Background noise in areas covered by marine plants in the Ria Formosa lagoon during the summer

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***Abstract*—This paper analyses the ambient noise recorded at two sites in the Ria Formosa lagoon, South Portugal aiming at developing passive acoustic methods for monitoring marine ecosystems status. The distance between the two sites is only 125 m, but covered by different marine plants: the seagrass *Cymodocea nodosa* and the seaweed *Caulerpa prolifera*. Both sites are very shallow (∼1 m in low tide) and subject to large tidal forcing (peak to peak amplitude of the order of 3 m). Small motor boats and yachting have a significant contribution to the ambient noise of the area, over a broad spectrum. Using a simple non-linear filtering technique, their contribution was removed from the background noise. The results show that the variability of the noise in both sites is complex, but the overall characteristics did not change significantly among sites. The variability pattern of background noise in a low frequency band (<2 kHz) suggests its correlation with human activity. In the frequencies above 2 kHz, the variability patterns are similar to those observed in other littoral environments due to marine taxa, such as fish and crustaceans. The variability of the dissolved O_2 is also similar among sites, and no correlation with the variability of noise level was found. These preliminary results contribute to the development of acoustic passive methods to monitor the health of seagrass ecosystems.**

I. Introduction

This paper reports on an experiment conducted in the Ria Formosa lagoon during a period of two days as a preliminary study to investigate a possible correlation between the O_2 supersaturation in areas covered by marine plants and the ambient noise level. Previous experiments, conducted along one year in a pond covered by the seagrass *Cymodocea nodosa*, have shown large O_2 supersaturation in summer and late spring with large impact in ambient noise [1], [2]. It was observed a significant noise attenuation during the photosynthetic production of oxygen, strongly anti-correlated with dissolved O_2 measurements. The attenuation of the noise was ascribed to bubbles formation in supersaturation conditions due to the plants' photosynthesis.

However, the pond is a relatively controlled environment, the meadow is dense and the currents are weak. During the day light, such conditions favor the O_2 supersaturation and bubble production by photosynthesis. Thus, the conditions in the pond may differ significantly from those encountered in seagrass meadows in Ria Formosa.

Therefore, the primary objective of the experiment reported herein was to establish the similarities and differences of O_2 release and its impact on ambient noise between the Ria Formosa and the pond environments. The acoustic data were

(a) (b)

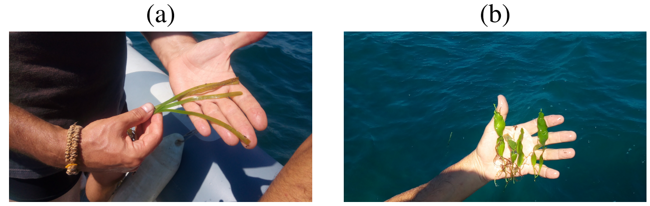

Fig. 1. Samples of *Cymodocea nodosa* (a) and *Caulerpa prolifera* (b) collected in the area

(a) (b)

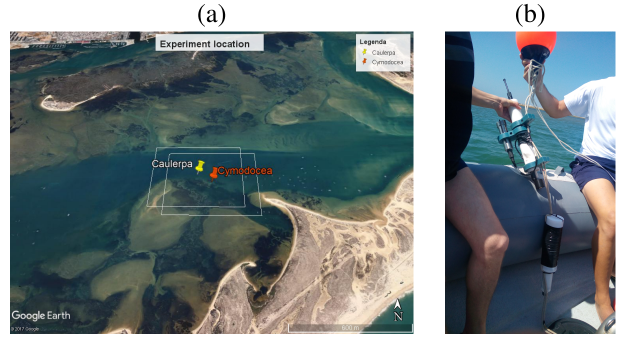

Fig. 2. Location of the *Cymodocea* and *Caulerpa* sites- ©Google Earth (a); *Caulerpa* mooring before deployment (b).

collected in two close located sites with the bottom covered by distinct vegetation, the seagrass *Cymodocea nodosa* and the green seaweed *Caulerpa prolifera*. Other objective of this experiment was the assessment of the daily cycles of background noise as a way to measure biological activity cycles and to investigate possible differences among these sites. In both sites, the ambient noise was composed by impulsive sources, that may be ascribed to biological activity and noise generated by motor boats crossing the area.

This paper discusses the variability of the background noise in three frequency bands, the low band (<2000 kHz) where the noise due to human activity, e.g. motor boats, should be dominant, and the middle band (2–7 kHz) and the high band (>7000 Hz), often linked with biological noise. The background noise, i.e the ambient noise where discrete motor boat events were discarded, was obtained using a simple nonlinear filtering procedure.

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II. Experiment location and setup

The data presented herein was gathered from July 26th to 28th in the Ria Formosa lagoon, South Portugal. During that period, the underwater ambient noise was recorded at two different sites, where the bottom was covered by the seagrass *Cymodocea nodosa* and by the seaweed *Caulerpa prolifera*, respectively. Figure 1 shows samples of both species that were gathered in the area. The seagrass *Cymodocea nodosa* is a native species in Ria Formosa, whereas the seaweed *Caulerpa prolifera* is a recently introduced species, rapidly spreading in the Ria Formosa lagoon.

Figure 2(a) shows the study area and the location of the *Cymodocea* and *Caulerpa* meadows, represented by the red and yellow icon, respectively. During the summer a large number of sailboats are anchored in the area, which is crossed by small motor boats of various types. The sites were about 125 m distant, both in a very shallow water area. At low tide, the water depth was about 1 m. During the period of the experiment, the difference of amplitude between low and high tide was on the order of 3 m (see Sec. III). The underwater noise was recorded by two self-recording hydrophones digitalHyd SR-1 [3] fixed at approximately 0.5 m from the bottom. Dissolved O_2, temperature, salinity and water depth measurements were performed simultaneously with underwater noise recordings. At the *Caulerpa* site the temperature, salinity, water depth and dissolved O_2 were measured by a CTD RBRConcerto. At the *Cymodocea* site, the temperature and dissolved O_2 were measured by an optode probe. Both, the CTD and the optode probe, were fixed at approximately 1 m from the bottom. The instruments were moored using a rope secured by 2x10 Kg iron disks and subsurface buoy, see Fig. 2(b).

III. Environmental measurements

The environmental data collected in both sites are shown in Fig. 3. The water depth presented in Fig. 3(a) was estimated from the CTD data installed in the *Caulerpa* site. It shows that the tidal amplitude was about 3 m and that the water depth at low tide was about 1 m. Water depth measurements were not available at the *Cymodocea* site, but by visual inspection it is believed that this site was even shallower.

The water temperature shown in Fig. 3(b) was gathered by the CTD at the *Caulerpa* site (solid line) and by the optode probe in the *Cymodocea* site (dotted line). It can be seen that the temperature varied between 21°C and 24°C, following a similar pattern at both sites. Surprisingly, the variability pattern of the water temperature shows peak values around midnight. These occur at low tide. The salinity (not shown) measured by the CTD at the *Caulerpa* site was about 36.4 ppm, almost constant (variability less than 0.2 ppm). Therefore, the estimated sound speed shown in Fig. 3(c) varied between 1525 and 1532 m/s.

The dissolved O_2 measurements are presented in Fig. 3(d) as a solid line for the *Caulerpa* site and a dotted line for the *Cymodocea* site. The curves show a similar pattern among sites. As expected the lowest values occur during the night, approximately from midnight to 7am. Supersaturation

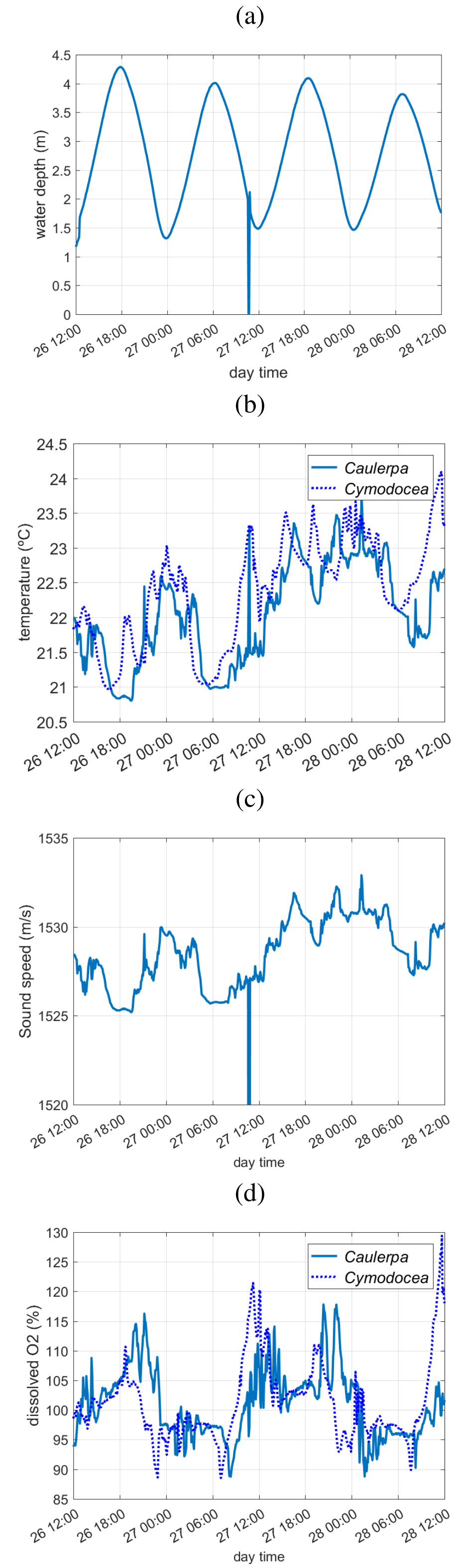

Fig. 3. Environmental measurements at *Caulerpa* site (solid line) and at *Cymodocea* site (dotted line): water depth (a), temperature (b), sound speed (c), dissolved O_2 (d)

conditions (values of dissolve O_2 above 100%) were observed, but the peaks was relatively low (<125% of dissolved O_2) compared with values observed in the pond [2]. These occur in the afternoon, as expected, but also in the evening. The curves are very peaky along the diurnal cycles, which may indicate the importance of tidal flows in the variability patterns of the dissolved O_2 (and the temperature).

IV. Acoustic noise measurements

Two digitalHyd SR-1 hydrophones recorded 90 s long snapshots of underwater noise at a sampling frequency of 52734 Hz, every 5 minutes at the *Cymodocea* site and every 10 minutes at the *Caulerpa* site. The acquisition systems does not allow for synchronization between them and time offsets of few seconds are expected.

Figure 4 shows a 90 s data snapshot recorded in July 27th, at 4h50 at the *Caulerpa* site on the left and at the *Cymodocea* site on the right. The top panels present the time series and the bottom panels present the respective spectrograms. From the beginning of the record until approximately 30 s, one can notice, in both spectrograms, broadband interferences (striations) typical for motor boats passing close to the receivers. The motor boats increase significantly the noise level at low frequencies, but the interference is visible in the whole spectrum. Visual inspection of the data shows at both sites impulsive waveforms that may be related to biological activity. These are present in all snapshots observed and may explain the global prevalence of increased noise level in the band between 3 and 6 kHz (also seen in spectrograms of Fig. 4). Similar pattern was already observed in experiments conducted in a *Posidonia oceanica* meadow [4].

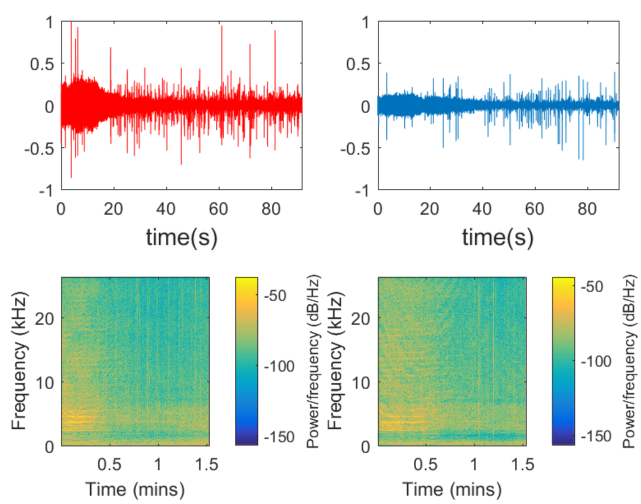

Fig. 4. Files recorded in July 27th, 4h50 am at the *Caulerpa* site on the left and at the *Cymodocea* site on the right: time samples (on the top) and respective spectrograms (on the bottom).

V. Variability of background noise

The noise produced by boats crossing the experimental area represents a major contribution to the noise power, particularly during the day. The contribution of boats passing close to the moorings are discrete events leading to an instantaneous increase of the noise power, that can last for several minutes. Figure 5 shows the noise level estimated at both sites in various bands, where the red line represents the low frequency band (<2 kHz), the blue line represents the medium frequency band (2–7.25 kHz) and the magenta line represents the high frequency band (≥7.25 kHz). The green and black lines represent the water depth and the dissolved O_2, respectively. It can be seen large instantaneous variability due to discrete events such as short range motor boats cruising the area. In order to filter out these discrete events from the background noise, which is partially due to biological activity, meteorological phenomena or diffuse anthropogenic noise from faraway sources, a non-linear sliding-window minimum filter was applied to the noise level estimates. The results are shown in Fig 6 for the various frequency bands (<2 kHz (a), 2–7.25 kHz (b), >7.25 kHz (c)) where the blue curve represents the *Cymodocea* site, and the red curve represents the *Caulerpa* site. The black and and the green curve on these plots represent the dissolved O_2 and the water depth, respectively. Detail of the noise level curves in the various bands and at both sites is shown in Fig. 6(d).

The variability pattern of background noise in the lower frequency band is similar at both sites with a maximum at afternoon and a minimum at the low tide at midnight. At the minimum, the noise level is about 10 dB higher at the *Caulerpa* site than at *Cymodocea* site. At these low frequencies the water depth has an important impact on propagation, because of the cut-off frequency of the waveguide. During the night, when the local boat activity is low, the contribution to this noise band is expected from faraway sources. Since, visual inspection showed that the *Cymodocea* site is shallower than the *Caulerpa* site, the attenuation is expected higher at the *Cymodocea* site. During the day, due to the large boat activity, the low frequency background noise is high, even at low tide (the filter only discards discrete sources passing very close to the moorings).

The overall behavior of the variability pattern of background noise in the medium and high frequency bands are similar among sites, as can be seen in Fig. 6 (b), (c) and particularly (d). The background noise is maximum before dawn, decreases to a minimum at midday and increases again during the afternoon and night to dawn. The noise peaks just before dusk and sunrise seen in our data were observed in coral reefs, where it was ascribed to sea urchins feed on algae and invertebrates [5]. Low tide has some effect on the noise, but it does not mask the overall trend. Nevertheless, it should be remarked that in the medium and high frequency bands the noise level at the *Caulerpa* site is about 5 dB higher than at the *Cymodocea* site. The actual reasons for this are unknown and deserve further investigation. But, a possible explanation, is that the acoustic characteristics of the seagrass *Cymodocea*

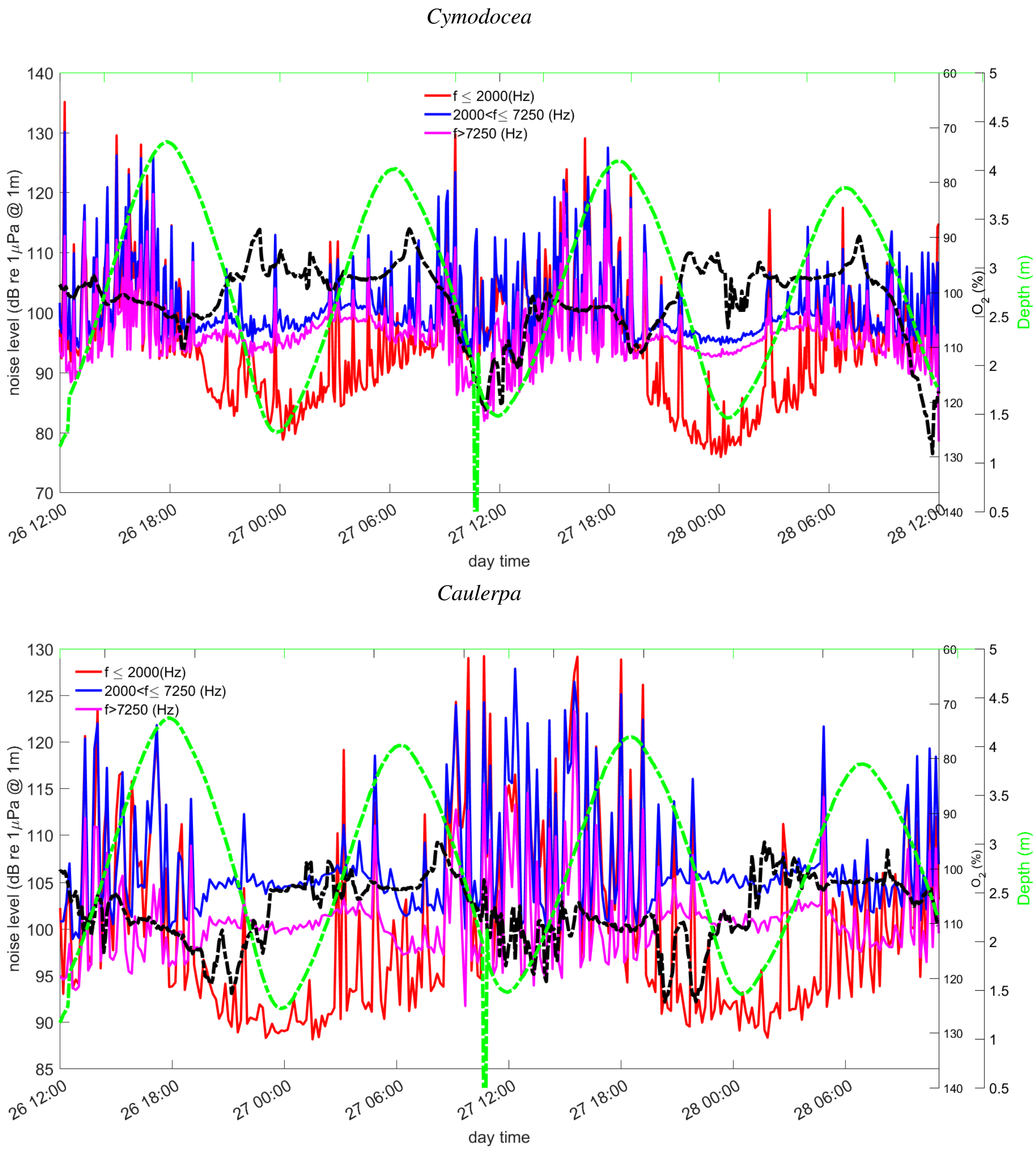

Fig. 5. Variability of the noise level in the bands 0–2 kHz (red), 2–7.25 kHz (blue) and 7.25–25 kHz (magenta) in the *Cymodocea* site (upper panel) and *Caulerpa* site (bottom panel). The green and black lines represent the water depth and dissolved O_2, respectively.

tissues and their longer leaves produce a higher attenuation effect of the acoustic signals than the seaweed *Caulerpa*. Other possible explanation, may be an increased biological activity in the *Caulerpa* site.

Due to the short period of the experiment of only two diurnal cycles showing low and peaky O_2 supersaturation and large tidal amplitudes it is difficult to conclude about the influence of the photosynthetic activity on the background noise variability.

VI. Conclusion

This experiment shows that the variability of the noise power in these very shallow water sites is very complex, although the overall characteristics did not change significantly among sites. During the day a large number of boats cross the area and dominate the ambient noise power spectra in all bands. The variability of the dissolved O_2 is also similar among sites, and no correlation with noise level was found. The tidal forcing may have an influence on environmental parameters (water temperature, dissolved O_2) and noise level, for the latter particularly at low frequencies. At these frequencies, the background noise has a maximum at midday and a minimum at midnight as this component is linked with human activity. There is a persistent background noise in the 2–7 kHz that may linked to biological activity. The background noise in this band is higher during the night than

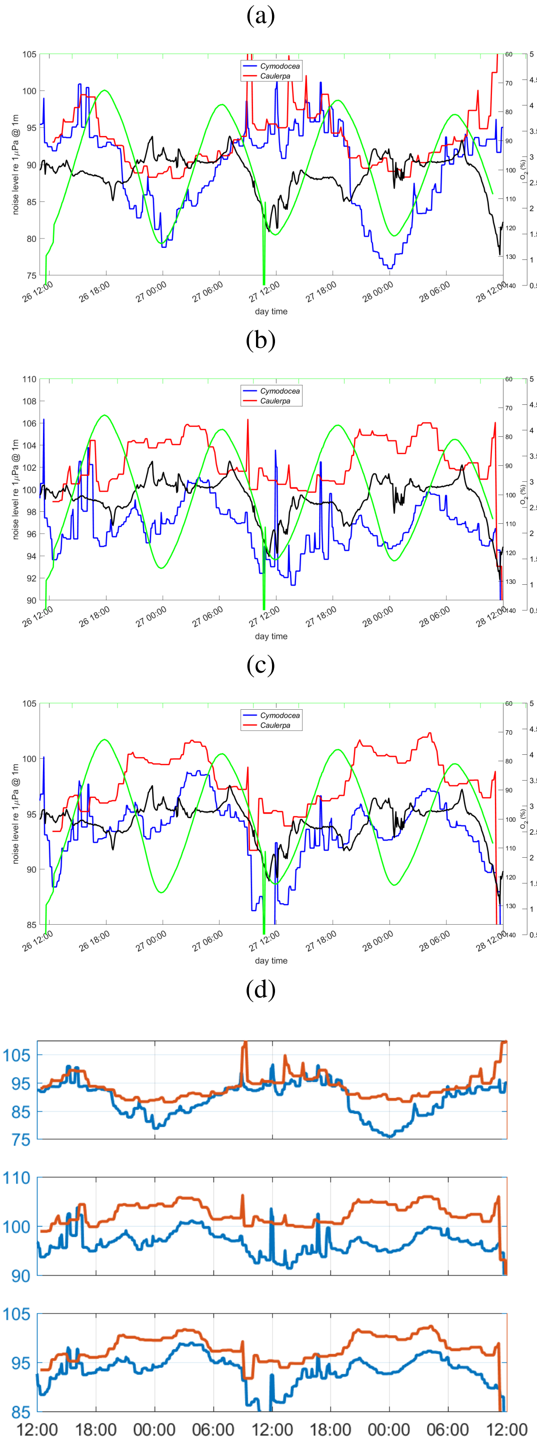

Fig. 6. Comparison of the background noise level at the various frequency bands and the environmental parameters water depth (green) and dissolved O_2 (black): <2 kHz (a), 2–7.25 kHz (b) and >7.25 kHz (c) (*Cymodocea* site blue, *Caulerpa* site red). Comparison detail of noise power only (d) for <2 kHz (upper),2–7.25 kHz (middle).and >7.25 kHz (bottom).

during the day, with two peaks at dawn and dusk due to biological activity, similar to patterns observed in other littoral environments. Although the variability pattern of noise level is similar at middle and high frequency bands, the noise level in the *Caulerpa* site is 5 dB higher than at *Cymodocea* site. This offset may be ascribed to the different plant morphology or biological activity. Complementary observations (videos and visual inspection) are needed to support these hypothesis. From the preliminary results, it is clear that longer lasting experiments are needed to support the development of methods to use noise as a proxy of the health of the seagrass ecosystem

Acknowledgment

The authors thank Marsensing Lda, for the technical support and loan of the digitalHyd SR-1 Self-recording hydrophone. This work was funded by National Funds through Foundation for Science and Technology (FCT) under project PTDC/EEIPRO/2598/2014 (SEAOX).

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