STURGEON HABITAT QUANTIFIED BY SIDE-SCAN SONAR IMAGERY

by

JOHN DAVID HOOK

(Under the Direction of Nathan P. Nibbelink and Douglas L. Peterson)

ABSTRACT

The assessment and monitoring of freshwater habitats is essential to the successful management of imperiled fishes. Recent introduction of recreational multi-beam and side-scan sonar equipment allows rapid, low cost acquisition of bathymetric data and substrate imagery in navigable waters. However, utilization of this data is hindered by a lack of established protocols for processing and classification. I surveyed 298 km of the Ogeechee River, Georgia using low-cost recreational-grade side-scan and bathymetric sonar. I assessed classification accuracy of three approaches to working with recreational-grade sonar and quantified potential spawning grounds for Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). I demonstrate that ecologically relevant habitat variables can be derived from low-cost sonar imagery at low levels of processing effort.

INDEX WORDS: Side-scan sonar, Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*), habitat, classification accuracy

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JOHN DAVID HOOK

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By

JOHN DAVID HOOK

Major Professors: Nathan Nibbelink

Douglas Peterson

Committee: Jeffrey Hepinstall-Cymerman

Thomas Jordan

Electronic Version Approved:

Maureen Grasso

Dean of the Graduate School

The University of Georgia

December 201

DEDICATION

I would like to dedicate this to my parents, John and Joyce, whose continued support, encouragement, and enthusiasm have made all my endeavors possible, and to Emily, whose love and patience seem to know no bounds. I would also like to thank my sister, Jen, whose own brilliance and success inspired me to pursue a graduate degree. And finally, to Adam Tybuszewski and Jessica Aufmuth, whose daily needling and insistence that I not schlep coffee forever were instrumental in my decision to return to school.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

The assessment and monitoring of freshwater habitats is essential to the successful management of imperiled fishes (Minns et al. 1996, Maddock 1999, Dudgeon et al. 2006). However, traditional, transect and direct observation based, methods of characterization of physical habitat in freshwaters are frequently limited in location and scope to stream reaches that can be practically accessed on foot (Wiens 2002), and may miss unique features that can have a disproportionate influence on the system (Fausch et al. 2002). To overcome this problem, especially where assessment of habitat is challenging due to deep, turbid, or difficult to access streams, sonar surveying allows a continuous sample of stream substrate and bathymetry. Recent advances in compact and inexpensive sonar systems facilitate deployment in the smallest of navigable streams (Humminbird 2005, Kaeser and Litts 2008). However, methods for analyzing sonar data from these inexpensive systems are in their infancy and an evaluation of available approaches is needed.

As one of the most imperiled groups of fish in the world, sturgeon may benefit from this technology. Blackwater rivers of the southeastern united states may provide important spawning grounds for shortnose (*Acipenser brevirostrum*) and Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*), and are characterized by poor visibility and poor access due to extensive private lands, especially in upper areas more likely having appropriate substrate for spawning. Particularly in the Ogeechee River, Georgia, recovery of a small population of Atlantic sturgeon may depend on successful identification and protection of spawning habitat. Therefore, the purpose of this thesis is to evaluate alternate methodologies for classifying riverine substrate using side-scan sonar imagery and then use side-scan and multibeam sonar data to identify potentially suitable spawning sites for Atlantic sturgeon in the Ogeechee River, Georgia.

Side-scan sonar

Side-scan sonar was pioneered in the 1960's, initially to identify shipwrecks and other large, man-made objects on the seafloor (Fish and Carr 1990). Major advances in instrumentation and processing equipment in the last 50 years have resulted in sensing systems, that when applied properly allow near photo-realistic images of the bottom (Blondel 2009). Along with single and multibeam echosounders, side-scan sonar is an effective tool for aquatic habitat mapping, and the preferred acoustic technique in shallow marine waters (Appledorn et al. 2001, Kruss et al. 2006, Houziaux et al. 2007). As equipment has decreased in size and cost, side-scan sonar has been used to map aquatic habitat in large freshwater bodies (Kaeser and Litts 2010.) Freshwater applications have included identifying potential spawning grounds of lake trout (*Salvelinus namaycush*) in Lake Michigan and pallid sturgeon (*Scaphirhynchus albus*) in the Missouri River (Edsall et al. 1989, Laustrup et al. 2007).

Side-scan sonar is an active sonar system that consists of a projector, a hydrophone, and a recorder or display unit. The projector converts an electrical pulse into sound waves, the hydrophone performs the reverse; in contemporary systems the projector and hydrophone are combined into a one transducer. In operation (Blondel

2009), the transducer emits a fan shaped acoustical pulse outward in both directions perpendicular to the path of the tow vessel. As the sound energy propagates outward portions of the energy are reflected back to the transducer with an intensity determined by the shape, density, and position of the objects encountered. The variation in intensity is displayed by the recorder as variation in brightness of the displayed signal, with light and dark portions of the display representing strong and weak echoes, respectively. Each pulse is followed by another, the resulting lines of display forming a coherent picture of the seafloor. Coupled with positional information from GPS, these images may be georeferenced for spatially accurate information about the seafloor.

By the 1970's side-scan sonar was being used for numerous marine investigations. Applications included examining bed morphology (Kellan and Halls 1972, Kenyon and Belderson 1973), current patterns (McKinney et al. 1974), oil exploration (Jenkinson 1976), and channel siltation (Hartman 1977). Use increased greatly in the 1980's with applications extended to a variety of mapping projects (Kolouch 1984, McGregor et al. 1986, Wright et al. 1987, Hill and McGregor 1988, Vaslet et al. 1989). This period also saw the first more ecologically directed uses of side-scan sonar with studies examining grey whale (*Eschrichtius robustus*) feeding grounds (Johnson and Nelson 1984, Kvitek and Oliver 1986), groundfish stock assessments (Barans and Holliday 1983), and tilefish (*Lopholatilus chamaeleonticeps*) habitat (Able et al. 1987). The first uses of side-scan sonar in freshwater also appeared at this time, with studies in Lake Ontario (Sly 1983), the Hudson River (Flood and Bokuniewicz 1985), and Lake Champlain, Vermont (Théorét 1980). Since then, use of side-scan sonar has grown dramatically as the cost of sensing equipment and computing resources has fallen (Blondel 2009).

Despite the broad application of side scan sonar in marine and lentic habitats, little research has been conducted with side scan sonar in riverine environments (Strayer et al. 2006). Several obstacles prevent the widespread application of side scan sonar in lotic systems. The main impediment is the size of research-oriented systems. The sensors are contained within a torpedo shaped towfish, which is towed from a research vessel. The towfish may range to over 2 meters in length. The size of this equipment, coupled with purchase prices of up to $50,000 or more makes their use in smaller systems impractical (Kaeser and Litts 2008, 2010). Deployment of these units without significantly damaging the towfish is impossible in all but the largest rivers.

This has changed with the recent introduction of side-scan sonar equipment aimed at the consumer market (Humminbird 2005, Lowrance 2009). These sonar systems are small, inexpensive (<$2000), and use boat mountable transducers suitable to any navigable stream (Kaeser and Litts 2010).

Techniques for working with this equipment are still emerging, and it is important to identify best practices and methods for working with recreational-grade side-scan sonar. Unfortunately, there is no manufacturer-supported venue for georeferencing recreational-grade side-scan imagery. Recently two approaches for georeferencing this imagery have become available. The first, demonstrated by Kaeser and Litts (2008, 2010), uses custom ArcGIS tools to generate sufficient control points to accurately warp still side-scan images to correct coordinates. This approach relies on screen captures made in the field in real time. The second is the DrDepth® software package, which is capable of reading and georeferencing the files generated by Humminbird® side-scan sonar units. Studies evaluating the trade-offs between approaches to georeferencing and classification of habitat are needed to make better use of recreational-grade side-scan sonar for riverine habitat studies.

Atlantic Sturgeon

Atlantic sturgeon are the largest anadromous fish of the North American Atlantic coast and range historically from Labrador, Canada to the Gulf of Mexico (NMFS, 1998). Their current range is diminished to populations using 16 Atlantic coastal rivers (Smith and Clugston 1997). Population declines began soon after the emergence of a large commercial fishery in the late nineteenth century (Secor and Waldman 1999). Harvest peaked at 3350 metric tons in 1890, and collapsed within 10 years, due to persistent overharvest (Smith and Clugston 1997, Secor and Waldman 1999). Landings continued at one percent of peak levels for most of the 1900's until the *Atlantic States Marine Fisheries Commission* imposed an emergency moratorium in December of 1995 (Bain et al. 2000, ASMFC 1998). The moratorium was made permanent in 1998, however, commercial harvest continues in Canadian waters.

Atlantic sturgeon eggs hatch four to six days after fertilization at water temperatures from 17°to 20° Celsius (Gilbert 1989). The larvae are 7mm at hatch and begin exogenous feeding in 8 days (Smith et al. 1980, Kynard and Horgan 2002). Growth is rapid, and juveniles may reach 500 mm in total length in their first year (Dovel and Bergen 1983, McCord et al. 2007). Influenced by temperature and food availability, juveniles utilize deepwater habitats near the interface of fresh and saltwater (Secor et al. 2000, Moser and Ross 1995, Hain et al. 2007, Sweka et al. 2007), and remain in their natal rivers for two to six years (Dovel and Berggren 1983). A longer growing season in southern populations allows earlier maturity, at age 8 for males and age 10 for females

(Stevenson and Secor 1999, Smith 1985). Northern populations may not reach maturity until age 20 or later (Scott and Crossman 1973). Males may grow to 2.1 meters total length, females 3.0 meters; and the largest Atlantic sturgeon recorded reached 4.3 meters and 368 kilograms (Vladykov and Greeley 1963). Maximum age for southern Atlantic sturgeon is 30 years, while fish in northern populations may survive to 60 (Smith 1985, Scott and Crossman 1973). Adults typically inhabit coastal areas near their natal rivers, although lengthy coastal migrations are common (Waldman et al. 1996, Dovel and Berggren 1983, Bain 1997).

Adults enter natal rivers to spawn in the late winter or spring, as water temperature warms to 7° to 10° C (Vladykov and Greeley 1963, Smith 1985). Males spawn every 1 to 5 five years, and females every 3 to 5, with less time in between spawning in southern populations versus northern (Smith 1985, Van Eenennaam et al. 1996). Atlantic sturgeon broadcast adhesive eggs into the demersal zone upstream of the saltwater interface (Gilbert 1989, Collins et al. 2000, Hatin et al. 2002). Spawning grounds occur at least 20 to 100 rkm upstream, with some sites documented at much as 221 rkm upstream (Van Eenennaam et al. 1996, Armstrong and Hightower 2002). Atlantic sturgeon spawning sites are characterized by the presence of hard bottom substrate such as rock, rubble, or hard clay (Gilbert 1989, Caron et al. 2002). In low gradient southern rivers, these conditions are often expressed as rock or limestone outcroppings (Gilbert 1989). Depth of documented spawning sites ranges from less than three meters to as much as 15 meters (Van Den Avyle 1984, Caron et al. 2002).

There are no recent studies quantifying the abundance of Atlantic sturgeon in the Ogeechee River, however Atlantic sturgeon are believed to spawn in the river based on the presence of age 1 juveniles (Grunwald et al. 2007, Peterson et al. 2008, Farrae 2010). While the frequent presence of age 1 fish indicate that Atlantic sturgeon are spawning in the Ogeechee River, little is known about their spawning grounds. I propose that the most efficient method for identification of potential spawning grounds (and direction of future sampling effort) is to use low cost side-scan sonar survey techniques.

Chapters

The second chapter of this thesis (Hook et al. in prep a) assesses three methods for georeferencing and classifying substrate from Humminbird® side-scan sonar images. I compare approaches that have differing effects on image quality and spatial accuracy and evaluate the ability of each approach to successfully classify major classes of stream substrate potentially important to fish habitat analyses. Chapter three demonstrates how side-scan and mulitibeam sonar data can be used in tandem to identify potential spawning grounds for Atlantic sturgeon. 298 kilometers of the Ogeechee River are examined and potential Atlantic sturgeon spawning grounds are identified.

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CHAPTER TWO

CLASSIFICATION OF RIVERINE SUBSTRATE USING RECREATIONAL-GRADE SIDE-SCAN SONAR: TRADEOFFS BETWEEN EFFORT AND IMAGE QUALITY[1]

[1] Hook, J. H., N. P. Nibbelink, A.J. Kaeser, and T.L. Litts. To be submitted.

Abstract

Recent introduction of recreational multi-beam and side-scan sonar equipment allows rapid, low cost acquisition of bathymetric data and substrate imagery in navigable waters. However, utilization of this data is hindered by a lack of established protocols for processing and classification. I surveyed three one-km sites on the Ogeechee River, Georgia, using Humminbird® side-scan and multi-beam sonar units. Substrate type was classified and assessed for accuracy using sonar data processed at three levels of effort and complexity; 1) georeferenced still sonar images that were then classified, 2) classified still images that were then georeferenced, and 3) sonar recordings that were georeferenced with DrDepth® software and then classified. Substrate type was classified using heads-up digitizing. Overall classification accuracy ranged from 85% to 82%. No significant differences in classification accuracy between methods were found. Ecologically relevant habitat variables were derived from maps produced from all three methods, but DrDepth® offered several advantages including ease of use and the ability to create areally accurate slant-range corrected maps. Results indicate that DrDepth® can be used to rapidly generate georectified images of benthic habitat with accuracy similar to more labor-intensive approaches.

INTRODUCTION

Freshwater habitats are home to 25% of known vertebrates while covering only 1% of the earth's surface (Balian et al 2008, Gleick 1996). This diversity is under constant pressure, as 40% of North America's freshwater fish are considered threatened or already extinct - a figure that grew by 92% in the 9 years since the last large scale assessment (Jelks et al. 2008) Habitat loss, degradation, and fragmentation due to anthropogenic disturbance are key drivers of this trend. Interactions between fish and their habitat are fundamental to their reproduction, growth, and survival (Levin & Stunz 2005).

Characterization and mapping of instream physical habitat variables has been performed in the field traditionally, with sampling and experimental sites limited in size and location by transects that can be practically observed on foot. Habitat intermediate to discreet sampling units, often widely spaced, can be extrapolated, but still provides an incomplete, discontinuous picture (Wiens 2002). Stream habitats are complex systems not easily characterized through 200-meter stretches, but rather linear systems where unique features at specific locations can have disproportionate influence over the entire system (Fausch et al. 2002).

Remote sensing techniques offer the ability to sample streams at a much broader scale, and often can capture entire riverscapes. Advances in instrumentation and processing techniques have allowed assessment of multiple water properties at increasingly finer resolutions, including water surface elevation, river discharge, inundation boundaries, surface temperature, turbidity, and algal concentrations (Mertes

2002). These advances are still, however, limited to surface visible features and can struggle with challenges posed by dense overhanging vegetation or turbidity.

In aquatic environments where water depth or turbidity precludes the use of aerial remote sensing techniques, side-scanning sonar allows researchers to develop comprehensive maps of substrate features (Kendall et al. 2005). Side-scan sonar, developed in the 1960's (Fish & Carr 1990), arrays sound waves reflected from the substrate into an 8-bit dynamic range and displays them as a grey scale (Lucieer 2008); creating very high-resolution images of bottom structure (Figure 2.1). In ideal conditions, photo-realistic images of the benthic zone are possible. These images may then be projected in a geospatially accurate context and combined to form a seamless mosaic.

Side-scan sonar is subject to geometric error, which can hinder accurate georeferencing of sonar images, including distortion introduced through temperature gradients in the water column, rotational movement in the sonar sensor, and slant range distortions (Cobra et al. 1992). Slant range distortion occurs because the sonar actually measures the time it takes for the transmitted sound pulse to travel to the bottom and reflect back (Blondel 2009). This distance is greater than the true, straight-line distance. This effect is greatest directly under the sensor, and images of the area directly under the sensor is displaced outward by an amount equal to the depth of the water below the sensor (Fish and Carr 1990). This is visible in raw side-scan sonar imagery as gap in the center of the image, frequently denoted as the water column. Slant range distortion may be corrected by remapping the pixels in an image to their true location, using measured range and depth, in a processed term slant range correction (Blondel 2009).

Despite the broad application of side-scan sonar in marine and lentic habitats, little research has been conducted with side-scan sonar in riverine environments (Strayer et al. 2006). Several obstacles prevent the widespread application of side scan sonar in lotic systems. The main impediment is the size of research-oriented equipment. The sensors are contained within a torpedo shaped towfish, which is towed from a research vessel. The towfish may range to over 2 meters in length. The size of this equipment, coupled with purchase prices of up to $50,000 or more makes their use in smaller systems impractical. Deployment of these units without significantly damaging the towfish is impossible in all but the largest rivers.

An alternative approach that has become available in recent years is to use sonar technologies manufactured for the recreational market. The introduction of side scanning “fishfinders” with sensors contained within small, transom-mountable transducers allows for safe use in shallow, structure-filled systems. Coupled with Wide Area Augmentation System (WAAS) enabled GPS receivers, these units are capable of creating images with accuracy measured in tens of centimeters (Witte 2005). Kaiser and Litts (2008) demonstrated the first use of Humminbird® fishfinders in a scientific setting, and recent advances in third party software (Perlin 2010), provide simpler processing pathways for the data gathered with this equipment.

Techniques for working with this equipment are still emerging, and it is important to identify best practices and methods for working with recreational-grade side-scan sonar. Unfortunately, there is no manufacturer-supported venue for georeferencing recreational-grade side-scan imagery. Recently two approaches for georeferencing this imagery have become available. The first uses custom ArcGIS tools to generate sufficient control points to accurately warp still side-scan images to correct coordinates (Kaeser and Litts 2008, 2010). This approach relies on screen captures made in the field in real time. The second is the DrDepth® software package, which is capable of reading and georeferencing the files generated by Humminbird® side-scan sonar units.

In this study, our objectives were to georeference Humminbird® side-scan sonar imagery and classify the substrate of the resultant sonar image mosaics (SIMs) using three different methods, and then compare classification accuracy. The first approach utilized a grid of control points to georeference still images generated from Humminbird®'s proprietary .dat recordings or "video" files. With this method, the imagery was first georeferenced and then classified. In this, and all further instances in this document, "classification" refers to interpretation by a human observer, not automated classification. The second approach was to classify imagery before georeferencing still images. The final approach was to georeference the sonar recordings with DrDepth® (Perlin 2010) and classify the resulting images.

Study Area - The Ogeechee River

At 394 kilometers, the Ogeechee River is the longest unimpounded river in Georgia, and one of 42 free-flowing rivers greater than 200 kilometers in the lower 48 states (Benke 1990) (Figure 2.2). The Ogeechee River is home to numerous rare and protected species, including shortnose sturgeon (*Acipenser brevirostrum*), Ironcolor shiner (*Notropis chalybaeus)*, and several rare freshwater mussels (Krakow 2007). A sixth order river, the Ogeechee River drains a watershed of 14,300 square kilometers. The Ogeechee River's headwaters are in the Georgia Piedmont, and the majority of its length and 95 percent of its drainage is located in the Coastal plain (Meyer et al. 1997). Below a small falls near Shoals, Georgia the river becomes a slow blackwater river with an average daily discharge of 63.6 m^3/s (USGS 2011). Spring flooding swells discharge to an average daily discharge of 146.4 m^3/s during the month of March (USGS 2011). The Ogeechee River has one major tributary, the Canoochee River -- a 160-kilometer long stream which joins the Ogeechee River at river-kilometer (rkm) 55 (Fleming et al. 2003).

METHODS

I surveyed four approximately 1000-meter reaches of the Ogeechee River. Sonar surveys were performed on the Ogeechee River at three sites selected for substrate diversity from May 28, 2010 to June 5, 2010. Surveys were performed at high flows to capture bank full width while minimizing navigational difficulties. The surveys were conducted using the Humminbird® 997si system. The sonar transducer was mounted to a boom off the front of the boat to minimize wake-induced turbulence. The GPS antenna was mounted to the top of the boom, directly above the transducer, to maximize locational accuracy. Operating frequency was set to 455 kHz. Range was set to 150% of estimated stream width. Side-scan sonar imagery was captured while navigating downstream at midchannel at 5.5 kph (3 knots). Sonar recordings were stored in the Humminbird® proprietary .dat/.son format. The .dat/.son format is intended for playback on the head unit on which it was recorded, or on that of a similar model. This format can be likened to a video recording of the sonar imagery.

To enable assessment of classification accuracy, a series of reference points were sampled in June of 2010 immediately after completion of the sonar surveys. Reference points were used for both training and accuracy assessment, so a simple random sampling design was attempted. Unfortunately, the realities of navigating to and holding position over the planned random points during high stream flow prevented collection in this manner. As such, reference points were collected systematically by taking the first sample at as close to the intended position as possible and then drifting down-current and collecting reference data at 5m intervals. Substrate was visually classified at each point using a boom mounted SeaView® underwater camera system. Where substrate class could not be confidently delineated from visual cues alone (i.e. packed clay or "mudrock" versus exposed limestone bedrock), the river bottom was raked or tapped with an iron rod to generate additional tactile and auditory cues. This was accomplished by inverting the camera and using the boom as a prod. The characteristic ring of a hollow iron pipe striking hard bottom enabled quick discrimination between bedrock and consolidated clay classes. Referenced points were logged, located, and differentially corrected using a Trimble® GeoXM handheld GPS receiver.

Three distinct processing methods were used to convert raw sonar images to sonar image mosaics (SIMS) (Table 2.1). The georeferenced still (GS) approach used still, waterfall images, named for the way in which the image cascades down a screen when viewed in real time (Figure 2.3). These images can either be screen captures from the head unit or in this case, still images extracted from video recordings created by the sonar head unit. While some distortion was introduced to the images in the georeferencing process, nearly the full detail of the original images was maintained. This process did not correct for slant range distortion. The water column was present in the end product, and the georeferenced images are not strictly accurate in terms of area. Similar approaches have required approximately 51 minutes per rkm mapped for image preparation and georeferencing (Kaeser & Litts 2010.)

In this approach, Humminbird® video files were converted to still images and then georeferenced in ArcMap 9.3 (Figure 2.4). The .dat files were first converted to the eXtended Triton Format (.xtf) (Triton Imaging, Inc. 2008). Once converted to .xtf, the recordings were opened in SIView (Norwood 2010), and exported as a series of bitmaps (.bmp), each corresponding to a 100-meter stream length. GPS waypoint and track data were exported in SIView as a text (.txt) file, imported into ArcMap 9.3, and saved as an ESRI shapefile. The shapefiles were then used to create an image-to-ground control point network consisting of 300 to 360 points per image in the set using the ArcGIS toolset developed by Kaeser & Litts (2008). The images were rectified to the ground control points at a pixel resolution of 10 cm. The resulting SIMs were saved as .png images with corresponding world files registered to UTM Zone 17 and projected on the North American Datum of 1983 (NAD83).

I used the same methods in the second, waterfall (WF) approach, but classified the substrate from waterfall images prior to georeferencing the images. The intent of this method was to achieve the highest quality images for classification, in hopes of achieving greater accuracy. Georeferencing introduces warping and a distortion to the waterfall images, in light of this, the highest quality imagery is seen prior to such manipulations. This is especially true when navigational constraints force deviation from straight lines surveys, where waterfall images do not correspond to linear travel. This approach required an additional processing step, and approximately 61 minutes per rkm mapped. However, the maps created are already classified.

The waterfall processing approach utilized the same processing tools as the georeferenced stills approach, but applied them to classified imagery. Sonar files were processed with Son2XTF and SIView to create a series of .bmp files. The .bmp files were then opened in ArcMap 9.3. A new shapefile was created and populated with polygons corresponding to unique substrate patches from the sonar images; this shapefile was then exported as a .bmp. Adobe Photoshop CS5 was used to remove a border region introduced in the export from ArcMap and to resize the classified image to the same proportions as the original sonar image. This image was again saved as a .bmp and processed in the exact manner as the unprocessed images to create SIMs.

The final approach (DD), the side-scan extension for the DrDepth® software package, is able to directly read the Humminbird® sonar recordings. The recordings are georeferenced without an intermediary still image, and are slant range corrected. This allows for accurate measurement of area and an end product without the artifact of the water column. This approach is the fastest of the three, requiring no more than 10 minutes per rkm mapped for georeferencing, and no image preparation. However, the additional manipulation of the image may reduce detail.

This path used DrDepth® to read the .dat files and rapidly generate SIMs. The .dat files were loaded into DrDepth® and opened at resolution of 12.5 cm per pixel. The images were exported as .bmp files with accompanying Google Earth .kml files. The .kml files were used to generate world files and the .bmp's were opened in ArcMap and projected onto NAD83, UTM Zone 17.

A classification scheme was determined from field observations and included four distinct classes, covering the dominant substrate types observed in the Ogeechee River.

The classes were sandy (S), hard-packed clay (C), gravel (G) and exposed bedrock (B) (Figure 2.5). Points designated sand were composed entirely of sand. Ground truth points were assigned to one of the non-sand classes if any amount of the substrate type in question was present. A minimum map unit (MMU) was defined in the field as one square-meter, or the approximate extent visible using the underwater camera.

Of the four reaches surveyed, one was held back as a training section and classified with the assistance of the reference data for that reach. The remaining the stretches were visually, or “heads up,” classified without foreknowledge of the reference data for those reaches. For consistency, all heads-up classification was conducted by the same observer. In all approaches, substrate classification of the SIMs was conducted in ArcMap 9.3. New shapefiles were created and populated with polygons corresponding to unique areas of contiguous like substrate greater than the MMU. The polygons were then assigned to one of the four substrate classes. The streambed was classified from bank to bank, with areas of shadow or uncertainty classified as such (figure 2.6).

Error matrices and classification accuracy statistics were calculated using reference data for all three processing approaches (Congalton and Green, 1999). In each instance reference points occurring within 3 meters of a substrate class boundary or within the water column of the un-slant range corrected SIMs were discarded, in an effort to minimize classification errors due to positional error.

RESULTS

We mapped 2441 linear meters of the Ogeechee River. Due to the effects of slant range distortion and variance across methods in classifying stream banks, area mapped varied by method - for a total of 8.01 hectare using GS, 8.97 ha using WF, and 10.03 ha using DD. Across all methods sand was the most common substrate identified, composing 75% of classified substrate using GS, 66% using WF, and 71% using DD (Tables 2.2, 2.3, & 2.4). The remaining classified areas were 14% exposed bedrock and 7% clay using GS; 17% bedrock, 6 % clay, and 3 % gravel using WF; and 18% bedrock, 8% clay, and 1% gravel using DD. Unsure areas totaled 4%, 7%, and 3% using GS, WF, and DD, respectively.

Overall classification accuracy was 85% using WS, 83% using WF, and 82% using DD. Producer's accuracy, or errors of omission, ranged from 0% to 98% with WS, 16% to 95% with WF, and 39% to 94% with DD. User's accuracy, or errors of commission, ranged from undefined to 93% using WS, 59% to 94% using WF, and 28% to 93% using DD. Undefined value were the result of no gravel being classified using GS, which resulted in a zero in the denominator when calculating user's accuracy. Kappa analysis of the error matrices resulted in a KHAT of 0.75 with WS, 0.73 with WF, and 0.70 with DD (Table 2.5), suggesting moderate to good agreement with the reference data (Landis and Koch 1977). Pairwise comparison of the error matrices yielded no Z statistic greater than 0.42 (Table 2.6), indicating that there was no significant difference between the matrices.

DISCUSSION

While error matrices among the three side-scan sonar processing approaches showed no statistical difference, there were some patterns worth noting. Across methods, classification accuracy was highest in the most common classes -- sand and bedrock.

These two classes were also frequently over-predicted, with producer's accuracy often notably higher than user's. This may be an artifact of the reference data sampling, as systematic sampling tends to over-represent common classes (Congalton and Greene 1999). Combined with the ubiquity of sand and bedrock in the survey sites, this may have led to habituated over-classification during the inherently subjective heads-up classification.

Classification of clay was also fairly successful; user's accuracy was highest in the clay class across all methods. Additionally, the clay substrate was found in one large and continuous patch. As one of the key difficulties in classification is discriminating boundaries in transition zones, this minimized a main source of error (Meyer and White 2007). Consolidated clay sediments only occurred at one of the survey locations, which may have minimized opportunities for over-prediction, as there were effectively only two clay/non-clay boundaries in the study area.

The most common source of error across all methods was difficulty in distinguishing between classes during heads-up classification. The gravel class was most problematic with no method resulting in a producer's accuracy higher than 39% in this class. Much of the difficulty in correctly classifying gravel lies in its similarity to other classes on the SIMs. In all methods except DD, gravel was more frequently classified as sand than correctly identified. Gravel was the rarest class, comprising no more than 10.5% of reference data; as such, there were little in the realm of training opportunities. Additionally, many of the samples identified in the field as gravel were mixtures of sand and gravel. Likewise, this patchiness may have compounded positional error, as some patches were smaller than the stated accuracy of the Humminbird® GPS – 3m (Humminbird 2007).

No gravel was successfully identified using GS. This was not due to an inability of the method to identify gravel, but rather to a drawback to the GS method. The sole patch of gravel in the survey areas was located in an area that required great deviation from straight line travel due to obstacles in the river channel. This resulted in waterfall images that could be interpreted and classified with difficulty. Deviation from straight line surveying likely suppressed classification accuracy across all methods, but the effect was most severe in the GS approach. When a control grid was created from the track data, the resultant rectified imagery was greatly distorted and no classification could be made using the imagery. While this effect can be minimized by georeferencing more and smaller waterfall images, it also illustrates the importance of maintaining straight line surveying paths. DD was the least affected by deviation from straight line surveying paths.

Discrimination between gravel and sand may be an inherent challenge to recreational-grade side scan sonar due to limited along track, or transverse resolution (Kaeser and Litts 2010) - which is the smallest recognizable detail of an image produced along a line parallel to the towpath (Fish and Carr 1990). Humminbird® side-scan sonar equipment has a stated transverse resolution of 63.5 mm (Humminbird 2007). This limitation results in SIMs that display similar appearances for all particles under 63.5 mm in size. In contrast, research oriented equipment operates at along track resolutions as low as 18 mm (EdgeTech 2011). Contextual cues and larger patterns in substrates can offset this limitation, especially in heads-up classifications (Kaeser and Litts 2010).

Overall accuracy was similar across all methods and compares well to previous studies. Overall accuracy in the only published study using Humminbird® side-scan equipment to classify stream substrate was 76%, 86% when the rocky substrate classes were simplified from three classes to two (Kaeser & Litts 2010). The overall accuracy of all methods here falls into that range. Similarly, lowest classification accuracy was seen in gravel substrates.

Limited substrate diversity in the Ogeechee River may have also contributed to poor differentiation among substrate classes. Low gradient southeastern rivers are frequently dominated by sandy substrate (Wallace & Benke 1984, Benke et al. 1985), and in this case, only a few small patches of rocky substrates could be located. The dominance of sand substrates likely hindered accurate classification of rocky substrates due to a lack of training opportunities. Regardless of which processing method is used, visual classification of stream substrate is a subjective process with a steep learning curve. Additional training opportunities with a variety of course substrates would have no doubt lead to greater classification accuracy. Repeating this study on a higher gradient stream likely would result in greater classification accuracy of rocky substrate classes.

Given the lack of statistical difference between approaches, and the speed and ease of use, I suggest that the DrDepth® approach is the most preferable method for georeferencing sonar imagery created by Humminbird® equipment. While overall accuracy was lowest with DD, this difference was not significant. There may also be training issues at play with DrDepth®. The SIView based approaches display the sonar images in a familiar way to the classifier; appearing very much as they do on the sonar head unit. DrDepth® in addition to generating images that appear comparatively unfamiliar had only been available for a few months at the time of classification. It is possible that with greater familiarity to these images, classification accuracy would improve.

Correction of slant range error is another reason to favor DD. Slant range corrected images offer a "bank to bank" picture of the river bottom and allow accurate measurements of area. Elimination of the water column in the image also provides a more intuitive picture of the river bottom. This feature alone may result in a superior end product, especially when creating maps for a non-technical audience. Slant range correction in DrDepth® does require resampling and remapping of the sonar imagery, and a subjective loss in image quality. This may be largely avoided by retaining uncorrected imagery for use as a reference when classifying corrected SIMs.

Conclusion

This study presents an evaluation of currently available processing tools for recreational-grade side-scan sonar imagery, which will assist in the application of this emerging technology. DrDepth® can be used to rapidly generate georectified images of benthic habitat with accuracy similar to more labor-intensive approaches. These tools can be used to efficiently examine aquatic habitat at a high level of detail without the limitations posed by transect based sampling in turbid or non-wadeable streams and lakes.

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Table 2.1. Key characteristics of the processing pathways used to georeference and classify sonar imagery.

	Georeferenced Stills	Waterfall Images	DrDepth®
Image quality	High	Highest	High
Speed	51 minutes/rkm	61 minutes/rkm	10 minutes/rkm
Ease of use	Moderate	Moderate	Simple
File processing	5 steps	6 steps	2 steps
Slant range correction	No	No	Yes
Areal bias	Yes	Yes	No
Transparency	Yes	Yes	No
Cost	Free	Free	$320

Table 2.2. Error matrix for georeferenced stills approach.

Classified data	**Reference site data (field data)**				**Row total**	**User's accuracy**
	B	**C**	**G**	**S**		
B	164	0	9	35	208	78.85%
C	0	53	4	0	57	92.98%
G	0	0	0	0	0	n/a
S	3	15	20	273	311	87.78%
Column total	167	68	33	308	576	
Producer's accuracy	98.20%	77.94%	0.0%	88.64%		Overall accuracy 85.07%

Table 2.3. Error matrix for waterfall image approach.

Classified data	Reference site data (field data)				Row total	User's accuracy
	B	**C**	**G**	**S**		
B	161	0	25	29	215	74.88%
C	0	51	3	0	54	94.44%
G	7	0	10	0	17	58.82%
S	2	11	26	282	321	87.85%
Column total	170	62	64	311	607	
Producer's accuracy	94.71 %	82.26 %	15.63 %	90.68 %		Overall accuracy 83.03%

Table 2.4. Error matrix for DrDepth® approach.

Classified data	**Reference site data (field data)**				**Row total**	**User's accuracy**
	B	**C**	**G**	**S**		
B	192	0	5	57	254	75.59%
C	0	53	4	0	57	92.98%
G	11	0	15	27	53	28.30%
S	2	11	14	321	348	92.24%
Column total	205	64	38	405	712	
Producer's accuracy	93.66%	82.81%	39.47%	79.26%		Overall accuracy 81.60%

Table 2.5. Error matrices analysis statistics.

Matrix	**K_{HAT}**	**Variance**	**Z**
Georeferenced Still	0.749	0.00935	7.74
Waterfall	0.725	0.00754	8.35
DrDepth®	0.697	0.00589	9.08

Table 2.6. Pairwise comparison analysis of variance between error matrices.

Pairwise Comparison	**Z Statistic**
Georeferenced Still vs. Waterfall	0.188
Georeferenced Still vs. DrDepth®	0.418
Waterfall vs. DrDepth®	0.241

Figure 2.1. An representative side-scan sonar image from the Ogeechee River, Georgia. Legend as follows; A: stream bank, B: first surface return, C: trigger pulse, D: first bottom return, E: shadow, F: woody debris, G: water column (Adapted from Fish and Carr, 1990).

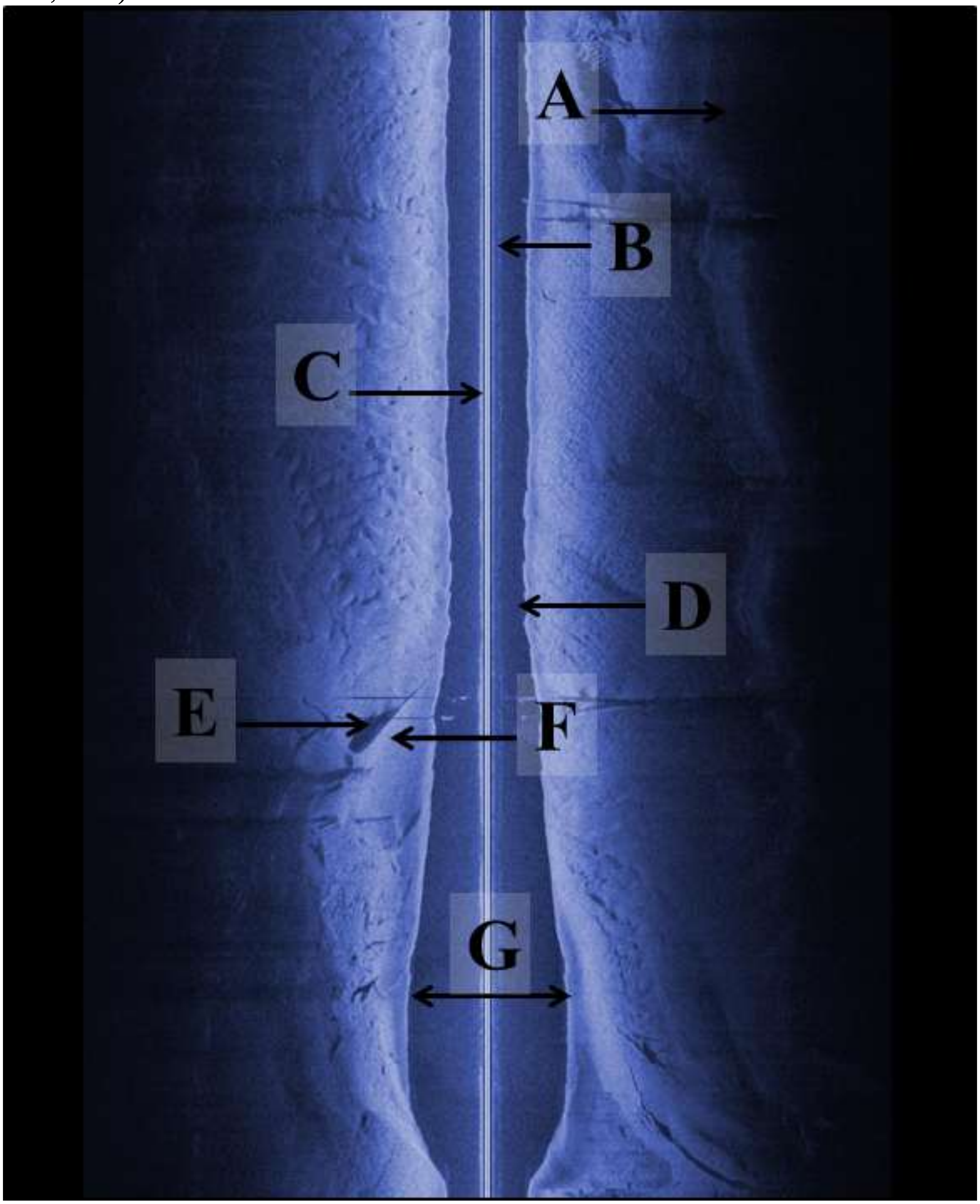


Figure 2.2. Study locations on the Ogeechee River, Georgia.

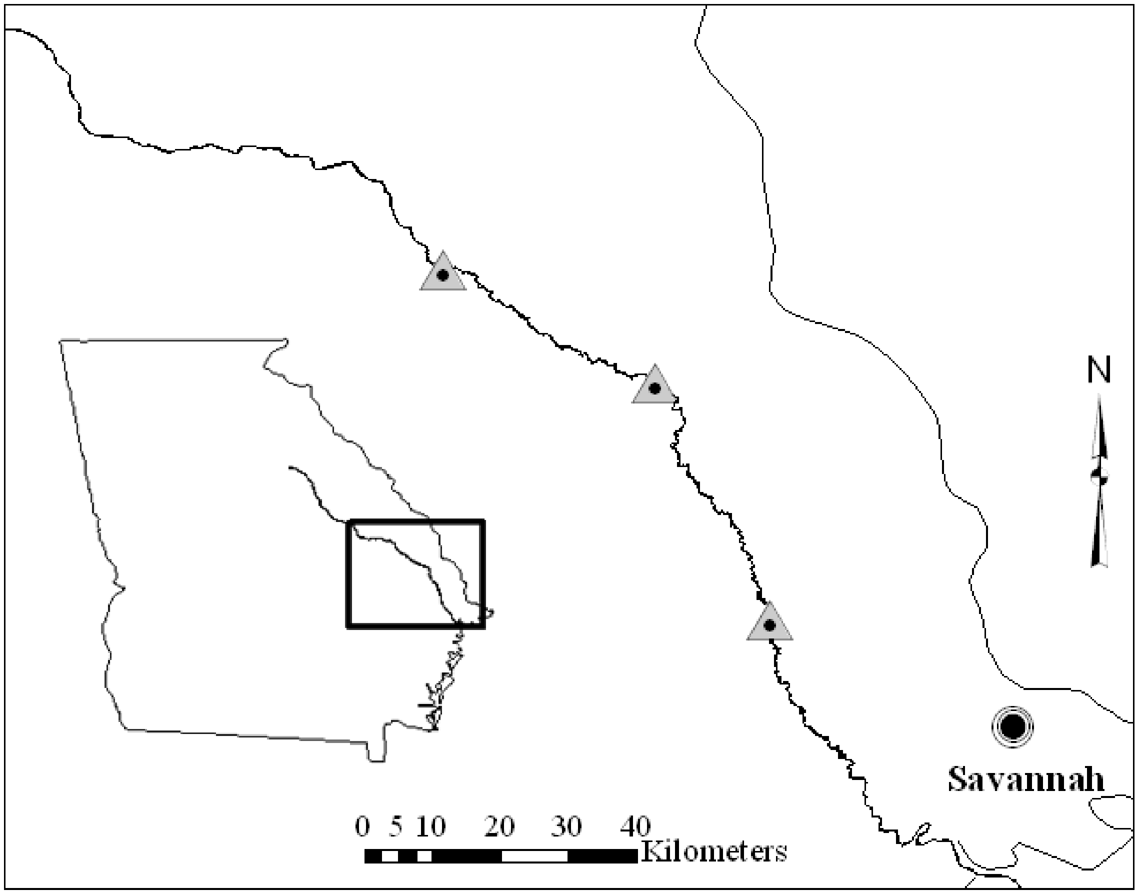


Figure 2.3. Waterfall (left) and georeferenced (right) side scan sonar imagery.

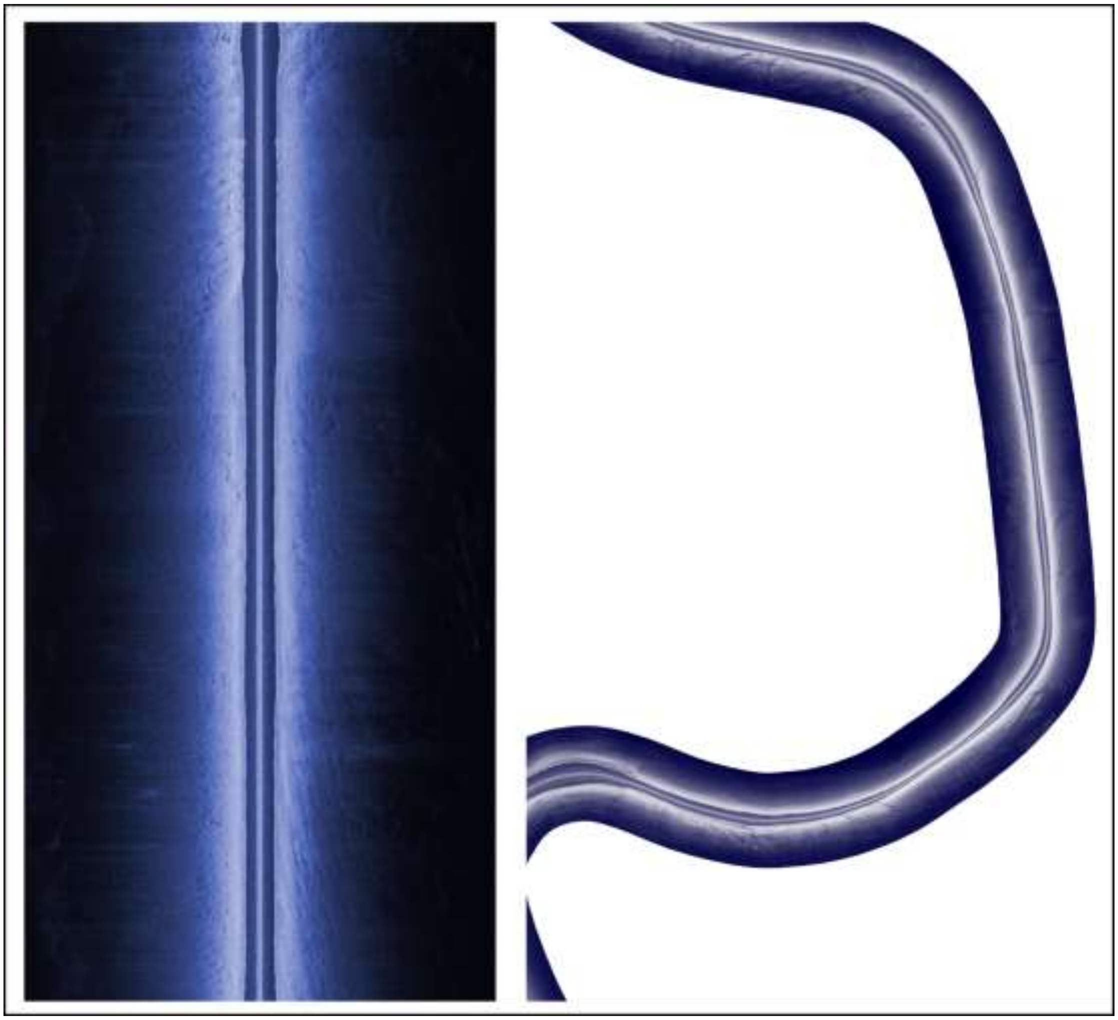


Figure 2.4. File processing pathways for Georeferenced Stills, Waterfall Image, and DrDepth® approaches.

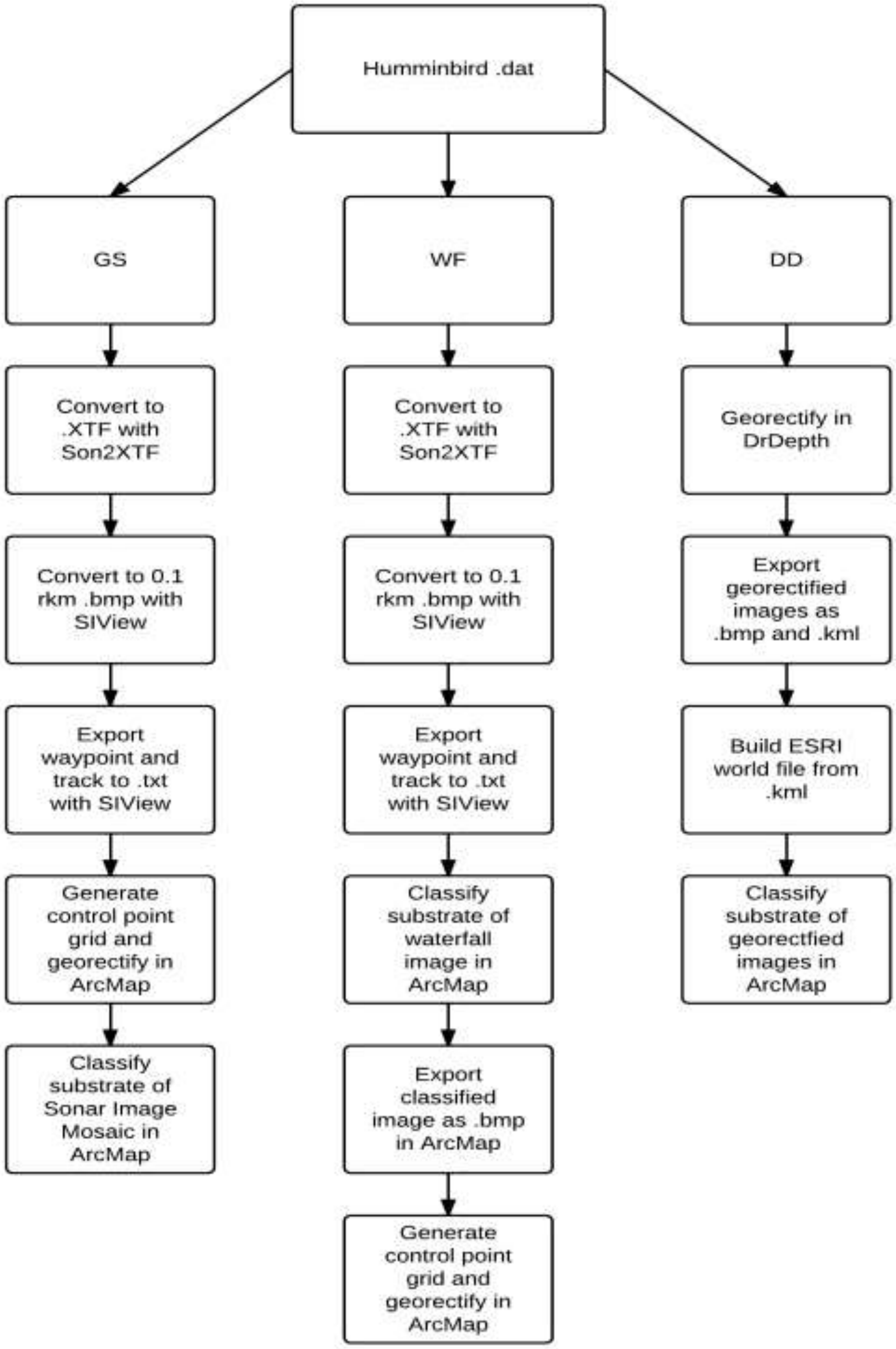
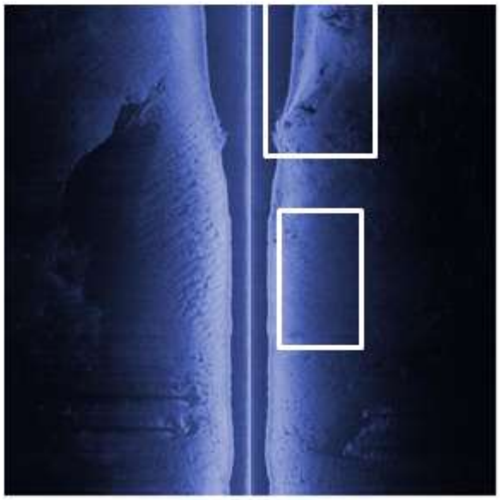
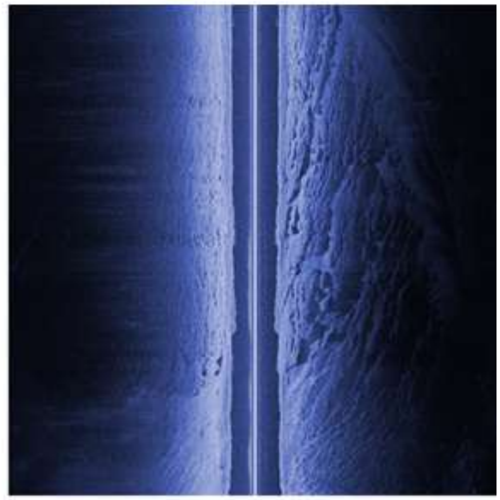


Figure 2.5. Interpretation key to four classes of stream substrate on the Ogeechee River, Georgia.



Gravel – Dimpled texture, strong return, larger (10cm) pieces of rock may be observable.

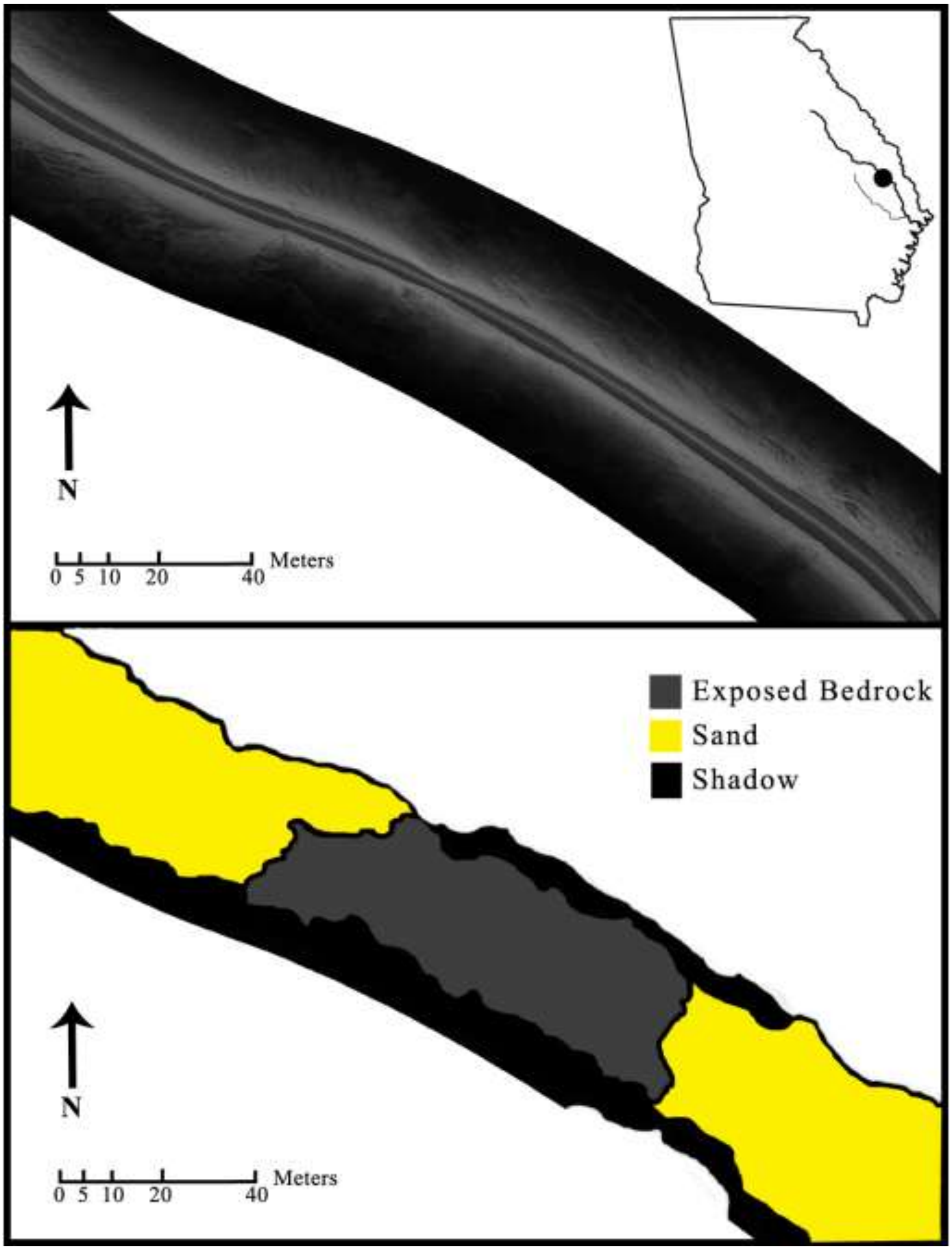


Clay – Dark or weaker return, irregularly striated texture, "puffy" or cloud-like appearance.

Bedrock – Strong return, smooth but irregularly marked texture, coarse dimpled appearance.

Sand – Bright return, wave patterns, ridges, patterns are frequently very regular, "looks like the beach".

Figure 2.6. Sample sonar image map created from Dr. Depth imagery recorded in the Ogeechee River, Georgia.



CHAPTER THREE

IDENTIFICATION OF POTENTIAL ATLANTIC STURGEON SPAWNING GROUNDS IN THE OGEECHEE RIVER, GEORGIA USING LOW-COST SIDE-SCAN SONAR[1]

[1]Hook, J.D., D.L. Peterson, and N.P. Nibbelink. To be submitted.

Abstract

As a group, sturgeon are among the world's most imperiled fish. In the Ogeechee River, Georgia, recovery of a small but unquantified population of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus)* is impeded by loss of nursery habitats and thermal refugia, as well as bycatch from a shad fishery. Knowledge of spawning habits is vital for the successful management and restoration of imperiled anadromous fish. However, most knowledge of Atlantic sturgeon spawning locations comes from northern rivers. There has been little work on locating spawning grounds in southern systems. Our primary objective was to define potential spawning locations for Atlantic sturgeon in the Ogeechee River of Georgia. A second objective was to demonstrate the application of low cost sonar survey techniques to a pressing conservation and management issue. These objectives were addressed by mapping stream reaches containing suitable spawning habitats using imagery from recreational-grade Humminbird® side-scan and multi-beam sonar equipment. We identified all hard substrates greater than 1.5 m depth as potentially suitable for sturgeon spawning. Eight stream reaches totaling 50,892 square meters were identified as potentially suitable for spawning use by Atlantic sturgeon, representing about 0.2% of the total estimated area of river-bottom. Especially where depth or turbidity precludes traditional habitat sampling, this approach offers an efficient method for locating habitat types for further targeted investigation. Recreational-grade sonar surveying is particularly useful in low-gradient Southeastern streams like the Ogeechee River, where habitat types of interest may be uncommon and scattered over hundreds of river kilometers.

INTRODUCTION

As a group, sturgeon are among the world's most imperiled fish. Worldwide, 23 of 25 species are categorized as threatened or endangered by the International Union for Conservation of Nature and Natural Resources (IUCN) Red List (IUCN 2010). Presently, Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) are classified as Near Threatened (Pierre and Paruka 2006), and the National Marine Fisheries Service has proposed listing four of the five Distinct Population Segments (DPS) recognized in the United States as endangered under the Endangered Species Act (NMFS 2010 NMFS 2010a). Threats to Atlantic sturgeon include loss of habitat through dams and dredging, pollution, and mortality associated with bycatch (Smith and Clugston 1997). In the Ogeechee River, Georgia, recovery of a small but unquantified population of Atlantic sturgeon is impeded by loss of nursery habitats and thermal refugia, as well as bycatch from the shad fishery (NMFS 1998).

Atlantic sturgeon are the largest anadromous fish of the North American Atlantic coast and range historically from Labrador, Canada to the Gulf of Mexico (NMFS 1998). Their current range is diminished to populations using 20 Atlantic coastal rivers (ASSRT 2007). Population declines began soon after the emergence of a large commercial fishery in the late nineteenth century (Secor and Waldman 1999). Harvest peaked at 3350 metric tons in 1890, and collapsed within 10 years, due to persistent overharvest (Smith and Clugston 1997, Secor and Waldman 1999). Landings continued at one percent of peak levels for most of the 1900's until the Atlantic States Marine Fisheries Commission imposed an emergency moratorium in December of 1995 (Bain et al. 2000, ASMFC

1998). The moratorium was made permanent in 1998, however, commercial harvest continues in Canadian waters.

Knowledge of spawning habits is vital for the successful management and restoration of imperiled anadromous fish. However, most knowledge of Atlantic sturgeon spawning locations comes from northern rivers. There has been little work on locating spawning grounds in southern systems. Atlantic sturgeon broadcast adhesive eggs into the demersal zone upstream of the saltwater interface (Gilbert 1989, Collins et al. 2000, Hatin et al. 2002). Spawning grounds occur at least 20 to 100 rkm upstream, with some sites documented at much as 221 rkm upstream (Van Eenennaam et al. 1996, Armstrong and Hightower 2002). Atlantic sturgeon spawning sites are characterized by the presence of hard bottom substrate such as rock, rubble, or hard clay (Table 3.1). In low gradient southern rivers, these conditions are often expressed as rock or limestone outcroppings (Gilbert 1989). Depth of documented spawning sites ranges from a minimum of 1.5 m to a maximum of 60 m (Van Den Avyle 1984, Collins et al. 2000, Caron et al. 2002, Hatin et al. 2002).

There are several reasons why hard bottom substrates are required for spawning. First, Atlantic sturgeon eggs are adhesive, and if deposited into sandy or other soft bottoms they may become encapsulated, suffocating the developing egg (Van Den Avyle 1984, Fox et al. 2000). Second, developing sturgeon free embryos inhabit the interstitial spaces between coarse, hard substrates (Kempinger 1988, LaHaye et al. 1992). Interstitial spaces provide several key benefits to pre-larval sturgeon including protection from predation and allow poor swimming free embryos to resist drift. Given that age 1 and younger fish of most sturgeon species are intolerant of even very low salt concentrations

(Jenkins et al. 1993, Kynard and Horgan 2002), drifting into brackish water would be lethal for developing larvae (Gessner et al. 2009). As such, interstitial spaces amongst hard substrates are necessary to the survival of Atlantic sturgeon during the early critical life stage.

There are no recent studies quantifying the abundance of Atlantic sturgeon in the Ogeechee River, however Atlantic sturgeon are believed to spawn in the river based on the presence of Age 1 juveniles. Farrae et al. (2009) estimated the abundance of age 1 Atlantic sturgeon in the Ogeechee River to be 450 in 2007, and numerous other researchers have captured age 1 Atlantic sturgeon in the system. (Table 3.2). Age 1 sturgeon have not yet developed salinity tolerance and remain in their natal rivers, as such the presence of age 1 Atlantic sturgeon in the Ogeechee River indicates that they were spawned there. This assumes the presence of age 0 sturgeon as well, however it is difficult to assess the presence of age 0 Atlantic sturgeon as they are not vulnerable to capture in entanglement gear (Schueller and Peterson 2010).

While the frequent presence of age 1 sturgeon indicate that Atlantic sturgeon are spawning in the Ogeechee River, little is known about their spawning grounds. Our primary objective was to define potential spawning locations for Atlantic sturgeon in the Ogeechee River of Georgia. A second objective was to demonstrate the application of low cost sonar survey techniques to a pressing conservation and management issue. These objectives were addressed by mapping stream reaches containing suitable spawning habitats using imagery from recreational-grade Humminbird® side-scan and multi-beam sonar equipment.

Study area - the Ogeechee River

At 394 kilometers, the Ogeechee River is the longest unimpounded river in Georgia, and one of 42 free-flowing rivers greater than 200 kilometers in the lower 48 states (Benke 1990). A sixth order river, the Ogeechee River drains a watershed of 14,300 square kilometers. The Ogeechee River's headwaters are in the Georgia Piedmont and the majority of its length and 95 percent of its drainage is located in the Coastal plain (Meyer et al. 1997). Below a small falls near Shoals, Georgia the river becomes a slow blackwater river with an average daily discharge of 115 cubic meters per second (Meyer et al. 1997). Spring flooding swells discharge to an average daily discharge of 146.4 during the month of March. The Ogeechee River has one major tributary, the Canoochee River -- a 160 kilometer long stream which joins the Ogeechee River at river kilometer 55 (Fleming et al. 2003).

METHODS

Side scan and multi-beam sonar surveys were performed on the Ogeechee River from river kilometer (rkm) 32 near Fort McAllister to approximately rkm 320 near Louisville, Georgia from January 2009 to June 2009. Surveys were performed at high flows to capture bank full width while minimizing navigational difficulties. The surveys were conducted using Humminbird® 997SI side scan and 967C multi-beam sonar systems. The 997SI sonar transducer was mounted to a boom off the bow of the 13.5 foot Riverhawk ghanoe to minimize wake-induced turbulence. The 967C sonar transducer was mounted to the transom, as it is relatively unaffected by wake. In both cases, the GPS antenna was mounted to the top of the boom, directly above the transducer, to maximize locational accuracy. Operating frequency was set to 455 kHz. Range was set to 150% of estimated stream width, as little as 20 meters at upstream sites and as much as the maximum range of the units, 100 meters, at lower locations. Side-scan sonar imagery was captured while navigating downstream at midchannel at 5.5 kph (3 knots). Bathymetric data was collected while navigating either upstream or downstream at speeds from 5.5 to 8.0 kph (3 to 5 knots). At least three and as many as seven passes were made at each site using the 967 system at positions spread evenly across the channel to maximize coverage. Sonar recordings were stored in the Humminbird® proprietary .dat/.son format. The .dat/.son format is intended for playback on the head unit on which it was recorded, or on that of a similar model. This format is similar to a video recording of the sonar imagery.

Side-scan recordings were converted to the eXtended Triton Format (.xtf) (Triton Imaging, Inc. 2008) using Son2XTF 1.001 (Humminbird 2008). Once converted to .xtf the side scan recordings were georeferenced using DrDepth® 3.9.23 (Perlin 2010). The recordings were georeferenced without slant- range correction at a 0.0625 meter per pixel resolution, and exported as .png image files with accompanying Keyhole Markup Language (.kml) files. ESRI World files were manually derived from the .kml files and the georeferenced images were projected in NAD83 in ESRI ArcMap 9.

In order to determine potentially suitable locations for Atlantic sturgeon spawning, I examined substrate type and depth. Stream substrate was manually interpreted and classified ("heads up" classification). Aerial photography was used to aid classification, primarily when identifying landowner placed rip rap and bank improvements. Stream substrate was classified into two categories, either potentially suitable for spawning use by Atlantic sturgeon, or unsuitable. While specific substrate associations with Atlantic sturgeon spawning grounds in literature are varied, nearly all described spawning locations contain some form of hard bottom substrate (Musick 2005). Thus, the potentially suitable class consisted of all hard substrates – exposed bedrock, cobble, gravel, boulders, and hard consolidated sediments. All other substrate types were classified as unsuitable. Areas of potentially suitable substrate were digitized as polygons. No efforts were made to further discriminate substrate type in areas deemed unsuitable.

Multi-beam data collected with the 967C was used to construct a bathymetric profile of stream reaches containing potentially suitable substrates. The .dat output of the Humminbird® sonar was converted to .xtf and then imported to MBSystem (Caress & Chayes 2009). The raw sonar data was exported as comma separated text files consisting of longitude, latitude, and depth values. Obvious outliers and spurious points were filtered by eliminating any points with depths less than zero or greater than 30 meters. The remaining points, at least 30 per river meter, were imported to ArcMap 9.2 and projected into NAD83. Side scan images were used to digitize the stream banks. A depth profile of the potentially suitable reaches during springtime flows was then created using Inverse Distance Weighting to interpolate between the digitized banks and the multi-beam swaths. The minimum depth associated with a documented Atlantic sturgeon spawning location is 1.5 m (Collins et al. 2000); therefore, this depth was deemed the minimum potentially suitable depth in this study.

RESULTS

I surveyed the Ogeechee River from rkm 30, near Fort McAllister, to rkm 320, near Louisville, GA, for a total of 298 rkm, from January to May 2009. Of these, approximately 272 rkm were survey above the furthest upstream occurrence of the salt wedge, at approximate rkm 56 (GADNR 2001). Navigational difficulties prevented surveying the river above rkm 320. As such, the river was not surveyed to the fall line, at approximate rkm 350.

Potentially suitable substrates found included exposed limestone bedrock, small limestone boulders, coarse gravel, hard-consolidated clay, and landowner placed rip rap. The remaining substrates identified consisted of sand, soft clay, and silt sediments. Surveyed depths ranged from 0.2 meters to 12.8 meters.

Eight stream reaches totaling 50,892 square meters were identified as potentially suitable for spawning use by Atlantic sturgeon (Table 3.3, Figure 3.1). This represents 0.2% of the roughly 23,900,000 m^2 surveyed. Of the 50,892 m^2 identified, 34,949 m^2 or 68% were naturally occurring hard substrates. The remaining15,943 m^2 consisted of introduced gravel and rip rap.

Depths at these locations during the survey periods ranged from 1.1 meters at the most downstream reach at river kilometer (rkm) 84.3 to a maximum depth of 5.6 meters at one of the most upstream reaches at rkm 219.6. Survey dates for these reaches were from February 23 to March 12, 2009. The Ogeechee River rose by more than three meters over the following two weeks, as such all reaches identified as containing suitable substrates would have met minimum depth requirements at some point during the February through April time-frame for Atlantic sturgeon spawning movements in southern rivers (Musick 2005, Greene et al. 2009).

Of the eight reaches identified as potentially suitable, four were relatively free from anthropogenic disturbance. These reaches were characterized by an intact riparian zone and floodplain, and contained exposed limestone bedrock substrates. These reaches were found at rkm 134.8, 138.9, 139.5, and 141.3. The remaining four reaches exhibited varying degrees of anthropogenic disturbances, including deforest riparian zones, stabilized banks, and heavy recreational usage. These reaches were located at rkm 84.3, 180.4, 219.0, and 219.6.

DISCUSSION

Many factors contribute to the difficulty of identifying spawning locations for Atlantic sturgeon. Possibly the most significant is that, ultimately, positive identification of a spawning site requires the collection of gravid females or eggs (Van Den Avyle 1984). The logistical difficulties of conducting telemetry over hundreds of river kilometers and the infrequent nature of individual spawning movements can make following individual fish to spawning sites a difficult and lengthy process. Telemetry also requires capturing fish and surgical implantation of a transmitter, a procedure that poses risks to threatened fishes and may disrupt the spawning movements of sturgeon (Moser and Ross 1995, Hastings et al. 1987, Secor and Gunderson 1998, Kynard et al. 2007). The use of egg collection mats, while quick, inexpensive, and non-invasive, requires some foreknowledge of potential spawning locations to be effective.

The morphology of southern blackwater rivers may present this foreknowledge in the form of limited substrate diversity. Low gradient southeastern rivers are frequently dominated by sandy substrates (Wallace and Benke 1984, Benke at al. 1985). The

Ogeechee River is typical of these systems with an average elevation change in the study area of 0.00028 m/m. I identified only five natural patches of hard bottom. Though there is little documentation of the spawning substrate preferences of southern populations of Atlantic sturgeon, given the importance of interstitial spaces within coarse substrates, it is reasonable to assume they, like northern populations, exclusively utilize hard bottom areas. Therefore, it is likely that Atlantic sturgeon spawning locations in the Ogeechee River are limited to these hard bottom locations. Targeted sampling for eggs or pre-larval sturgeon may be used to confirm the use of these locations as spawning grounds by Atlantic sturgeon.

Although no verification data were collected in this survey, previous work using similar techniques and equipment demonstrated the effectiveness of these methods. Kaeser and Litts (2010) used Humminbird® side-scan sonar and heads up classification to delineate substrate in the Ichawaynochaway Creek, Georgia to four classes with an overall classification accuracy of 77%. A large portion of the classification errors in their study were between rocky classes, when coarse substrates were folded into only two classes, overall accuracy improved to 86%. Similarly Hook et al. (*in prep*) found an overall accuracy of 81.6% classifying substrates in the Ogeechee River using Humminbird® sonar, DrDepth® software, and heads up classification.

A large portion of error in both of these studies was found in the borders between different substrate patches (Kaeser and Litts 2010, Hook et al. *in prep*). Border error is a result of positional error and the difficulty in identifying precise transition points between substrate types. These results suggest that patch interiors are typically assigned to the correct classes, but the borders, and therefore areal measurements, are subject to error.

Compounding errors in areal measurement is additional error introduced through slant range distortion, the difference between the distance from the sonar sensor to a given point perpendicular to the trackline and the true across track distance to that point (Fish and Carr 1990). This distortion results in a given point appearing further away from the sensor across track than it is in reality, with the greatest displacement directly underneath the sensor. The distortion can be roughly estimated at any point across track by using the Pythagorean Theorem. Assuming constant depth, the true across track distance is equivalent to the square root of the difference of the squared apparent distance along track and the squared depth under the sensor (Blondel 2009). At the shallow depths observed in this study, the effect is small. The area of a substrate patch that extended from bank to bank would be exaggerated by at most 2%.

Correcting for slant range error is preferred and would reduce areal measurement error, but this was not possible with Humminbird® sonar recordings made prior to the 4.57 firmware version. However, correcting for slant range error does compromise image quality, as it requires resampling and remapping the sonar imagery. In a prior study using these techniques, image degradation was noticed, but it did not result in a significant difference in classification accuracy (Hook et al. *in prep*). Given access to the most recent versions of Humminbird® firmware and DrDepth®, I recommend classifying slant range corrected imagery, while using uncorrected georeferenced images as a visual reference.

While it is likely that some extant hard bottom areas were not identified, coarse substrates are rare on the Ogeechee River. The extremely low gradient and wide floodplain of the Ogeechee limits occasions were high flows would scour the riverbed (Benke et al 1985), and sandy substrates dominate the river. However, where the riparian zone is developed, coarse substrates are often introduced in the form of bank modifications. The Ogeechee River has a wide and flat riparian zone that typically floods in March and April (Benke et al. 1985), and a substantial amount of introduced rip rap is needed to create a permanent artificial bank. Bank stabilization measures are most often used in outside river bends and other incised areas. Due to distance from and angle to the sonar transducer, these features can be among the hardest to discriminate in side-scan imagery. While a large flood plain and limited road access limits development of the banks of the Ogeechee River, there are likely more patches of rip rap that I failed to detect. While there is no evidence that Atlantic sturgeon spawn over rip rap, these areas do meet the minimum standards I applied. Spawning over introduced substrates is not unheard of among acipensers, as lake sturgeon (*Acipenser fulvescens*) have been documented spawning over a variety of introduced substrates including rip rap placed by private landowners for bank stabilization (Priegel and Wirth 1974, Bruch and Binkowski 2002, Caswell et al. 2004, Johnson et al. 2006).

Overall, this method presents a highly effective “first-cut” approach for locating substrates of interest. At 12 minutes per rkm on the water and 10 minutes per rkm for projection and interpretation (Hook et al. *in prep*), hard bottom areas can be identified far more rapidly than is possible with transect based, physical sampling. This approach is ideal for low gradient coastal plain rivers with little substrate diversity, where substrates of interest may occur in small patches that may be missed entirely when using transect based physical sampling.

Recreational-grade sonar surveying is an ideal technique in the Ogeechee River, as it can be used to identify preferred spawning substrates for three listed species in the watershed. In addition to Atlantic sturgeon, the Ogeechee River holds a small population of federally endangered shortnose sturgeon (*Acipenser brevirostrum*), estimated at 203 individuals in 2009 (Farrae 2010). Shortnose sturgeon utilize coarse substrates as spawning grounds similar to those favored by Atlantic sturgeon (Buckley and Kynard 1985, Kieffer and Kynard 1996). While the Ogeechee River shortnose sturgeon population is considered a sink for the much larger Altamaha River population (Farrae 2010), preservation of potential spawning grounds may be critical to establishment of a reproductive population in the Ogeechee.

The Ogeechee River is also home to a stocked population of robust redhorse (*Moxostoma robustum*), a species thought extinct until 1991 and classified as endangered by the Georgia Department of Natural Resources (Freeman 1999). In an effort to reestablish populations of this rare fish, 43, 048 robust redhorse have been stocked in the Ogeechee River since 1997 (Slaughter 2011). Spawning robust redhorse utilize substrates dominated by medium to coarse gravel located at depths from .29 to 1.1 meters (Freeman and Freeman 2001). While this study struggled to identify gravel substrates, other researchers have successfully located coarse gravel using these techniques (Kaeser and Litts 2010). However, gravel is uncommon is the Ogeechee River, the only gravel substrates I identified were introduced by the Southeast Aquatic Resources Partnership and Georgia Division of Wildlife Resources in an effort to create spawning habitat for the robust redhorse (SARP 2011).

Recreational-grade sonar surveying is not limited in application to low-gradient southern rivers, and is well suited to rivers that share a suite of characteristics. Critical characteristics of rivers for successful application of recreational-grade sonar surveying are depth, current velocity, channel width, and canopy cover. The maximum depth supported by Hummibird® side-scan sonar equipment is 45.7 meters (Humminbird 2005), while the minimum depth is that which is required for navigation. However, where depth is great enough to allow the use of a research-grade sonar system and towfish, recreational-grade equipment may not be the preferred choice. Ideal current velocity is under four kph. Wake induced turbulence begins to degrade recreational-grade side-scan sonar at speeds above five kph, higher speed surveying may be attempted if effective efforts are made to isolate the transducer from the effects of turbulence. Humminbird® side-scan sonar supports swath widths of up to 146 meters (Humminbird 2005), and wider channel and lakes may be surveyed by creating seamed mosaics. However, signal attenuation can degrade the image quality of large swaths – highest image quality with this equipment is seen in channels less than 75 meters in width. A final consideration is canopy cover; the canopy must be open enough to permit GPS reception.

Conclusion

Atlantic sturgeon successfully spawn in the Ogeechee River, as demonstrated by the frequent presence of juvenile sturgeon. There remains a need to identify the exact location of spawning grounds. Given the paucity of hard bottom areas in the Ogeechee River, I feel the areas identified here have a very high potential for use by Atlantic sturgeon. To confirm the use of these reaches as spawning grounds I recommend direct sampling, using egg collection mats, at the patches identified here.

This study demonstrates the use of low cost recreational-grade sonar to identify and map areas of interest in navigable waters. Especially where depth or turbidity precludes traditional habitat sampling, this approach offers an efficient method for locating habitat types for further targeted investigation. Recreational-grade sonar surveying is particularly useful in low-gradient Southeastern streams like the Ogeechee River, where habitat types of interest may be uncommon and scattered over hundreds of river kilometers.

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Table 3.1. Spawning substrates found at Atlantic sturgeon spawning grounds in published literature (Adapted from Greene et al. 2009).

Substrate Type	Location	Source
Rubble and Gravel	Delaware River, PA	Dees 1961
Clay	Delaware River, PA	Scott & Crossman 1973
Exposed bedrock and clay	Hudson River, NY	Bain et al. 2000
Limestone outcroppings	Edisto River, SC	Collins et al. 2000
Rock interspersed with clay and sand	St. Lawrence River, Quebec	Caron et al. 2002
Bedrock and rock	St. Lawrence River, Quebec	Hatin et al. 2002

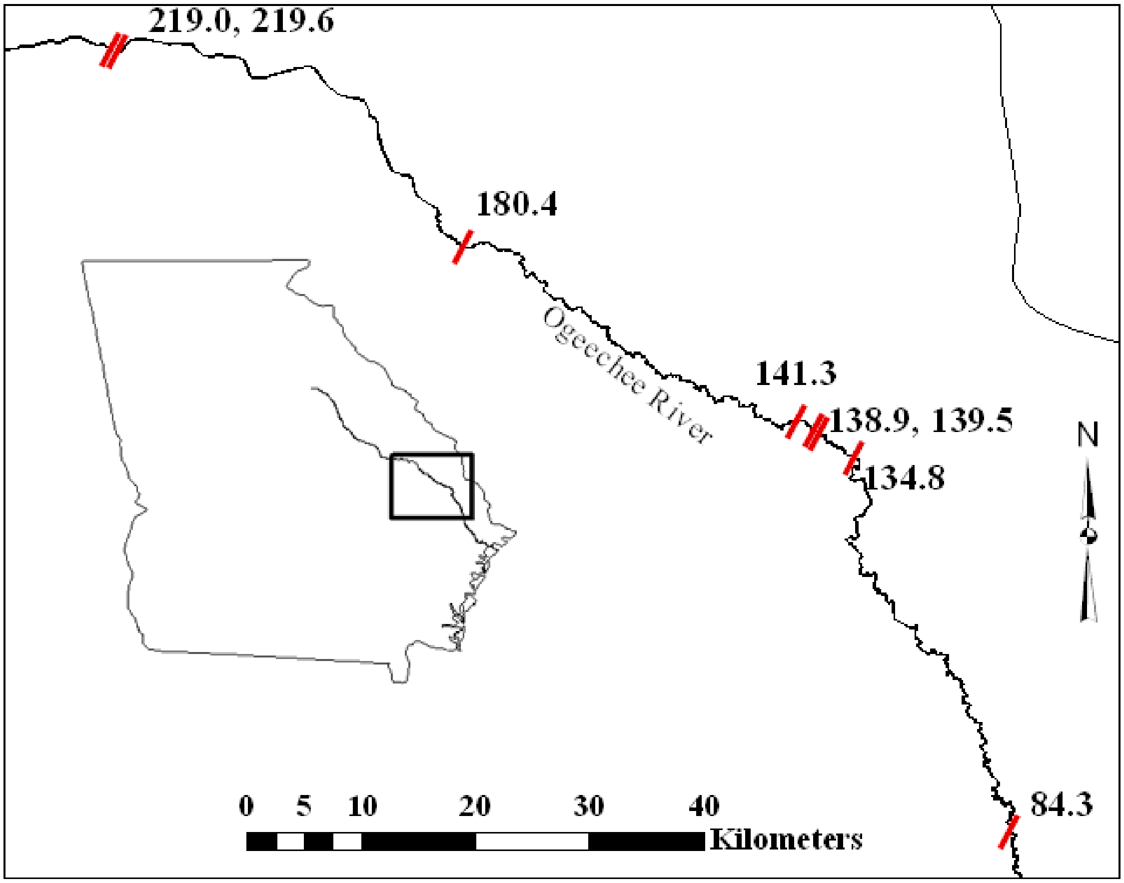
Table 3.2. Collections of Age 1 Atlantic sturgeon in the Ogeechee River, Georgia, 2000 – 2009.

Quantity	Date	Source
3	2000	Grunwald et al. 2007
17	2003	Army Environmental Division from ASSRT 2007
37	2003	Grunwald et al. 2007
9	2004	Army Environmental Division from ASSRT 2007
7	2004	Grunwald et al. 2007
43	2004-2005	Peterson et al. 2008
48	2007-2009	Farrae 2010

Table 3.3. Location, size, depth, and composition of potentially suitable spawning grounds for Atlantic sturgeon in the Ogeechee River, Georgia.

River Kilometer	Size	Depth	Composition
84.3	6774.3 m^2	1.1 – 2.4 m	Consolidated clay, “mudrock”
134.8	2076.6 m^2	1.3 – 3.1 m	Exposed limestone bedrock
138.9	4934.1 m^2	1.4 – 3.8 m	60 cm or smaller limestone boulders mixed with sand
139.5	5816.1 m^2	2.1 – 3.9 m	Exposed limestone bedrock
141.3	10711.2 m^2	2.3 – 4.6 m	Matrix of sand, exposed bedrock, and small boulders
180.4	4636.7 m^2	2.3 – 4.6 m	Exposed limestone bedrock and coarse gravel
219.0	4365.3 m^2	2.4 – 5.6 m	Concrete chunks, rip rap
219.6	11578.2 m^2	2.5 – 4.8 m	Concrete chunks, rip rap

Figure 3.1. Locations in river kilometers of potentially suitable spawning grounds for Atlantic sturgeon in the Ogeechee River, Georgia.



CHAPTER FOUR

CONCLUSIONS

This thesis presents a method for rapid characterization of stream habitat using low-cost recreational-grade sonar. Chapter Two identifies DrDepth® as the preferred approach to working with imagery created by recreational-grade side-scan sonar. Of the three investigated methods, the DrDepth® software package is preferable because it is capable of slant rant correction and is the least affected by deviations from linear survey transects. Given its low cost and ease of use, I feel that DrDepth® is the clear choice for georeferencing sonar recordings created by Humminbird(R) side-scan sonar equipment.

Chapter Three demonstrated how DrDepth® and recreational-grade side-scan sonar can be applied to a conservation or management concern. Recreational-grade side-scan sonar allows researchers to quickly identify stream substrate, and in areas where depth or turbidity precludes traditional habitat sampling, this approach offers an efficient method for locating habitat types for further targeted investigation. Recreational-grade sonar surveying is particularly useful in low-gradient Southeastern streams like the Ogeechee River, where habitat types of interest may be uncommon and scattered over hundreds of river kilometers.

Future studies of recreational-grade side-scan sonar are needed to overcome difficulties in classification of difficult to interpret substrates, especially gravel. Because of limited substrate diversity in the Ogeechee River, I was unable to perform a full accounting of this equipment’s ability to discriminate between gravel and similar appearing substrates. Future efforts should focus on rivers with greater amounts of hard substrates.

The frequent presence of YOY and juvenile Atlantic sturgeon in the Ogeechee River indicates that Atlantic sturgeon are successfully spawning in the river. Focused sampling with egg collection mats on the Ogeechee River may confirm utilization of the potential spawning grounds I identified.