1aAO7. Investigation of low-frequency acoustic tissue properties of seagrass

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Understanding the acoustic properties of seagrass is important for applications in mine hunting, shallow water sonar performance, and acoustic remote sensing for ecological surveys. Previous laboratory and field investigations have shown that the plant biomass and tissue structure of seagrass, rather than just the overall gas content, play a determinant role in its acoustic behavior. Hence, effective medium models of propagation through seagrass meadows have been ruled out, and a complete description of both tissue structure and tissue elastic properties is required to describe the acoustic response of seagrass meadows. To begin to address these deficiencies, a resonance tube experiment was set up to determine the low-frequency acoustic response of multiple species of seagrass in relation to leaf biomass and tissue acoustic compliance independent of tissue structure. Responses to frequency-modulated signals in the range from 0.5-kHz to 10-kHz were obtained for Thalassia testudinum (turtle grass) and Halodule wrightii (shoal grass), two species with well-differentiated morphological features. An elastic waveguide model was used to account for the minor effect of the tube walls on the resonance characteristics. Initial measurements of tissue compliance will be presented. [Work supported by ONR and ARL:UT.]

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INTRODUCTION

The acoustic properties of seagrass are of interest in applications ranging from mine hunting and shallow water sonar operation, to acoustic remote sensing for ecological studies. To optimize all of these applications a predictive acoustic model of sound propagation in seagrass beds is desired. [1] Previous laboratory research [2] has been conducted on whole leaves of seagrass and water in a resonator tube to determine the effective low frequency sound speeds of two particular species, *Thalassia testudinum* (turtle grass) and *Halodule wrightii* (shoal grass), but an accurate predictive model was not found. Subsequent research showed that various implementations of three-phase Wood’s Equation-based models were not sufficient to describe the measured sound speeds, even with accurate knowledge of the volume fractions and tissue structure derived from micro-computed tomography imaging. Nor was it possible to extract tissue properties from measurements of intact leaves via inversion of low frequency sound speed alone. [3] Upon failure of the simplified effective medium models, it was concluded that sound propagation in seagrass must depend on the tissue acoustic properties, the tissue physical structure, and the entrained air masses inside the leaves. The goal of the present work was a first attempt at measurement of the intrinsic low frequency (1 kHz to 4 kHz) leaf tissue acoustic compressibility of the two seagrass species previously mentioned. The resonator method was again used to measure the effective low frequency sound speed of a mixture composed of finely divided seagrass leaf tissue suspended in seawater as described by Urick [4] and Richardson et al. [5] The experiment and preliminary results are described.

EXPERIMENT

Acoustic measurements were conducted in a one-dimensional acoustic resonator apparatus shown in Fig. 1. The borosilicate glass tube was 45.6 cm tall of circular cross section with an outer diameter of 6.88 cm and an inner diameter of 5.09 cm. An LDS V10 L shaker was placed at the top of the tube to produce periodic wideband chirps (50 Hz to 15 kHz). A Reson model 4013 hydrophone placed near the top of the tube was used to measure the acoustic pressure response of the system. The air-water interface at the top of the tube, and a thin latex rubber membrane and a block of Styrofoam at the bottom of the tube provided approximate pressure release boundary conditions. This arrangement results in normal modes composed of integer multiples of half wavelengths, and hence the phase speed inside the tube can be determined from the measured resonance frequencies.

![Diagram of resonator apparatus](image)

**FIGURE 1.** Acoustic resonator and measurement instrumentation are shown in (a). A photograph (b) of the finely divided seagrass tissue and water mixture is shown inside the tube. The stinger and hydrophone sheath are also visible.

Freshly field-collected (within 24 hours from littoral waters near Port Aransas, TX) samples of *Thalassia testudinum* and *Halodule wrightii* were weighed and measured for volume. Each sample was then mixed with artificial salt water (Instant Ocean and distilled water, salinity 35.9 ppt) and placed in a food processing blender and processed until the composition of the “seagrass soup” was consistent and the particle size was less than 0.1 mm. The resulting mixture was then thoroughly degassed under vacuum and finally placed in the glass tube for the
acoustic measurements. Acoustic spectra of the finely divided seagrass-saltwater mixtures were measured at five-minute intervals. By visual inspection the mixtures had nearly no change in consistency during the span of testing.

RESULTS

The acoustic spectra are shown in Figure 2. Note the differentiation between species visible in the acoustic response. Effective phase speed of the material inside the tube was inferred from the resonance frequencies, and corrections for the elastic waveguide effect were made using the procedure described in [2]. The resulting phase speed

![Figure 2](image-url)

**FIGURE 2.** Acoustic spectra as a function of time during the measurements. *Thalassia testudinum* (left) and *Halodule wrightii* (right). Red represents acoustic resonances of the system. Blue represents acoustic nulls. For *T. testudinum*, note two prominent resonance peaks near 1200 Hz and 2700 Hz, used to extract phase speed. For *H. wrightii*, note three to four prominent resonance peaks between 1000 Hz and 4000 Hz.

![Figure 3](image-url)

**FIGURE 3.** Free-field phase speeds for finely divided *Thalassia testudinum* leaf tissue in seawater (and seawater alone, black curve) after accounting for elastic waveguide effects. At the experimental temperature 27.5 °C, the seawater sound speed should be 1541 m/s, [6] which agrees well with the present measurement.
FIGURE 4. Free-field phase speeds for finely divided *Halodule wrightii* leaf tissue in seawater (and seawater alone, black curve) after accounting for elastic waveguide effects. At the experimental temperature 23.5 °C, the seawater sound speed should be 1532 m/s, [6] which agrees well with the present measurement.

Speeds are shown in Figure 3 for *Thalassia testudinum* and in Figure 4 for *Halodule wrightii*. In each figure the measured sound speed in seawater alone is also shown at the top of the plot, and in both cases the measured values for seawater sound speed correspond well to values determined from the experimental temperature and salinity, using the relations of Ref. [6], with details given in the figure captions. In both cases, we see an increase in measured seagrass tissue phase speed as time progresses inside the resonator. The reason for this systematic effect is not known. It is possible that stratification of the material was occurring, or that the actual material properties of the tissue were changing as a function of time after being disintegrated. Dispersion is observed in both cases as well, and discovering its cause will require more work. In general, the sound speed in the *Thalassia testudinum* mixture was near 1300 m/s and the sound speed in the *Halodule wrightii* mixture was near 920 m/s.

Since the ultimate goal of this work was to extract the low frequency tissue bulk modulus, there was no attempt to keep the volume fractions the same for the two species, and hence comparing these sound speed measurements is of little direct value. Instead Wood’s Equation was used to infer the tissue bulk moduli as described by Urick [4] and briefly repeated here for convenience. The effective sound speed of the mixture in the tube (after correction for the elastic waveguide effect) is given by

\[ c_{\text{eff}} = \sqrt{\frac{\rho_{\text{eff}}}{\beta_{\text{eff}}}}, \]  

where the effective density is \( \rho_{\text{eff}} = \beta_{\text{grass}}\rho_{\text{grass}} + \beta_{\text{water}}\rho_{\text{water}} \), the volume fractions of the finely divided grass tissue and the seawater are \( \beta_{\text{grass}} \) and \( \beta_{\text{water}} \) respectively, and all of these parameters are known or were directly measured in this work. The sound speed \( c_{\text{eff}} \) was obtained from the measurements presented in Figs. 3 and 4 for each species. For these calculations, the mean value (across frequency and time in tube) of all of the speeds for each species was calculated, and the mean value was used as \( c_{\text{eff}} \). Finally, the bulk moduli of the tissue was calculated from

\[ 1/B_{\text{eff}} = \beta_{\text{grass}}/B_{\text{grass}} + \beta_{\text{water}}/B_{\text{water}}. \]  

Since \( B_{\text{eff}} \) is known from the sound speed measurements, and the volume fractions and \( B_{\text{water}} \) were measured and known, respectively, \( B_{\text{grass}} \) was calculated using the parameters given in Table I.
The resulting calculation yields the low-frequency tissue bulk modulus $B_{\text{grass}} = 1.11 \times 10^9$ (Pa) for $T. \text{testudinum}$ and $B_{\text{grass}} = 5.35 \times 10^8$ (Pa) for $H. \text{wrightii}$. Note that these are preliminary results and proper measurement uncertainty calculations have not yet been conducted.

Since no previous measurements of seagrass tissue bulk moduli $B$ could be found in the literature, the expected bulk moduli was estimated from published values of elastic moduli $E$ and the Poisson ratio $\nu$. A range of values of the elastic modulus has been reported [7] for $T. \text{testudinum}$: $4 \times 10^8$ Pa to $2.4 \times 10^9$ Pa. No direct reporting of Poisson’s ratio could be found for seagrass, but a typical Poisson’s ratio for terrestrial leaf parenchyma is $\nu = 0.3$. [8] From these values and the familiar relationship $B = E/3(1-2\nu)$, the range of expected bulk moduli is $3 \times 10^9$ Pa to $2 \times 10^8$ Pa, which brackets the measurements reported here. One might also consider comparing these bulk moduli measurements to previously reported low frequency sound speed measurements. Unfortunately, due to the differences in plant leaf biomass, internal structure, and gas content, bulk moduli are not directly related to the low frequency sound speed, which was one of the original motivations for this work.

**CONCLUSIONS**

In this study, the first measurement (to the authors’ knowledge) of the low frequency (1 kHz to 4 kHz) leaf tissue bulk moduli of two species of seagrass Halodule wrightii and Thalassia testudinum was reported. These measurements were obtained using an acoustic resonator technique in which finely divided leaf tissue was mixed with seawater. Acoustic resonances were then related to the effective speed of sound within the resonator, and corrections were applied to address the systematic error induced by tube wall elasticity. Finally, Wood’s equation was used to relate the measured sound speed to the tissue bulk modulus, using the known constituent volume fractions and densities. The bulk modulus measurements fall within the range of expected values inferred from measurements of elastic moduli and Poisson’s ratio reported in the literature. Future models of acoustic propagation in seagrass meadows, needed to optimize mine hunting, shallow water sonar, and acoustic remote sensing applications, will incorporate these and similar future measurements.

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**REFERENCES**


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**Table 1:** Parameters used with Eqs. (1) and (2) for the calculation of tissue bulk moduli $B_{\text{grass}}$, which is displayed in the right-most column.

<table>
<thead>
<tr>
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<th>$c_{\text{eff}}$ (m/s)</th>
<th>$\rho_{\text{eff}}$ (kg/m$^3$)</th>
<th>$\beta_{\text{grass}}$</th>
<th>$\beta_{\text{water}}$</th>
<th>$B_{\text{water}}$ (Pa)</th>
<th>$B_{\text{grass}}$ (Pa)</th>
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<td>1309</td>
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<td>0.518</td>
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<tr>
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<td>965</td>
<td>0.556</td>
<td>0.444</td>
<td>$2.46 \times 10^9$</td>
<td>$5.35 \times 10^8$</td>
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