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STUDYING AND MODELING OF SUBMERGED AQUATIC VEGETATION ENVIRONMENTS SEEN BY A SINGLE BEAM ECHOSOUNDER

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1 INTRODUCTION

Shallow coastal water investigations are mainly motivated by ecological and economical issues. One important item is the study of Submerged Aquatic Vegetation (SAV). Ecologically, SAV beds stabilize bottom sediments through their roots, attenuate currents and waves, promote sedimentation and reduce erosion [1].They also provide shelter and refuge for adult animals and serve as nurseries for juvenile fishes [2]. The infauna and epifauna of SAV also serve as preys, for larger invertebrates and fishes [3]. Furthermore, the distribution of vegetation meadows is an indicator of the water quality [4]. Economically, seaweeds (algae) are used in industry very extensively [5]. So, in order to protect and detect general ecosystem changes, an accurate monitoring of SAV beds is required.

Numerous techniques for characterizing and monitoring SAV have been used. These can roughly be divided into three categories: physical (manual) methods, optical methods, and acoustic methods. Physical techniques include direct physical sampling and observation by divers [6]. Although they provide the greatest level of fidelity, they are both time consuming and labor intensive. Optical methods use imagery acquired from airbone and spaceborne sensors or underwater camera data [7]. These techniques work well under ideal conditions, but their performances are severely degraded by uncontrollable factors such as poor water clarity, water surface roughness and clouds. Nowadays, the most efficient techniques for mapping and monitoring the subsurface oceans over large areas are acoustic methods [8]. There are three major acoustic systems: side-scan sonars, multibeam and single beam echosounders. According to the previous studies, it is easier to separate SAV and bottom reflectivity with the help of temporal information along the water column. Most of the time, single beam echosounders give that information contrary to side-scan sonars and conventional bathymetric multibeam echosounders. Moreover, single beam echosounders are not affected by the grazing angle effect. Therefore, the single beam echosounder is the most specific tools to have the more information about SAV.

Several studies have been done to characterize and monitor SAV with the echo time series of a single beam echosounder [9,10]. Without ground truth data and calibration, few information about SAV are available. Absence/presence of vegetation and the height of the canopy are easy to get. The types of species or geoacoustic coefficients are harder to obtain. Getting of these SAV properties, with only a single beam echosounder, is tested by the comparison between real data of three species of SAV and their substrate and also by the use of a numerical model of echo time series. After a presentation of the raw data and their pre-processing, the results of the data observations are exposed. Then, a numerical model which is designed to give new information about vegetation environments is presented and results are discussed.

2 DATASET

2.1 Description of SAV available from our data

In this paper, the SAV comparison is limited to three species, Laminaria hyperborea, Posidonia oceanica and Zostera marina.

2.1.1 Laminaria hyperborea

Laminaria hyperborea is a specie of large brown alga; it is kelp of the family Laminariaceae. It is found in the sublittoral zone of the northern Atlantic Ocean. Laminaria hyperborea is usually hooked on rock and other hard substrata. The holsfast is large and conical. The stipe is stiff, rough textured, thick at the base and tapers towards the frond. It is about 1-2m long. The stipe stands erect when out of water. The blade is large, tough, flat and divided into 5-20 straps of 5-10cm [5].

2.1.2 Posidonia oceanica

Posidonia oceanica is a seagrass specie that is endemic to the Mediterranean Sea. It is a flowering plant which lives in dense meadows and which is found at depths from 1-35m on sand. The rhizome type stems have two possible forms: one growing beneath the sand and other rising above the sand. This arrangement of rhizomes eventually forms a mat. The surface contains the active parts of the plant (the leaves), whereas the centre is a dense network of roots. The leaves are ribbon-like, appearing in tufts of 6 or 7, and up to 1.5m long. Average leaf width is around 1cm. The leaf terminus is rounded or sometimes absent because of damage [11].

2.1.3 Zostera marina

Zostera marina is a specie of seagrass that is found mostly in the northern sections of north Atlantic and Pacific coasts. It is a flowering plant which is lived at depths from 0-10m. It anchors via rhizomes in sandy or muddy substrates. Rhizomes are 2-6mm width with 5-20 roots at each node. Rhizomes are creeping and blind the sediment. The leaves are hairlike and narrow and measure up to 1.2cm wide and may reach over a 1m long. Leaf sheath forms a tube around stem [11].

2.2 Data acquisition

The data used for the study have been acquired by the Semantic TS company, using a small hydrographic vessel (DGA/REI contract: “Cartographie de la couverture du fond marin par fusion multi-capteurs”). During all the surveys, the same acoustic system with fixed setting was used. It consists in a Simrad ES60 echo-sounder by Kongsberg Company. This echo-sounder allows to obtain echo time series at 38 and 200 kHz for each ping. Respectively, for low and high frequencies, the beamwidths are 15° and 7° and the pulses lengths are 256 and 64µs. The data for this project are acquired in .raw format. The raw data lecture and all the processing are done with the help of Matlab.

Each survey contains only one type of SAV and vegetation characterization was achieved by divers. On the 9th June 2010, a survey was done in Lézardrieux, in the north of France. In that area, Laminaria hyperborea was found. On the 17th June 2010, a survey was carried out in Douarnenez, north of France. In that site, two types of environment were detected, bare sand and sand with Zostera marina. Eventually, on the 22th September 2009 a survey in La Vaille (south of France) was done. Bare sand and sand with Posidonia oceanica were observed.

3 PRE-PROCESSING

3.1 General idea

In our work, the pre-processing step is essential. First, because only the average backscattering intensity is studied here, then a solid comparison between the different type of SAV and their substrate is waited for.

To estimate the average backscattering intensity, the ping to ping variability has to be reduced. At high frequency, it is mainly due to speckle, so to filter it, stacking of echoes is done with a sliding window of 10 pings. To do a solid comparison, the average backscattering intensity should only depend on bottom reflectivity. However, echo time series are affected by other parameters, mainly depth and seabed slope [12].

Therefore, pre-processing is essential to reduce the depth and slope dependence. To be independent of slope, only data on relatively flat seabed are studied. To weaken depth effect, a depth-compensation is done. In our pre-processing, depth-compensation is also used before stacking echoes together for the alignment step.

3.2 Depth-compensation

Depth has a great influence on the shape of the echo time series. Echoes acquired at a depth lower than another depth are expanded whereas echoes received at a higher depth are compressed in time. Moreover, the total loss of intensity due to spreading, footprint and attenuation increase as depth increases. Therefore, depth compensation is divided in three steps: bottom detection, then time-scaling and power corrections. Time scaling and power corrections are done according to the studies of [13].

Bottom detection is a recurrent challenge. Indeed, if the bottom is rough, three information may be detected: the minimal depth of the seabed, the maximal depth and the mean depth. In our case, the mean bottom is attended. Approximately, in echo time series, the localisation of the mean bottom appears a half pulse length time before the maximum of the echo. Indeed, if the roughness is considered as Gaussian and the skewness of the signal is light [14], the maximum of reflectivity occurs when the pulse length is centred on the mean bottom. Because of the high ping to ping variability of the data, it is difficult to detect the real maximum of the echo. Therefore, data is filtered with a mean filter of width the pulse length.

The pre-processing data mainly consists to do depth-compensation. With this step, it is possible to do quantitative studies. However, it is necessary to be aware that time-scaling and power corrections are not sufficient to make the echoes acquired at various depths similar. The slight difference of shape in the echoes is due to the effect of macro-roughness which does not increase linearly with depth and which is not compensated here [14]. With the help of a statistical model developed by [15], a rapid study of the sensibility of the depth-compensation was done. It was seen that for a compensation of 3m, an inaccuracy of 1dB in power is found and a maximum shift of 10cm of the mean bottom depth is observed.

4 DATA ANALYSES

4.1 Results

In this part, observations and comparisons between the different types of seabed are done with the aim to understand the interaction between the acoustic wave and SAV.

First, the differences between a bare substrate and a substrate with SAV are observed at 38 and 200 kHz. Unfortunately, in our case, this information is only available for two species, Posidonia oceanica and Zostera marina.

Figure 1 shows the echograms of the average backscattering intensity for the two available species at 38 and 200 kHz. The mean bottom detected is pointed to a blue line. The data are pre-processed according to the part 3. First, in agreement with the previous studies, an absence/presence localisation can be done and the height of the canopy can be determined. It is also possible to notice a perfect continuity between the mean bottom of the bare substrate and the substrate with SAV, at the both frequencies. Moreover, there is no specific echo at the interface between the water and the SAV environment. Thus, there is not a large impedance break between the two environments.

In figure 2, Posidonia oceanica and Zostera marina are compared with their respective bare substrate. Data are pre-processed according to the part 3. A depth-compensation at 13m is done for the Posidonia oceanica environment and at 7.5m for the Zostera marina environment. First, for the two species, a significant difference is observed between the bare substrate and its SAV. In both cases, the vegetation signal has a relatively strong backscatter component before the bottom detection time. For Posidonia oceanica, this observation is accentuated at 200 kHz. For Zostera marina, it is nearly the same at both frequencies. Secondly, for the seabed responses, the sand reflectivity is attenuated when it is covered with SAV. However, the behavior is different with the species. The absorption is significant for Posidonia oceanica (-18dB at 38 kHz, -10dB at 200 kHz), it is smaller for Zostera marina (-3dB at 38 kHz, -5dB at 200 kHz).

Figure 3 presents the average backscattering intensity of the three species of SAV introduced in part 2, at 38 and 200 kHz. Data are pre-processed according to the part 3. The mean depth for all the data is 10m, so a depth-compensation at this level is done. First, at both frequencies, before the bottom detection time and up to the canopy top, the shape is characteristic of the species. Indeed, in that part of the signal, Posidonia oceanica has constant increase of reflectivity until the bottom detection time. For Zosteria marina, the signal starts with a little step of reflectivity and then a constant increase until the bottom detection time. For Laminaria hyperborea, the step is higher than for the other species and then the reflectivity level stays constant until the bottom detection time. Eventually, at 38 kHz, Laminaria hyperborea and Zostera marina have the same maximum level of reflectivity which is higher than the one of Posidonia oceanica. At 200 kHz, the observation is different; Laminaria hyperborea and Posidonia oceanica have the same maximum level which is lower than the maximum of reflectivity of Zostera marina.

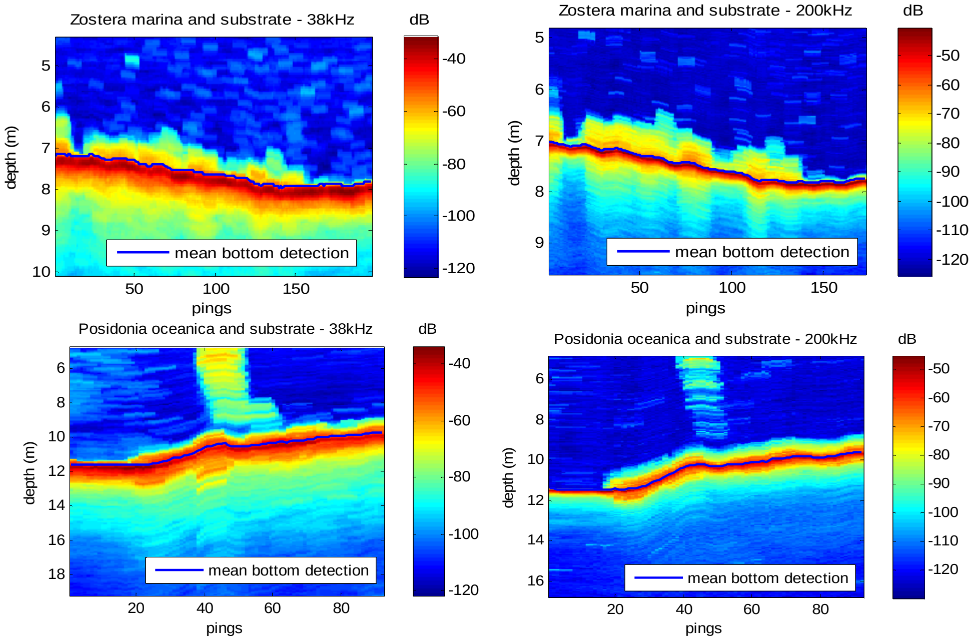

Figure1: Echogram of the average backscattering intensity in dB (received power reference of 1W. At the emission, the power is 100W at 38 kHz and 300W at 200 kHz). Localisation of the mean bottom in meter (blue line).

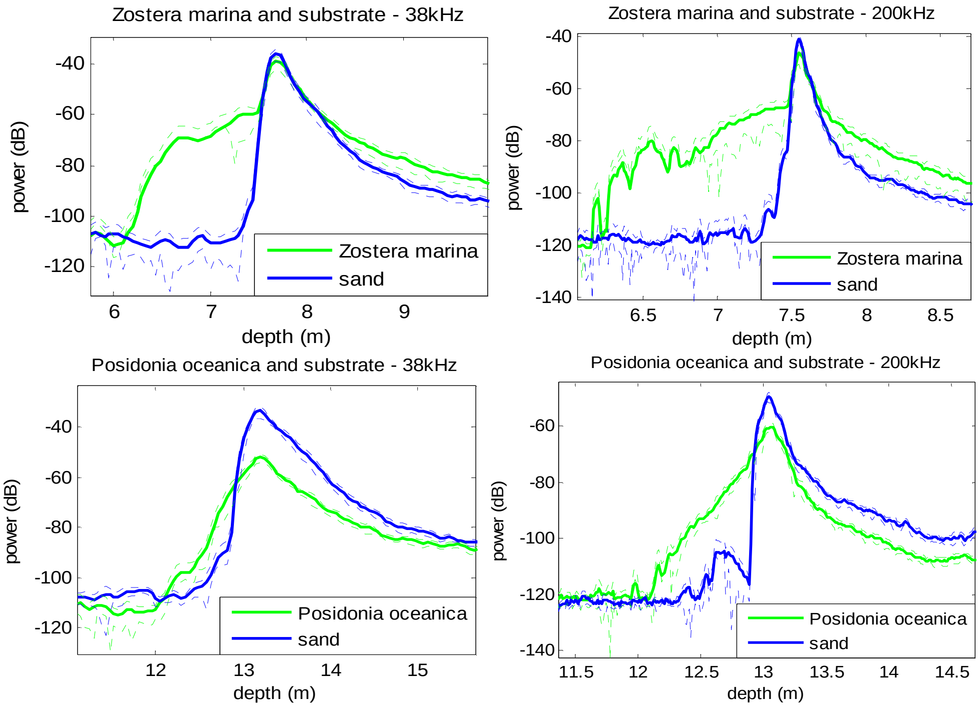

Figure 2: The average backscattering intensity for different types of seabed and frequencies, in solid lines (received power for a reference of 1W. At the emission, the power is 100W at 38 kHz and 300W at 200 kHz). The dash lines represent the empirical standard deviation.

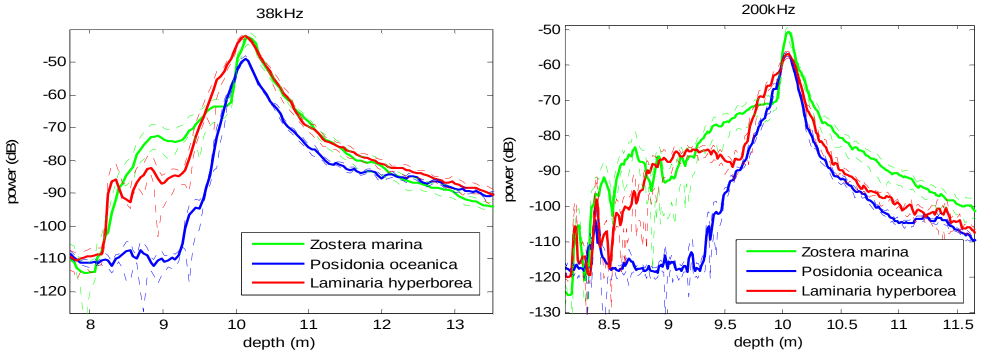

Figure 3: The average backscattering intensity for different types of SAV and frequencies, in solid lines (received power for a reference of 1W. At the emission, the power is 100W at 38 kHz and 300W at 200 kHz). The dash lines represent the empirical standard deviation.

4.2 Data analyses

At first place, it is important to notice that one ping doesn't translate only the response of the vegetation, but of the entire environment into the footprint of the single beam echosounder. Thus the acoustic signal is the response of the environment made up to SAV and water.

Figure 1 has not highlighted a difference of impedance between the bare substrate and the SAV. Thus in first approximation, the sound velocity and the density of the SAV environment can be approximated by the water sound velocity and density. It can be also considered that there is no surface reflection at the water/SAV interface.

However, figure 2 shows a relatively strong backscatter before the bottom. Therefore, the SAV environment has its own backscattering coefficient which can be modelled as volume reverberation. Moreover, the volume backscattering coefficient into SAV has different shape function of the species, so it should help the species characterization (figure 3). The presence of SAV involves signal attenuation and therefore an absorption coefficient. The latter seems to be specific to species. Posidonia oceanica has a higher absorption than Zostera marina (figure 2).

In our example, the observations allow to think that other information than the height of the canopy could be obtained with only single beam echosounder information. Volume backscattering and absorption coefficient of the SAV environment can be observed. Direct measurements of these two coefficients are difficult to obtain. Therefore, in the next part, with the help of a numerical model, the quantification of this information is studied.

5 THE SAV APPARENT SCATTERING INDEX

5.1 Model

According to the latter observations and information provided by the Kongsberg Company, it is possible to link the received power with the volume backscattering and the absorption coefficient [16]. First, the sound velocity and the density of the SAV environment are assumed to be the same as water. Then, no surface reflection at the interface water/SAV is seen. Eventually, as we work on shallow water (0-15m), the acoustic wave curvature can be considered negligible. Therefore the SAV environment can be viewed as homogeneous into the insonified volume at the instant t.

Thus, to be in agreement with the real data into the SAV environment, the average backscattering intensity, in dB and inside the vegetation, is modelled at each corresponding time using the following equation:

$$P_r(t) = 10\log\left(\frac{P_e\, G_0^2 \lambda^2 c\, \tau\, \psi}{32\pi^2}\right) - 2\alpha r_c - 20\log\big(r(t)\big) + S_v\big(r(t)\big) - 2\beta\big(r(t)\big)\big(r(t) - r_c\big) \tag{1}$$

P_r is the received power at the time t (dB re 1 W), P_e is the transmitted power (W), G_0 is the transducer peak gain (non-dimensional), λ is the wavelength (m), c is the sound velocity (m/s), τ is the transmit pulse duration (s), α is the absorption coefficient of water (dB/m), r_c is the distance between the transducer and the top of the canopy (m), r is the distance between the transducer and the wave at time t, S_v and β are the volume backscattering coefficient (dB re 1m^{-1}) and the accumulated absorption coefficient starting from the canopy top (dB/m) of the SAV environment at time t.

The aim is to find S_v and β for all time into the SAV environment. However, as it is possible to notice on the real data, it is not satisfactory to consider S_v and β as constants. Indeed, the increase of P_r from the vegetation layer is gradual. Therefore, S_v and β vary probably during the propagation. So, we have not enough equations to immediately solve the problem.

In order to define new descriptor about the SAV environment, we introduce the SAV apparent scattering index A_v which is

$$\begin{aligned} A_v &= S_v\big(r(t)\big) - 2\beta\big(r(t)\big)\big(r(t) - r_c\big) \\ &= P_r(t) - 10\log\left(\frac{P_e\, G_0^2 \lambda^2 c\, \tau\, \psi}{32\pi^2}\right) + 2\alpha r_c + 20\log\big(r(t)\big) \end{aligned} \tag{2}$$

Further studies will be done in order to separate the contribution of S_v and β .

5.2 Results

Figure 4 shows the SAV apparent scattering index, A_v, at 38 and 200 kHz, for the species available. A_v combines the volume backscattering and the wave extinction. The three species have different behaviours. First, for all the species, A_v has frequency dependence. The SAV apparent scattering index is higher at 200 kHz than 38 kHz. Then this index should be characteristic of species. Indeed, each species has its own dominant value of A_v (table 1).

	Zostera marina	Posidonia oceanica	Laminaria hyperborea
Dominant value of A_v at 38 kHz (dB re 1m^{-1})	-40	-80	-70
Dominant value of A_v at 200 kHz (dB re 1m^{-1})	-30	-70	-50

Table 1: Dominant value of A_v for each species at 38 and 200 kHz.

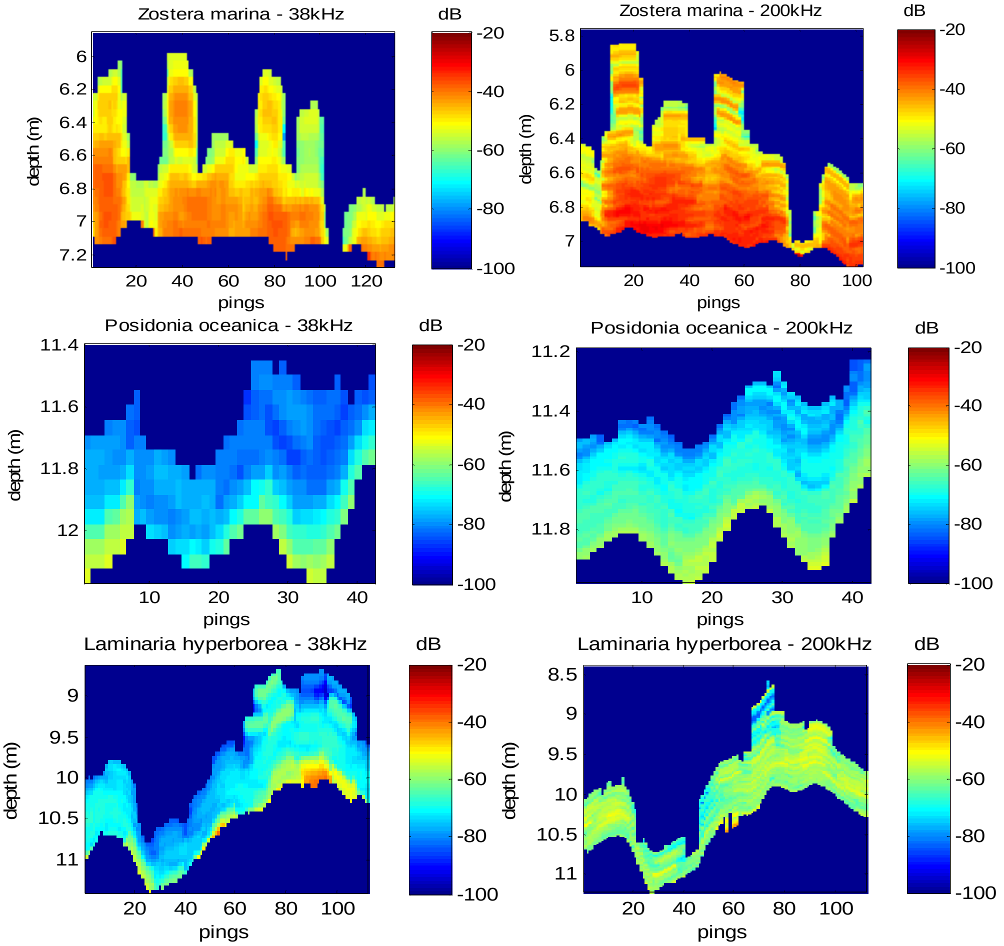

Figure 4: the SAV apparent scattering index for the species available, at 38 and 200 kHz. All the data outside the SAV environment are in dark blue.

6 DISCUSSIONS AND PERSPECTIVES

Three species of vegetation were observed in this study. Significant differences of the acoustic response are found for each species. First, the evolution of the volume reflection between the canopy top and the bottom vary with the vegetation type. This may be due to the density or the leaves size.

Then a great difference in the signal attenuation is found for Posidonia oceanica and Zostera marina. A smaller attenuation is observed for Zostera marina whereas it has a higher SAV apparent scattering index. This difference between the attenuation and reflexion evolution might be a consequence of the vegetation density. Indeed, a discontinuity of the Zostera marina meadows inside the sonar footprint could explain that observation.

Eventually, A_v shows a possible interest for the SAV characterisation. Indeed, specific values of the SAV apparent scattering index are observed functions of the species and the frequencies.

It is obvious that these conclusions have to be verified with other data set. In a future work, the same species will be studied coming from other spatial areas. Moreover, data with different densities for the same species of SAV will be surveyed.

Then, we will try to separate S_v and β in order to explain the different observations above-quoted. Moreover, a connection between the SAV biomass and the coefficients S_v and β will be searched.

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