursery habitat near the head of tide during the summer, and then disperse and move downstream during the winter. This pattern is likely driven by interactions between water temperature and salinity tolerance (Niklitschek and Secor 2005). Similar up- and downstream seasonal movements were reported for RRJ Atlantic Sturgeon in the Hudson River by Bain et al. (2000), and the pattern is likely common for populations throughout the species' range. Although critical habitat for Atlantic Sturgeon was recently designated

(Federal Register 2017), those areas are very broad and include both spawning and nursery habitats. This study clearly defines Atlantic Sturgeon nursery habitat in Georgia, which will help managers make informed decisions about potential habitat alteration in those river reaches.

Little is known about the transition from RRJ to marine migratory juvenile (MMJ), but this study provides some of the first quantitative data about Atlantic Sturgeon outmigration. During the winter, as juveniles disperse into more saline habitat, some individuals move downstream and leave their natal river. A minimum of 25% of RRJs tagged in this study outmigrated during the winter of age-2. The transition of these individuals from RRJ to MMJ was confirmed by telemetry detections of these fish by acoustic receiver arrays located in non-natal rivers and estuaries, and offshore of the Georgia coast. We observed no evidence of outmigration before the winter of age-2. There was no consistent directional pattern among these newly-minted MMJs, and they were detected in a variety of riverine, estuarine, and offshore environments.

My results have several important implications for the management of Atlantic Sturgeon populations. First, the rediscovery of a population in the St. Marys River demonstrates that remnant Atlantic Sturgeon can survive, undetected, for years or even decades. Over the six years of directed sampling by this study and Fritts and Peterson (2011), RRJ were only detected in one year. The persistence of the St. Marys population has important ramifications for populations in other river systems. Similar long-term monitoring is necessary to detect any rare, intermittent recruitment events, and should be employed in rivers, like the St. Johns or the river of Chesapeake Bay, where the species is currently thought to be extirpated.

The recently-designated critical habitat for Atlantic Sturgeon includes all rivers in the species' historic range, from the mouth to the lowest downstream dam (and even above that, in some systems) (Federal Register 2017). This critical habitat does not specifically address which reaches of the river are important for which sturgeon life stage (e.g., spawning, nursery habitat, adult holding). The seasonal pattern of habitat use that we found in the Ogeechee, Altamaha, and Satilla Rivers may provide the clearest picture of RRJ nursery habitat to date. In all three rivers, sturgeon exhibited the same seasonal movements- fish concentrate upstream in summer, and disperse downstream in the cooler months. This has important implications for any channel modification projects that might take place in Georgia's rivers in the future. If construction or dredging must occur in the lower reaches of an estuary, the direct impact on RRJs could differ greatly depending on the timing of the project.

Although the pattern of habitat use was consistent between the Ogeechee, Altamaha, and Satilla Rivers, the amount of available nursery habitat did differ among systems. One of the biggest differences we observed among the three rivers was that a greater proportion of tagged RRJ sturgeon outmigrated from the Altamaha River than from the other two rivers. This may be due to the Altamaha population approaching full recovery. As the population approaches the carrying capacity of the nursery habitat, density-dependent interactions may drive RRJs to outmigrate earlier, compared to the smaller populations in the Ogeechee and Satilla, which are much earlier in the recovery process.

An important result of this study is that it supports several assumptions that underpin the mark-recapture studies that have been used to quantify the age-1 RRJ cohorts in Georgia Rivers (i.e., recruitment). Our telemetry data confirm that age-1 RRJs are constrained to relatively small areas of nursery habitat during the summer months; these are the areas which have been historically targeted by mark-recapture studies in those rivers (Farrae et al. 2009; Schueller and Peterson 2010; Fritts et al 2016). Additionally, no RRJs were observed to outmigrate before the winter of age-2, confirming the assumption that the population is closed during the summer of age-1.

Future studies are needed to better understand the environmental tolerances of juvenile Atlantic Sturgeon in the southern reaches of their range. The water temperatures and other environmental parameters we observed during our studies were very different from those reported in more northerly populations (Bain et al. 2000; Niklitschek and Secor 2005). More detailed knowledge about the salinity, temperature, and dissolved oxygen tolerances of southern sturgeon would help determine if water quality is a bottleneck to recovery, as well as predict the effects of climate change on these populations. Effective management strategies for the recovery of Atlantic Sturgeon require a better understanding of the status of each population, and our studies provide new insights into the under-studied populations at the southern margin of the species' range.

References

ASSRT (Atlantic Sturgeon Status Review Team). 1998. Status review of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), 126 p. Report prepared for Natl. Mar. Fish. Serv., Silver Springs, MD.

ASSRT 2007. Status review of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*), 174 p. Report to Northeast Reg. Off., Natl. Mar. Fish. Serv., Gloucester, MA.

Bain, M., N. Haley, D. Peterson, J. R. Walrman, and K. Arend. 2000. Harvest and habits of Atlantic Sturgeon *Acipenser oxyrinchsu* Mitchill, 1815 in the Hudson River estuary: lessons for sturgeon conservation. Biol. Inst. Esp. Oceanogr. 16:43-53.

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 Law Practicum.

Federal Register. 2017. Endangered and Threatened Species; Designation of Critical Habitat for the Endangered New York Bight, Chesapeake Bay, Carolina and South Atlantic Distinct Population Segments of Atlantic Sturgeon and the Threatened Gulf of Maine Distinct Population Segment of Atlantic Sturgeon. Fed. Register 77:5880–5912.

Niklitschek, E. J., and D. H. Secor. 2005. Modeling spatial and temporal variation of suitable nursery habitats for Atlantic Sturgeon in the Chesapeake Bay. Estuar. Coast. Shelf Sci. 64:123-148.