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1aAO6. Acoustics and estuarine ecology: using active and passive methods to survey the physical environment, vegetation and animals in North Carolina's coastal estuaries

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Estuarine systems have complex interactions of physical and biological processes. Regular observations are needed in order to understand their dynamics. Acoustic observation systems (echosounders, acoustic Doppler current profilers (ADCPs), passive acoustic dataloggers) can provide observations on a wide spectrum of processes in estuaries. We have used echosounders to monitor changes in bathymetry, submerged aquatic vegetation, fishes, and invertebrates over time. In addition, sediment changes, resupsension events, turbidity and waves are monitored using ADCPs. The higher trophic level species of fishes and marine mammals that are soniferous have been monitored by passive acoustic methods. We provide examples of each acoustic method used to study the dynamics of seagrasses, fishes, and the physical environment of the Albemarle, Pamlico, Currituck and Core Sounds in North Carolina. While it is possible to combine methods to use acoustics to measure the dynamics of estuarine systems (estuarine observing systems), the challenge we face is to ground-truth these acoustic metrics using traditional sampling methods (e.g., quadrats for plants, trawls for fishes, water samples for sediments) and integrate each of these measures. We could then examine the effect of storms, waves, and resuspension events on estuarine plant and animal distributions and abundances using acoustics metrics.

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INTRODUCTION

Estuarine systems have complex interactions of physical and biological processes. Regular observations are needed in order to understand their dynamics. Acoustic observation systems (echosounders, acoustic Doppler current profilers (ADCPs), passive acoustic dataloggers) can provide observations on a wide spectrum of processes in estuaries. We have used echosounders to monitor changes in bathymetry, submerged aquatic vegetation, (Kenworthy et al. 2012), fishes (Krahforst 2010), and invertebrates over time. Echosounders are now being used to survey submerged aquatic vegetation (McCarthy and Sabol, 2000; Sabol *et al.*, 2002), which is a critical habitat for the juvenile fishes that spawn in Pamlico Sound in late summer (Adams, 1976; Heck *et al.*, 2003; Ford *et al.*, 2010). In addition, sediment changes, resupsension events, turbidity and waves are monitored using ADCPs (Hoitink and Hoekstra, 2005). The higher trophic level species of fishes and marine mammals that are soniferous have been monitored by passive acoustic methods (Rountree *et al.*, 2006; Gannon, 2008; Lowerre-Barbieri *et al.*, 2008; Luczkovich *et al.*, 2008a). Here, we provide examples of each acoustic method used to study the dynamics of seagrasses, fishes, and the physical environment of the Pamlico Sound and other estuaries in North Carolina.

Passive SONAR Detection of Fishes

We used passive acoustic dataloggers (LARS, Loggerhead Instruments) with a low-frequency hydrophone and digital recording of wave files to compact flash media. Recordings were made every 15 min for 10s per recording, and the digital recordings were processed using MATLAB scripts to make composite spectrograms of sound production by key soniferous species throughout the spring summer and fall in 2006-2008 Pamlico Sound. The composite spectrogram of Pamlico Sound is shown in Figure 1. As water temperatures increased, (starting at far left in Figure 1), the sounds of silver perch (*Bairdiella chrysoura*) and weakfish (*Cynoscion regalis*), spotted seatrout (*C. nebulosus*, middle bottom in Figure 1), Atlantic croaker (*Micropogonias undulatus*) and red drum (*Sciaenops ocellatus*, far right in Figure 1), all in the Family Sciaenidae, were recorded nightly. These species were loudest on the recordings at different points during the season, progressing in a sequence that corresponded to their spawning activities (Luczkovich *et al.*, 2008b). The silver perch and weakfish are spring spawners, making peak sounds in May and June, while spotted seatrout make peak sounds in July and August, and Atlantic croaker and red drum making peak sounds in September and October. Also recorded were oyster toadfish (*Opsanus tau*, Family Batrachoididae), marine mammals like bottlenose dolphins (*Tursiops truncatus*), snapping shrimp (*Alpheus* and *Synalpheus* spp.), vessel noises, wind and wave noises, rainfall events, and other unidentified sounds. Sound production greatly decreased after October, when fish spawning in Pamlico Sound is largely ended.

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Active Echosounder Measurement of Fishes

Fishes and marine animals will reflect sound from echosounders and much can be learned about their spatial and temporal distribution from echosounder surveys. We used an echosounder (BioSonics, Inc., DTX) with 200-kHz split-beam transducer to conduct surveys in Pamlico Sound (Krahforst, 2010). The echosounder will reflect from the swim bladder of most fishes and give an indication of the target strength (*TS*) of the swim bladder, which can be converted to an approximate fish size using Love's equation (Love, 1971) (1):

$$TS = 19.1 \times \log L + 0.9 \times \log w - 34.2 \quad (1)$$

Where *L* is the total fish length in feet (although Love measured length in feet, we converted fish lengths to mm for our work here), *w* is the wavelength (here we used 199 kHz). *TS* was predicted by Love for various fish species using this equation in laboratory studies using a dorsally directed acoustic beam. It is noteworthy that Love developed this model using some of the same species (bay anchovy, *Anchoa mitchilli*, and spotted seatrout) that we have in our trawl surveys for these sites in Pamlico Sound and the Pamlico estuarine system.

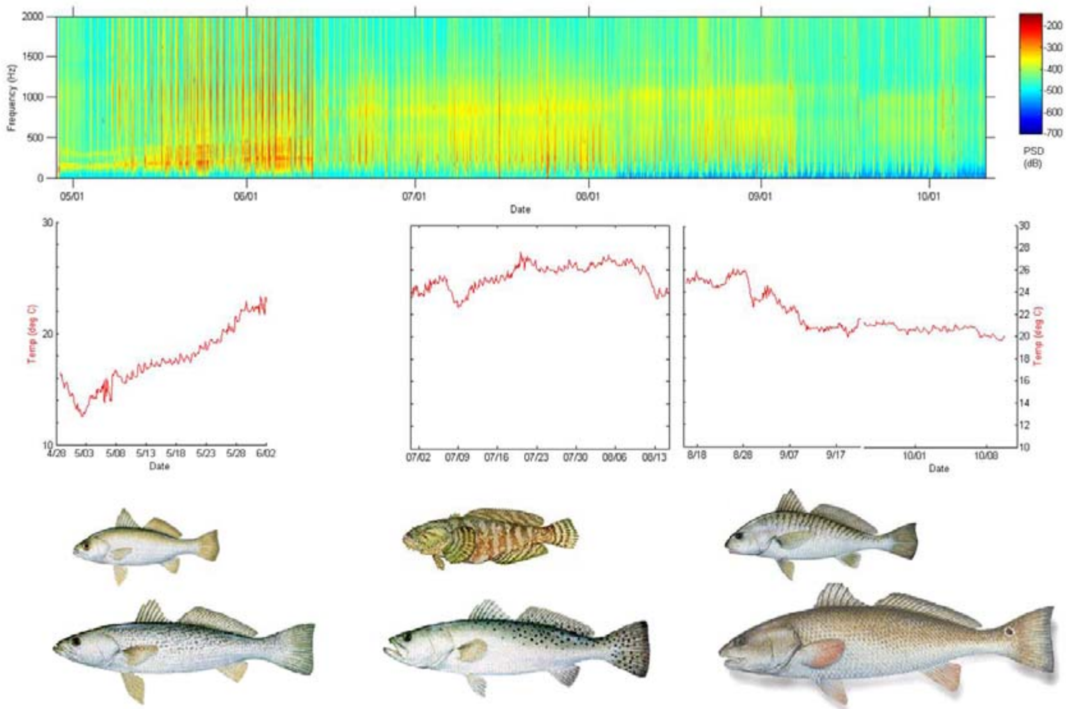
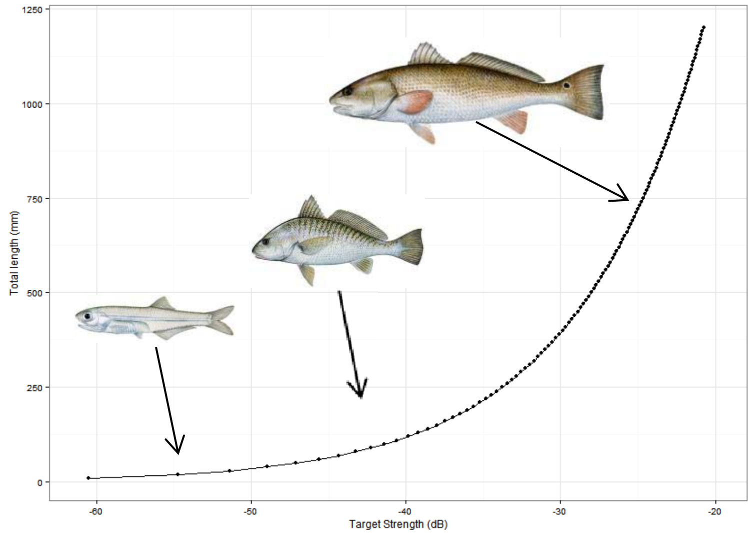


FIGURE 1. a) The sound producing fishes in Pamlico Sound (bottom) a water temperature plot (middle) and the composite spectrogram of sounds of fishes, marine mammals, and other sources (top). Fish species from left to right, silver perch (top left), weakfish (bottom left), oyster toadfish (top middle), spotted seatrout (bottom middle), Atlantic croaker (top right) and red drum (bottom right).

By using equation (1) we can estimate the size of a fish target passing under the echosounder (Figure 2a) and obtain a size distribution from the calibrated echosounder's classified target strengths (Figure 2b). Using a target-strength threshold of -60 dB and echo-integration algorithm in BioSonics Visual Analyzer 4.1 software, we counted the fish targets and obtained the size estimates for all the fishes along transects (mean =147 m length) at two sites in Pamlico Sound during September – November of 2008. We also used a small otter trawl (3.2-m mouth with 3.2-mm mesh in the cod end) pulled along at a depth ~1.5 m above the bottom at each site while simultaneously collecting the echosounder data to get a size and species composition sample at the same places and times. It is apparent that the trawl underestimated the density of the fishes present, especially small fish (Figure 3). This is due to net avoidance behavior by the fish and the fact that the trawl only sampled the bottom 1.5 m of the water column, but many of the targets were above that depth (Figure 2b). The composition of the trawl catch is shown in Figure 4, and shows that most of the fishes collected in trawls were small (< 50 mm total length) spotted seatrout and bay anchovy, but some larger species (individual fish 75 mm – 175 mm total length), including spot and Atlantic croaker. The spotted seatrout were juveniles, which were recently spawned. The smallest fish were clearly underestimated by the trawls (Figure 4), so the echosounder provides a better estimate of the abundance of spotted seatrout than the trawls. However, the presence of another species (bay anchovy) in this same size range (TS range) makes the species identification of such targets problematic. Nonetheless, abundance estimates for these small fishes were order of magnitudes larger than in trawl data, and if some assumptions are made to apportion the abundance according to the representation in the trawl data, better estimates of abundance and biomass can be made for ecosystem-based models. These sampling locations were near areas documented by us as spawning areas for spotted seatrout (Luczkovich *et al.*, 2008b), so we feel this result can be used to estimate recruitment and spotted seatrout spawning success in the future.

a



b

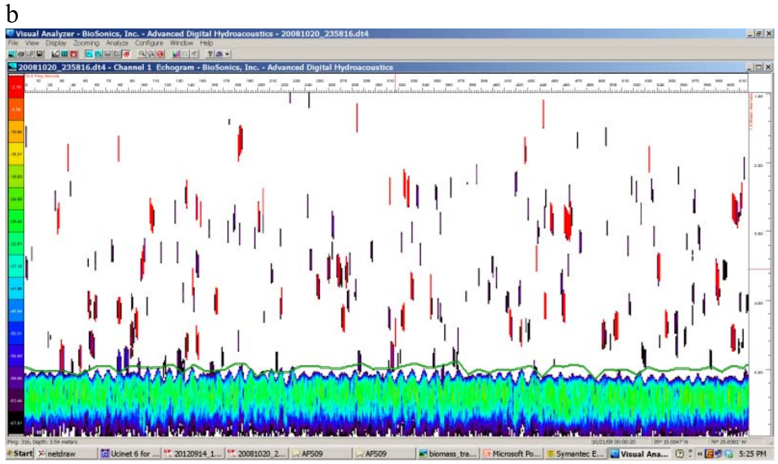


FIGURE 2. a) The relationship between target strength (dB) and fish total length (ft), following Love's equation. Red drum (*Sciaenops ocellatus*) are large and have a high target strength (-25 dB), whereas Atlantic croaker (*Micropogonias undulatus*) and bay anchovies (*Anchoa mitchilli*) have a lower target strength (-45 and -55 dB). b) An echogram from Oct 20, 2008 in Pamlico Sound, showing individual targets in blue (exceeding the threshold of the display -70 dB, with -130 dB threshold used for data collection). The echo-target algorithm-identified targets having target strengths > -60 dB are shown in red. Depth is shown on right hand bar (1 – 5 m) and a color ramp bar showing the target strengths. The bottom is shown as a green band at the bottom (target strength > -30 dB).

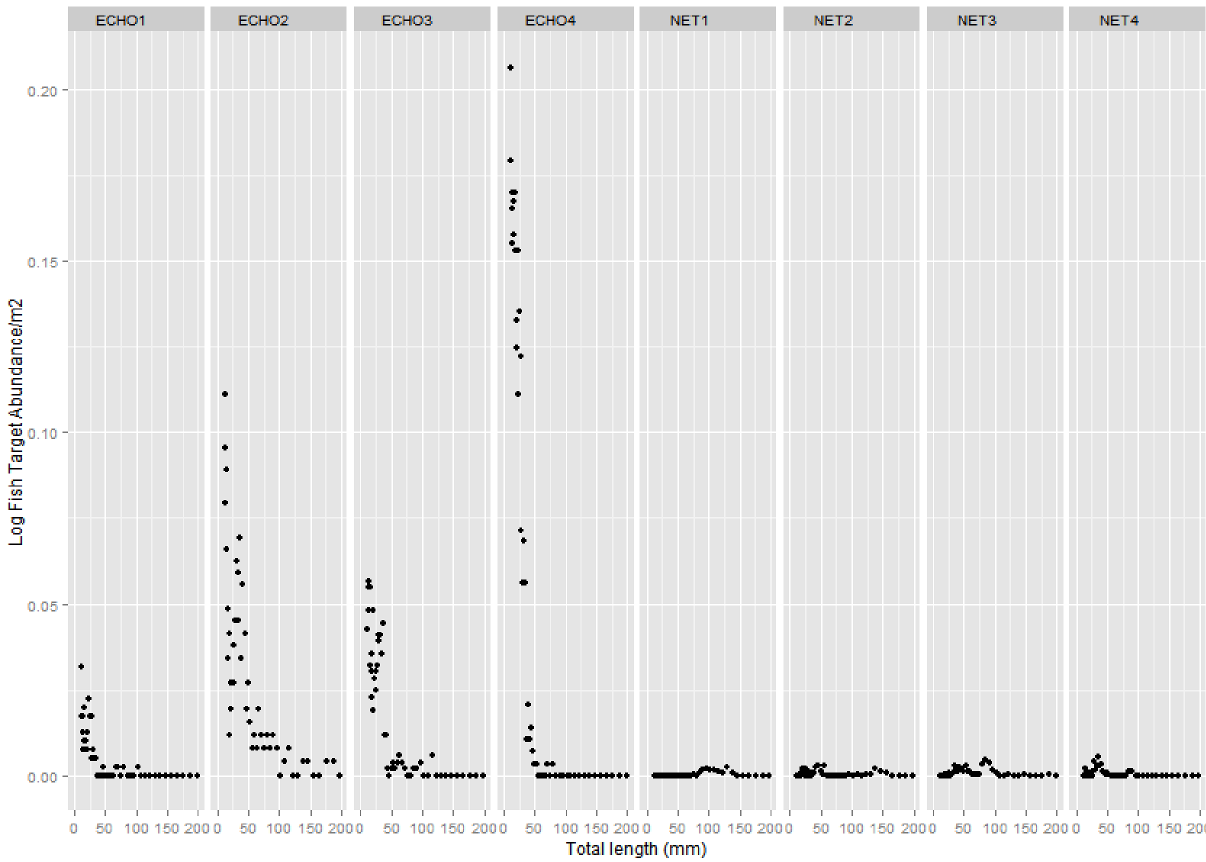


FIGURE 3. The relationship between log-transformed fish target abundance (per m^2) and fish total length as measured by the echosounder, converted from target strength (dB) using equation (1), and compared with lengths of fishes in trawl catches. The left panels (Echo1, Echo2, Echo3, and Echo4) were derived from four echosounder files processed with an echo-integration algorithm in Visual Analyzer. The right panels (Net1, Net2, Net3, and Net4) were fish lengths obtained from otter trawls pulled simultaneously along the same transects while the echosounder was recording data. Trawls captured many fishes that were small (< 50 mm, see Figure 4), but only those bigger than the mesh in the cod end (3.2 mm). When compared to the echosounder abundance estimates, it appears that escapement from trawl net capture of both small and large fishes is likely to have occurred.

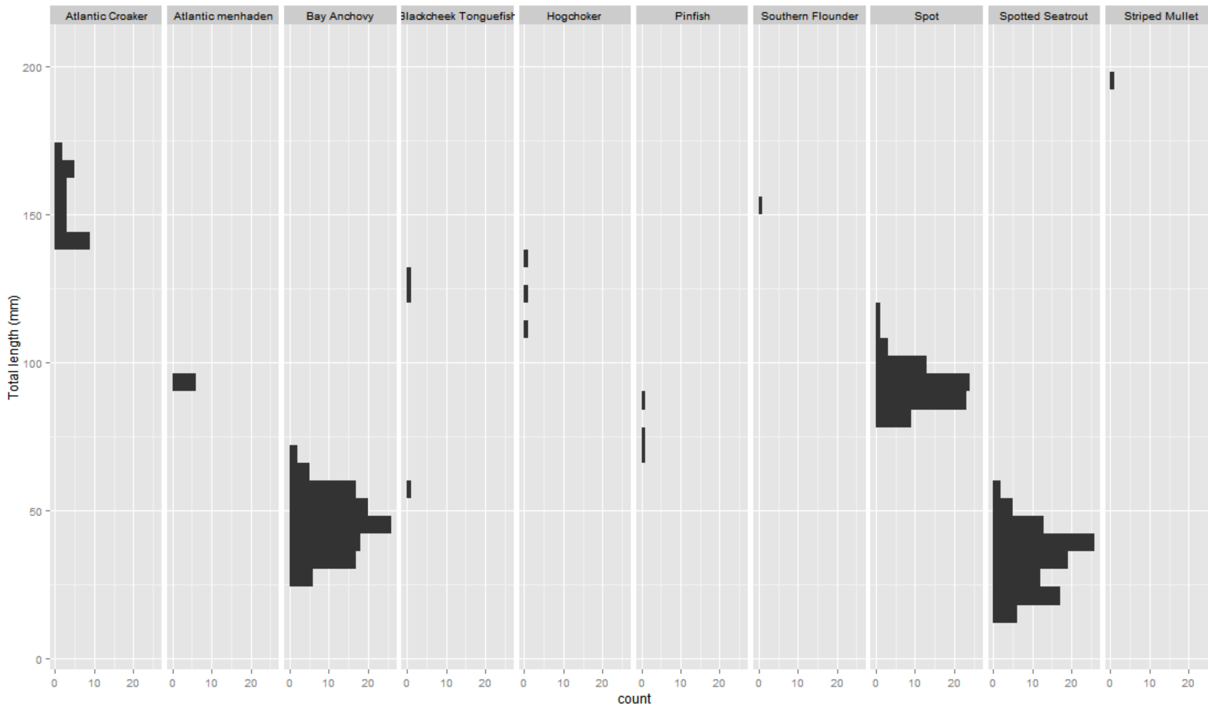


FIGURE 4. The size distribution based on total length (mm) of fishes captured by trawls in Pamlico Sound, NC during Sep-Nov 2008. Catches were pooled from the four otter trawls pulled simultaneously with a scientific echosounder.

Active Echosounder Surveys of Submerged Aquatic Vegetation

We also used the same scientific echosounder to survey submerged aquatic vegetation in low-salinity region of the Pamlico estuarine system. We show as an example the results of SAV surveys from a site in Blount's Bay, Pamlico River, and the seasonal variation of SAV cover. We used a single-beam, 420-kHz transducer to survey submerged aquatic vegetation and the ECOSAV2 algorithm from BioSonics, Inc. (Figure 5) to classify echoes into SAV present and absent acoustic reports (10 pings/report) along shore-normal transects of varying lengths (~ 300 m) in shallow water (> 4 m) (Figure 6). Echosounder transects were surveyed from a flat-bottomed boat that could navigate in shallow water, moving in an inshore and offshore orientation. Depths > 0.5 m were too shallow for acoustic surveys, being in the near field of the transducer. Diver quadrats and video drop cameras were also obtained at randomly selected points along these transects to assess the accuracy of the echosounder surveys (judged to have an overall accuracy of 77%, Kenworthy et al. 2012). Underestimates of SAV occurred in shallow water and when plants were very short, below the plant height threshold in in ECOSAV2. We conclude that the echosounder may underestimate SAV coverage. Nonetheless, a seasonal pattern of SAV coverage emerged. Echosounder surveys were repeated at the Blount's Bay site during the spring and summer (May through September) to document changes in the SAV coverage, which peaked in September in this and other low-salinity sites (Figure 6). This peak in SAV cover is associated with the arrival of summer-spawned juvenile spotted seatrout juveniles from spawning areas in the open water of the Pamlico Sound. SAV coverage increased during the summer and reached the greatest cover in September, approximately 2 months after the peak sound-production and spawning of spotted seatrout and at the time of the peak sound production and spawning of red drum. Blount's Bay is a location where juvenile red drum and spotted seatrout have been collected in SAV in a recent survey during the fall months. Thus, the active acoustic echosounder methods have been used successfully to survey the SAV habitat of the sciaenid fishes, demonstrating that a peak in coverage of SAV habitat occurs as juvenile spotted seatrout and red drum are arriving from the pelagic zone.

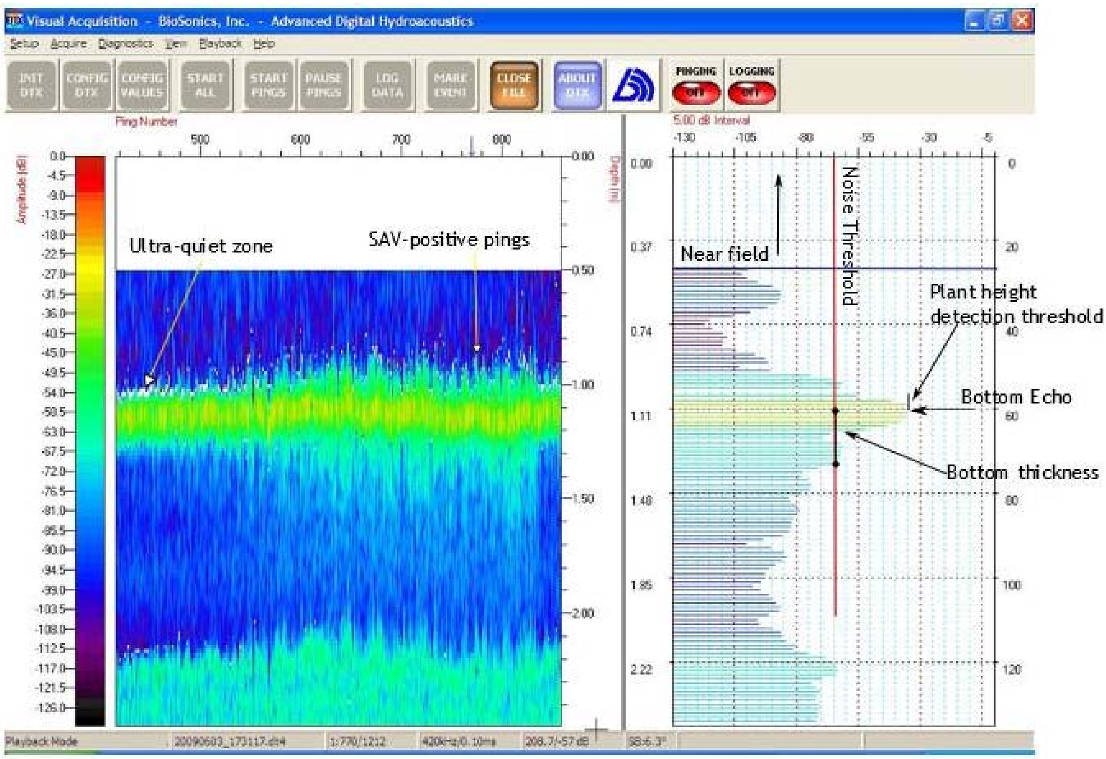


FIGURE 5. An echogram of a submerged aquatic vegetation (SAV) bed in Newport River, NC during June 2009. The ultra-quiet zone (white region) is characteristic of a bare sand bottom, and SAV shows as tall greenish echoes above the bottom. A labeled oscillogram on the right shows the ECOSAV2 parameters used to classify SAV-positive echoes, but especially the plant height threshold, which is set to 3.5 cm. Plants must be taller than this threshold to be classified as "plant" by the algorithm.

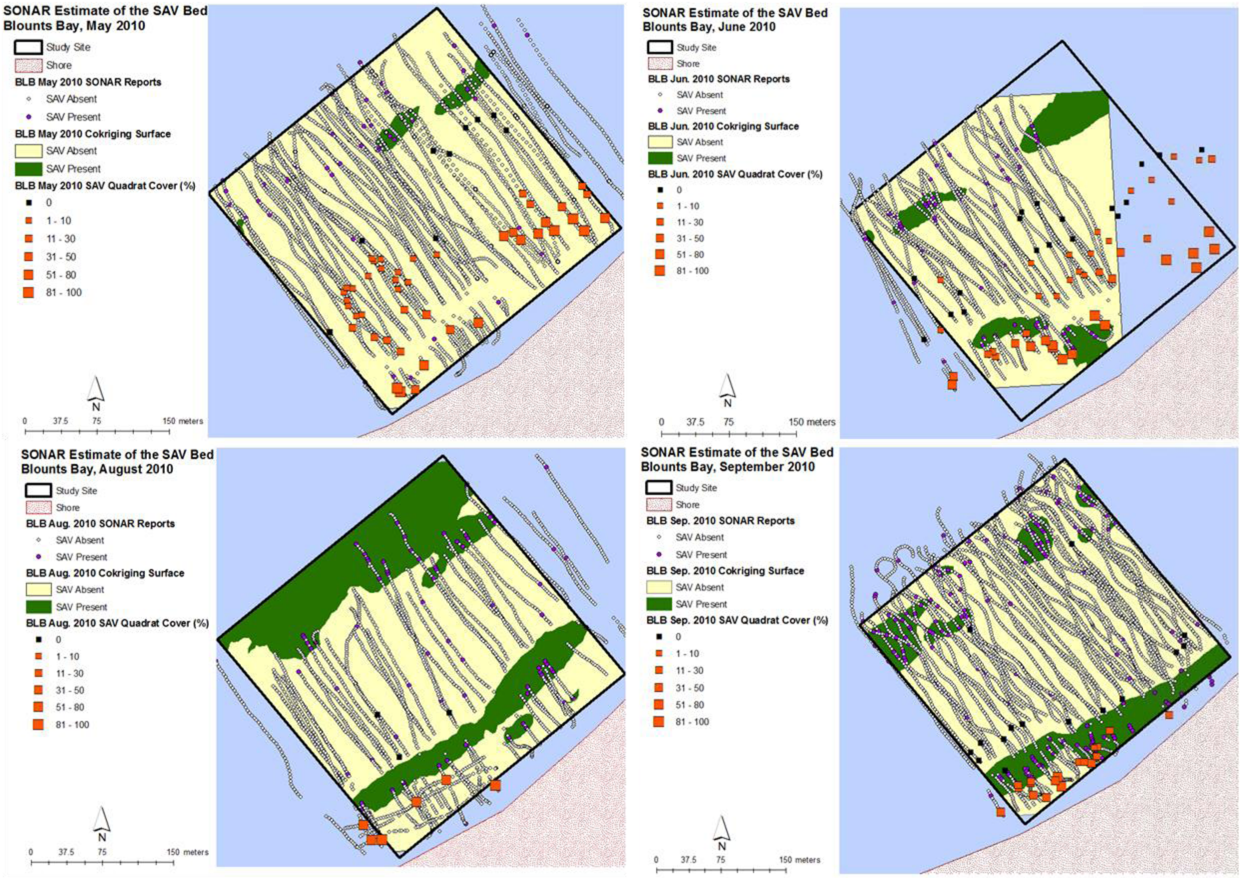


FIGURE 6. Maps of changes in submerged aquatic vegetation (SAV) bed in Blount's Bay, Pamlico River Estuary, NC during May – Sep 2010. The echosounder transects are represented by circles with both SAV-positive (purple) and SAV-negative (white) acoustic reports shown. Co-kriging prediction was used to create an interpolated surface of SAV presence and absence, based on the echosounder's bathymetry measurement and ECOSAV2 presence/absences data for each acoustic report. The co-kriging prediction resulted in a GIS layer for each date shown as SAV-positive (green) polygons and SAV-negative (cream) polygons. Diver survey quadrat locations are indicated in squares. Quadrats without SAV are black, quadrats with SAV have proportionally increasing orange squares. From Kenworthy et al. (2012).

DISCUSSION

We provide examples here of passive and active acoustic methods to survey fishes in Pamlico Sound, their spawning-associated sound production, and variation in their juvenile SAV habitat. While these studies were not done synoptically, they show that acoustical methods can be used to rapidly survey the spawning, recruitment and habitat variability in Pamlico Sound for key species like spotted seatrout, Atlantic croaker, spot, and other species in the Sciaenidae. In addition, variation in the habitat used as juvenile nursery areas by these species can be monitored over time. In the future, such acoustic surveys can be used to supplement and calibrate standard juvenile fish surveys, currently based on trawl data alone. SAV survey protocols using the echosounders in conjunction with video and quadrat verification described here have been proposed for North Carolina (Kenworthy et al. 2012). We suggest that trawl and other net-based surveys be similarly compared for evidence of net avoidance and be calibrated using scientific echosounders.

There are many obstacles to overcome when using such passive and active acoustic surveys, notably one being the ground-truthing the acoustic measurements using standard methods that are labor-intensive (trawling for fishes, and diver quadrats for SAV surveys). But these are essential for the verification of the acoustic approaches described here. Ground-truthing efforts revealed that some fishes are underestimated in trawls because of trawl avoidance and that SAV is underestimated in echosounder surveys, especially when plants are not taller than the plant height detection threshold in the algorithm and occur in shallow water. While it is theoretically possible to combine these methods to use active and passive acoustics to monitor the dynamics of estuarine systems (estuarine observing systems), the challenge we face as acoustical ecologists is to ground-truth these acoustic metrics using traditional sampling methods (e.g., quadrats for plants, trawls for fishes, water samples for sediments), explain when the acoustic and standard methods disagree, why they disagree, assess their accuracy, and to integrate each of these acoustic measures into a sampling paradigm. With proper validation of the methods described here, we could then examine the effect of fishing, storms, waves, and resuspension events on estuarine plant and animal distributions and abundances using acoustics metrics.

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