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Use of a 600-kHz Acoustic Doppler Current Profiler to measure estuarine bottom type, relative abundance of submerged aquatic vegetation, and eelgrass canopy height

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Abstract

The acoustic backscatter intensity signal from a high-frequency (600 kHz) Acoustic Doppler Current Profiler (ADCP) was used to categorize four different types of bottom habitat (sand, mud, sparse and dense vegetation) in a shallow-water estuary (Shinnecock Bay, NY, USA). A diver survey of the bay measured sediment and bottom vegetation characteristics at 85 sites within the bay. These data were used to groundtruth the acoustic data. Acoustic data were collected at four sites with known bottom types and used to develop an algorithm that could categorize the bottom type. The slope of the echo intensity profile close to the bottom was used to determine the bottom type and the relative numerical density (sparse or dense) of Submerged Aquatic Vegetation (SAV). In areas where eelgrass (*Zostera marina*) was the dominant SAV species, the intensity profile data were analyzed to measure the height of the vegetation canopy. An acoustic survey which categorized the bottom type of the bay was conducted from a small vessel. The percentage of sampled sites categorized as each bottom habitat type from the acoustic survey was similar to those obtained by the diver survey. These methods may provide a means to rapidly survey estuarine habitats and measure spatial and temporal variations in SAV populations, as well as changes in the height of the eelgrass canopy.

Keywords: acoustics; seagrass; estuaries; USA; NY; Long Island; Shinnecock Bay

1. Introduction

Shallow coastal waters are ecologically and economically important ecosystems. However, as human population growth increases in coastal areas, changes in the quality, quantity and timing of nutrient loading have also increased. The major water quality challenge has been an increase in nutrient loading, which has caused eutrophication of many estuaries and near-coastal waters. Shifts in the relative importance of planktonic primary producers and submerged vascular plants are concomitant with eutrophication. Estuarine and marine macrophytes, common in relatively oligotrophic areas, have often been replaced by faster growing benthic microalgae and phytoplankton in areas with increased anthropogenic nutrient loading (Duarte, 1995). Of particular concern are perturbations to productive seagrass habitats (Dennison et al., 1993; Short and Wyllie-Echeverria, 1996). Seagrasses are submerged vascular plants that form extensive meadows in shallow marine and estuarine environments. Because of the well-recognized ecological importance of seagrass beds including high primary production, nursery habitat for many fishery species, sediment stabilization, oxygenation of the sediments and filtration of land runoff (McRoy and Helfferich, 1977; Phillips and McRoy, 1980; Williams and Heck, 2001), preserving and restoring these beds is often a goal of environmental management programs (Dennison et al., 1993). While light availability is an important determinant of the persistence of seagrasses, it is only one of a number of environmental factors that sets the bounds of the habitat requirements of submerged aquatic vegetation (SAV) (Koch, 2001). Temperature, salinity, sediment accumulation, water currents, waves and nutrient

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availability within the sediments can also determine the suitability of an area for SAV. To deal with these environmental changes, resource managers require tools that will allow them to observe the large-scale response of ecological communities to alterations, both anthropogenic and natural, in the environment.

One key criterion for measuring the decline or recovery of an estuarine habitat is the abundance and distribution of the SAV. The presence of SAV is often used as an indicator of the overall health of an estuary (Dennison et al., 1993; Duarte, 1995; Valiela et al., 1997). Previous techniques for characterizing and monitoring SAV have included either physical sampling of the vegetation (Fourqurean et al., 2001a), which is both time consuming and labor intensive, or optical based techniques such as aerial surveys or underwater camera systems (Meulstee et al., 1986; Hewitt et al., 2004), which are severely degraded by factors such as poor water clarity, water surface roughness, and clouds. One alternative method for assessing SAV is the use of scientific echosounders to measure the amount of acoustic energy scattered by these plants (Maceina and Shireman, 1980; Duarte, 1987; Thomas et al., 1990). This technique has the advantage of being able to rapidly and cost-effectively map SAV populations, with the disadvantage that acoustic scattering data are an indirect measure of SAV and can be difficult to interpret.

In order to accurately interpret acoustic field survey data, it is necessary to understand the scattering processes that are occurring in the water column and at the water–bottom interface. There are many sources that can scatter sound in the water column including, but not limited to, biological organisms (fish, zooplankton), suspended sediments, bubbles, turbulent processes, or even gradients of salinity or temperature (Medwin and Clay, 1998; Lavery et al., 2003; Warren et al., 2003). However, two of the most important contributors to backscatter intensity for this study (and for many other estuarine areas) are the bottom sediments and the aquatic vegetation that resides on or above the bottom.

Several studies have shown that acoustic techniques can be used to estimate the amount of plant biomass near the bottom (Stent and Hanley, 1985; Carbo and Molero, 1997; Guan et al., 1999; Sabol et al., 2002), as well as to characterize estuarine bottom habitat type (Forsgren et al., 1993; Wewetzer, 1999; Smith et al., 2001; Wienberg and Bartholomä, 2005). These studies utilize either scientific echosounders with proprietary software packages specifically designed to measure SAV or side-scan sonars, which provide high-resolution images of the bottom. This study sought to determine if data from an Acoustic Doppler Current Profiler (ADCP), a commonly available acoustic instrument typically used to measure current velocities, could be used to categorize benthic habitat and to characterize the SAV population. The methods described in this study are not specific to an ADCP and would be applicable to any system which produces a vertical profile (with cm-scale resolution) of acoustic backscatter intensity. In particular, some SAV species which contain gas-filled chambers (such as eelgrass and *Fucus* spp.) are well suited for study by acoustic methods as gas inclusions are known to be strong acoustic scatterers in the frequency range used by ADCPs (Anderson, 1950; Warren et al., 2001). However, little is known about the specific scattering mechanisms of eelgrass or other SAV species. As acoustic methods become more refined and widespread, they may provide a powerful tool to scientists and managers who seek to monitor the distribution and abundance of SAV in estuarine and coastal habitats.

2. Methods

2.1. Bottom habitat diver survey

An initial survey of SAV populations in Shinnecock Bay on Long Island, NY, USA was conducted from May 18 to July 23, 2004, using a diver-assisted sampling design, which rapidly and accurately estimates SAV abundance and density. Surveys of SAV communities were accomplished using a modified Braun-Blanquet scoring technique (Braun-Blanquet, 1932; Fourqurean et al., 2001b) with 0.5-m^2 quadrats (Table 1). Sites were established using a stratified, random sampling design to acquire 85 random points throughout Shinnecock Bay (Fig. 1). At each of the sites chosen, 10 haphazardly placed quadrats were assessed around the site.

Benthic cover, as defined for our purpose, is the fraction of the total quadrat area that is obscured by a particular plant taxon when viewed from directly above. From the raw observations of species cover in each quadrat at a site, a single density estimate was calculated for each plant taxon encountered in the quadrats at a site. Braun-Blanquet score (BB) was calculated as $\mathrm{BB}_i = \Sigma S_{ij}/N$, where BB_i is the density of taxon i; j the quadrat number from 1 to N, the total number of quadrats sampled at a site; and S_{ij} is the Braun-Blanquet score for taxon i in quadrat j. For any taxon, BB can range from 0 to 5, the maximum Braun-Blanquet score (Table 1). Braun-Blanquet scores were calculated for each taxon type (including unidentified species) found in Shinnecock Bay. The sum of the Braun-Blanquet scores (for all vegetation types) at each site was calculated and is used as a measure of the total vegetation present.

In addition to the quadrat assessment of SAV, bottom sediments were collected to categorize each site. Sediment samples of the top 2 cm were collected from each site using separate small cores (5 ml syringes with the tips removed) and were analyzed for porosity. Sediments were placed in pre-weighed, 20 ml, glass scintillation vials and returned to

Table 1
Braun-Blanquet scores defining benthos coverage by submerged aquatic vegetation

Cover class	Description
0	Absent
0.1	Solitary individual, less than 5% cover
0.5	Few individuals, less than 5% cover
1	Many individuals, less than 5% cover
2	5–25% Cover
3	25–50% Cover
4	50–75% Cover
5	75–100% Cover

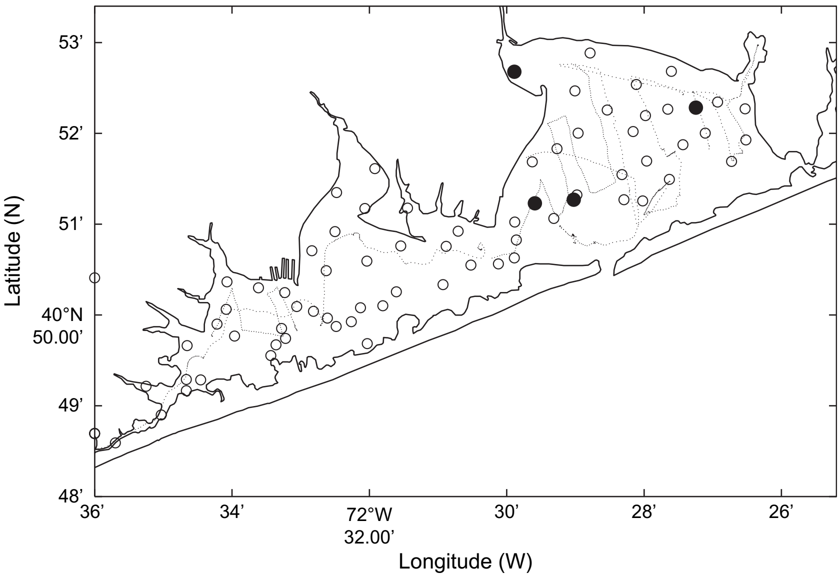

Fig. 1. Map of Shinnecock Bay showing cruisetrack (line), location of diver-sampled sites (open circles), and the four diver-sampled sites that were acoustically studied after divers had identified bottom type (filled circles, from topmost site in clockwise order: sand, mud, sparse vegetation, dense vegetation).

the lab. After recording the wet weight of the sediment core, the samples were dried to a constant mass at 60 °C and weighed to obtain the percentage of water content. Porosity is a quantitative measure used to differentiate between sand and mud bottoms. In addition, one large core (id = 6.3 cm) was used to collect the top 15 cm of sediment at each site. These cores were also returned to the lab and the sediments were extruded. The top 5 cm of the core was placed into crucibles, dried at 60 °C and weighed, then ashed for 5 h at 500 °C and reweighed to determine total organic matter.

Species commonly found within Shinnecock Bay included *Zostera marina* (eelgrass), *Codium fragile*, *Ulva lactuca* (green algae), *Gracillaria folifera*, and *Agardhiella tenera* (red algae), *Fucus* spp. (brown algae) and unidentified green, red, and brown algae species, with eelgrass being the dominant and most prevalent SAV species. In order to determine the utility of high-frequency acoustics as a method for estimating the presence and distribution of SAV, a controlled study was conducted in which four different sites with different bottom substrate were identified by diver surveys. From this initial survey, four sites with distinct bottom types (mud, sand, sparse SAV, and dense SAV) were selected in Shinnecock Bay (Fig. 1). The difference between sparse and dense SAV was approximately a 60% difference in above-ground cover (Table 2). Both SAV sites contained little to no vegetation other than eelgrass, which was typical for the majority of diver sites in Shinnecock Bay. All four study sites were located in very shallow areas, with water depths ranging from 1.4 to 2.0 m.

2.2. Acoustic measurements at sites with known bottom type

Acoustic backscatter data were collected at each site on July 10–11, 2004 using a 600-kHz Acoustic Doppler Current Profiler (RDI Rio Grande Workhorse, RDI Instruments, San Diego, CA, USA). The ADCP was powered by a 12-V battery which also powered a DC to AC power inverter housed inside a modified 60-l ice chest. This chest also contained a GPS unit to record time and position information, a laptop computer to record the ADCP and GPS data, and a modified lid with a viewing port and LCD monitor. During this study, the system was deployed in a variety of weather and sea conditions without exposing the data acquisition equipment to the elements.

The ADCP was mounted to a bracket along the side of a small boat such that the transducer face was 20 cm below the waterline. At each site, the boat was anchored, and vertical profiles of acoustic backscatter intensity were recorded approximately every 20 s with a vertical depth bin size of 5 cm. The profile used in the analysis was the average of the four individual ADCP transducers, however, similar results occurred using any one of the transducer intensity profiles since all four profile shapes were similar. Data were collected for

Table 2
Bottom characteristics of the four sample sites with known bottom type (10 quadrats sampled per site) from diver surveys (porosity, %organic matter, and Braun-Blanquet score) and acoustic backscatter intensity data. The unit for acoustic data is intensity units/m and the data are uncalibrated

Site	Porosity	%Organic matter	Braun-Blanquet score	Slope of backscatter intensity from 20 cm to bottom (mean ± std dev)
Sand	21.34	0.67	0	320 ± 39
Mud	69.67	10.35	0	257 ± 16
Dense eelgrass	25.94	2.71	4.21	38 ± 25
Sparse eelgrass	28.15	1.78	1.8	9 ± 6

30–45 min at each site. During the data collection runs, the acoustic system sampled different areas of the bottom since the boat would swing about the anchor depending on the wind and currents. Thus, the data for each study site are not for a single point on the bottom but rather for an area (roughly 100 m^2 from GPS position data) that consisted primarily of each bottom type. Visual observations from the boat confirmed that the boat generally remained over the same bottom type despite its movement. The acoustic backscatter intensity data for this instrument (like the majority of ADCPs) were not calibrated. Therefore, the intensity data are reported as a logarithmic, relative measure of backscattered acoustic intensity, instead of the usual units of dB relative to a specific sound pressure level as most calibrated acoustic backscatter data are.

The quantitative comparison of backscatter intensity data from an ADCP can be difficult because of variability in the absorption of sound by seawater when temperature and salinity vary, as well as the non-linear behavior of backscatter intensity at the maximum ranges of the instrument when instrument noise is comparable to recorded backscatter intensity (Roe et al., 1996). In this study, these problems are unlikely to affect the backscatter intensity profiles collected due to the shallow water depth of the estuary (typically less than 5 m deep). The water column in this bay is well mixed due to wind stress even during summer months with vertical variations in temperature and salinity typically being less than 5%. However, this issue may be important in other estuarine regions where larger vertical variations in temperature and salinity can occur due to stratification from freshwater input. The non-linear behavior of ADCP backscatter intensity is important at the maximum ranges of the instrument which are typically an order of magnitude larger than the water depths in this study or the depths where SAV will be found.

The backscatter vertical profile data were processed in several steps. First, the depth bin with the largest backscatter intensity value was found. This depth usually is the same as the bottom depth. The bottom substrate has a sharp contrast in both density and sound speed from the water and is, in general, the strongest acoustic scatterer present in an estuary. However, if there are substantial concentrations of scatterers in the water column, then these might produce a stronger echo return than the bottom since less acoustic energy would actually reach the bottom to be reflected. Second, the difference in acoustic backscatter intensity from one depth bin to the next was calculated. The depth bin with the largest change in backscatter intensity from the one above it, referred to as the depth with the maximum change in intensity, was recorded.

The general shape of the acoustic backscatter intensity profile can also provide information about the distribution and amount of scatterers present above the bottom. For the third step, the shape of the near-bottom backscatter intensity profile was quantified by calculating the slope of the intensity (change in intensity divided by the change in depth) for each depth bin from the bottom to 20 cm above the bottom. The slope values at each depth bin were then averaged for each acoustic intensity profile producing a mean slope value for each ping of the ADCP. Slopes were also calculated for 10 and 40 cm above the bottom and provided similar results. This suggests that the slope should be calculated over a height less than the vegetation canopy height for useful results. The 20-cm data were used for all further analysis as these values were approximately half the measured height of the vegetation canopy and provided the most robust measure of vegetated benthic habitat.

At each of the two vegetated sites, approximately 40 eelgrass shoots were collected by divers who placed the samples in plastic bags containing seawater for transport back to the laboratory. When the individual shoots were removed from the sample bag, the length, thickness, width, mass, and displacement volume of each individual blade were measured. Blade length was measured from the point on the shoot where the coloration changed (indicating the bottom–water interface) to the blade tip.

2.3. Acoustic surveys of estuarine bottom type

In order to test whether acoustic backscatter intensity profiles from a vessel moving over different bottom habitat types could be used to categorize the bottom, a survey of Shinnecock Bay was conducted with the ADCP (Fig. 1). The survey tracklines are quite irregular due to the bathymetry of the bay which contains many extremely shallow sand bars. The majority of Shinnecock Bay is shallower than 3 m which is ideally suited for the ADCP configuration which has a maximum range of about 7 m when set to collect data in 5 cm depth bins. The survey was conducted on multiple days during the summer and early fall of 2004 (14 June–15 September). The vessel (5 m length) traveled at a typical speed of 3 m/s in conditions ranging from calm seas to 0.5–1 m waves (during which, vessel speed was much slower). The majority of the survey was done when conditions were ideal; however, under the roughest conditions, where the boat experienced large amounts of pitch and roll, data quality was poor and approximately 25% of echoes collected were flagged by the ADCP software and therefore not usable.

The same ADCP configuration used for the anchored measurements was used for the survey with an acoustic profile being collected every 20 s. Logistical constraints and experimental design (attempting to have regular tracklines for the acoustic survey, random locations for diver survey) prevent an exact site-by-site comparison between the two methods, instead the percentage of samples classified as each bottom type is compared between the two methods. This approach compares two methods (acoustic survey using an ADCP and diver survey using visual evaluation of quadrats) for assessing bottom type and density of vegetation throughout Shinnecock Bay.

3. Results and discussion

Acoustic backscatter intensity profiles collected at each of the four study sites with a known bottom show a strong acoustic return (typically the maximum intensity value) from the bottom sediments (Fig. 2). For the sand and mud bottoms, there was

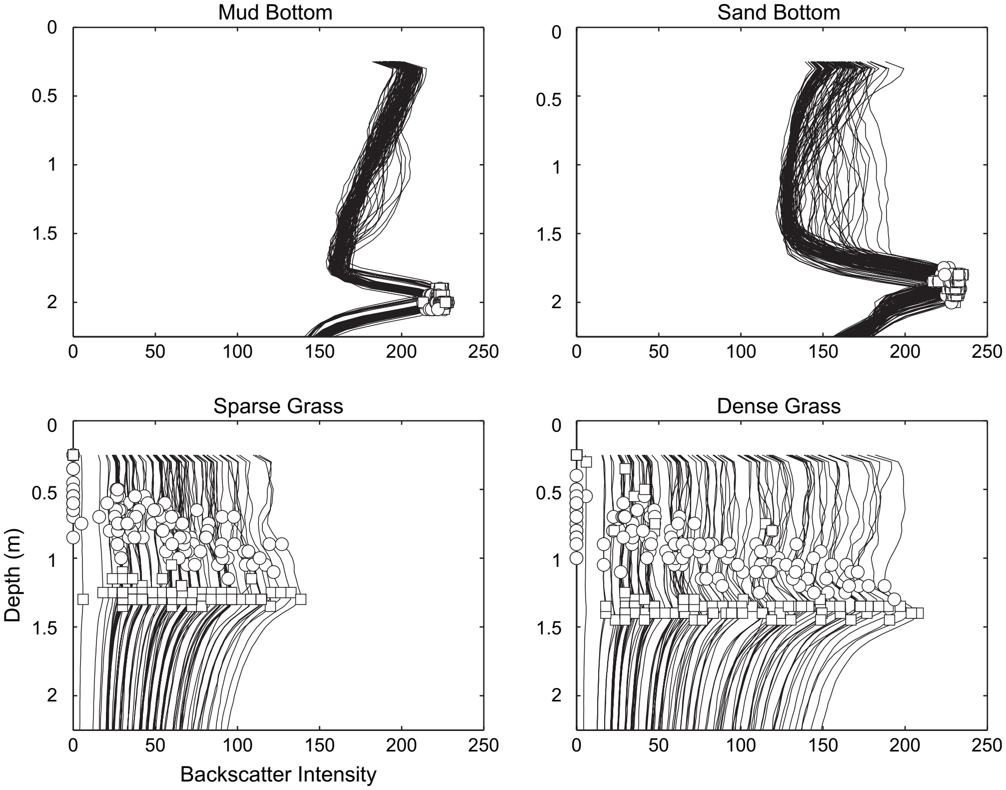

Fig. 2. Vertical profiles of acoustic backscatter intensity for each of the four bottom types. Squares represent the depth at which the maximum intensity value occurred, while circles represent the depth bin that had the greatest change in backscatter intensity. Backscatter intensity has units of dB and is uncalibrated.

little other scattering occurring in the water column, so the echo from the bottom was very strong and appeared as a distinct peak in the intensity profile. The depth of this echo return was fairly consistent throughout the sampling period, and the small variations that were observed can be attributed to the fact that the boat was moving over different areas of the bottom that would change (slightly) the depth of the sediment bottom.

The intensity profiles for the two eelgrass sites are different in appearance from the barren (sand and mud) bottom data, for they show much stronger backscatter occurring in the water column caused by the SAV. The barren bottoms had the largest change in intensity at the sea floor (or within a single range bin of 5 cm from the bottom) where the largest overall intensity value occurred. The vegetated bottoms show that the largest change in intensity occurred in the water column itself, well above the bottom echo. This dramatic change in intensity occurred when the acoustic energy struck and was reflected from the top of the vegetation canopy. Acoustic energy can be scattered by any change in density or sound speed of the medium it travels through, and the SAV reflected a measurable amount of acoustic energy.

In a few echoes, the maximum intensity and largest change in intensity switched their positions in the water column, due to the dense vegetation scattering more energy than the bottom. Though relatively rare in the data, the situation where the vegetative canopy shades the bottom from acoustic energy may have important implications (such as erroneous bottom depths being reported) for a variety of bottom detection situations.

At the vegetated sites, the distance between the depth bins with the largest change in acoustic backscatter intensity and the largest overall intensity should be directly related to the distance between the top of the SAV canopy and the bottom. To test this hypothesis, the distribution of blade lengths as measured in the lab was compared with acoustic estimates of canopy height (Fig. 3). The mean and standard deviation of blade length from lab measurements (40.2 ± 18.6 cm) and canopy height from acoustic measurements (39.3 ± 17.7 cm) were very similar. This result suggests that canopy height can be measured using this method.

Given that the shapes of the vertical profiles of acoustic backscatter intensity were quite different for the different bottom types (Fig. 2), the slope of the intensity above the bottom could indicate the bottom type. This hypothesis assumes that the scattering in the water column is dominated by SAV since the bottom types with no material present above the bottom (sand and mud) had very strong changes in acoustic intensity, while the vegetated bottoms showed a more gradual change in intensity above the bottom.

The data from the four bottom types show a dramatic difference in slope values for the unvegetated and vegetated bottoms (Fig. 4). The sand bottom's slope is larger than the mud bottom, which is expected since a sand bottom is a stronger scatterer than a mud bottom (Urick, 1954; Hamilton, 1970; LeBlanc et al., 1992). The data collected from the sand bottom site suggest that the boat moved over a mud-covered area (pings 70–85 in Fig. 4). Although the

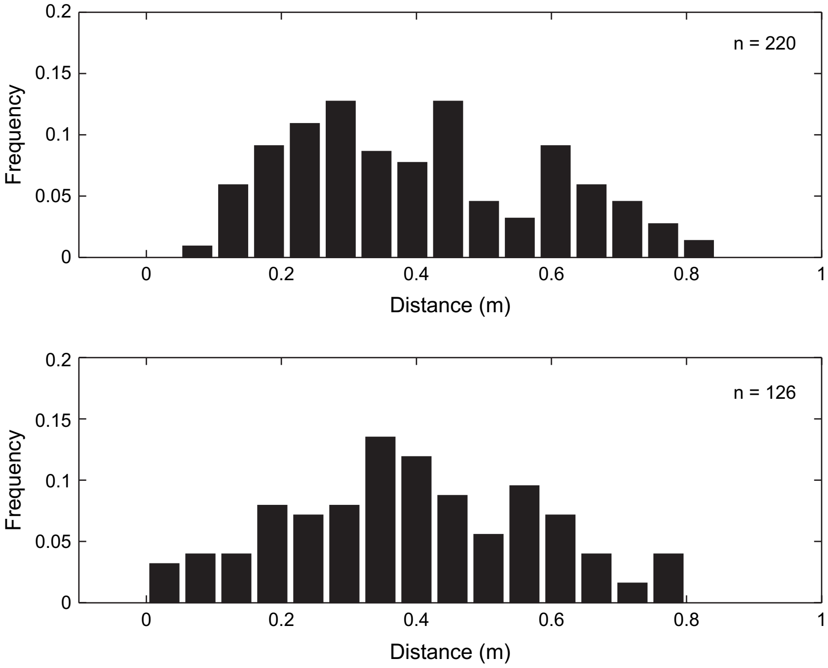

Fig. 3. Distribution of lab-measured blade lengths (top) of the SAV and acoustic estimates (bottom) of the height of the SAV canopy which is a rough estimate of blade length. Height is calculated as the distance between the depth bin with the largest change in intensity and the bin with the largest intensity. Number of measurements (*n*) in each distribution is given within each figure. The mean and standard deviation of blade length from lab measurements was 40.2 ± 18.6 cm and canopy height from acoustic measurements was 39.3 ± 17.7 cm.

boat was anchored at this time, it did swing over a fairly large area; so it is possible that different bottom types were encountered.

The slope data at each site were not normally distributed. Therefore, to determine if the data could be used to distinguish between different bottom types, the Kruskal–Wallis One-Way ANOVA on ranks was performed. There was a highly significant difference between the four bottom types assessed ($p < 0.001$). In addition, the Dunn's Method of multiple comparison between the four bottom types revealed that the slope intensity data for each site were significantly different from all of the others ($p < 0.05$).

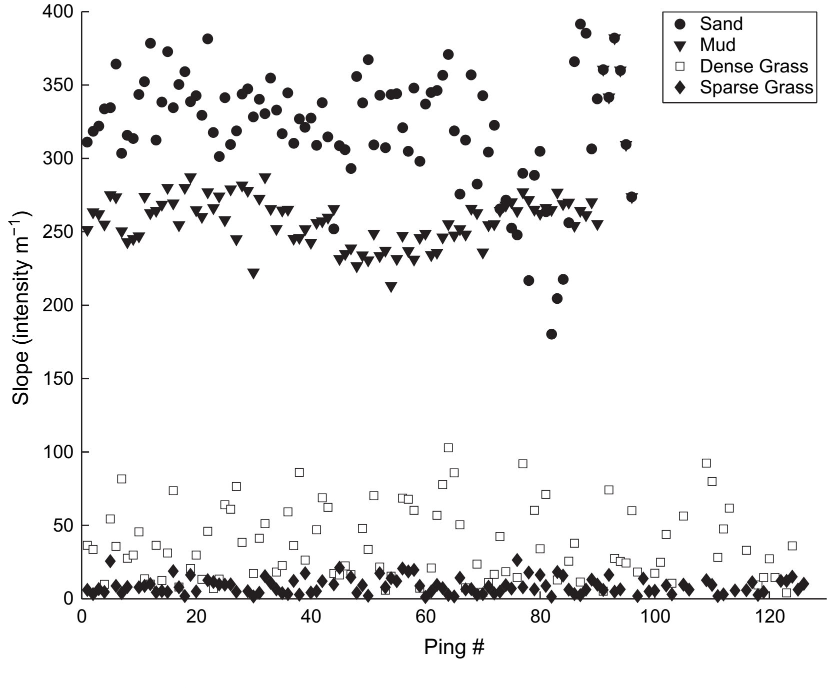

Fig. 4. The slope of the acoustic backscatter intensity from 20 cm above the bottom to the bottom averaged for each ping for the data collected at each bottom site. The four bottom types were sand (circle), mud (triangle), dense grass (square), and sparse grass (diamond). Using these data, the four sites were found to be statistically significantly different from each other ($p < 0.001$).

Using a classification algorithm developed from the sites with known bottoms (Table 3), each acoustic ping was categorized as one of the four bottom types based upon the value of the slope of the acoustic backscatter intensity from the bottom to 20 cm above the bottom. The slope criteria were sand: $\text{slope} \geq 300$; mud: $300 > \text{slope} \geq 200$; dense vegetation: $200 > \text{slope} \geq 75$; sparse vegetation: $\text{slope} < 75$, where the units of slope are intensity units/m. The acoustically classified bottom type data did not vary greatly from ping to ping (a spatial scale of ~60 m), such that 75% of the slope measurements were within 30% of the previous ping's slope value. This may suggest that changes in bottom type in Shinnecock Bay occur on spatial scales greater than this distance.

While the specific criteria used to classify the acoustic data were determined empirically from the data collected at the four sites with known bottom types, it is unclear how applicable these criteria were for all of Shinnecock Bay. Given that the Braun-Blanquet (BB) score is a semi-quantitative measure, the transition point from sparse to dense vegetation is somewhat arbitrary. Therefore, several different classification schemes were used to categorize the diver-surveyed sites as sand, mud, sparsely vegetated or densely vegetated (Table 3). Braun-Blanquet scores of total vegetation density ranged from 0 to 5 for the random diver survey sites within Shinnecock Bay. Sites were considered to be non-vegetated if the BB score (of all SAV) was less than 0.5. The non-vegetated sites were considered to be mud if the porosity was greater than or equal to 50% and sand if less than 50%. This criterion was used for all diver site samples. Because of the difficulty in quantifying sparse and dense vegetation, three different classification approaches were used to analyze the vegetation at diver-surveyed sites. These approaches differ in the BB score that was the minimum value for the bottom to be classified as dense vegetation. The Dense Vegetation Criteria (DVC) variable was 1.5, 2, or 3, corresponding to a bottom vegetation coverage of 10%, 25%, or 50%, respectively (Tables 3 and 4). The criteria for classification of diver-surveyed sites were dense vegetation if $\text{BB} \geq \text{DVC}$; sparse vegetation if $\text{DVC} > \text{BB} \geq 0.5$; mud if $\text{BB} < 0.5$ and porosity $\geq 50\%$; and sand if $\text{BB} < 0.5$ and porosity $< 50\%$. The BB score for total vegetation was used. Bottom type data from the acoustic survey were compared to data collected during the diver survey (Table 4), although it should be noted that very few of the acoustic samples were co-located with diver sites.

Table 3
Criteria for bottom type classification of acoustic- and diver-surveyed sites. The criteria for classification of each acoustic profile were sand: $\text{slope} \geq 300$; mud: $300 > \text{slope} \geq 200$; dense vegetation: $200 > \text{slope} \geq 75$; sparse vegetation: $\text{slope} < 75$, where the units of slope are intensity units/m. Because of the semi-quantitative nature of the Braun-Blanquet score (BB), three different analyses of the diver site data were performed where the Dense Vegetation Criteria (DVC) variable was 1.5, 2, or 3 (Table 4). The criteria for classification of diver-surveyed sites were dense vegetation if $\text{BB} \geq \text{DVC}$; sparse vegetation if $\text{DVC} > \text{BB} \geq 0.5$; mud if $\text{BB} < 0.5$ and porosity $\geq 50\%$; and sand if $\text{BB} < 0.5$ and porosity $< 50\%$. The BB score for total vegetation was used

Bottom type	Acoustic site criteria (slope)	Diver site criteria (BB)
Sand	$\text{slope} \geq 300$	$\text{BB} < 0.5$, porosity $< 50\%$
Mud	$300 > \text{slope} \geq 200$	$\text{BB} < 0.5$, porosity $\geq 50\%$
Dense vegetation	$200 > \text{slope} \geq 75$	$\text{BB} > \text{DVC}$
Sparse vegetation	$75 > \text{slope}$	$0.5 \leq \text{BB} < \text{DVC}$

Table 4
Percentage of sites of each of the four bottom habitat types in Shinnecock Bay as determined by acoustic and diver sampling. The number of sample sites for the acoustic method was 1621, while the diver method surveyed 85 sites. Three different classification approaches were used to analyze the diver-surveyed sites. These approaches differ in the Braun-Blanquet score that was the minimum value for the bottom to be classified as dense vegetation. The Dense Vegetation Criteria (DVC) variable was 1.5, 2, or 3, corresponding to a bottom vegetation coverage of 10%, 25%, or 50%, respectively. The other classification criteria are provided in Table 3. Acoustic categorization was based on the slope of the backscatter intensity from the bottom to 20 cm above the bottom for each ADCP ping. Diver categorization was based on quadrat sampling of total vegetation for sparse and dense vegetation and porosity determined from sediment samples for mud and sand bottoms

Bottom type	Acoustic sampling ($n = 1621$)	Diver sampling ($n = 85$)		
		DVC = 1.5	DVC = 2	DVC = 3
Sand (%)	22.1	23.5	23.5	23.5
Mud (%)	35.7	32.9	32.9	32.9
Dense vegetation (%)	24.6	25.9	21.2	14.1
Sparse vegetation (%)	17.6	17.7	22.4	29.4

The acoustic and BB score criteria that were used to determine whether vegetation was present or absent agreed very well with the results from diver-sampled sites (Table 4) as the percentages of bay bottom sites were nearly identical for both assessment methods. Therefore, an ADCP can be used to detect the presence or absence of SAV in a shallow-water estuary. There was also agreement between the two methods (acoustic and diver) in the percentage of bottom classified as sparsely vegetated or densely vegetated, although the choice of DVC changed how well the two methods agree. Based on the three DVC values used in this study, it appears that the acoustic criteria for differentiating sparse and dense vegetation will report SAV coverage of more than 10% of the bottom as dense vegetation. Since only two types of vegetated sites were used in this study, it may be possible to obtain better acoustic measurements of vegetation density if more types of vegetated sites (e.g. 10%, 20%, 40%, 80% SAV coverage) were used to determine the acoustic criteria.

To demonstrate that the acoustic method can be used to rapidly survey estuarine habitat and measure spatial and temporal variations in SAV populations, data from both acoustic- and diver-based categorization methods are presented from surveys of Shinnecock Bay. As previously mentioned, logistical constraints prevented an exact site-by-site comparison of these two methods other than the four sites used to develop the categorization algorithm. However, the two survey methods show similar results in terms of the proportion of each bottom type (Table 4) and the spatial distribution of the different bottom types (Fig. 5). The spatial resolution of the acoustic survey provides an order of magnitude more samples than the diver-based methods which provides insight to the patterns

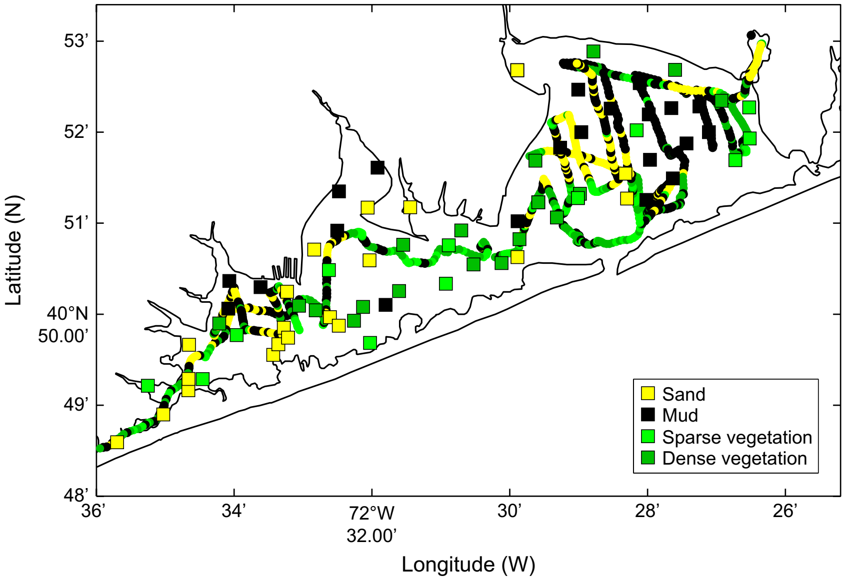

Fig. 5. Composite overlay of both the acoustic- and diver-based surveys of Shinnecock Bay. Bottom type categorizations by acoustic methods (circles) and diver surveys (squares) are shown. Both methods show agreement in the large-scale patterns occurring in the bay with the eastern portion of the bay being predominately mud, the middle being vegetated and the western portion being a mix of vegetated and sand-covered areas.

and spatial scales of the bottom habitat types and where changes in the bottom type will occur. Large-scale features (where multiple consecutive acoustic pings indicate the same bottom type), such as the far eastern portion of the bay being dominated by vegetated sites, the area just west of that being primarily mud, the middle of the bay being primarily vegetated, and a mixture of sand and vegetated bottoms in the far western portion of the bay, appear using both survey methods. These data, along with those from Table 4, suggest that surveys of submerged aquatic vegetation using acoustic methods can be conducted from a moving vessel and these methods provide quantitative assessments of bottom type. We do not suggest that the acoustic methods are completely accurate in characterization of each individual ping (as indicated by isolated pings in Fig. 5); however, the acoustic method provides a similar picture as the diver-survey method as to the distribution of different bottom types throughout this shallow bay.

4. Conclusions

A high-frequency ADCP is a useful instrument for measuring the presence of SAV in a shallow-water estuary. In addition to its primary function of measuring currents, this type of instrument can be used, in at least some areas, to measure presence and relative abundance of SAV as well as the canopy height of eelgrass beds. A method was presented for discriminating between different bottom types (mud, sand, vegetated bottom) that is simple to calculate and only requires vertical profiles of acoustic backscatter intensity. This method does not require a particular type of acoustic system or software package, allowing it to be used with numerous types of acoustic echosounders. What remains to be determined is whether this method is valid for other geographic locations which contain deeper estuaries or bays, water columns containing more acoustic scatterers such as bubbles, zooplankton, or suspended sediments, areas with a dominant SAV species other than eelgrass, or areas with rocky or cobbled bottoms.

The ability of acoustic backscatter intensity data to measure the height of the SAV canopy may provide ecosystem managers with a valuable tool to monitor many aspects of SAV ecology. Since SAV blades tend to curve slightly and are not oriented perfectly vertical in the water column, the acoustic estimate of canopy height was expected to be a slight underestimate of the lab measurements of the straight blade length which our results support. Acoustic height estimates of the SAV canopy could be used to infer either growth of the SAV population (if one assumes a general blade curvature or shape in the water column) or movement of the blades due to currents or other processes (if one assumes that blade length has not changed during the sampling period). Either of these measurements would be suitable for a seasonal or annual study of a specific location which would allow non-invasive measurements of the physical properties of the SAV.

Acoustic surveys of SAV populations provide a significant advantage in terms of spatial and temporal coverage of an area relative to diver-based surveys, although diver surveys are a necessary component of an acoustic survey in order to groundtruth the acoustic data. In this study, a two-person team using a small boat was able to survey the entire bay in approximately 20 h with more than 1500 bottom positions classified as compared to a two-person diver team also using a small boat that needed approximately 100 h, or five times as long, to classify 85 bottom locations. Even with the addition of several days to collect ground-truthing data and refine the analysis procedures by running the acoustic system over known bottom types, the acoustic system provides a very efficient sampling method for SAV populations compared to traditional diver-based methods. It is also important to note the limitations of an acoustic system that were experienced in this study, namely rough seas and high vessel speeds will often produce unusable data. Processing of the ADCP data for this entire survey including slope calculations and classification of bottom type can be performed in a matter of minutes on a personal computer, or written into hardware or software code such that classifications could be done in real-time during a survey provided the classification parameters were known.

Acoustic data from an ADCP can provide a useful complement to conventional sampling techniques for measuring SAV distribution, at least in shallow-water areas where the dominant SAV component is eelgrass. While the use of an ADCP to measure bottom habitat type or vegetation height is likely not as accurate as existing specialized acoustic systems designed for this task, the widespread use of ADCPs throughout the world provides numerous situations where this approach could be easily implemented by users who are not acoustic experts. Additionally, the methods outlined here are not specific to ADCPs and may be applied to any echosounder that produces a suitable vertical profile of backscatter intensity. An acoustic method for assessment of SAV populations allows for rapid coverage of a large area without dependence upon water clarity like conventional optical methods (e.g. diver survey, aerial photography, camera systems). Despite the great utility of acoustics as a measurement tool for SAV, it is necessary to remember that as an indirect measure of SAV, its use should always be in conjunction with conventional sampling and assessment methods.

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