Mapping Potential Spawning Substrate for Shortnose and Atlantic Sturgeon in Coastal Plain Rivers of Georgia Using Low-cost Side-scan Sonar

Thomas L. Litts, *Georgia Department of Natural Resources, Wildlife Resources Division, 2065 Highway 278 SE, Social Circle, Georgia 30025*

Adam J. Kaeser, *U.S. Fish and Wildlife Service, 1601 Balboa Avenue, Panama City, FL 32405*

Abstract: Characterizing the habitat of large, navigable rivers is difficult, yet this information is critically important to the conservation of a variety of resident aquatic species. We used low-cost sonar habitat mapping to map benthic substrates throughout nearly 1000 km of four Coastal Plain rivers in Georgia and to quantify the distribution of rocky substrates that may serve as potential spawning habitat for two imperiled sturgeon species, the shortnose sturgeon (*Acipenser brevirostrum*) and the Atlantic sturgeon (*Acipenser oxyrinchus*). Although we identified hard, rocky substrates in roughly half of the river km suggested by previous researchers as potential spawning zones, mapping revealed hard substrates in many other locations as well. Our approach provided a detailed view of the distribution, configuration, and extent of these habitats across the riverscape; these results can be used to support future research to gain a better understanding of other key factors associated with spawning habitat selection and habitat change over time. The ability to train novice technicians to execute all phases of the mapping process, and the overall classification accuracy achieved (82%) in this study demonstrated the practicality of this methodology for providing the spatially explicit, and continuous perspective of habitat required for effective conservation across the freshwater range of migratory species like sturgeon.

Key words: Acipenser brevirostrum, *Acipenser oxyrinchus*, spawning, habitat distribution, GIS

Journal of the Southeastern Association of Fish and Wildlife Agencies: 3:80–88

Characterization and assessment of habitat is challenging in large and turbid river systems inhabited by sturgeon and other imperiled aquatic species, yet this information is fundamental to conservation success. Several coastal plain rivers of Georgia are inhabited by two federally-protected species of sturgeon, the endangered shortnose sturgeon (*Acipenser brevirostrum*), and the endangered South Atlantic population segment of Atlantic sturgeon (*Acipenser oxyrinchus;* National Marine Fisheries Service 1998, 2012). As anadromous fish, adult sturgeon migrate from estuaries into freshwater rivers seeking rocky or coarse substrates such as gravel, cobble, boulder, and bedrock to deposit their adhesive eggs during spawning (Hall et al. 1991, Collins et al. 2000, Schueller and Peterson 2010). Within Georgia, shortnose sturgeon ascend rivers during winter to presumably spawn in the spring; whereas Atlantic sturgeon enter rivers either in spring or late summer to presumably spawn in the fall (Peterson and Ingram 2015). Although the availability of clean, hard substrates is essential to spawning success, coastal plain rivers of Georgia are typically predominated by sandy substrate, and patterns of fine sediment deposition are dynamic and influenced by hydrologic regimes and regulation, channel alteration, and land-use practices that affect sediment inputs and sediment transport (Garman and Nielsen 1992, Watters 1999). Thus, the ability to identify and quantify potential spawning substrates, and to monitor changes in the availability and condition of these habitats over time, is an essential element of species recovery and habitat conservation (National Marine Fisheries Service 1998, 2012). Moreover, such information is critical to a variety of legal mechanisms associated with species conservation under the Endangered Species Act, such as Section 7 consultation and Section 4 recovery (U.S. Fish and Wildlife Service 1973).

Until recently, production of high-resolution maps of classified benthic substrates and other habitat features over large spatial extents in inland freshwater systems was logistically impractical, and thus infrequently conducted, due to expense and technical requirements. Between 2006 and 2008, the Georgia Department of Natural Resources (GADNR) pioneered a methodology for producing such maps using the inexpensive (~US$2500) Humminbird Side Imaging system, a recreational-grade, side scan sonar device (Kaeser and Litts 2008, 2010). Sonar imaging of entire river channels is possible with this equipment, and interpretation of imagery allows for the delineation and classification of major substrate classes and the mapping of large woody debris, river banks, and other key features within a geographic information system (GIS) environment. Methods for riverine habitat mapping were successfully demonstrated and validated on ~200 km of rivers and creeks in southwest Georgia (Kaeser and Litts 2008, 2010; Kaeser et al. 2012). The success of these efforts suggested that low-cost sonar habitat mapping might be used to characterize benthic habitats throughout entire river basins, providing both the high spatial resolution necessary to identify discrete patches of suitable spawning substrate for stur-

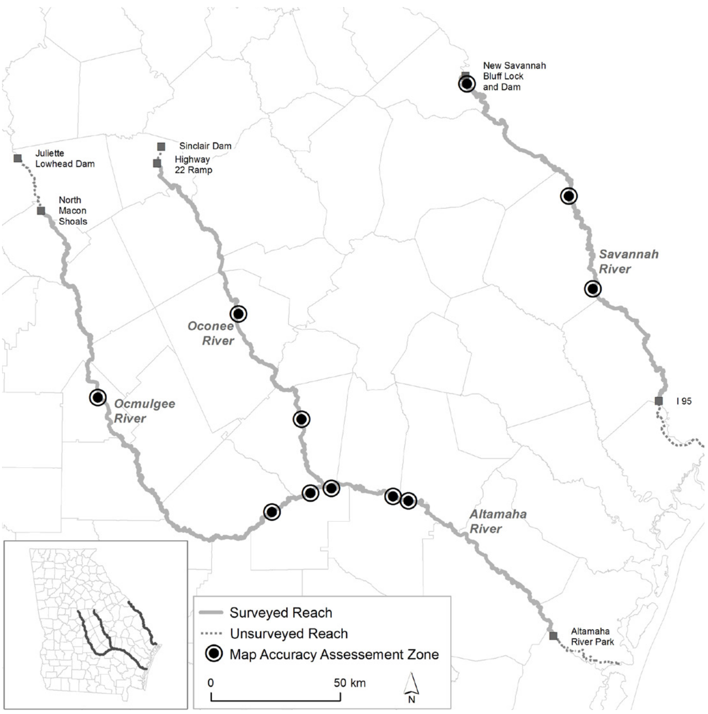

Figure 1. Map of the study area and accuracy assessment reach locations on the Altamaha, Ocmulgee, Oconee, and Savannah rivers in Georgia.

geon and the large-scale spatial coverage required to quantify these patches across the vast reaches of river traversed by migratory fish. Thus, the objective of this study was to characterize and quantify potential shortnose sturgeon and Atlantic sturgeon spawning substrate across ~950 km of the Altamaha, Ocmulgee, Oconee, and Savannah rivers in Georgia. The distribution of rocky substrates revealed by sonar mapping was compared to suggested spawning zones identified through previous telemetry investigations of sturgeon in the Altamaha and Savannah rivers.

Methods

Study Area

Three of the study rivers, the Altamaha, Ocmulgee, and Oconee, flow entirely within the state of Georgia; whereas, the Savannah River forms the boundary between Georgia and South Carolina for much of its course (Figure 1). The headwaters of the Ocmulgee, Oconee, and Savannah rivers originate above the "Fall Line," a geologic feature oriented northeast to southwest across the middle of Georgia that represents the boundary between the Piedmont and Coastal Plain ecoregions (Wharton 1989). The Ocmulgee, Oconee, and Savannah rivers are each impounded at multiple locations; the most downstream impoundment on each river is the Juliette Lowhead Dam, the Sinclair Dam, and the New Savannah Bluff Lock and Dam, respectively (Figure 1). Passage of sturgeon above these impoundments is not possible; therefore, the barriers represent the upper limit to sturgeon migrations. The Ocmulgee and Oconee rivers join to form the Altamaha River, which flows unobstructed to the Atlantic Ocean. This study targeted the free flowing portions of each river, beginning below the most downstream impoundments where navigation was feasible (e.g., North Macon Shoals on the Ocmulgee River) and concluding at Altamaha River Park on the Altamaha River and the I-95 bridge across the Savannah River. Survey end points were selected for practical reasons associated with river widening and braiding in lower reaches and the notion that additional spawning substrate would not be found further downstream.

Sonar Survey and Data Processing

To identify and plan sonar surveys, we first mapped all accessible boat ramps, calculated inter-ramp distances, and identified river segments (25–50 km) that could be surveyed in a day. Optimal flows for surveys that permitted safe navigation and provided full inundation of river channels were identified by reviewing hydrographs and consulting with biologists familiar with study river reaches. The majority of sonar survey work on the Ocmulgee, Oconee, and Altamaha rivers was completed between December 2010 and April 2011. The Savannah River was surveyed the following year during March and April 2012; additional survey details can be found in the final project report (GADNR 2013). All surveys were conducted downstream at a pace of ~8 km h^{-1} using a Humminbird 1198c SI system, with a front-mounted transducer. The transducer was attached to a galvanized pipe, mounted at the front of a powered 5-m long johnboat using a trolling motor mounting bracket, and was set ~10–13 cm below the river surface. The SI system was networked to WAAS-enabled Garmin GPSMAP 76 GPS to provide coordinate data at image capture locations and a series of track points representing the survey path and associated depth observations at 3-sec intervals. The GPS antenna was positioned near the transducer to maximize image capture location accuracy. Sonar imagery was collected as a series of consecutive overlapping screen snapshots. All rivers were surveyed using an operating frequency of 455 kHz and sonar range settings between 27 m and 49 m, selected to optimize image resolution relative to average channel width and depth (Fish and Carr 1990). Whenever channel width exceeded a maximum swath width of 98 m per side, a multi-pass, parallel-transect survey approach was employed to maintain high image resolution across the river channel and minimize unclassified areas of the channel (Kaeser et al. 2012).

Sonar image geoprocessing was conducted according to methods described in Kaeser et al. (2012) but adapted for ArcGIS 10.0. Once processed, the sonar image maps (SIMs, i.e., rectified im-

Table 1. Substrate classification scheme used for mapping the Altamaha, Ocmulgee, Oconee, and Savannah rivers in Georgia during 2010–2012.

Substrate class	Acronym	Definition
Sand	S	≥75% of area composed of particles <2 mm and >0.075 mm diameter, excepting those classified as clay/mud.
Rocky fine	Rf	>75% of area composed of rocks >63 mm but <500 mm in diameter across the longest axis (i.e. cobble/small boulder).
Rocky boulder	Rb	An area that includes ≥3 large boulders, each ≥500 mm diameter across longest axis, each boulder within 1.5 meters of the next adjacent boulder. Any area meeting these criteria, regardless of underlying substrate, is classified rocky boulder.
Bedrock	B	≥75% of area composed of bedrock (e.g., limestone, sandstone, or claystone).
Clay/mud	CM	>75% of area composed of clay or mud (<0.075 mm diameter)
Vegetated bank	Vb	An area consisting of emergent or submerged vegetation, excluding LWD as defined below. Examples may include: cypress knees, stumps, willow stands, trunks, sedges and other grasses generally occurring in bank / riparian zone interface. Any area meeting these criteria, regardless of underlying substrate, is classified Vb.
Unsure	Uns	An area of the sonar map difficult to classify due to insufficient image resolution.
Sonar shadow	SS	An area of the sonar map within range that was not imaged because the sonar signal was blocked by reflective object(s), or down sloping features.
No data	No	An area of the sonar map beyond sonar range but within the boundaries of the wetted river channel.
Island	Isl	Any area of land wholly contained within the river channel that is surrounded by water during typical winter/spring discharge.
Other	0	Areas that do not meet any of the above classifications.

age datasets) were loaded into an ESRI ArcGIS 10.0 workspace to provide a spatially continuous, 2-dimensional representation of the river bottom across the entire study area. Sonar waypoints and track points recorded during surveys were merged to create point shapefiles representing water depth below the transducer along all survey routes. These data were used to chart and summarize river depths at the time of survey for all study rivers.

Substrate Mapping

A substrate classification scheme was developed that borrowed elements from schemes used to map other Georgia rivers (Kaeser and Litts 2010, Kaeser et al. 2012), but also included new classes to represent substrates observed during field reconnaissance on the study rivers. All substrate categories used in this study and their definitions can be found in Table 1.

Sonar image maps were inspected at scales from 1:400 to 1:600 to manually delineate river banks, then substrate class boundaries were delineated around areas of similar sonar signature that were greater than a minimum mapping unit of 314 m^2. Substrate polygons were classified based on visual interpretation of image signatures using texture, tone, shape, and pattern. All mapping was conducted by a technician with no prior experience with the methodology who received training by the authors. Map products were reviewed and edited by T. Litts wherever necessary prior to finalization.

To summarize the resulting map data in a standardized manner, study rivers were each subdivided into discrete, consecutive 1-km reaches that were numerically ordered. This procedure was enabled by segmenting the National Hydrography Dataset (NHD) high-resolution flow line for each study river and assigning the appropriate river kilometer (rkm) to each segment starting with rkm 0 at the mouth or confluence/tail of each river. The NHD flow line was edited wherever necessary to follow the actual path taken by the sonar survey vessel. As a result, rkm designations for rivers in this study may differ somewhat from rkm assignments appearing elsewhere in the published literature. We adjusted the rkm assignment for the Altamaha River by 7 km to align the starting point of our sonar survey at Altamaha Park with the assignment of 44 rkm used by Rogers and Weber (1995).

The resulting map data was extracted and summarized using the rkm-reach designations. River channel widths were measured at all rkm segment breaks to generate estimates of minimum, maximum, and average widths for each study river.

Map Accuracy Assessment

A classification accuracy assessment was conducted in three assessment reaches in each study river. Reaches that exhibited high substrate heterogeneity and were located in close proximity to boat ramps were selected to facilitate reference data collection. Assessments were conducted on the Altamaha, Ocmulgee, and Oconee rivers during August–September 2011 during a period of low flows and during July 2012 on the Savannah River when flows were similar to those experienced during the sonar survey.

In total, 342 map polygons were inspected from each of the following classes: rocky boulder, rocky fine, sand, bedrock, vegetated bank, and clay/mud. Map polygons were randomly selected within each assessment reach with the exception of the Savannah River where polygons were selected opportunistically based on their availability within assessment reaches. Discrete reference data points were randomly placed within a 5-m internal buffer of each map polygon, a measure taken to minimize co-registration errors associated with map and GPS positional accuracy in the field (Congalton and Green 1999). Coordinates for reference data points were uploaded to a Trimble Pro XR GPS device with accuracy <1 m, and navigated to by johnboat. When a reference point was located, the johnboat was either anchored atop the point or was taken ashore and the substrate in the vicinity of the point was inspected, classified, and recorded. Substrate inspection tech-

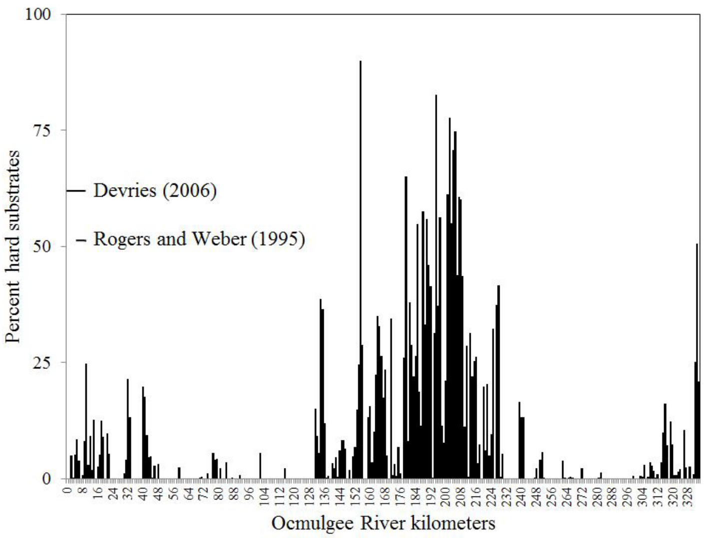

Figure 2. Proportion of hard substrates (i.e., bedrock, rocky boulder, and rocky fine classes) mapped using side scan sonar within each 1-km reach of Ocmulgee River river kilometers 0–334 during 2010–2011. Solid lines identify reaches of the river suggested by Rogers and Weber (1995) and Devries (2006) as spawning zones for shortnose sturgeon and Atlantic sturgeon.

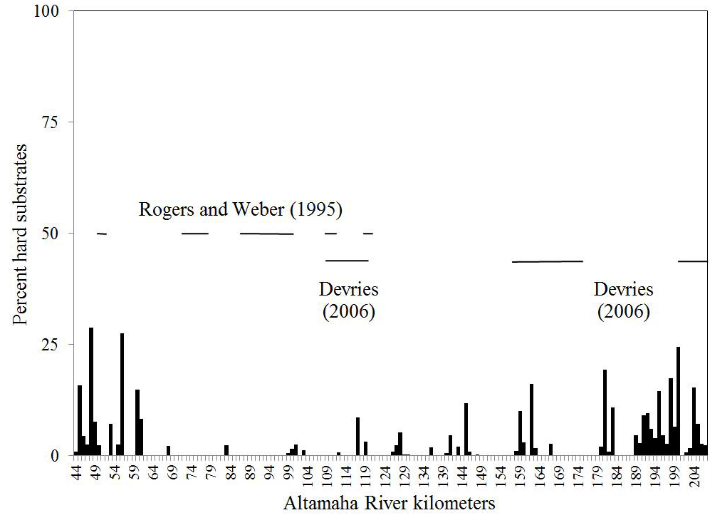

Figure 4. Proportion of hard substrates (i.e., bedrock, rocky boulder, and rocky fine classes) mapped using side scan sonar within each 1-km reach of Altamaha River river kilometers 44–207 during 2010–2011. Solid lines identify reaches of the river suggested by Rogers and Weber (1995) and Devries (2006) as spawning zones for shortnose sturgeon and Atlantic sturgeon.

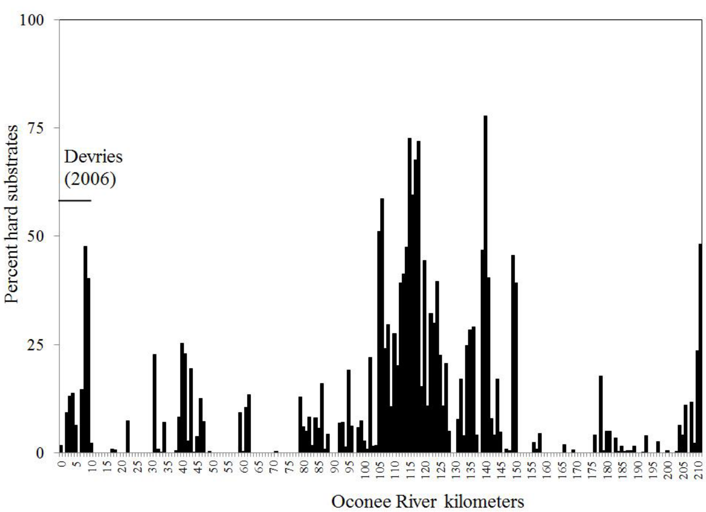

Figure 3. Proportion of hard substrates (i.e., bedrock, rocky boulder, and rocky fine classes) mapped using side scan sonar within each 1-km reach of Oconee River river kilometer 0–211 during 2010–2011. The solid line identifies reaches of the river suspected by Devries (2006) as spawning zones for shortnose sturgeon.

niques included the use of a drop camera with video DVR recording capability, snorkeling, grab sampling, visual assessment, and tactile and auditory observations obtained with a ~2-m long aluminum sounding rod (Kaufmann 2000) used to scrape and prod the substrate. Map substrate classifications were not available during reference data collection.

Error matrices and classification accuracy statistics were computed using reference data combined from assessments in all four study rivers (Congalton and Green 1999). Overall mapping accuracy, a statistic that represents the proportion of correctly classified sites visited during reference data collection, was calculated from error matrix data. Producer's accuracy, a statistic that represents the map maker's ability to correctly identify substrates appearing in the sonar image maps, and user's accuracy, a statistic that describes the proportion of classified areas on the map that were confirmed in the field, were also calculated from error matrix data. The standard error matrix was normalized, an iterative proportional fitting procedure that allows individual cell values within the matrix to be directly compared regardless of differences in sample size, and a Kappa analysis was performed using MARGIT (Congalton 1991).

To compare the distribution of hard substrates as revealed by sonar mapping to habitat use by sturgeon, we examined the following reports of suspected or confirmed spawning activity of shortnose sturgeon and Atlantic sturgeon within the study rivers: Hall et al. (1991), Collins and Smith (1993), Rogers and Weber (1995), Devries (2006), and Peterson and Ingram (2015). These studies typically involved telemetry monitoring of sturgeon during riverine migrations coincident with suspected spawning periods. In these studies, the upstream limits of migration and areas of concentrated activity were interpreted as suspected or potential spawning zones; these zones were labelled in Figures 2–5 according to literature source. Although several authors examined sturgeon movements in the Ocmulgee and Oconee rivers, suggested spawning zones within the two rivers were either very limited (i.e., few rkm) or imprecise (> 100 rkm), so we limited our qualitative comparisons to the Altamaha and Savannah rivers. For the sake of clarity, and wherever necessary, references to specific rkm appear-

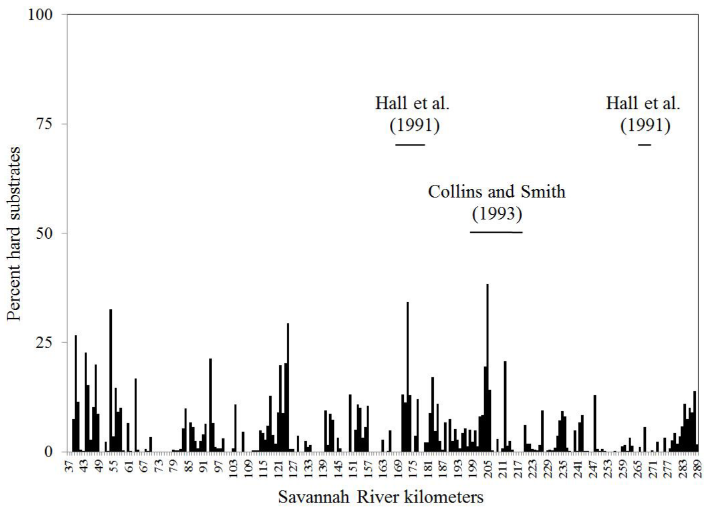

Figure 5. Proportion of hard substrates (i.e., bedrock, rocky boulder, and rocky fine classes) mapped using side scan sonar within each 1-km reach of Savannah River river kilometers 37–289 during 2012. Solid lines identify reaches of the river suggested by Collins and Smith (1993) and Hall et al. (1991) as spawning zones for shortnose sturgeon.

Table 2. Percent composition (%) and total area (ha) of substrate classified via side scan sonar mapping in the Altamaha, Ocmulgee, Oconee, and Savannah rivers in Georgia during the period 2010–2012. Substrate class acronyms are defined in Table 1.

	Altamaha		Ocmulgee		Oconee		Savannah	
Class	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)
B	1.6	40.7	0.6	16.0	4.6	86.2	2.3	63.1
Rb	0.6	14.7	3.4	88.3	1.8	33.6	0.5	14.1
Rf	0.2	4.7	4.2	110.0	1.2	23.0	1.2	32.7
CM	0.4	10.8	2.2	56.4	1.3	23.6	1.2	31.6
S	87.4	2293.8	80.4	2085.3	86.5	1626.3	89.0	2392.7
O	0.0	0.6	0.1	2.0	0.0	0.3	0.8	21.6
Vb	1.6	42.6	5.9	151.9	0.8	15.6	0.2	4.3
SS	0.1	2.9	0.2	4.9	0.9	17.7	0.3	9.2
Isl	1.2	30.5	0.6	16.8	0.1	1.0	0.1	1.9
Uns	0.0	0.2	0.1	2.1	0.0	0.4	0.0	1.2
No	7.0	184.1	2.3	58.7	2.8	52.2	4.3	115.2
Total	100	2625.5	100	2592.4	100	1880.0	100	2687.6

ing in literature sources were calibrated to those designated and reported in this study.

Results

Map Statistics

A total of 961 rkm was mapped throughout the four study rivers, encompassing 9785 ha. The Oconee River had the highest mean depth observed during the sonar surveys (4.3 m), with a mean width of 89 m. The Ocmulgee and Savannah rivers varied in mean width (77 m vs. 109 m, respectively), but the mean depth of both rivers was 3.7 m. The Altamaha River was the widest and shallowest of the four rivers with an average wetted width of 160 m, and average depth of 2.7 m. Both the Altamaha and Savannah rivers were surveyed using a multi-pass (i.e., parallel transects) approach. By conducting multi-pass sonar surveys wherever necessary, we limited the amount of unclassified substrates in the Altamaha River to ~7%. Unclassified substrates in the remaining study rivers ranged from 2%–4% of the total mapped area.

The dominant substrate class observed was sand; percent composition of this substrate varied from 80%–89% across the study rivers (Table 2). Hard substrates, or those classified as bedrock, rocky boulder, or rocky fine, were present in all study rivers although the relative proportions, distributions, and total amounts of these substrates varied among rivers. The Ocmulgee and Oconee rivers contained the largest overall percentages (8.2% and 7.6%, respectively) and total areal extents (214 ha and 143 ha, respectively) of hard substrates. Bedrock was the dominant hard bottom substrate class in the Oconee River, whereas rocky boulder and rocky fine dominated in the Ocmulgee River (Table 2). Both rivers exhibited a broad reach of hard substrates occurring in high proportion relative to the remaining substrate classes. In the Ocmulgee River this reach extended from approximately rkm 131–228, and in the Oconee River this reach extended from rkm 105–150 (Figures 2, 3).

The Altamaha River exhibited the smallest total area of hard substrates (60 ha); these substrates were relatively rare and widely scattered throughout the middle reach of the mapped portion of the river (Figure 4), and most of this substrate was bedrock (Table 2). Hard-bottom substrates were widely distributed throughout the mapped portion of the Savannah River (110 ha total); however, the relative proportions of these substrates rarely exceeded 25% within any particular 1-km reach (Figure 5). In the Savannah River, bedrock was also the dominant hard substrate type (Table 2).

The class vegetated bank was represented in all four study rivers although this class was rarely observed in the Savannah River because sonar surveys were conducted during a period when water levels were not high enough to inundate much streamside vegetation. On the other hand, the class other was most frequently used in the Savannah River map (21.6 ha total), as several broad areas composed of coarse sand and gravel substrates were mapped just downstream of New Savannah Bluff Lock and Dam.

Map Accuracy

Overall mapping accuracy for the six primary substrate classes was 82% (Table 3). Normalized mapping accuracy was slightly lower (80%) because fewer reference data points were visited in

Table 3. Standard error matrix representing accuracy assessment data compiled for the Altamaha, Ocmulgee, Oconee, and Savannah rivers in Georgia. Substrate mapping and accuracy assessment work was conducted during 2010–2012. Substrate acronyms are defined in Table 1. Diagonal, shaded cells of the matrix represent correct classifications for each substrate type.

	Reference site data (field data)							
Classified data	S	Rf	Rb	B	Vb	CM	Row total	User's accuracy
S	37	3	1	0	0	0	41	0.90
Rf	8	68	7	2	0	2	87	0.78
Rb	2	10	52	7	0	1	72	0.72
B	1	2	2	49	0	8	62	0.79
Vb	2	0	0	1	29	0	32	0.91
CM	2	0	0	2	0	44	48	0.92
Column total	52	83	62	61	29	55	342	
Producer's accuracy	0.71	0.82	0.84	0.80	1.00	0.80		0.82 (82%)[a]

a. Overall accuracy statistic

Table 4. Normalized error matrix representing accuracy assessment data compiled for the Altamaha, Ocmulgee, Oconee, and Savannah rivers in Georgia. Substrate mapping and accuracy assessment work was conducted during 2010–2012. Substrate acronyms are defined in Table 1. Diagonal elements of the matrix shaded in gray represent correct classifications for each substrate type.

	Reference site data (field data)					
Classified data	S	Rf	Rb	B	Vb	CM
S	0.799	0.087	0.051	0.018	0.030	0.014
Rf	0.079	0.743	0.112	0.030	0.013	0.024
Rb	0.022	0.110	0.754	0.087	0.013	0.014
B	0.018	0.035	0.048	0.777	0.017	0.105
Vb	0.036	0.011	0.015	0.028	0.901	0.010
CM	0.046	0.014	0.020	0.060	0.026	0.834
			Normalized accuracy = 0.80 (80%)			

the classes exhibiting the highest map accuracy values (Table 4). Producer's accuracy ranged from 71%–100%. Producer's accuracy was lowest for the class sand, indicating that several areas mapped as other substrate types (e.g., rocky fine) were actually composed of sand substrate at the time of accuracy assessment. With regard to this substrate type, 52 locations visited in the field were identified as sand, but only 37 of these had been classified in the map as sand (Table 3). Producer's accuracy was highest for the vegetated bank and clay/mud classes. User's accuracy ranged from 72%–92%. User's accuracy was highest for sand, vegetated bank, and clay/mud classes, and lowest for the rocky boulder class. Kappa analysis on the error matrix yielded a KHAT statistic of 0.78 (variance = 0.0006) and a Z statistic of 30.14. These results indicate that the mapping accuracy results were significantly better than random.

Substrate Distribution and Potential Spawning Habitat

The correspondence between rocky substrates identified by sonar mapping and suspected spawning zones identified via prior telemetry investigations was variable. Of the 57 rkm identified as potential spawning zones in the Altamaha River, only 19 rkm (33%) contained hard substrates. Outside the suggested spawning areas we mapped an additional 48 rkm in the Altamaha River that contained some hard bottom substrate (Figure 4). Of the 37 rkm identified as potential spawning areas in the Savannah River, 24 rkm (65%) contained hard bottom substrates. Similarly, we mapped an additional 152 rkm outside these potential spawning zones that contained hard substrates (Figure 4).

Within suggested spawning zones of the Altamaha River we mapped patches of hard bottom substrate that varied both in area and composition. Below rkm 100, Rogers and Weber (1995) suggested 3 discrete spawning zones. In these zones we identified only a single large outcrop of bedrock (~16,000 m^2) straddling rkm 49–50 and a single outcrop of bedrock (8500 m^2 total area) in rkm 51. Both Rogers and Weber (1995) and Devries (2006) proposed a shortnose sturgeon spawning zone within rkm 109–121 (Figure 4). Although this zone was predominately composed of sand, we identified a large outcrop of bedrock (11,490 m^2) that covered ~8% of rkm 117. Within rkm 119 we identified two patches of rip-rap, an artificial substrate classified as rocky boulder in the map. We did not identify any hard substrates between rkm 120–121.

Farther upstream, between river kilometers 157–175 on the Altamaha River, Devries (2006) identified a suspected shortnose sturgeon spawning zone. Our mapping results found this zone was predominantly sand (90%) with scattered rocky boulder (2%), boulder and rocky fine (<1%) patches. Of particular interest, rkm 159–160 contained a complex of rocky boulder (10,000 m^2) and rocky fine (6700 m^2) substrates. The area near the junction of the Ocmulgee, Oconee, and Altamaha rivers was also identified by Devries (2006) as a suspected spawning zone for Atlantic sturgeon and/or shortnose sturgeon. Although no specific location was provided, this author confirmed spawning in the zone with the collection of two shortnose sturgeon eggs. Within this reach bedrock covered 17% (30,000 m^2) of rkm 198 and was located in a deep outer bend. Another large outcrop (36,000 m^2) was located within rkm 200. Below Highway 221 (rkm 204) we mapped a shoal complex consisting of rocky boulder (11,000 m^2), rocky fine (5000 m^2), and boulder (13,000 m^2). River kilometer 205 also contained substantial areas of boulder (7000 m^2) and smaller associated patches of rocky boulder and rocky fine located immediately below a railroad trestle.

Within suggested spawning areas of the Savannah River a variety of hard bottom substrates were mapped. Hall et al. (1991) suspected spawning by shortnose sturgeon in zones corresponding to rkm 170–181 and 267–270 on our map. Within rkm 170–181, boulder (72,000 m^2) and rocky fine (15,000 m^2) were the most prevalent hard substrates. Savannah River rkm 268, however, contained only a single patch of rocky fine substrate (6000 m^2). Collins and Smith (1993) identified a potential shortnose sturgeon spawning zone corresponding to rkm 199–219 (Figure 5). In this zone we mapped 66,000 m^2 of bedrock, 27,000 m^2 of rocky boulder, and 24,000 m^2 of rocky fine substrate.

Discussion

Through this study we successfully demonstrated that sonar mapping can be undertaken in large, broad rivers and conducted at the river system scale. Overall, map accuracy achieved during this study was comparable to previous sonar habitat mapping projects on smaller systems using the same equipment and configurations (Kaeser and Litts 2010, Kaeser et al. 2012), thus scaling up did not appear to negatively affect map quality. We attribute this result to the attention paid to pre-survey planning, river discharge conditions, proper range selection during sonar surveys, and the use of multiple passes to maintain desired image resolution.

Despite the experience gained by the authors mapping other rivers in Georgia, classification errors were still encountered. One of the more prevalent errors in the map involved the classification of rocky fine areas in the map that were identified in the field as sand during accuracy assessment work. This type of producer's error occurred in previous mapping projects but to a lesser degree (Kaeser and Litts 2010, Kaeser et al. 2012). Rocky fine and sand substrate typically exhibit very different sonar signatures, and so confusing the two is somewhat perplexing. One potential cause of these errors likely involved the redistribution of fine sediments between periods of time associated with the sonar survey and field reference data collection. A striking example of this phenomenon was documented on the Altamaha River when we compared imagery obtained from a reach of the river during low flows on 11 February 2011 to imagery obtained during the actual sonar survey conducted 12 days later (GADNR 2013). A high-flow event occurred between the two surveys, resulting in downstream transport of a large mass of sand that covered an area previously composed of bedrock and rocky fine material. This dramatic example, if repeated in other areas prior to reference data collection, may help explain some of the errors associated with the confusion of coarse textured substrates with sand. Given the preponderance of sand substrate in these rivers, we suspect the lower producer's accuracy for sand is indicative of the dynamic nature of sediment distribution in the study systems.

Moreover, if fine sediment deposition were to occur at the same time and over the same substrates selected by sturgeon during egg deposition, survival of eggs might be compromised (McDonald et al. 2010). A study undertaken to identify factors affecting sturgeon recruitment could assess availability of hard substrates using sonar mapping and change detection analysis, a procedure that examines two substrate maps prepared from different time periods. This approach was recently used by Smit (2014) to monitor changes in substrate bedforms following a flood event.

Early versions of the substrate maps included an experimental class labelled coarse sand/gravel. This class was initially included to evaluate whether it was possible to map this substrate type using the project equipment and configuration. We assessed 40 polygons in this experimental class but only 11 had been correctly identified. Low classification accuracy of the class precluded it as an 'official' map class. Instead, all areas initially classified as coarse sand/gravel were reclassified into the other category. Difficulty associated with resolving and delineating surficial gravel deposits was also noted by Kaeser and Litts (2010); the use of a higher operating frequency such as 800 kHz, a frequency option available on the Humminbird SI system, may improve the rate of success with visual resolution of this substrate class (Fish and Carr 1990), as may the application of emerging, automated procedures for classifying sediment using spectral analysis (Buscombe et al. 2015).

Sonar mapping revealed that hard substrate patches were widely distributed in study rivers and often located in reaches not identified during prior telemetry studies as focal areas during sturgeon spawning periods. Whether sturgeon habitually frequent the same areas for spawning, or rather choose optimal areas depending on conditions occurring during the spawning period is not well understood in our study systems. Although hard substrates are required for egg deposition, factors such as temperature, depth, and current velocity are also likely essential components (Bain et al. 2000, Caron et al. 2002, National Marine Fisheries Service 2007, 2012). Given the variability in hydrologic conditions occurring during spring and fall spawning periods, having a diversity of patches to choose among a broad, longitudinal scale may be important to the recovery of sturgeon populations in the study rivers.

We identified all three classes of hard substrates within areas frequented by sturgeon, yet whether sturgeon preferred one hard substrate over another during spawning was unknown. Knowledge of substrate preference could be used to filter mapping results or assign weighted importance values to areas of hard substrate. Such knowledge could be gleaned by strategically deploying egg pads or larval traps (National Marine Fisheries Service 2010) in frequented areas and among patches of each hard substrate type to test for differences in habitat selection. In addition to substrate type, whether a minimum size (i.e., area) threshold exists for spawning site selection is also unknown. Patch size may also be a factor associated with persistence of surficial hard substrates during spates that redistribute fine sediments. Knowledge of patch area requirements might also be used to filter mapping results and focus attention to specific areas for long-term monitoring.

When encountered in the Altamaha and Savannah rivers, hard substrates typically covered only small proportions of the channel relative to sand. On the other hand, high proportions of hard substrates were found across broad, upstream reaches of both the Ocmulgee and Oconee rivers. Among published accounts, only Petersen and Ingram (2015) documented visitation of these upstream areas by sturgeon. The importance of access to hard substrates in distant Ocmulgee and Oconee reaches is not yet understood, but the Altamaha River system, unlike many other Coastal Plain rivers, offers an opportunity to further investigate the frequency with which sturgeon access and utilize such distantly located habitat (i.e., > 300 total rkm from estuary) during the spawning period.

While our discussion of mapping results has relied heavily on summarizing information at the tractable scale of rkm, the level of detail provided in the habitat maps has not been fully explored or utilized. Moreover, to more fully understand sturgeon spawning habitat requirements, future work must move beyond substrates to address associated key factors. We recommend that the substrate maps produced during this study be used as a template and foundation for future investigations of shortnose sturgeon and Atlantic sturgeon habitat selection at finer spatial scales than provided for by traditional telemetry investigations. By providing a snapshot-in-time look at substrate distribution, these maps also yield the details necessary to monitor and assess changes in substrate availability over the temporal scale of species recovery (i.e., decades). In conclusion, low-cost sonar habitat mapping represented an effective methodology for characterizing potential spawning substrates for sturgeon in Coastal Plain river systems of Georgia. By integrating additional biological and physical data through future investigations, the goal of fully identifying, characterizing, quantifying, and conserving the essential habitat of sturgeon in Georgia rivers may be realized.

Acknowledgments

This study could not have been completed without the dedication and hard work, often during adverse conditions, of Tanner Williamson and Reuben Smit who served as sonar technicians on this project. The efforts of Melanie Riley, GIS Specialist with the Georgia Department of Natural Resources, to produce figures and review the final project report were greatly appreciated. We wish to acknowledge the assistance provided by Steve Sammons and reviewers to improve the manuscript. This study was made possible by a grant from the National Marine Fisheries Service, award number NA10NMF4720390. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

Literature Cited

Bain, M. B., N. Haley, D. Peterson, J. R. Waldman, and K. Arend. 2000. Harvest and habitats of Atlantic sturgeon *Acipenser oxyrinchus* Mitchill, 1815, in the Hudson River estuary: lessons for sturgeon conservation. Instituto Espanol de Oceanografia. Boletin 16:43–53.

Buscombe, D., P. E. Grams, and S. M. C. Smith. 2015. Automated riverbed sediment classification using low-cost sidescan sonar. Journal of Hydraulic Engineering DOI: 10.1061/(ASCE)HY.1943-7900.0001079. Accessed 1 January 2016.

Caron, F., D. Hatin, and R. Fortin. 2002. Biological characteristics of adult Atlantic sturgeon (*Acipenser oxyrinchus*) in the St. Lawrence River estuary and the effectiveness of management rules. Journal of Applied Ichthyology 18: 580–585.

Collins, M. R. and T. I. J. Smith. 1993. Characteristics of the adult segment of the Savannah River population of shortnose sturgeon. Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies 47: 485–491.

———, ———, W. C. Post, and O. Pashuk. 2000. Habitat utilization and biological characteristics of adult Atlantic sturgeon in two South Carolina rivers. Transactions of the American Fisheries Society 129: 982–988.

Congalton, R.G. 1991. A review of assessing the accuracy of classification of remotely sensed data. Remote Sensing Environment 37: 35–46.

——— and K. Green. 1999. Assessing the accuracy of remotely sensed data: principles and practices. Lewis Publishers, New York.

Devries, R. J. 2006. Population dynamics, movements, and spawning habitat of the shortnose sturgeon, *Acipenser brevirostrum*, in the Altamaha River System, Georgia. Master's thesis, University of Georgia, Athens.

Fish, J. P. and H. A. Carr. 1990. Sound underwater images. Lower Cape Publishing, Orleans, Massachusetts.

Georgia Department of Natural Resources (GADNR). 2013. Sonar mapping of sturgeon habitat in coastal rivers. NA10NMF4720390 Final Report. GADNR, Social Circle, Georgia.

Garman, G. C. and L. A. Nielsen. 1992. Medium-sized rivers of the Atlantic Coastal Plain. Pages 315–349 *in* C. T. Hackney, S. M. Adams and W. H. Martin, editors. Biodiversity of the Southeastern United States. John Wiley and Sons, New York.

Hall, J. W., T. I. J. Smith, and S. D. Lamprecht. 1991. Movements and habitats of shortnose sturgeon, *Acipenser brevirostrum* in the Savannah River. Copeia 3:695–702.

Kaeser, A. J. and T. L. Litts. 2008. An assessment of deadhead logs and large woody debris using side scan sonar and field surveys in streams of Southwest Georgia. Fisheries 33:589–597.

——— and ———. 2010. A novel technique for mapping habitat in navigable streams using low-cost side scan sonar. Fisheries 35:163–174.

———, ———, and T. W. Tracy. 2012. Using low-cost side scan sonar for benthic mapping throughout the lower Flint River, Georgia. River Research and Applications. DOI: 10.1002/rra.2556.

Kaufmann, P. R. 2000. Physical habitat characterization–non-wadeable rivers. Chapter 6 *in* J. M. Lazorchak, B. H. Hill, D. K. Averill, D. V. Peck, and D. J. Klemm, editors. Environmental monitoring and assessment program—surface waters: field operations and methods for measuring the ecological condition of non-wadeable rivers and streams. U.S. Environmental Protection Agency, Cincinnati, Ohio.

McDonald, R., J. Nelson, V. Paragamian, and G. Barton. 2010. Modeling the effect of flow and sediment transport on white sturgeon spawning habitat in the Kootenai River, Idaho. Journal of Hydraulic Engineering 136:1077–1092.

National Marine Fisheries Service. 1998. Recovery plan for the shortnose sturgeon (*Acipenser brevirostrum*). Prepared by the Shortnose Sturgeon

Recovery Team for the National Marine Fisheries Service, Silver Spring, Maryland.

———. 2007. Draft spawning habitat suitability index models and instream flow suitability curves, model I: shortnose sturgeon, Southeastern Atlantic Coast river basins. P. H. Brownell, editor. NMFS, Charleston, South Carolina.

———. 2010. Atlantic sturgeon research techniques. NOAA Technical Memorandum NMFS-NE-215. Woods Hole, Massachusetts.

———. 2012. Endangered and threatened wildlife and plants; Final listing determinations for two distinct population segments of Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*) in the Southeast. Federal Register, Volume 77: 5914–5982.

Peterson, D. and E. Ingram. 2015. Temporal and spatial patterns of shortnose sturgeon (*Acipenser brevirostrum*) and Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) spawning migrations in the Altamaha River System, Georgia. Pages 133–171 *in* W. Post, editor. Research and Management of Endangered and Threatened Species in the Southeast: Riverine Movements of Shortnose and Atlantic Sturgeon. Final Report to the National Marine Fisheries Service.

Rogers, S. G. and W. Weber. 1995. Movements of shortnose sturgeon in the Altamaha River system, Georgia. Georgia Department of Natural Resources, Contributions 57, Social Circle.

Schueller, P. and D. L. Peterson. 2010. Abundance and recruitment of juvenile Atlantic sturgeon in the Altamaha River, Georgia. Transactions of the American Fisheries Society 139:1526–1535.

Smit, R. B. 2014. Using sonar habitat mapping and GIS analyses to identify freshwater mussel habitat and estimate population size of a federally endangered freshwater mussel species, *Amblema neislerii*, in the Apalachicola River, FL. Master's thesis, Auburn University, Alabama.

U.S. Fish and Wildlife Service. 1973. Endangered Species Act of 1973; as amended through the 108th Congress. Department of the Interior, Washington, D.C.

Watters, G. T. 1999. Freshwater mussels and water quality: a review of the effects of hydrologic and instream habitat alterations. Proceedings of the First Freshwater Mollusk Conservation Society Symposium, pages 261–274. Ohio Biological Society, Ohio.

Wharton, C. H. 1989. The natural environments of Georgia. Georgia Department of Natural Resources, Atlanta.