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Source: Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 5(5) : 211-223

Published By: American Fisheries Society

URL: https://doi.org/10.1080/19425120.2013.816396

Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 5:211–223, 2013

ISSN: 1942-5120 online
DOI: 10.1080/19425120.2013.816396

ARTICLE

A Novel Approach to Surveying Sturgeon Using Side-Scan Sonar and Occupancy Modeling

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Abstract
Technological advances represent opportunities to enhance and supplement traditional fisheries sampling approaches. One example with growing importance for fisheries research is hydroacoustic technologies such as side-scan sonar. Advantages of side-scan sonar over traditional techniques include the ability to sample large areas efficiently and the potential to survey fish without physical handling—important for species of conservation concern, such as endangered sturgeons. Our objectives were to design an efficient survey methodology for sampling Atlantic Sturgeon *Acipenser oxyrinchus* by using side-scan sonar and to develop methods for analyzing these data. In North Carolina and South Carolina, we surveyed six rivers thought to contain varying abundances of sturgeon by using a combination of side-scan sonar, telemetry, and video cameras (i.e., to sample jumping sturgeon). Lower reaches of each river near the saltwater–freshwater interface were surveyed on three occasions (generally successive days), and we used occupancy modeling to analyze these data. We were able to detect sturgeon in five of six rivers by using these methods. Side-scan sonar was effective in detecting sturgeon, with estimated gear-specific detection probabilities ranging from 0.2 to 0.5 and river-specific occupancy estimates (per 2-km river segment) ranging from 0.0 to 0.8. Future extensions of this occupancy modeling framework will involve the use of side-scan sonar data to assess sturgeon habitat and abundance in different river systems.

Sturgeon populations worldwide have declined from historic levels due to a combination of factors, including overharvest and habitat alteration (Secor 2002; Pikitch et al. 2005). In the eastern United States, Shortnose Sturgeon *Acipenser brevirostrum* and Atlantic Sturgeon *A. oxyrinchus* were listed as endangered under the Endangered Species Act in 1967 and 2012, respectively. Endangered status restricts the methods that researchers can employ to sample sturgeons, and extra care must be taken when sampling and handling specimens (Damon-Randall et al. 2010; Kahn and Mohead 2010). Concerns about causing harm to endangered populations create a need to find and develop new sampling techniques that can provide similar types of information about populations as provided by traditional gears while reducing or eliminating the need to handle individuals of the target species.

The most common technique for sampling Atlantic Sturgeon and Shortnose Sturgeon is netting, typically with set trammel nets and gill nets (Collins et al. 1996; Moser et al. 2000; Peterson

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Received January 15, 2013; accepted June 10, 2013

et al. 2008). Electrofishing and other methods are much less effective (Moser et al. 2000) and are prohibited as methods for capturing Gulf Sturgeon *A. oxyrinchus desotoi*, Green Sturgeon *A. medirostris*, Atlantic Sturgeon, and Shortnose Sturgeon (Kahn and Mohead 2010). Most of the netting in southeastern rivers occurs during summer months (Moser and Ross 1995; Collins and Smith 1997; Zehfuss et al. 1999), when water temperatures are approaching upper thermal tolerances for Atlantic Sturgeon and Shortnose Sturgeon (>30°C; Ziegeweid et al. 2008), and the handling of individuals can induce stress and potential mortality (Moser and Ross 1995; Collins et al. 1996). Riverine netting is often performed in summer since both sturgeon species are commonly available and easily sampled (Moser and Ross 1995; Collins and Smith 1997).

Hydroacoustics may represent a nonintrusive alternative for sampling endangered species. Sturgeon and the related Paddlefish *Polyodon spathula* have been identified as potentially suitable targets for hydroacoustic studies (Hale et al. 2003; Nealson and Brundage 2007; Bergman 2011). Hydroacoustics includes sonar technologies that use sound waves to provide information about underwater environments and in various forms has been used in oceanographic studies to locate and map underwater features. With recent improvements in technology and decreases in cost, hydroacoustics has become more attractive for use in fisheries studies. Several different forms of hydroacoustics have been used in fisheries studies, including split-beam sonar, dual-frequency identification sonar (DIDSON; Sound Metrics Corp.), and side-scan sonar, each with its own characteristics and applications. Targets that are imaged by hydroacoustics, including side-scan sonar, often produce silhouettes or acoustic shadows that yield shape information about the target and can be used to identify fish (Moursund et al. 2003; Langkau et al. 2012).

Side-scan sonar is a relatively old hydroacoustic technology that has been used increasingly in fisheries studies in recent years (Kaeser and Litts 2008; Foote 2009). Side-scan sonar units can produce high-quality still images of the bottom, allowing detection of subsurface objects (e.g., sunken vessels) and geologic features (Johnson and Helferty 1990). These images can be georeferenced and combined into a mosaic image of the bottom in a survey area. Historical fisheries applications of side-scan sonar have primarily focused on habitat (Oliver and Kvitek 1984; Kaiser and Spencer 1994; Kaeser and Litts 2008), but side-scan sonar can also detect fish, which appear as distinct targets in the image. The ability of side-scan sonar to detect fish depends on specifications of the individual unit, with higher-frequency units typically having greater image resolution. Software plays a part in imaging as well, and advances in this area have improved the processing and interpretation of side-scan sonar data (Johnson and Helferty 1990). Side-scan sonar has been used to count fish (Barton 1982, 2000), but in those cases the identification of species was unnecessary.

Our study in the Carolinas encountered both Shortnose Sturgeon and Atlantic Sturgeon populations, but we chose to focus primarily on Atlantic Sturgeon, as they are more abundant than Shortnose Sturgeon in these systems, attain larger sizes, and are of heightened interest because of their recent listing status. Both species were found historically throughout the southeastern United States, but their numbers are now greatly reduced in many systems (Secor 2002). Sturgeons have not been well studied in many southeastern U.S. systems since the closure of commercial sturgeon fisheries in 1998 (ASSRT 2007; Peterson et al. 2008).

The large body size and distinctive shape of Atlantic Sturgeon make them ideal hydroacoustic targets. Atlantic Sturgeon can attain maximum sizes in excess of 3 m and live for approximately 60 years (Gross et al. 2002). Atlantic Sturgeon are anadromous, spending large amounts of time feeding and migrating in marine environments and using freshwater rivers for spawning and a summer dormant period (ASSRT 2007). During summer, both Shortnose Sturgeon and Atlantic Sturgeon may aggregate in the lower portion of rivers, often in deep holes near the freshwater–saltwater interface, although the exact location can vary based on individual river characteristics and flow conditions (Moser and Ross 1995; Collins et al. 2000).

The objective of our study was to develop a sampling protocol for rapidly surveying rivers by using side-scan sonar to detect the presence of sturgeon. Conservation concern and a lack of status knowledge across the range of these sturgeons indicate a need for new methodologies and surveys, especially those involving noninvasive technologies like hydroacoustics. This method may allow for efficient, effective sampling to confirm the presence–absence of sturgeon in systems without the need for direct handling of the sturgeon. The use of side-scan sonar should be an improvement over current protocols that require a large amount of effort with traditional sampling gears (e.g., gill nets) and the handling of sturgeon. The survey protocol should be effective regardless of whether there is prior knowledge of sturgeon habits in a specific system. We utilized occupancy modeling to analyze the data and to estimate (1) the detection probability achieved by the side-scan sonar and (2) the probability of sturgeon presence in various rivers.

METHODS

Study sites.—Field work took place in six river systems in North Carolina and South Carolina (Figure 1; Table 1). Systems were chosen based on available information about the status of sturgeon populations or the potential for sturgeon presence in that system. The goal was to sample rivers with sturgeon populations ranging from high to low abundance. Population status was approximate—based primarily on anecdotal observations or limited directed sampling. Mark–recapture studies and other types of sturgeon population studies have not been performed in these systems.

Side-scan sonar unit.—Our side-scan sonar unit was an Edgetech Model 4125-P dual-frequency unit, which is a high-end, towed, portable unit for use primarily in marine waters and large water bodies. The sonar unit operates at frequencies of 450

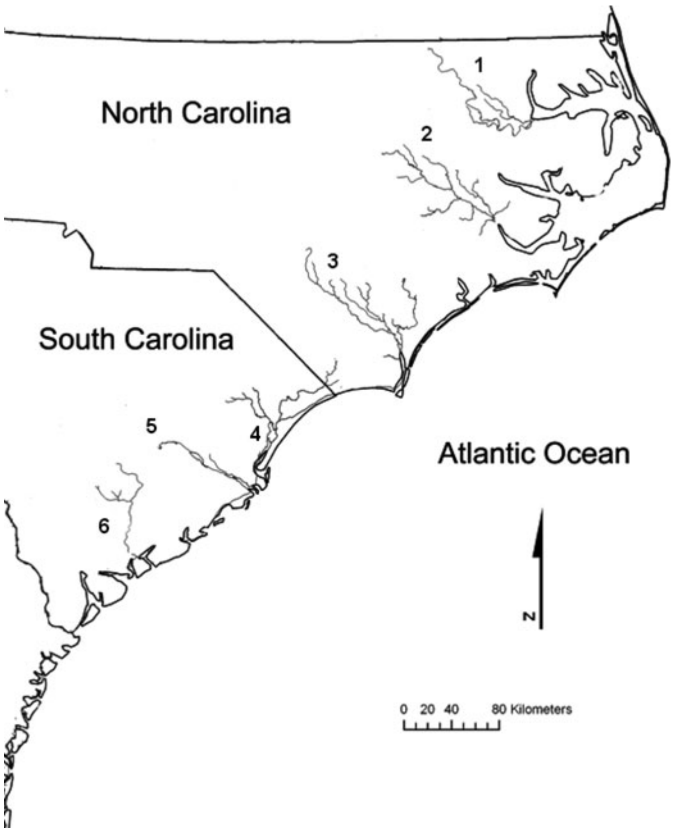

FIGURE 1. Lower portions of six river systems were sampled for sturgeon during our study (1 = Roanoke River; 2 = Neuse River; 3 = Cape Fear River; 4 = Pee Dee–Waccamaw River; 5 = Santee River; 6 = Edisto River).

and 1,250 kHz, with maximum side-to-side scan ranges of 300 and 100 m, respectively. The side-scan sonar unit was towed behind a 5.5-m fiberglass work boat operating at optimal speeds between 6.4 and 9.6 km/h. We used Chesapeake Technology's SonarWiz.Map software to capture, process, and analyze the side-scan sonar data. This software creates a real-time, georeferenced mosaic display of sonar imagery while the survey is performed, allows the marking and measuring of potential sonar targets, and can export data into a GIS program for further processing.

Side-scan sonar surveys.—Side-scan sonar surveys were performed over 3 d on each of the six rivers (Supplement A in the online version of this article). The three sampling days were selected to be as close as possible (often consecutive) in order to reduce the chance of fish movement between sites. Sturgeon have been previously found in lower portions of coastal rivers near the freshwater–saltwater interface (Moser and Ross 1995; Collins et al. 2000; Peterson et al. 2008), and we designed our surveys accordingly. Riverine survey reaches began downstream in tidal portions of elevated salinity (>15 mg/L) and ranged upstream by a distance of at least 30 km inland on the main stem or to a point where the river depths were too shallow to permit effective operation of the side-scan sonar. Several rivers had multiple braids, and surveys included the main-stem river channels and significant branches. As a result, the total distance surveyed in each river varied from 40 to 80 km.

The side-scan sonar unit was deployed at a depth of approximately 1 m below the water's surface. Depth remained constant for all systems and surveys except where occasional shallow depths required us to temporarily pull the tow-fish at a shallower depth. We used our side-scan sonar in high-frequency (1,250-kHz) mode, with a total swath width of 60 m. In previous trials, these settings were found to provide the best compromise in terms of area swept and target detail. In most cases, we could not scan from bank to bank at the 60-m range; as a result, we followed the center of the river, usually the main channel, during surveys.

Side-scan sonar data were later analyzed in the laboratory by reviewing each side-scan sonar file and identifying potential sturgeon targets. When a potential sturgeon was observed, the target was marked, GPS coordinates were taken, and length was measured. Target body length was the standard measurement; however, in a few cases where the body image was weak, distorted, or obscured, the length of the target's shadow was used. The target was described in terms of quality and shape and then

TABLE 1. Results of river surveys for detecting sturgeon in each sampled system with prior anecdotal abundance of sturgeon. Sturgeon were detected in five of the six rivers and by all three gear types (side-scan sonar, video, and telemetry; detection of sturgeon is indicated as yes or no). The last column provides the number of 2-km sample sites where sturgeon were detected and the total number of sites surveyed in each river.

		Sturgeon detection method			
River	Anecdotal population level	Side-scan sonar	Video	Telemetry	Sites with a detection/ total number of sites
Roanoke, NC	Low	Yes	Yes	No	12/30
Neuse, NC	Low	Yes	No	No[a]	3/22
Cape Fear, NC	Medium	Yes	Yes	Yes	19/38
Pee Dee–Waccamaw, SC	High	Yes	Yes	Yes	24/37
Santee, SC	Low	No	No	No[a]	0/30
Edisto, SC	Medium to high	Yes	Yes	Yes	18/22

[a]No sturgeon were telemetry tagged in the Neuse River or Santee River, although tagged individuals could have immigrated from other systems.

was classified as a sturgeon ("yes"), not a sturgeon ("no"), or possibly a sturgeon ("maybe"; see example images in Supplement B in the online version of this article). Classification was a subjective judgment of the observer, made generally on the basis of target size and shape. Two independent observers processed the side-scan sonar files and classified targets; neither observer was explicitly aware of whether sturgeon were detected by one of the other gears at the individual sites. The observers had different levels of experience in viewing side-scan sonar files; one observer had used and viewed side-scan sonar images for several years, whereas the other observer had done so for only a few months.

To assess the assumption of closure, we simultaneously attempted to detect telemetry-tagged sturgeon during side-scan surveys. In four of the six study systems, Atlantic Sturgeon had been tagged with VEMCO telemetry transmitters within the past year as a part of a separate, ongoing research project. Although sturgeon were not tagged in the other two systems, it would have been possible for tagged sturgeon to migrate into those systems from other systems. A VEMCO VR-100 receiver with an omnidirectional hydrophone was submerged and attached to the side-scan sonar cable. Although we could detect tagged fish while collecting side-scan data, acoustic noise limited the speed at which we could travel. When a fish was detected, the individual tag code, time, and GPS location were recorded. Locations were approximate since we could not stop the side-scan sonar run to determine the exact position of the fish; however, tag reception range was likely limited to less than 300 m.

Atlantic Sturgeon also have a habit of jumping entirely out of the water (ASSRT 2007), and this behavior could be used to assess presence. To detect jumping sturgeon in a standardized manner, two video cameras were mounted on the boat, one looking forward and one looking rearward. We used simple webcams connected to two computers to constantly record video footage during the surveys. Each camera had a fixed viewing angle, and video quality was optimized for detail and file size. We chose a smaller video size (640 × 480 pixels) and medium quality option, although exact settings may vary by camera and software set-up. Observations of jumping sturgeon were recorded, and positions were estimated by using video time stamps to coordinate with the side-scan sonar file times and locations.

Side-scan sonar, video camera, and telemetry detections were all plotted in ArcGIS and were recorded by site and day. It is important to note that failure to detect sturgeon by using side-scan sonar at a site that is known to be occupied (i.e., through observations with the video camera, telemetry, or both) was not solely a function of an inability to identify a sturgeon with the side-scan sonar. Limited side-scan sonar swath size could result in sturgeon not being ensonified and therefore not observed.

The large amount of data collected during the surveys required extended time for analysis. Every survey day created approximately 16 h of video and over 30 km of side-scan sonar files to be analyzed. Side-scan sonar file processing took 1–3 d per survey day, depending on how many targets had to be recorded. Maps generated by using detection data provided an excellent overview of sturgeon positions in each system (Supplement A). Mapping illustrated the spatial similarities between sturgeon located by side-scan sonar and sturgeon detected by other gear types.

Occupancy modeling.—Occupancy modeling has been suggested as a useful approach to sampling rare and elusive species for which the acquisition of sufficient data to estimate abundance is difficult (MacKenzie et al. 2004, 2005). An occupancy modeling approach is based on repeated sampling of a given study area to estimate the proportion of the area in which the species of interest is present (MacKenzie et al. 2002, 2006). A key aspect of occupancy models is that they can account for imperfect detection by sampling gear. Because the method only requires presence–absence data, an occupancy approach tends to require less effort than studies that are designed to estimate abundance (MacKenzie et al. 2002). Our occupancy model assumptions include (1) the occupancy state of sites is constant during all single-season surveys; (2) the probability of occupancy is equal across all sites within a river; (3) the gear-specific probability of detection given occupancy is equal across all sites and rivers; (4) detection of the target species during each survey of a site is independent of those on other surveys; and (5) detection histories at each location are independent (MacKenzie et al. 2006). These assumptions can be relaxed depending on model specification.

In our study, repeated sampling occurred over three survey days. The study area is typically broken into sampling units, or sites, that are suitable for the species and study objective. Our objective was to determine (1) sturgeon presence in the river systems and (2) the areas where they were present within individual river systems. For this purpose, each river was an individual study area divided into 2-km sites; thus, there was a total of 179 sites. The 2-km size was selected based on telemetry data, since this distance was greater than the maximum distance traveled in 1 d by any telemetry-tagged sturgeon (~1 km) during the study. It was also the smallest size to contain movement while also providing some information about local habitat if desired. We compared the model based on 2-km sites with those based on study areas divided into 1-km sites ($n = 358$) and 4-km sites ($n = 90$) in order to evaluate site size and closure assumptions.

Occupancy modeling incorporated three sampling methods but not the same three gears used in the survey. Telemetry-tagged Atlantic Sturgeon were not available throughout all systems, so we excluded those data from occupancy analysis. Instead, we used video cameras and two independent observers of side-scan sonar data. Side-scan sonar data for each observer were kept separate and were treated as two independent sets of observations (i.e., each observer represented a "gear"). Only targets identified as sturgeon ("yes") were used in the occupancy analysis. Side-scan observer and video camera data were compiled into a binary $9 \times N$ detection history matrix, where a 1 was entered if at least one sturgeon was detected at a site by a given gear, and a zero was entered if no sturgeon were detected. Individual rivers were used as site-level covariates for model scenarios.

We used the free program PRESENCE (Hines 2006) to perform our occupancy modeling. PRESENCE is specifically designed to run a wide variety of different occupancy models that take into account different study designs. We chose the single-season, multiple-method model (Nichols et al. 2008), which is designed for studies using multiple gears on multiple occasions during a single sampling season. Model-estimated parameters included site occupancy (ψ), detection probability (p), and the probability that animals, if present, are available for detection by a given gear (θ). For our model, ψ is the proportion of sites occupied within a given river, and p is the probability of a gear detecting sturgeon at a site if sturgeon were present. The θ is used to model the case in which individuals may be present at the sampling site but are not necessarily available to the gear. For example, this could be used to account for the fact that the swath width of our sonar did not cover the entire site area. By fixing θ at a value of 1.0, we would assume that individuals were fully available for detection if a site was occupied.

We evaluated candidate occupancy models that were chosen based on biological factors; Akaike's information criterion (AIC) was used to evaluate the support for each model. Candidate models included those in which p was constant or varied by gear type but remained constant across rivers and survey days. It is possible that there were differences in cameras and side-scan sonar and that experience levels differed between the observers, thereby influencing p. We evaluated models that allowed p to vary by river, but there was little reason to assume that p would vary by day or river. It is possible that characteristics of individual sites (turbidity, depth, etc.) varied, but this variation was similar across the six rivers based on their summer low-flow conditions and similarity in geographical setting. We evaluated models in which ψ varied across rivers or were constant for all rivers but did not vary by survey day. Differences among rivers would be expected given anecdotal reports and target counts among river systems.

We used Pearson's chi-square test to assess independence in observations between gears; the null hypothesis was that observations made by video cameras and telemetry were independent of side-scan sonar observations. Fisher's exact test was used to test for independence in a similar manner, but we also examined the odds ratio provided by this test. The objective of these tests was to compare raw results among the different gears. Both of these tests utilized observation data for each individual site summarized by gear in a 2×2 contingency table. Sites were grouped in categories based on whether or not sturgeon had been detected at a given site by a given gear, and separate tables were used for each side-scan sonar observer.

RESULTS

The strongest AIC-supported occupancy model was ψ(r), p(g), θ(.) (this model and other models are defined in Table 2), where ψ varied across rivers, p varied with gear, and θ was constant across all gears and surveys. There was also weak support for the ψ(r), p(g), θ(g) model, which differed by estimating individual values of θ for each gear. Models with θ fixed at 1.0 were not supported as strongly as their counterparts (Table 2), suggesting that sturgeon may have been present at a site but were not available for detection by a gear during that survey. Despite the varying amount of AIC support, model parameter estimates were similar across different models. Estimates of ψ ranged from a minimum of zero to a maximum of approximately

TABLE 2. Candidate occupancy models denoted by parameterization (ψ = site occupancy; p = detection probability; θ = probability that sturgeon, if present, were available for detection by a given gear; r = river; g = sampling gear; ss = side-scan sonar; v = video). Model selection was based on Akaike's information criterion (AIC; ΔAIC = AIC difference between the given model and the best-performing model; L = likelihood).

Model	AIC	ΔAIC	AIC weight	Likelihood	Parameters	$-2\cdot\log(L)$
ψ(r), p(g), θ(.)	954.71	0.00	0.807	1.000	10	934.71
ψ(r), p(g), θ(g)	957.77	3.06	0.1747	0.2165	12	933.77
ψ(r), p(ss, v), θ(.)	962.68	7.97	0.015	0.0186	9	944.68
ψ(r), p(ss, v), θ(g)	965.73	11.02	0.0033	0.004	11	943.73
ψ(r), p(g), θ(fixed)	997.09	42.38	0.000	0.000	9	979.09
ψ(r), p(ss, v), θ(fixed)	1,001.79	47.08	0.000	0.000	8	985.79
ψ(.), p(g), θ(.)	1,008.27	53.56	0.000	0.000	5	998.27
ψ(r), p(.), θ(.)	1,010.52	55.81	0.000	0.000	8	994.52
ψ(.), p(g), θ(g)	1,011.33	56.62	0.000	0.000	7	997.33
ψ(r), p(.), θ(g)	1,013.57	58.86	0.000	0.000	10	993.57
ψ(r), p(.), θ(fixed)	1,040.05	85.34	0.000	0.000	7	1,026.05
ψ(.), p(g), θ(fixed)	1,050.65	95.94	0.000	0.000	4	1,042.65
ψ(.), p(.), θ(.)	1,064.08	109.37	0.000	0.000	3	1,058.08
ψ(.), p(.), θ(g)	1,067.13	112.42	0.000	0.000	5	1,057.13
ψ(.), p(.), θ(fixed)	1,093.61	138.90	0.000	0.000	4	1,089.61

TABLE 3. Parameter estimates for the top-five occupancy analysis scenarios for sturgeon: estimates of detection probability (p) for each gear, occupancy (ψ) for each river, and individual availability (θ; probability that sturgeon, if present, were available for detection by a given gear). Side-scan sonar observer 1 was the more experienced of the two observers. Models are denoted by parameterization (r = river; g = sampling gear; ss = side-scan sonar; v = video).

	ψ(r), p(g), θ(.)		ψ(r), p(g), θ(g)		ψ(r), p(ss, v), θ(.)		ψ(r), p(ss, v), θ(g)		ψ(r), p(g), θ(fixed)	
Parameter	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
p(side-scan sonar observer 1)	0.701	0.045	0.701	0.045	0.607	0.036	0.607	0.036	0.484	0.035
p(side-scan sonar observer 2)	0.526	0.045	0.526	0.045	0.607	0.036	0.607	0.036	0.363	0.033
p(video camera)	0.266	0.037	0.266	0.037	0.263	0.037	0.263	0.037	0.184	0.026
θ(side-scan sonar observer 1)	0.653	0.046	0.611	0.069	0.660	0.047	0.618	0.069	1.000	
θ(side-scan sonar observer 2)	0.653	0.046	0.654	0.069	0.660	0.047	0.661	0.070	1.000	
θ(video camera)	0.653	0.046	0.696	0.069	0.660	0.047	0.704	0.070	1.000	
ψ(Roanoke River)	0.431	0.097	0.430	0.097	0.431	0.097	0.430	0.097	0.408	0.091
ψ(Neuse River)	0.147	0.079	0.147	0.079	0.147	0.079	0.147	0.079	0.139	0.075
ψ(Cape Fear River)	0.453	0.087	0.453	0.087	0.453	0.087	0.453	0.087	0.429	0.082
ψ(Pee Dee River)	0.699	0.086	0.698	0.086	0.699	0.086	0.698	0.086	0.662	0.080
ψ(Santee River)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ψ(Edisto River)	0.881	0.091	0.880	0.091	0.881	0.091	0.880	0.091	0.834	0.084

0.88 across all rivers and models (Table 3). No sturgeon were observed in the Santee River. Estimates were generally similar to the anecdotal estimates of abundance proposed for each river (Table 1).

Estimates of p varied by gear and were higher for side-scan sonar than for the video cameras (Table 3). There was stronger support for models with differences in p for each side-scan sonar observer than for models with observer p-estimates pooled. Estimates of p were influenced by θ, with decreasing θ values producing an increase in p-estimates. This implies that the availability of sturgeon to be observed by a given gear at a given site was variable. Models that allowed p to vary among rivers produced unrealistic parameter estimates and did not properly differentiate the effects p and ψ.

We successfully detected sturgeon in five of the six surveyed rivers, and in most cases sturgeon were detected with multiple gears (Table 1) over the 179 2-km sites. Telemetry-tagged sturgeon were generally observed to move less than 1 km during the course of the surveys, supporting our occupancy modeling assumption of closed sites. We had some prior knowledge about sturgeon whereabouts in several systems, but in at least one system (Edisto River) we had no knowledge at all but were still able to detect sturgeon. Side-scan sonar targets that could potentially be sturgeon were detected in all river systems, ranging in number from 58 to 1,331 targets/river for both observers. The vast majority of potential sturgeon targets were classified as "maybe" and fewer were classified as "yes," but the proportion varied among rivers and between observers. Most targets that were classified as sturgeon were at least 1 m in length (Figure 2), and this appeared to be a minimum length required to provide sufficient information about body shape. The Santee River had a high number of side-scan sonar targets, but all were classified as "maybe," with most being smaller and having an indistinct shape.

Video cameras were effective in detecting jumping Atlantic Sturgeon (Figure 3), despite the apparent random and infrequent character of those events. In total, 39 jumping events were detected during all surveys in approximately 290 h of video footage. Cameras could detect sturgeon outside the swath covered by side-scan sonar, but most sturgeon that were present in an area would not jump at precisely the time to be recorded. In total, 40 individual telemetry-tagged Atlantic Sturgeon were detected during the side-scan sonar surveys in three systems: the Cape Fear, Pee Dee, and Edisto rivers.

Our study rivers were relatively shallow, with maximum depths in the range of 8–10 m (excluding the Cape Fear River shipping channel); these depths did not present an issue with our choice to use a fixed tow-fish depth. There were isolated areas in which the water was too shallow and side-scan sonar image quality was poor, although targets could still be seen. Where the water was too deep, side-scan sonar beams could not reach the bottom and only objects in the water column were detected. This was the case at two sites in the shipping channel of the lower Cape Fear River, where the bottom could not be consistently scanned; as a result, we excluded those two sites from our occupancy analysis.

In general, side-scan sonar image quality was good across all rivers, and better image quality improved target detection. Only on a few occasions was image quality impaired, primarily by environmental conditions or boat traffic (Figure 4). Only a few of our side-scan sonar targets exhibited high-quality acoustic shadow shapes that made it easy to identify them as sturgeon. Most of the sturgeon targets with lower-quality silhouettes were classified based on a combination of size and shape information (Figure 5; Supplement B). In most systems, sturgeon were expected to be the largest fish species commonly encountered, with a few exceptions. The fish most similar to sturgeon that

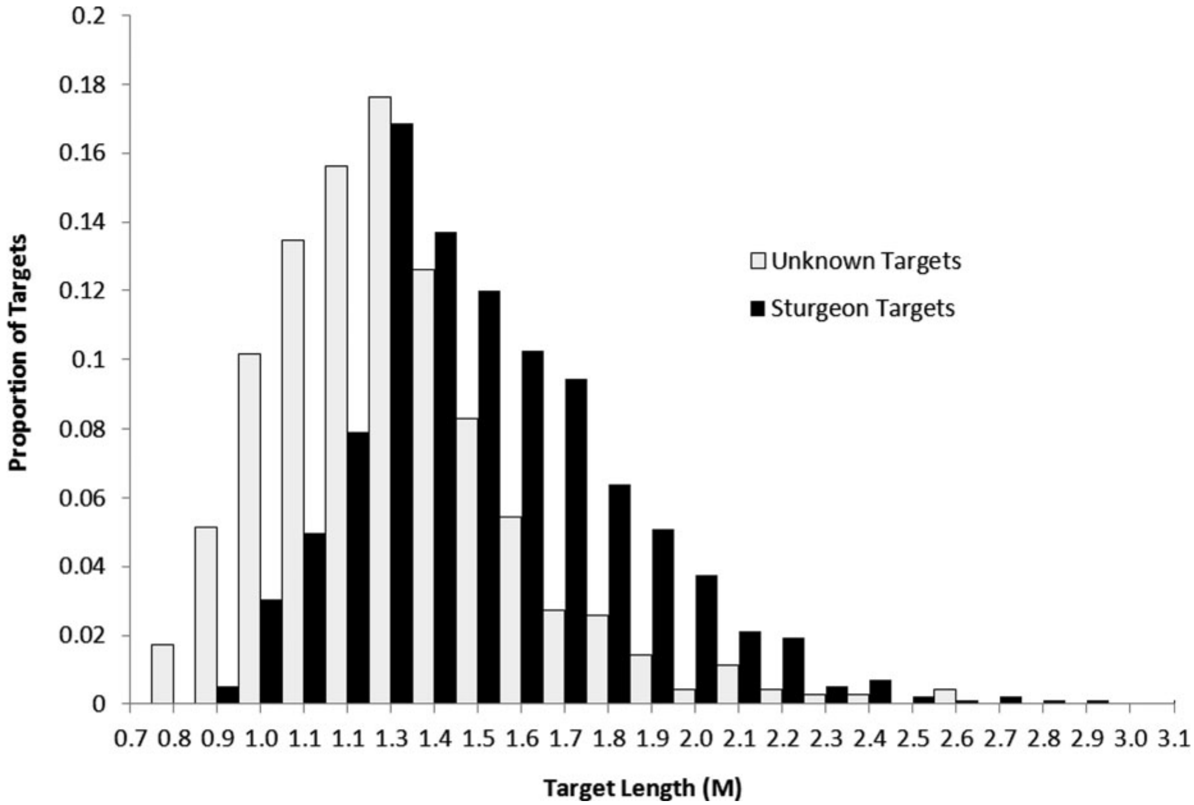

FIGURE 2. Proportional length frequency histogram of detected side-scan sonar targets for all six rivers (see Figure 1). Smaller targets ($N = 985$) were more difficult to positively identify (unknown targets), whereas targets that were identified as sturgeon ($N = 698$) were generally larger. Targets longer than 2.5 m were probably distorted.

were encountered during surveys, both by side-scan sonar and visually by jumping, were Tarpon *Megalops atlanticus*, but they were observed in areas with much higher salinity than sturgeon and their acoustic shadows differed from those of sturgeon (Figure 6). Longnose Gars *Lepisosteus osseus* were commonly seen in areas where sturgeon could be found, but the shape of this species was distinctive. Common bottlenose dolphins *Tursiops truncatus* were encountered, but they were usually observed visually before scanning and they had distinctive shapes.

Overall, the two side-scan sonar observers were able to detect sturgeon at approximately 70% of the sites where sturgeon were also detected by telemetry, video camera observations, or both. The null hypothesis was that side-scan sonar detections of sturgeon were independent of sturgeon detections by other gears. Results of Pearson's chi-square test suggested that side-scan sonar observations of sturgeon were dependent on sturgeon presence and were not random (side-scan sonar observer 1: $\chi^2 = 53.92$, df = 1, 179, $P = 2.09 \times 10^{-13}$; observer 2: $\chi^2 = 46.54$, df = 1, 179, $P = 8.98 \times 10^{-12}$). Additionally, odds ratio estimates from Fisher's exact test suggested that the odds of sturgeon being detected at a site by telemetry, video camera observations, or both was 16.54 times greater (95% confidence interval = 7.10–40.94) if sturgeon were detected by side-scan sonar observer 1 and 12.06 times greater (95% confidence interval = 5.35–28.58) if sturgeon were detected by side-scan sonar observer 2.

DISCUSSION

Our results demonstrated that we could reliably detect sturgeon in multiple systems by using side-scan sonar. Sturgeon locations agreed with historic observations based on netting and telemetry. Within the Cape Fear River, we detected sturgeon in the same areas that Moser and Ross (1995) selected for gill-net sampling locations. Similarly, side-scan sonar results were similar to those of Collins and Smith (1997), who reported large numbers of sturgeon in the Pee Dee–Waccamaw and Edisto rivers during netting studies. Collins and Smith (1997) observed Atlantic Sturgeon ranging in size from 33 to 254 cm TL in these systems, representing both juvenile and mature individuals. Their upper bound for observed lengths is consistent with those of our side-scan sonar estimates (Figure 2). Collins and Smith (1997) observed Atlantic Sturgeon in the Santee River previously during summer months, but those fish were all subadults (<105 cm) and the river discharge was much greater than during our surveys. Few sturgeon—mainly juveniles—have been observed in the Neuse River (Oakley 2003) or Roanoke River (Armstrong and Hightower 2002);

FIGURE 3. Video frame capture of a jumping sturgeon in the Edisto River, South Carolina.

however, adult Atlantic Sturgeon have recently been captured and observed in the Roanoke River (our unpublished data).

As our study and other studies have shown (Moser and Ross 1995; Collins and Smith 1997; Peterson et al. 2008), Atlantic Sturgeon use riverine habitat during summer. It is generally believed that juvenile Atlantic Sturgeon remain in riverine habitats over the summer (Moser and Ross 1995; Collins and Smith 1997; Peterson et al. 2008), but the considerable number of sturgeon larger than 1.5 m based on measurements using side-scan sonar seems to indicate that adult sturgeon are present as well (Figure 2). Riverine summer habitat use by at least some adults may be a characteristic shared by southern Atlantic Sturgeon and Gulf Sturgeon populations (Wooley and Crateau 1985; Zehfuss et al. 1999). Knowledge that sturgeon can be found reliably in riverine habitats during summer is useful for monitoring programs, as it establishes a potential time for locating sturgeon in rivers when they may be relatively stationary and accessible. At other times of the year, sturgeon are spawning and migrating, which can be problematic for sampling programs. This is exacerbated when spawning runs are small in size and when their seasonality is unknown.

Even though we tried to monitor fish movement, closure was the assumption that was most likely to have been violated during our study. There probably were instances in which sturgeon moved from one site to another during our study, especially for individuals that were close to a site boundary. This occurrence may have been mitigated by high sturgeon abundance at some sites, such that even though a particular individual moved, the net site occupancy did not change because additional individuals were present. Larger sites could protect against some of this movement. Varying the site size from 2 km to either 1 km or 4 km did not change the relative ranks of rivers or the relative performance of the gears, suggesting that closure was not violated (Figure 7). It makes sense that occupancy would increase as site size increased.

The AIC scores suggested that our survey data were better described by an occupancy model that decomposed the detection process into availability (i.e., θ) and detection given availability (i.e., p; Hines et al. 2010). Such models have proven useful for large-scale surveys where detection is a local process within a much larger site (Hines et al. 2010). In our case, there are several possibilities for why this decomposition might be useful. The most obvious is for a site that is occupied by sturgeon but in which the sturgeon are unavailable for detection by video camera because of the fish's low probability of jumping. Given that a sturgeon was available for detection by video (i.e., jumped), the probability of detection would depend on the fraction of the site that was within the field of view for the two cameras at the instant when the fish jumped. Similarly, detection given availability could account for a sturgeon that was within the path

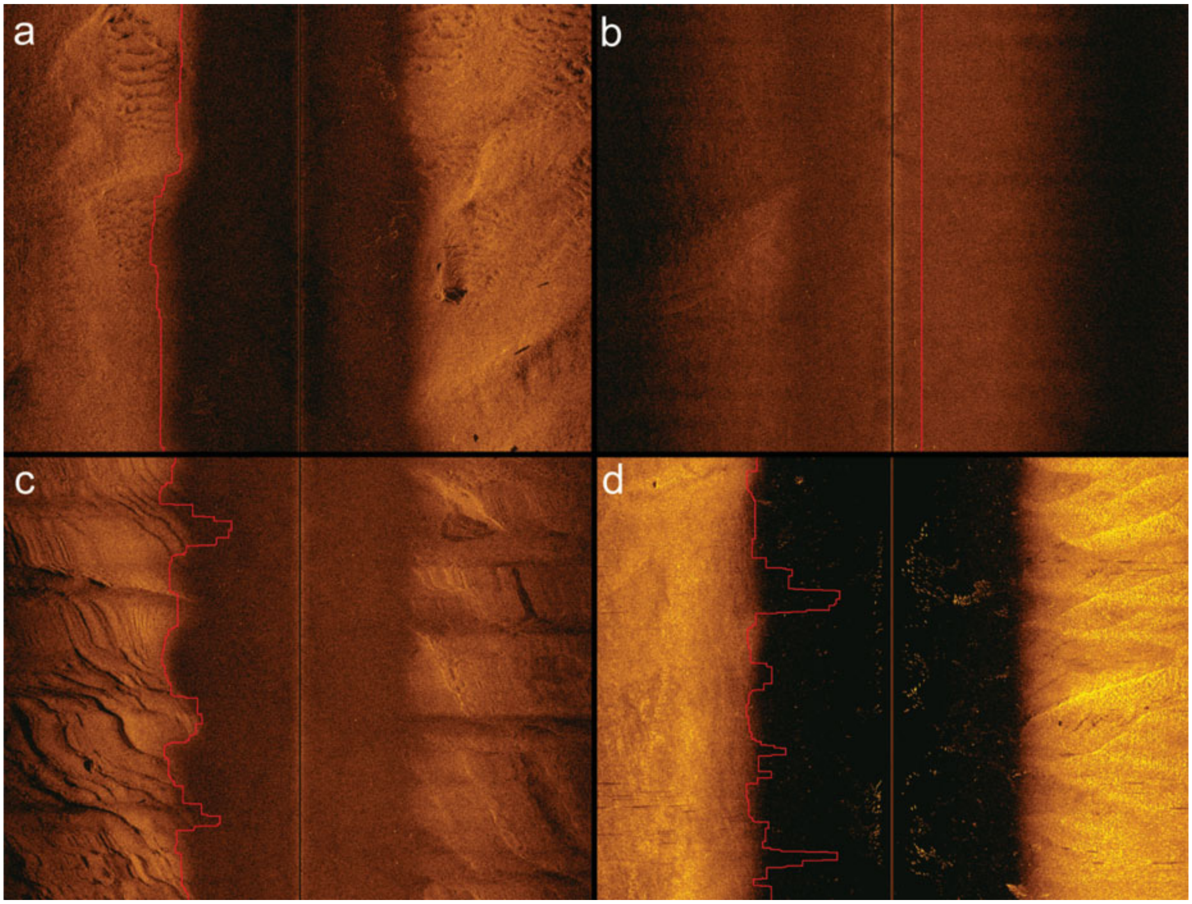

FIGURE 4. Example side-scan sonar images, demonstrating variability in image quality (each image represents a swath width of 60 m): **(a)** typical side-scan image; **(b)** image from the same location but with high turbidity or turbulence; **(c)** image showing distortion from surface waves (horizontal banding) and moderate turbidity or turbulence; and **(d)** image showing small fish and other objects in the water column. The red line in each image represents the river bottom as perceived by the side-scan sonar software (prior to any manual correction): panel (a) is a typical image of the river bottom; in panel (b), excessive turbidity or turbulence obscures the bottom from detection; and in panels (c) and (d), interference prevents the software from properly tracking the bottom.

of the sonar but produced an image with insufficient clarity to allow for confident classification of that individual as a sturgeon. Availability to the side-scan sonar would depend on the cross-channel distribution of sturgeon. Our field observations suggest that sturgeon tend to be concentrated in the deeper parts of a river channel and therefore are available for detection.

One approach for refining the estimate of θ would be to include, as separate gear types, side-scan sonar passes made in different depth zones. If fish are mostly concentrated in the deeper parts of the channel, θ would be low for shallow sonar passes and higher for mid-channel passes. Another approach that might improve the decomposition of the detection process would be to include a separate side-scan pass at a swath width that encompasses the entire river cross-section. Availability could be fixed at 1.0 for that gear type and then estimated for all other gear types.

Acoustic image quality was dependent on several factors, including target orientation, water turbidity and turbulence, vessel motion, and bottom features. These factors were site specific and were randomly encountered within all rivers. Boat wakes and wind created surface motion, resulting in wavy distortion in side-scan sonar images. Wind, tidal motion, and other factors could increase the amount of reflective small particulates and air bubbles in the water column, producing "cloudy" images in which objects might be obscured. Other environmental factors (e.g., bottom type or reflectivity) and the presence of schools of small fish could also affect image quality.

Prior to this study, informal field trials were conducted to evaluate the ability of side-scan sonar to identify fish, including sturgeon, but the trials produced mixed results. Our side-scan sonar unit was accurate for determining the lengths of fish and other targets but was not generally successful in determining species, although most target fish were less than 1 m in length. Tethered and netted Atlantic Sturgeon were presented to the side-scan sonar in the field, but they did not maintain natural swimming positions and did not represent good targets. At least one other study (Bergman 2011) involved attempts to ensonify and identify a 1-m frozen sturgeon, with little success; however,

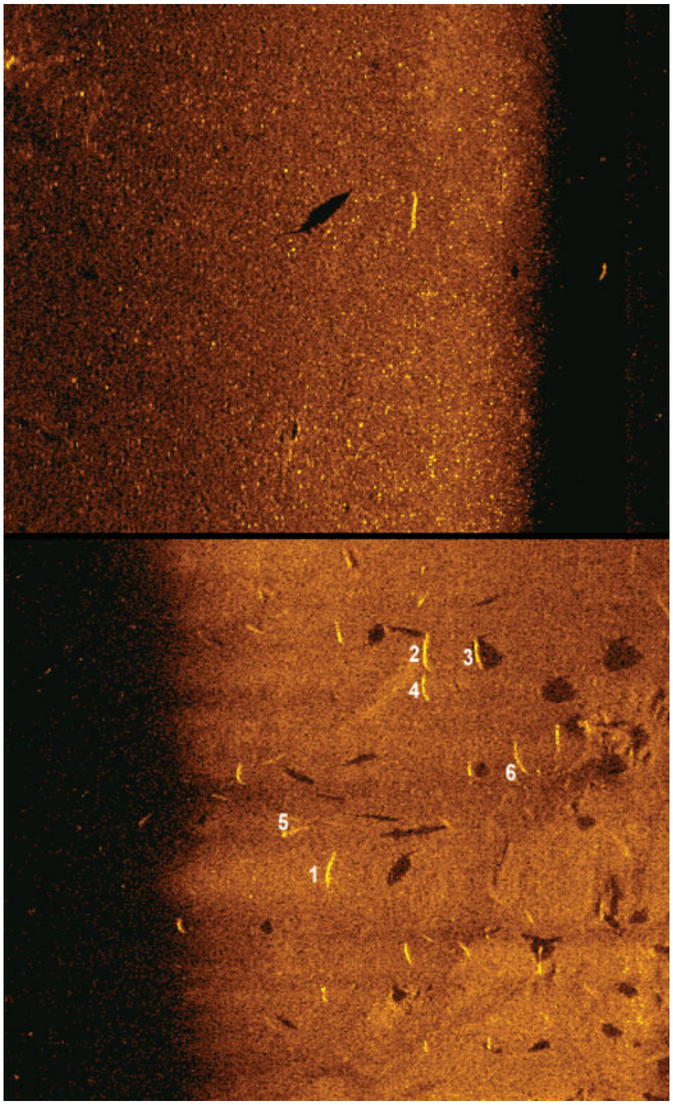

FIGURE 5. Composite image showing a side-scan sonar target identified as 1.9-m sturgeon in the Roanoke River (top) and multiple targets in the Pee Dee River (bottom) that were identified as sturgeon and unknowns. Sturgeon in the bottom image are numbered, with estimated lengths as follows: fish 1 = 1.5 m; fish 2 = 1.6 m; fish 3 = 1.4 m; fish 4 = 1.3 m; fish 5 = 1.2 m; and fish 6 = 1.6 m. Other targets in this image ranged in size from 0.4 to 1.2 m.

a lower-resolution (800-kHz) side-scan sonar unit was used in that study. Side-scan sonar units are likely to be most effective when targeting larger species over 1 m in length (Bergman 2011; Gonzalez-Socoloske and Olivera-Gomez 2012).

The critical issue in our study was the certainty with which we could positively identify sturgeon. Since we could not fully validate our field observations, we relied on independent evidence to support our side-scan sonar observations; such evidence included historical records of distribution patterns, our telemetry data, our observations of jumping sturgeon, and sturgeon size relative to other species. Unlike other hydroacoustic systems, with side-scan sonar it is difficult to create a fully objective method for identifying fish. With DIDSON, swimming motion as well as target shape can be evaluated to identify species; using split-beam sonar, it is possible to quantify target strength with prior calibration (Nealson and Brundage 2007; Mueller et al. 2008). While DIDSON may be more useful for identifying species, it is more limited in scanning range, is more expensive than side-scan sonar units, is more cumbersome to deploy in the field, and lacks mapping capability.

Improving the quality of side-scan sonar images should increase detection ability. We could have improved our image quality by reducing the width of the side-scan sonar swath, but this would incur the tradeoff of a reduced area swept by our surveys. Higher-resolution side-scan sonar units used in combination with software that better processes and displays side-scan sonar data should also improve the ability to detect and identify fish. Software that can automatically process data is available for other hydroacoustic systems and can decrease analysis time, although there are identification errors associated with these analyses (Mueller et al. 2008). Increasing the number of surveys in a season could also improve occupancy estimates, but there would be a tradeoff in terms of field and processing time. In systems that are significantly deeper, it may be necessary to evaluate different towing arrangements, such as those that allow for variable depth, to achieve optimal side-scan sonar performance.

Human observers are an integral part of side-scan sonar usage, and the skill and experience of the observer will affect the results of side-scan sonar analysis. Even though experience varied between the observers, the less-experienced observer was estimated to detect sturgeon with a probability greater than 0.5, and detection results were similar when examined for individual sites (Table 4). Observer effects could be better quantified by additional means, such as laboratory trials evaluating the ability of observers to correctly classify example side-scan sonar images. Incorporating additional information sources (e.g., video cameras and telemetry data as in the present study) can help to reduce observer uncertainty by confirming the presence of sturgeon at a site.

Side-scan sonar could be used independently or in conjunction with standard fisheries sampling approaches. Use of side-scan sonar could eliminate the need to handle sturgeon unless dictated by the study (e.g., mark–recapture or genetic studies). Stand-alone side-scan sonar surveys have the potential to provide time and monetary savings in comparison with traditional sampling. Although the initial cost of the side-scan sonar may be higher, use of a side-scan sonar unit instead of other gears could pay for itself in time. Sampling of sturgeon with traditional gears such as nets requires a large amount of effort. For example, a minimum of 288 net-hours over 8–10 weeks was suggested for determining Shortnose Sturgeon presence in a single river system (Moser et al. 2000). This might require a sizeable field crew and associated logistical supplies to support sampling efforts. The time required to review side-scan files would be less than that required to perform netting surveys over

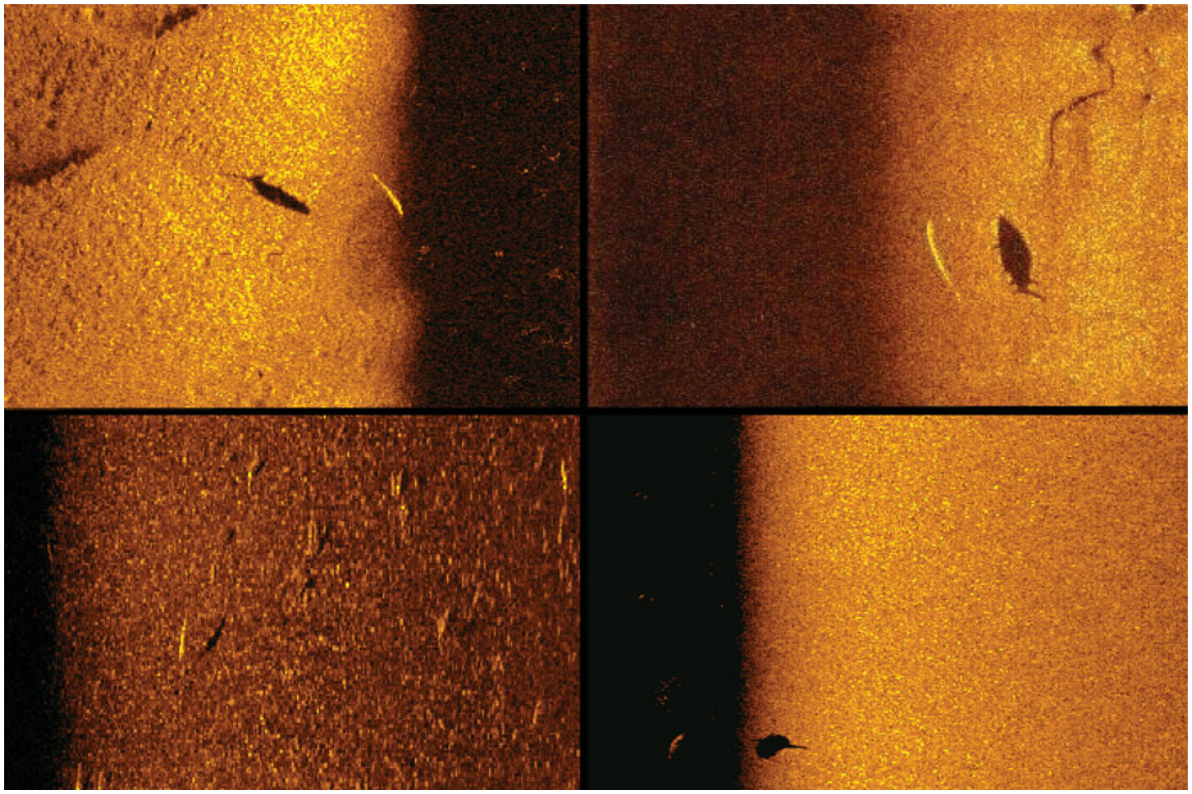

FIGURE 6. Examples of different large-fish targets as seen with the side-scan sonar (clockwise from top right): Atlantic Sturgeon (length = 1.8 m), common bottlenose dolphin (1.2 m; confirmed visually), Longnose Gar (0.9 m; confirmed by netting), and Tarpon (1.6 m; confirmed visually). These images demonstrate the detail that can be seen in the acoustic shadow of each target; notice the body shape, proportion, and fin position for each.

a similar area, although the inclusion of video data would extend overall processing time.

Side-scan sonar data could be used with other occupancy and nonoccupancy modeling approaches. We used a basic occupancy model, but more sophisticated occupancy models could be created, incorporating covariates into the model to assess different environmental, biological, and behavioral conditions that may affect occupancy and the ability to detect individuals (MacKenzie et al. 2006). Occupancy models can be modified to produce abundance estimates as well (Royle and Nichols 2003; MacKenzie et al. 2006). Nonoccupancy approaches like *N*-mixture abundance models (Royle 2004) could be used to incorporate counts of individuals at sites to generate abundance estimates from surveys. Estimates of density or abundance in specific areas could improve traditional surveys, such as gill-netting, by providing estimates of gear efficiency for capturing or detecting the target species. Repeated standardized side-scan surveys over a series of years could also be used to monitor population changes in a CPUE framework by identifying changes in fish density in designated areas. A program like this could be performed relatively cheaply, requiring only a few days in the field each year.

An ideal combined sampling approach would incorporate (1) side-scan surveys to rapidly and efficiently identify areas where sturgeon are present and (2) subsequent netting to positively assess fish species and size and to allow for other measurements and tagging. Side-scan sonar can be used to identify areas where sturgeon are present, leading to a reduction in the amount of effort (including length of time for net sets) required to find sturgeon for a sampling program. Side-scan sonar images can also be used to identify bottom hazards that may interfere with sampling operations.

A common application of side-scan sonar is to map and characterize habitat in areas where fish are found. The relatively small size of sturgeon populations in many river basins has made habitat utilization patterns difficult to establish with certainty (Collins et al. 2000). Methods for using side-scan sonar to map habitat have previously been described, and doing so is a relatively simple process (Kaeser and Litts 2010). Summer habitat in multiple rivers can be surveyed in just a few weeks, although file processing takes considerable time if individual fish positions and sizes are determined. This information could be used to better inform monitoring programs and to identify areas that need protection under the auspices of Endangered Species Act requirements. Side-scan sonar surveys could provide data on habitat types and usage, which are valuable since little detailed information about specific sturgeon habitats is available in all river systems. Habitat data could also be used with occupancy

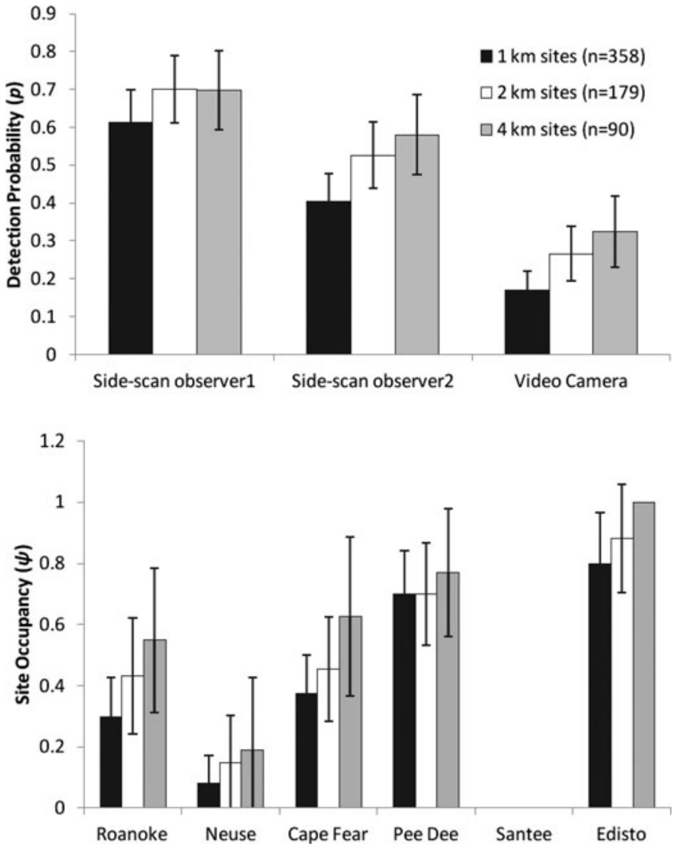

FIGURE 7. Parameter estimates ($\pm$95% confidence interval) of detection probability (p) for each gear type (side-scan sonar observers 1 and 2 and video camera; top panel) and site occupancy (ψ) for each river (bottom panel). Sturgeon were not detected in the Santee River.

models to describe factors that influence sturgeon habitat use.

Our results demonstrate that side-scan sonar can be used to survey sturgeons and potentially other large fishes. A primary advantage of using side-scan sonar to sample sturgeon was that physical handling of sturgeon was not required, thus eliminating the risk of mortality. We detected individual fish with a multitude of gears and even identified targets to species with some confidence. Video cameras were surprisingly effective for detecting jumping sturgeon, and the use of telemetry-tagged individuals helped to inform our study. An occupancy modeling approach was well suited for analyzing side-scan sonar data, providing useful information about the status of sturgeon within our sampled river systems. We were able to confirm the presence of sturgeon in river systems by using a fraction of the effort associated with traditional netting programs and without having to handle the target species.

TABLE 4. Sturgeon survey detection contingency tables for each side-scan sonar observer. Note the similarity in sturgeon detections across methods.

Observer number	Variable	Telemetry and video camera		
		Detections	Nondetections	Total
1	Detections	36	17	53
	Nondetections	14	112	126
	Total	50	129	179
2	Detections	34	19	53
	Nondetections	16	110	126
	Total	50	129	179

Side-scan sonar and other hydroacoustic methods should become a more attractive option for sampling as technology improves and as prices decrease. New ideas and uses should develop as more researchers and managers use hydroacoustic technologies. We plan to extend our side-scan sonar data analysis to an evaluation of sturgeon abundance and habitat use in the study systems. The greatest potential for side-scan sonar may lie in situations where it can be used in conjunction with traditional sampling methods and integrated into monitoring programs. Combined approaches to studying fish populations should always be considered when practical.

ACKNOWLEDGMENTS

Funding for this project was provided by the National Oceanic and Atmospheric Administration. We thank T. Jackson for his work in the field and laboratory and in reviewing side-scan sonar and video data. We appreciate C. Collier and M. Loeffler (North Carolina Division of Marine Fisheries) and W. Post (South Carolina Department of Natural Resources) for allowing us to use their telemetry-tagged sturgeon during the course of the study. We also thank N. Cole, J. Hughes, and A. Prince for assistance during preliminary phases of our side-scan sonar work. The Cooperative Fish and Wildlife Research Unit is jointly supported by North Carolina State University, North Carolina Wildlife Resources Commission, U.S. Geological Survey, U.S. Fish and Wildlife Service, and Wildlife Management Institute. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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