Influence of microphytobenthos photosynthesis on the spectral characteristics of the signal reflected from Baltic sandy sediments

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The use of hydracoustical techniques to classify benthic fauna and flora is one of the important challenges in present marine research. It is crucial to understand the microphytobenthos photosynthesis impact on the backscattering properties of the sea floor in the Baltic Sea, where the techniques are actively developed now. This motivated our study. The data used in the analysis was collected in the multiday laboratory experiment conducted in the frame of the grant of the National Science Centre, Poland (No. N306 773940). In this experiment, during changing light conditions (light/dark photocycles), the hydroacoustical backscattering data was acquired in the aquarium with a sandy bottom. The constant temperature and salinity conditions, typical for the Southern Baltic, were kept, and oxygen content was monitored. In this paper data collected at 280 kHz, was processed. It was studied how the energy of echo and power spectral density of the echo signal, are sensitive to the microphytobenthos photosynthesis.

Keywords: hydroacoustics, backscattering, microphytobenthos photosynthesis, Baltic Sea

1. Introduction

According to the recommendation of the International Council for the Exploration of the Sea [ICES] [1]; the development of hydroacoustical techniques, for benthic habitat classification in the Baltic Sea, requires to understand how the benthic biological processes impact the echo from the sediments surface, in the typical (for this basin's) conditions.

The impact of microphytobenthos photosynthesis on the acoustical backscattering properties of sandy sediments was studied by Holliday et al. [2] and Wildman and Huettel [3] for the Atlantic, and by Gorska et al. [4] for Southern Baltic. It was shown that photosynthesis of benthos microalgae during the day, leads to the appearance of gas bubbles on sediment surface, causing the change of acoustic backscattering properties of the sediment. Gorska et al. [4] demonstrated the diel variation of energy of echo, and arrival time of acoustic signal. The study was done mainly for a 250 kHz acoustic pulse.

In our paper another approach to the data analysis is proposed and diel variation of power spectral density (PSD) of echo signal due to the microphytobenthos photosynthesis is examined and compared with the diel changes of energy of echo. This approach enables you to analyze separately different frequency components of the backscattered pulse. Pulses with a central frequency 280 kHz are studied. To better understand the microphytobenthos photosynthesis impact on the echo signal, the diel variation of the hydroacustical data are compared with diel change of dissolved oxygen content in water**.**

2. Materials and methods

2.1. Description of experiment

To study how microalgae photosynthetic activity impacts on the acoustic signal reflected from Southern Baltic sandy sediments, a multiday laboratory interdisciplinary experiment was conducted. The experiment methodology was described in detail in the paper of Gorska et al. [4]. According to the paper the “day” and “night” illumination cycles were modeled in a 50x50x50 cm aquarium (Fig. 1) by using a 400 W sodium lamp (produced by Philips), mounted above the aquarium, which gives radiation intensity 500±15 μmol $m^{-2}s^{-1}$ in PAR range. The radiation intensity corresponds to the values registered in place of sediment origin during the summer period. Medium size sandy sediments were placed in aquarium (7 cm thickness layer on the aquarium bottom) and were taken from an internal part of Puck Bay (Gulf of Gdansk, southern Baltic Sea, Poland, coordinates: 45° 50‟ 20” N, 18° 18‟ 56” W). From the beginning to the end of the experiment, the sediments, and therefore the microalga community, were undisturbed by any external forces.

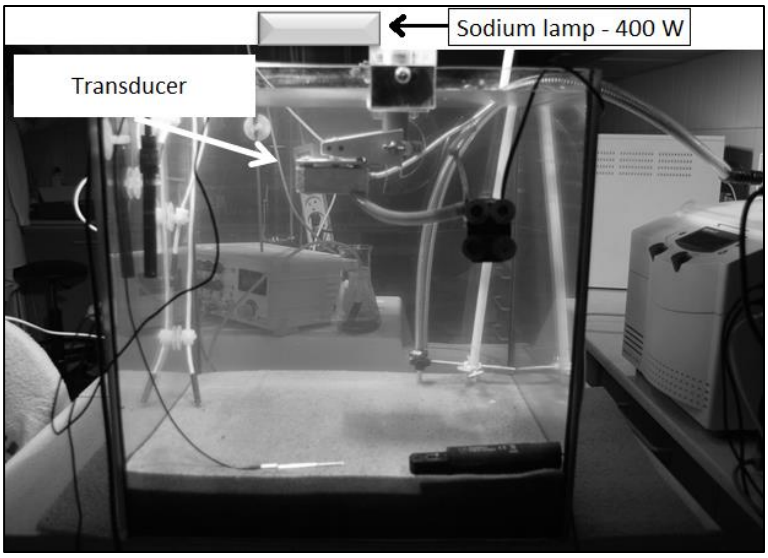

Fig. 1. Photography of aquarium with equipment, in which measurements were done.

Experiment lasted 11 days, during which each modeled photocycle involved a 9h period of light and a 15h period of dark. The salinity of the water was 6.9 PSU and the temperature was 18°C. Both parameters, being typical for the Southern Baltic, were left constant and monitored throughout the time of experiment. Simultaneously, the dissolved oxygen concentration (saturation) was monitored.

The hydroacoustical measurements were conducted every day, starting 2h before the lamp was turned on, during entire light period and then 5h after lamp was turned off. The used hydroacoustical equipment, and the data processing, were described in details in the paper Gorska et al. [4]. It is worth to note that the data was collected, by a vertically down-looking transducer, in the wide frequency band: from 200 kHz to 700 kHz, and the multiple reverberation did not "pollute" the echo signal because of the narrow directivity pattern of the transducer over the entire frequency range.

2.2. Data analysis

The hydroacoustical data, collected at the frequency 280 kHz during the experiment, described in the previous part, were processed to reveal the diel changes of power spectral density and the energy of echo from the sandy sediments surface.

Firstly, the transducer low-frequency resonance components (their peaks were observed at 39 kHz and 48.8 kHz) were eliminated from the collected echo signals using a fast Fourier transform (FFT) algorithm, and then applying high-pass filtration (with the limit at 135 kHz). After the filtering in frequency domain, the inverse fast Fourier transform was applied. Using the Eq. (1) and the "energy of echo" (term introduced in Gorska et al. [4], the energy of echo was calculated for the signals obtained in the processing:

$$E_i = 10log_{10}(\sum_{j=n_1}^{n_2} U_{ij}^2) \tag{1}$$

where E_i denotes energy of echo of ping number i, n_1 and n_2 describe the number of the first and last sample corresponding to the beginning and the end of the time window selected to the computation, in which echo from the surface of sediment is present. U_{ij} stands for voltage in time sample number j, and in echo ping number i.

Assessment of the power spectral density (Stoica and Moses, 2005 [5]) of the processed echo signals was done in a Matlab computing environment using a built-in function, which uses short-time Fourier transform.

3. Results and discussion

3.1. Diel changes of the energy of echo and power spectral density

Diel changes of energy of echo (for the collected 280 kHz-signals after the high-pass filtering) and the echo signal power spectral density (280 kHz-component) for 11 days of the experiment are presented by blue and red lines respectively in Fig. 2a. The grey and white backgrounds correspond to dark and light periods respectively. The temporal variation of the dissolved oxygen saturation is represented by the green line (the scale is presented on the right vertical axis). Both hydroacoustical characteristics were normalized by their mean values calculated for prior "night" period between 7:00 and 9:00 a.m. This was done in order to demonstrate the difference between the light and dark periods.

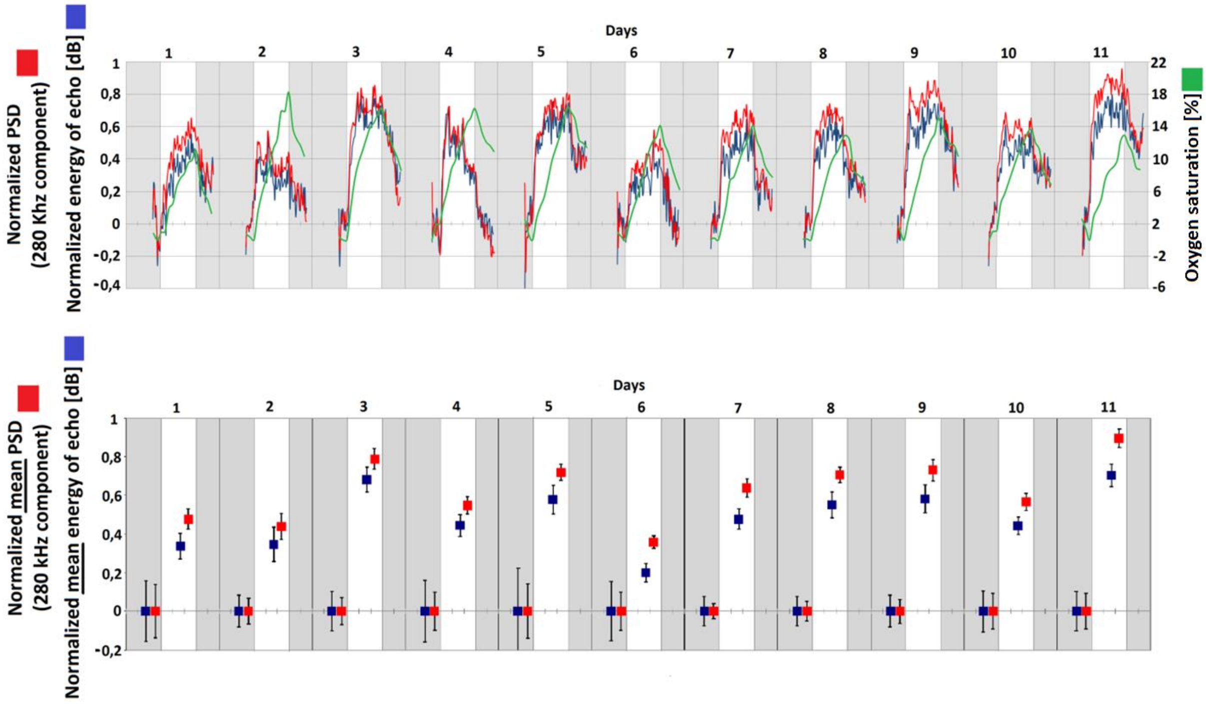

Fig. 2(a,b). Upper panel (a): Time variation of normalized energy of echo (blue) and power spectral density (280 kHz component) (red) with oxygen content changes (green) during 11 days; lower panel (b): Differences between dark (grey background) and light period (white background) for normalized mean energy of echo (blue) and normalized mean power spectral density (red).

Fig. 2a demonstrates that the power spectral density of the echo signal, and the energy of echo, had a rapid rise after the sodium lamp was turned on. This trend was observed for each day of measurements. After approximately 2-3h of initial growth, and till the end of the light period, the characteristics were stable. An exception was day 2 and day 4, for which a decrease of the PSD and the energy of echo were observed at the end of light period. The power spectral density, and the energy of echo, declined after the sodium lamp was turned off.

Diel variation of the energy of echo was between 0.4 and 0.8 dB, while daily changes of PSD were higher - up to about 1 dB (Fig. 2a).

Fig. 2a shows also that dissolved oxygen saturation was higher during the light period, relative to the end of the dark period. Unit of saturation is %, and the value presented in the right axis is saturation of water in the measurement minus saturation of water at the beginning of the light period. Before normalization the oxygen saturation of water in the aquarium was between 65–80 %, depending on day. Oxygen saturation of water had a multiday increasing trend with the characteristic diel variations due to the microphytobenthos photosynthesis. This trend was observed in the publication Gorska et al. [4]. From the beginning of the light period the oxygen saturation had risen almost linearly, reaching its peak at the end of the period, and started to decline from the beginning of dark period. The rise of oxygen saturation during the illumination period was due to the oxygen production caused by the benthic microalgae photosynthesis. The good correlation of the diel variations, of oxygen saturation and echo energy (the correlation coefficient was 0.8377 with p=0.01), confirms that the "day/night" difference in the energy of echo was caused by the microphytobenthos photosynthesis.

During the light periods, single gas bubbles, with dimension around 1mm, were present on the surface of sediments, and in the water column. The bubbles disappeared at the dark periods. Taking into account the fact, that the gas bubbles can strongly impact the sound propagation (Leighton, 1997 [6]; Medwin, 2005 [7]; Ainslie and Leighton, 2011 [8]), it can be concluded that the diel cyclical variation of their number was responsible for the “day/night” variation of the echo energy.

The presence of the healthy diatom community in the sediments, mentioned in the paper Gorska et al. [4], is an additional argument confirming that only the microphytobenthos photosynthesis was responsible for the “day/night” difference in the backscattering properties of the sediment.

Fig. 2b was generated in order to compare diel change of the mean power spectral density (280 kHz-component) with the diel variation of the mean energy of echo. The blue boxes correspond to the normalized mean energy of echo, while the red boxes represent the normalized mean power spectral density (component at 280 kHz). The mean values of the energy of echo and PSD were calculated separately for each consecutive light and dark period. To understand the diel variation of the energy of echo for each diel cycle, the means of the energy of echo, both, for “day” and prior “night” times, were normalized by the mean energy of echo from this dark period. The same was done for the mean power spectral density at 280 kHz. Whiskers in the figure represent the standard deviation values. It is demonstrated (Fig. 2b) that the “day/night” difference of the mean power spectral density (up to about 0.9 dB) is greater than the difference of the mean energy of echo (up to 0.7 dB). Additionally, the standard deviations are slightly smaller for the power spectral density.

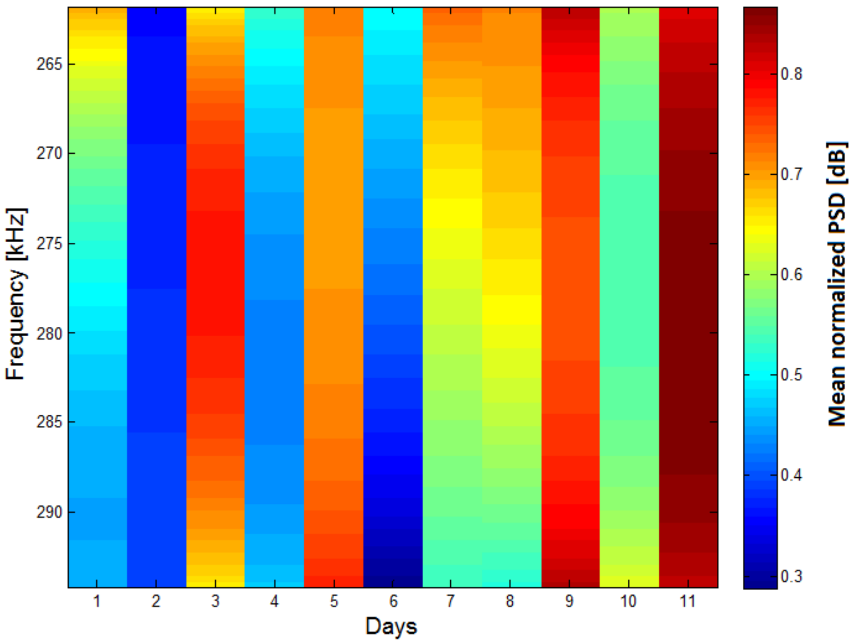

Fig. 3. Daily differences in the mean power spectral density between “day” and “night” time.

In Fig. 3 the difference between mean power spectral density in “day” and “night” time is demonstrated over the acoustic frequency range from 263 to 294 kHz, for all days of the experiment. The PSD of the echo signal decreased by 3 dB from the central frequency 280 kHz, to the 264 kHz and 294 kHz frequencies, and therefore we refer to this frequency range as a useful part of signal. The acoustic frequency, and the number of the experimental day are presented on the vertical and horizontal axis respectively. Each pixel in the figure corresponds to one frequency and one experimental day. Its color corresponds to the difference in the mean PSD between “day” and prior “night” period. The colored dB-scale presents the values of the mean PSD in light period normalized by mean PSD in prior dark period.

Fig. 3 shows that that the “day/night” difference depends on the frequency, and that this dependency changed from day to day. The “day/night” difference varied up to about 0.2 dB between frequencies in the presented, in Fig.3, frequency range (in days number 1, 7 and 8). The fact that the maximum “day/night” difference of the mean PSD occurred at a different frequency on different days may be connected with the variation of the size distribution of gas bubbles, produced due to microphytobenthos photosynthesis, from day to day. It is known, that the relationship of the radius of the bubble to the acoustic wave length is a key parameter responsible for the bubble impact on the acoustical wave (Leighton, 1997 [6]; Medwin, 2005 [7]; Ainslie and Leighton, 2011 [8]).

When comparing normalized mean energy of echo (Fig.2b) with normalized mean PSD (Fig.3) in different days, it can be shown that the normalized mean PSD during the six days (days: 1,5,6,9,10 and 11) was higher than mean energy of echo, not only at 280 kHz, but over the entire presented frequency range. It means that in these days the diel variation of the mean PSD was more significant, than the variation of the mean energy of echo. In the other days the variations were comparable (days: 2, 4) or were higher for the normalized mean PSD at some frequencies (days: 3,7,8).

4. Conclusions

Diel changes of the energy and power spectral density of acoustic echo, from Southern Baltic sandy sediments, due to photosynthesis of microphytobenthos were observed in laboratory conditions. During light (“day”) period the energy and power spectral density increased relative to the dark (“night”) period.

The “day/night” difference of mean power spectral density is higher (up to about 0.9dB for 280 kHz component) than for the mean energy of the return signal (up to 0.7 dB). There were days in which mean “day/night” difference was higher for PSD in entire 263 – 294 kHz frequency band, comparing to the mean energy of echo “day/night” difference.

The difference of the power spectral density between “day” and “night” period depends on the frequency, and this dependence varies from day to day. The “day/night” difference of the normalized mean PSD could change up to about 0.2dB between frequencies in the frequency range 263 – 294 kHz.

It was also shown that the diel variations of dissolved oxygen content in water have good correlation with diel variations of the energy of echo: the correlation coefficient is 0.8377 with $p=0.01$.

Including power spectral density analysis, in the study of the impact of the microphytobenthos photosynthesis on the backscattering properties of the sediments, enables you to obtain additional information for energy of echo analysis.

1) PSD can be more sensitive to the photosynthesis of microphytobenthos;
2) It gives the information in a wide frequency range.

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