Acoustic Characterization of Submerged Aquatic Vegetation

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Abstract

The acoustic characteristics of submerged aquatic vegetation (SAV) were investigated in order to enhance the performance of mine-hunting and weapon sonars in littoral regions. The species of seagrass initially studied was Zostera marina. Laboratory measurements of target strength and backscatter were made under controlled conditions in an acoustic tank. Experimental target strength measurements compared well to the theoretical value. Target strength for an individual blade of Zostera was measured to be approximately -21 dB from 300-700 kHz. No frequency dependence was found in this range. Beam patterns for individual specimens were also generated and displayed a strong dependence on blade orientation. In-situ measurements were carried out in the shallow water eelgrass beds of Narragansett Bay with both side-scan and single beam sonars. These experiments clearly illustrated the backscatter and potential masking effects of submerged aquatic vegetation in the 100-400 kHz frequency range. This experimental data will aid in the verification of theoretical models and in the development of methods to enhance the performance of mine-hunting and weapons sonars. The data will also supply environmental input to range-dependent sonar models and enhance tactical and environmental databases. Another application of this research includes remote sensing of seagrass beds to monitor pollution and aid in species distribution and density studies.

1. Introduction

The US Navy's emphasis on shallow water research dictates the need for improved range dependent sonar models and a better understanding of bottom interactions. This project was initiated after naval operations in littoral regions indicated that acoustics were often ineffective in finding mines in part due to extensive seagrass beds [1]. Seagrass is known to adversely affect the Navy's ability to detect mines, thus compromising shallow water mine countermeasures. Backscatter from seaweeds and seagrasses creates interference with sonars and could mask the presence of a mine during mine-hunting. Some foreign mines are designed specifically to exploit this backscatter effect.

In Tarut Bay, in the Arabian Sea, a survey of fifty locations yielded an estimate of 66% grass cover for the entire bay; i.e. 175 sq. km of seagrass coverage [2]. In the Gulf of Oman, *Sargassum aquifolium* , a seaweed, may grow to a length of about 1.50 meters and produce dense masses of plants. The leaves contain hundreds of tiny air sacs (radii from 0.02 to 0.17 cm.) and act as effective sound scatterers; their air sacs are resonant at frequencies of 5 to 20 kHz at pressures of 2 to 5 atmospheres [3]. This may have a significant effect on many mine-hunting systems. In addition to physically creating interference with mine burial during placement, algal fouling can create problems for mines which have been deployed for some time (weeks to months) as it can plug and interfere with the acoustic detonator. This can damp out signals and make the mines ineffective against targets [4].

1.1 Previous Work

There is no published literature on the physics of wave scattering by submersed vegetation. Overwhelmingly the literature consists of papers which investigate acoustics of marine mammals, plankton or fishes. An informal study was carried out by the Army Corps of Engineers which used acoustics to determine the presence of "nuisance species" in estuaries [5]. More recently a Russian effort attempted to develop physical models for estimation of scattering [6].

1.2 Approach

The Naval Undersea Warfare Center Division, Newport, RI (NAVUNSEAWARCENDIV NEWPORT) received funding in Fiscal Year 1996 from the Deputy Assistant Secretary of the Navy (Environment and Safety) to initiate a preliminary investigation of the acoustic characteristics of submerged aquatic vegetation for environmental monitoring applications. The vegetation initially investigated was *Zostera marina*, a well-documented seagrass which was chosen because it is widely studied and abundant in the local waters of Narragansett Bay. Commonly called eelgrass, it is broadly distributed in both the northern Pacific and Atlantic Oceans. It extends from the intertidal zone to the subtidal, often in extensive meadows. In clear waters it can be found in water depths as great as 30 m. [7].

The shallow water eelgrass beds of Narragansett Bay, Rhode Island created an ideal testbed to gather experimental data. This allowed for the development of a methodology which could later be applied to other areas of strategic importance such as the Persian Gulf and the Adriatic Sea. The experience gained from studying eelgrass can be carried over to other types of submerged aquatic vegetation such as kelp and Sargassum which will likely have even more pronounced acoustic signatures.

1.3 Physiology of *Zostera marina*

The plant is composed of a rhizome 2-5 mm wide with numerous roots and a leaf at each node. The leaf blade is up to 2 m. long and 1.5-12 mm wide [7]. Gas pockets or tubes called lacunae run the length of the plant. These lacunae are shown in Fig. 1. Any backscatter created by the plant is primarily a volume-scattering phenomena likely caused by these gas-filled lacunae.

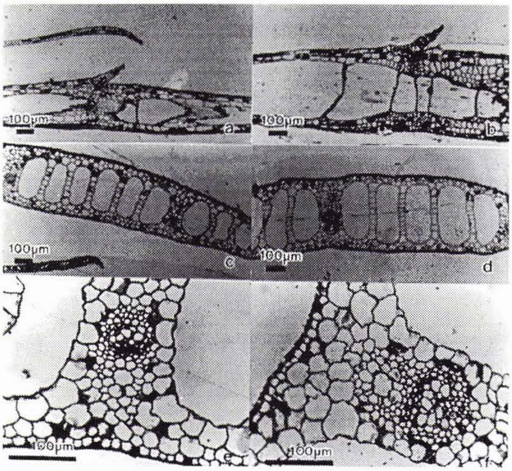

Fig. 1. Lateral cross-section of *Zostera* lacunae. The lacunae run the entire length of each blade.

2. Experimental Approach

It was proposed to carry out acoustic measurements in controlled conditions in the laboratory to determine the fundamental acoustic characteristics of eelgrass. These experiments were carried out on a single specimen of grass in order to investigate frequency response and determine resonance. Aggregate testing was then carried out in large tanks of eelgrass (mesocosms) which provided testing of the grass as it is found in-situ but still under controlled conditions. The final component of experimentation involved field testing in Narragansett Bay using various sonars in existing eelgrass beds and ground-truth referencing by a dive team.

2.1 Tank Testing

Monostatic target strength measurements were made in controlled conditions in the acoustic tank at the Naval Undersea Warfare Center in Newport. An individual blade of healthy *Zostera* approximately 30 cm in length was suspended in the acoustic tank which measures 20 meters long by 13 meters wide by 12 meters deep. The location of the grass within the tank was accurately measured. Due to the specimen size and the high frequencies being used, the majority of the experiments were carried out in the near field. The reflected sound from the grass was measured and recorded at a range of frequencies from 300-750 kHz. The grass was then removed and a 20 cm. radius, solid aluminum sphere of known target strength was then positioned in the tank in the same location and its backscatter was measured. The target strength of the eelgrass could then be determined. This was carried out at a range of frequencies in an attempt to determine frequency dependence. Little frequency dependence was found in the range of 300-750 kHz. The average target strength over this range was measured to be -21 dB. This figure compares well with fish of the same size; the size of the eelgrass lacunae can be compared with the similarly-sized swim bladders of these fish. The ensemble of cylindrical-shaped gas-filled lacunae are the dominant scatterer and the overall target strength level in the 300-750 kHz frequency range is consistent with scattering by a similar number of air-filled cylinders of the same dimensions. Fig. 2 shows the target strength of the eelgrass as a function of frequency.

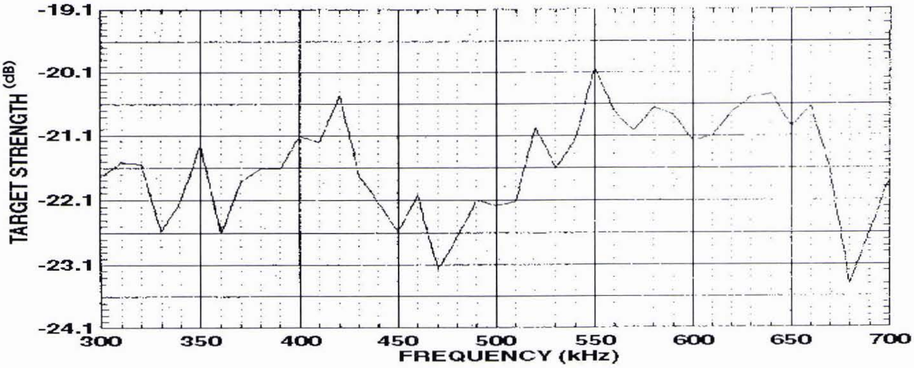

Fig. 2. Target strength of eelgrass blade as a function of frequency. These values are calculated from a 2 cycle sample FFT for rms value.

Beam pattern at a fixed frequency was also plotted during these tank tests to investigate the backscatter intensity from various angles of incidence. The blade of grass was rotated in 0.5 degree increments over a 12 hour period to cover 200 degrees. There was a strong return when the blade was insonified on its main axis (broadside) and a sharp drop-off beyond this angle. The results are shown in Fig. 3

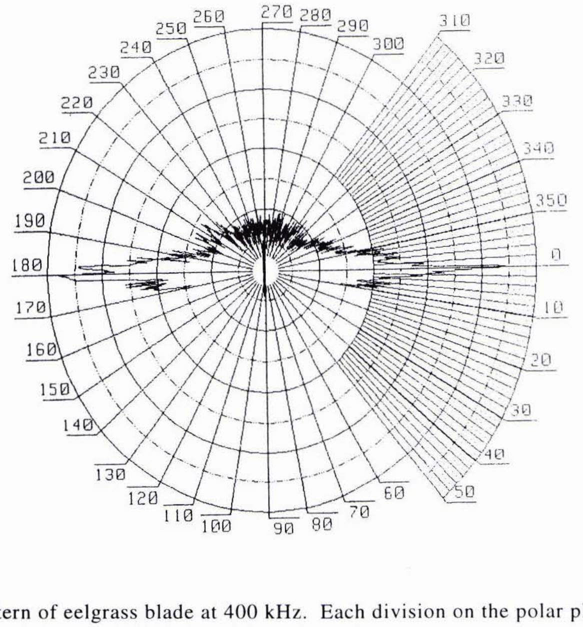

Fig. 3. Beam pattern of eelgrass blade at 400 kHz. Each division on the polar plot represents 5 dB.

2.2 Mesocosm Testing

Mesocosm testing allowed for examination of grass behavior in beds as it is found in-situ. The experiments were carried out in the University of Rhode Island mesocosm tanks which are designed to grow communities of eelgrass for biological and ecological experiments. These tanks measure approximately 1.5m square by 1.2 meters deep and contain approximately 15 cm of sediment. The bottom of each tank is densely covered in *Zostera* (Fig. 4). Monostatic measurements were made in increments of 50 kHz from 200-750 kHz. The backscatter measured was significant. As demonstrated earlier in the acoustic tank tests, backscatter was again pronounced throughout the frequency range but no clear frequency dependence was found.

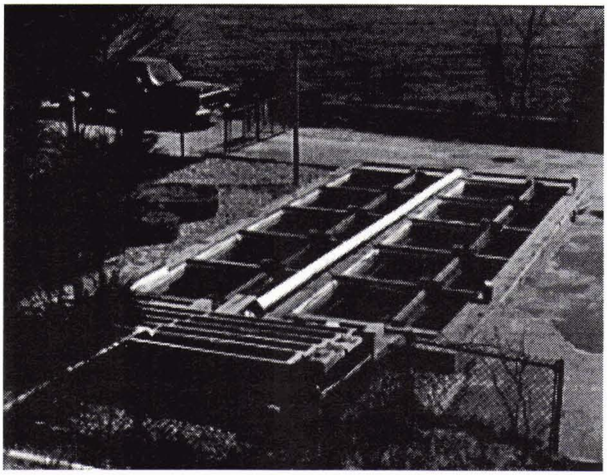

Fig. 4. Mesocosm tanks at the University of Rhode Island.

2.3 In-situ Testing

During August 1996 a brief field study was conducted in the East Passage of Narragansett Bay in an area with well-established beds of eelgrass. Several types of hydroacoustic measurement equipment and sampling procedures were deployed from a shallow-draft, coastal vessel. A team of Navy divers made visual inspections, took underwater video imagery, and collected eelgrass samples at ground truth locations.

2.3.1 Ground truth sampling

Four locations of varying densities of eelgrass were selected based on a preliminary survey with the single beam sonar. The vessel was anchored above the selected location and stationary depth sounder measurements were collected. An anchor and buoy marked the insonified area and a dive team then placed a 0.25 square meter quadrat on the bottom in the marked area and measured the in-situ height of eelgrass and then removed all vegetation within the quadrate at the base of the plants. The area and sampling operation were filmed by a diver with an underwater video camera and sediment samples were also taken. Eelgrass samples were iced and stored in darkness until laboratory measurements were performed the next day. Laboratory measurements included blade count, blade length, width and thickness, and wet and dry weights. Sample means for blade density ranged from 500-1200 blades per square meter with the average blade length ranging from 30 to 70 cm. Sediment samples indicated a sand bottom composed primarily of fine sand (54.3 %) in this area.

2.3.2 Single beam sonar

A single beam 420 kHz, 6 degree beam width sonar (Biosonics, Inc., Seattle, Washington) was integrated with a differential GPS to yield a digitized file of amplitudes as a function of latitude and longitude. Figure 5 illustrates the return from the eelgrass in a bed at a depth of approximately four meters. The eelgrass can be clearly seen growing up from the steep slope in the 2-4 meter water depth.

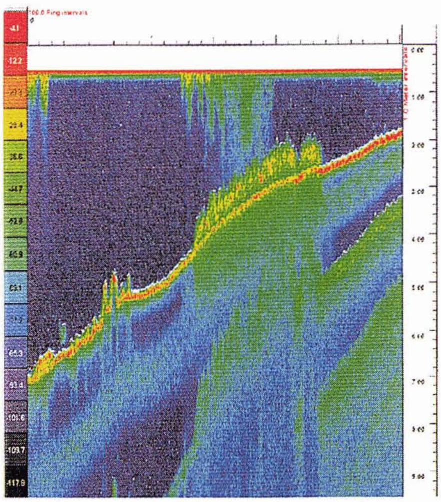

Fig. 5. Bottom return and eelgrass bed off Rose Island, Narragansett Bay, Rhode Island.

2.3.3 Side-scan sonar

An EG&G 272TD dual frequency side scan sonar was used to map known eelgrass beds in Narragansett Bay. The tow fish was deployed from a small shallow draft coastal vessel and operated at 100 kHz. Figure 6 illustrates an image from the starboard channel of the sonar. The bottom appears quite hard and well defined in the deeper water. Rocks and distinct features can be seen here. The grass bed begins to show in the 4 meter water depth. At this point, the sonar image is quite fuzzy and the grass can be seen growing up from the bottom. If a mine were located in this area, it would be acoustically masked and likely not detected by sonar. In addition to diver observations, underwater video confirmed the presence and boundary of the eelgrass bed just as shown in the sonar images.

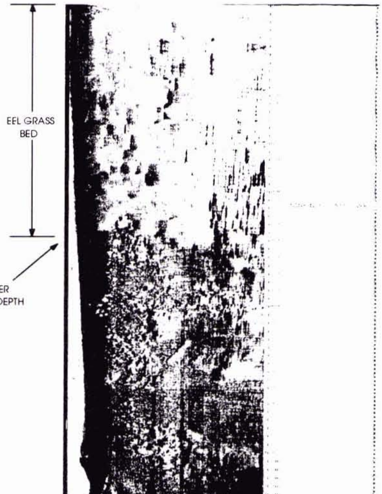

Fig. 6. The starboard trace from a side-scan sonar showing the boundary of an eelgrass bed and the backscatter it creates.

3. Model development

Presently no model exists which explains the acoustic behavior of submerged aquatic vegetation. This is the first effort to gather experimental data in support of model development. Based on the data from these experimental measurements and the fundamental physical acoustics, a model is under development for a single blade of *Zostera marina*. Due to the large volume of gas in the grass, the blade can be modeled as a small air-backed structure. The model will be parameterized by frequency, water depth, blade size, and orientation. An aggregate model which combines the effects of the many blades which are found in a bed of eelgrass can then be develop

4. Future Work

Future research would support model development and allow for field testing with mine-like objects. Additional efforts are also required to measure target strength and backscatter from seagrasses at lower frequencies (20 - 200 kHz). The development of new signal processing techniques and waveforms may be required to specifically exploit the unique characteristics of seagrasses which in turn would help distinguish mine returns from seagrass acoustic effects. Finally, in-situ experiments should be carried out with operational mine-hunting sonars to further quantify the effect of the seagrass on actual fleet hardware.

5. Dual Use Applications

Eelgrass meadows are critical to the health of their ecosystem; they provide sanctuaries for many fish, reduce shoreline erosion by slowing currents, clean the water by filtering nutrients and particles, and provide food for crabs, ducks, and other marine life. Eelgrass beds are six times more productive than any other bottom cover. Other applications of this research include tracking seagrasses acoustically to monitor pollution and help biologists carry out distribution and density studies. Discussions with the Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries (NMFS), and Army Corps of Engineers (among others) indicate that a reliable, cost-effective method for monitoring and locating eelgrass beds in regions of turbid water (i.e. Boston Harbor) is required. Conventional methods involving aerial photography can be difficult and expensive if water clarity is not sufficient. Physical techniques for detection and characterization are labor and cost intensive and provide little insight into spatial distribution.

This eelgrass acoustics study has been identified as a Coastal America Program which integrates the capabilities of existing resources with those of federal, state and local agencies and non-governmental concerns. It is expected that the same technology that the Navy develops to eliminate the "noise" from seagrass during mine-hunting operations will be used to locate and track seagrass for environmental projects such as the National Estuary Project.

6. Conclusions

Results from initial laboratory and in-situ testing have indicated that seagrass may adversely affect the Navy's ability to detect mines by creating backscatter or acoustic interference with mine-hunting sonars. A more thorough understanding of the acoustic properties of seaweeds and seagrasses is therefore essential for optimal performance of mine-hunting sonars in littoral regions.

Research to date has provided for experiments with side-scan sonar and conventional single beam sonars which have clearly shown the backscatter effects of submerged aquatic vegetation in the 100 - 700 kHz frequency range. No frequency dependence was found from 200-700 kHz although backscatter is significant in this region. The target strength measured approximately -21 dB. The acoustic response of a single specimen of grass was found to be largely dependent on orientation.

It is hoped that these measurements will aid in the development of methods to enhance the performance of mine-hunting and weapon sonars. The data should also supply important environmental input to range-dependent sonar models and enhance tactical and environmental databases.

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