DIRECT MEASUREMENTS OF THE GEOACOUSTIC PROPERTIES OF SEAGRASS BEARING SEDIMENTS

Kevin M. Lee,[a] Megan S. Ballard,[a] Andrew R. McNeese,[a] and Preston S. Wilson[a,b]

[a]Applied Research Laboratories, The University of Texas at Austin, Austin, TX 78713, USA
[b]Department of Mechanical Engineering, The University of Texas at Austin, Austin, TX 78712, USA

Contact author: Kevin M. Lee, Applied Research Laboratories, The University of Texas at Austin, Austin, TX 78713, USA; email: klee@arlut.utexas.edu

Abstract: *Biological processes and physical characteristics associated with seagrass can greatly affect acoustic propagation in coastal regions. An important acoustical effect is due to bubble production by the plants, which can have significant impact on both object detection and bottom mapping sonars by increasing clutter through reflection, absorption, and scattering of sound. In addition to photosynthesis-generated bubbles and gas-bearing leaf tissue in the water column, the plant rhizomes also contain aerenchyma (gas-filled channels), which allow for diffusion of oxygen into the surrounding sediment. Whereas previous studies on the acoustic properties of seagrass have focused on sound propagation and backscatter in the water column, little prior work has focused on measurement of acoustic properties below the water-sediment interface where the plant rhizome and root systems exist. To study these effects, in situ acoustic measurements were conducted in a bed of Thalassia testudinum in east Corpus Christi Bay, Texas, USA. Direct measurements of sound speed and attenuation were obtained in the water column above the seagrass canopy, inside the seagrass canopy, and at discrete depths within the sediment. A complimentary set of measurements were obtained in a bare sediment region located a few meters away. In addition to standard measurements of geoacoustic properties (sediment density, grain size, etc.), biomass was also estimated from cores collected at each site. Generally, the sediment beneath the seagrass bed had significantly lower wave speed and higher attenuation compared to the bare sediment. Frequency dependence of the sound speed and attenuation in the seagrass bed relative to the bare sediment was also investigated.*

Keywords: *seagrass, sediment acoustics, underwater acoustics measurements*

INTRODUCTION

Environmental characteristics associated with seagrass beds can affect acoustic propagation in coastal regions; therefore, the presence of marine vegetation in very shallow water environments has the potential to affect sonar performance.[1–4] An important acoustical effect is due to photosynthesis-related bubble production by seagrass, which can have significant impact on both target detection and bottom mapping sonars by increasing clutter. In addition to gas-bearing leaf tissue in the water column, the rhizomes contain aerenchyma that allow for diffusion of oxygen into the sediment.[5] Furthermore, the rhizome and root structures contain large amounts of carbon and create layers rich in organic carbon within the sediment below the seagrass.[6,7] This paper focuses on the effects of the seagrass on acoustic propagation within the sediment, as opposed to sound propagation in the water column, which has seen significantly more attention in past research.

Preliminary measurements of sound speed and attenuation within the sediment beneath a bed of *Thalassia testudinum* in Corpus Christi Bay, Texas, USA were previously reported.[8] The measurements were conducted during the winter (dormant growth season) at varying depths within the sediment and at a single acoustic frequency of 50 kHz. For comparison, measurements were conducted in a nearby region of bare sediment a few meters away. In this paper we report a new set of measurements, acquired in the same seagrass bed, but several months later during the summer (active growth season). Biomass and carbon-reserve dynamics are temporally variable over long time scales (seasonal and longer),[7] necessitating that study of potential effects on acoustic propagation take into account this time dependence. This paper presents a preliminary comparison between the dormant and active growth seasons. Additionally, the acoustic measurements in the active growth season were obtained at 50 kHz, 100 kHz, and 200 kHz to examine frequency dependence of the sound speed and attenuation.

FIELD EXPERIMENT

The field experiment site was located in east Corpus Christi Bay, Texas, USA, an area where the seagrass species *Thalassia testudinum* is abundant. During the active growth season, the thick, lush canopy extended into the water column 30 cm from the sediment/water interface, and abundant photosynthesis bubbles were observed in the water column. For comparison, during the dormant season, the canopy was much sparser and extended only 5 cm to 10 cm from the sediment, and bubbles from photosynthetic activity were not readily observed during the experiment. The water depth at the experiment site was approximately 1 m, and the site was accessible by a small motorboat with a shallow draft.

The acoustic measurements were conducted using the small, manually deployed system described system described in Ref. 8. The system consisted of an acoustic source and a receiver affixed to a small aluminium framework. The framework enabled insertion of the probes to varying depths beneath the water-sediment interface. Additionally, the measurement apparatus could be supported above the sediment to obtain measurements in the water column. The source and receiver were cabled back to the boat where the source excitation and data acquisition electronics were operated. During the course of the acoustic measurements, the water temperature and salinity were monitored so that the water sound speed could be calculated.

First, a set of measurements was conducted in the water above a region of bare sediment to obtain an acoustic calibration of the source-receiver separation distance and the amplitude of the received signal in seawater. Measurements were then conducted at depths of 5 cm to 20 cm in 5-cm increments below the water-sediment interface in the bare sediment region. Next, the measurement system was moved to a seagrass bed a few meters away and measurements were conducted with the source/receiver pair 12-cm above the sediment (but within the seagrass canopy) and then at the same depths below the water-sediment interface as in the bare sediment case. For both the bare and seagrass measurement sites, five iterations of the measurement process were conducted at slightly different locations (a meter or less apart) to assess variability of the measured acoustic parameters. The data analysis methods used to extract the sound speed and attenuation, as well as error analysis related to the single source/receiver method, are detailed in Ref. 8.

Four cores were collected each at the bare sediment and seagrass sites for sediment characterization and quantification of biomass below the water-sediment interface. The cores were inserted to depths approximately between 20 cm and 25 cm into the sediment. Care was taken to remove the cores from the sediment while keeping the core contents intact. The cores were capped underwater, stored vertically in a cooler on the boat, and transported back to an onshore laboratory for analysis.

In the laboratory, a core extruder was used to section the cores in approximately 2-cm increments. First, wet mass measurements were performed to obtain estimates of bulk sediment density, including the plant matter when present. Then, the samples were dried and all macroscopic plant matter was removed to obtain the dry-weight plant biomass for each core section. Finally, the remaining material from each core section was processed according to the wet-sieving procedure and subsequent steps outlined Ref. 8 to obtain the grain-size distribution for each core section. The mean grain size was then calculated for each layer using the graphical method of Folk and Ward.[9]

RESULTS

Sound speed and attenuation depth profiles taken at 50 kHz in the active season are shown in Fig. 1, along with depth profiles of macroscopic biomass, bulk sediment density, and mean grain size. The black curves in Fig. 1 correspond to bare sediment site whereas the green curves represent data from the seagrass site. The closed circles in Fig. 1 indicate mean measured values, and the horizontal error bars indicate the variability (the range of the data) between different measurements. The sound speed is presented as the sound speed ratio = c/c_w, where c is the sound speed measured by the acoustic measurement system, and c_w is the seawater sound speed obtained from measurements of the water temperature and salinity. Within the seagrass canopy, the mean sound speed ratio is 0.64, and the horizontal error bars do not overlap with the open-water sound speed. The attenuation in the canopy is 114 dB/m. In the sediment below the seagrass bed, the mean sound speed ratio ranges between 0.55 and 0.88, with the minimum occurring 5 cm below the water-sediment interface. In contrast, the bare sediment sound speed ratio is always above unity, typical for sandy sediments. The attenuation in the seagrass-bearing sediment is a maximum at 5 cm depth, taking on a value of 222 dB/m. At greater depths, the attenuation in the seagrass-bearing sediment decreases and approaches that of the bare sediment. In general, there is greater variability in the sound speed and attenuation measurements in the seagrass site than in the bare sediment site, indicated by the larger horizontal error bars in on the seagrass site measurements.

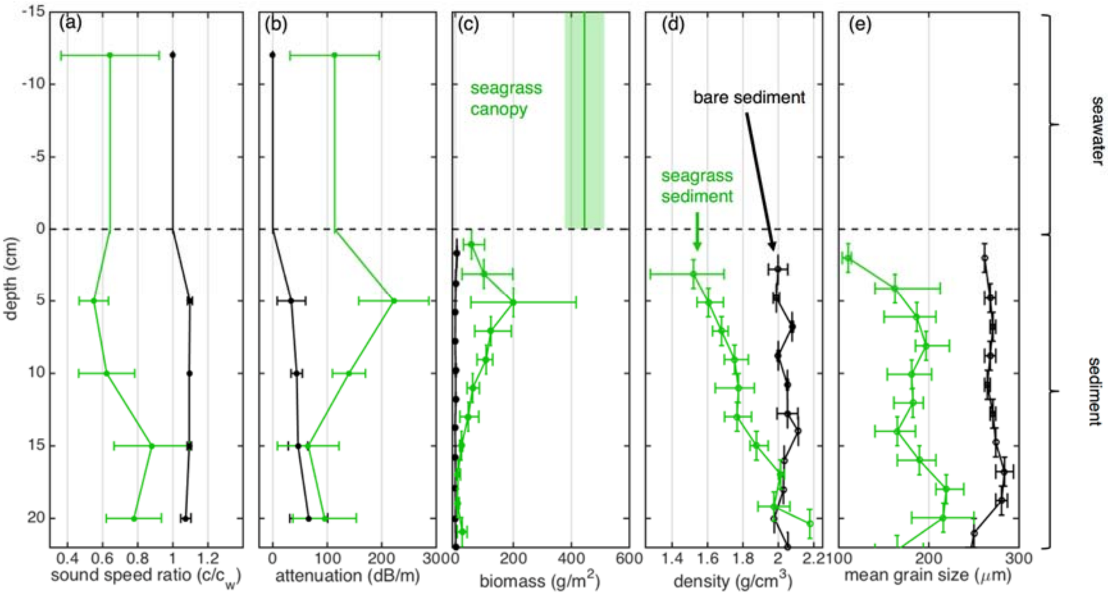

Fig.1: Acoustic measurements at 50 kHz acquired during the active growth season for the bare sediment site (black) and the seagrass site (green): (a) sound speed ratio and (b) attenuation. The horizontal error bars in (a) and (b) indicate the variability in the acoustic quantities between the multiple measurement system deployments at each site. Physical measurements obtained from cores: (c) dry-weight biomass, (d) bulk sediment density, and (e) mean grain size. The horizontal error bars in (c), (d), and (e) indicate the spread of values across the four cores from each site. The vertical error bars indicate the length of each core section. The solid green line in (c) represents the mean biomass value in the canopy, and the shaded green region indicates the standard deviation.

Differences are also seen in the sediment properties obtained from the cores. The macroscopic biomass below the seagrass bed peaks at 5 cm, which is coincident in depth with the lowest sound speed and highest attenuation. Progressing to greater depths, the biomass below the seagrass bed decreases. The bare sediment biomass is negligible at all depths. The bulk density measurements indicate that the density at the seagrass site is 24% lower than the bare sediment site at the shallowest depth into the sediment. The density at the seagrass increases with depth until it is similar to the bare site density at a depth 15 cm. The bulk density values are influenced by the presence of the seagrass tissue and associated gas volumes since no effort was made to remove the tissue before the density measurements were made. Finally, the seagrass site is characterized by finer grain sediment than the bare site, as indicated by lower values of mean grain size, because the canopy damps out water currents and wave motion, allowing fine sediment particles suspended in the water column to settle.

The frequency dependence of the sound speed and attenuation are shown in Figs. 2 and 3. As the frequency increases from 50 kHz to 200 kHz, the sound speed ratio in the seagrass-bearing sediment approaches that of the bare sediment. The sound speed ratio error bars in the canopy overlap the open-water sound speed at 100 kHz and 200 kHz, and the attenuation in the canopy is lower at these higher frequencies than at 50 kHz. At 5 cm and 10 cm in the sediment, the sound speeds are lower and the attenuations are greater in the seagrass site than the bare site at all frequencies. At depths of 15 cm and 20 cm in the sediment and at the higher frequencies, the sound speed and attenuation measured in the seagrass site are statistically similar to the values measured in the bare site, indicated by the overlapping error bars.

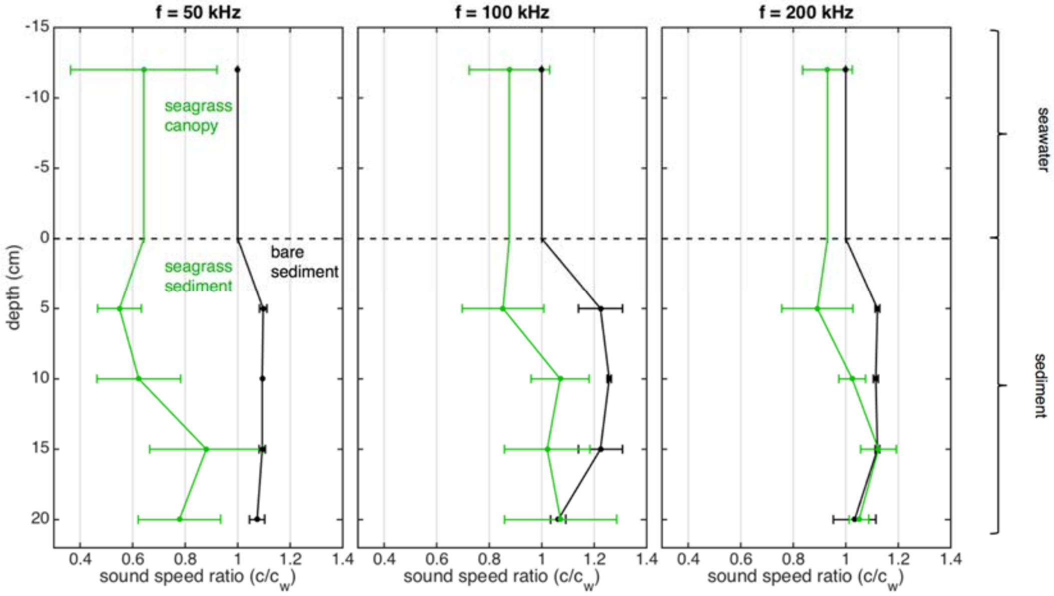

Fig.2: Measurements of sound speed at 50 kHz, 100 kHz, and 200 kHz (from left to right) acquired during the active growth season for the bare sediment site (black) and the seagrass site (green).

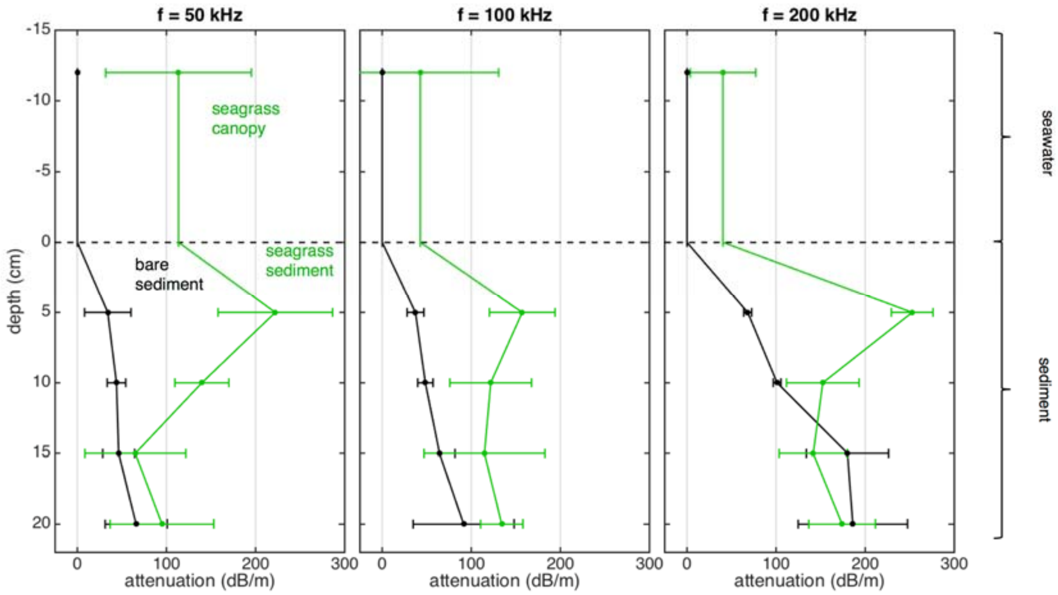

Fig.3 Measurements of attenuation at 50 kHz, 100 kHz, and 200 kHz (from left to right) acquired during the active growth season for the bare sediment site (black) and the seagrass site (green).

Comparisons of the active and dormant season sound speed and attenuation at 50 kHz and biomass measurements are presented in Fig. 4. An importance difference between he two sets of measurements is that five independent sets of measurements were conducted at each depth during the active season (green curves), but only a single set of measurements was taken at each depth for the dormant season (brown curves). The horizontal error bars on the active season acoustic data represent the spread at each depth over all 5 measurements whereas the horizontal error bars on the dormant acoustic season data were estimated from experimental uncertainties and propagation of error from Eqs. (2) and (4) of Ref. 8.

There are a few stark differences between the two data sets. Above the water-sediment interface in the canopy, the mean active season sound speed ratio (0.64) is lower than the dormant season value, which takes on a value of 0.97. The spread in the active-season canopy sound speed ratio ranges from values close to the dormant season, perhaps due to shorter leaf height at that particular individual measurement site, to values lower that 0.4. The mean attenuation in the canopy is similar for both sites, near 100 dB/m, but the spread in the active season data ranges from 32 dB/m to 195 dB/m. Below the water-sediment interface, the mean sound speed ratio was general lower in the active season with the exception of the shallowest measurement depth in the sediment. Also, the attenuation within the sediment tended to be higher in the dormant season that the active season.

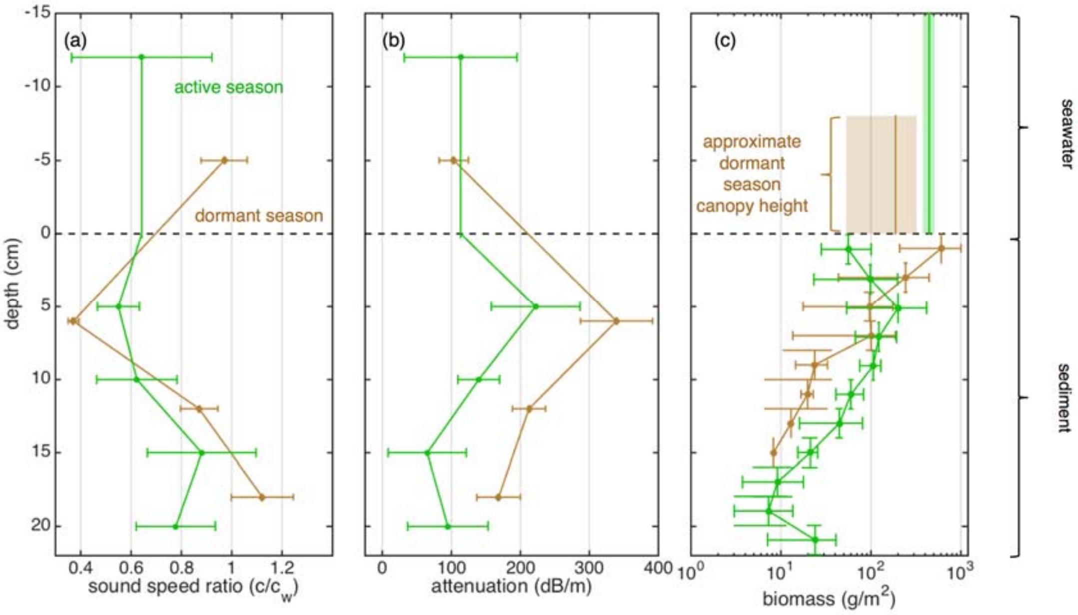

Fig.4 Comparison of the active (green curves) and dormant seasons (brown curves): (a) sound speed at 50 kHz, (b) attenuation at 50 kHz, and (c) biomass (shown on a log scale).

The canopy biomass (shown on log scale in Fig. 4) in the active season is approximately two to three times higher than in the dormant season, likely accounting for the differences between the acoustic parameters from the two different measurement times. The below-ground biomass in the top 2 cm of the sediment was nearly an order of magnitude greater in the dormant season that in the active season, and consisted of thick knots of rhizome tissue. Only buried leaf and sheath tissue and no rhizome tissue were observed at these shallow depths within the active season cores. In contrast, no buried leaf and sheath tissue was observed in the sediment in the dormant season cores, and it was only observed above ground in those cases. Between 4 cm and 6 cm, the two data sets had similar levels of biomass in the sediment although primarily root material was present in the dormant season cores and rhizome tissue was observed in the active season cores. The biomass measurements indicate that below-ground biomass was generally greater in the active season below about 8 cm with primarily root tissue being present. In general, the type of plant tissue (e.g. root, rhizome, sheath, leaf) seems to be shifted to greater depths in the active season cores as compared to the dormant season cores. This trend is possibly due to seasonal burial of parts of the plants (the sheaths and parts of the leaves), which are normally exposed in the dormant season. As the canopy becomes taller and thicker in the active season, it has the capacity to damp out currents in the water column, allowing for suspended fine-grained sediment to settle and cover the formerly exposed portions of the plants.

CONCLUSIONS

In situ measurements of sound speed and attenuation in a bed of *Thalassia testudinum* were compared with measurements of biomass, bulk density, and mean grain size from cores. The measurements indicate that the presence of biomass has a complicated influence on the acoustic parameters above and below the water-sediment interface. While some of these effects likely come from direct acoustic interaction with the seagrass tissue itself and associated gas volumes within the tissue, the plants can have other effects on the propagation environment, such as diffusion of oxygen into sediment from the rhizomes. More detailed characterization of the distribution of above- and below-ground biomass and the sediment gas content would likely provide further insight into both the dispersion characteristics observed in the active season measurements as well as the differences in below-ground acoustics between the dormant and active seasons.

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