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# On diel variability of marine sediment backscattering properties caused by microphytobenthos photosynthesis: Impact of environmental factors

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ABSTRACT

The study has been motivated by the development of the hydroacoustic techniques for mapping and classifying the benthic habitats and for the research of the microbenthos photosynthesis in the semi-enclosed Baltic Sea, particularly sensitive to human activity.

The investigation of the effect of the benthic microalgal photosynthesis on the echo signal from the Baltic sandy sediments is continuing. The study clarifies the impact of the abiotic and biotic factors on the diel variation of the backscattering caused by the benthic microalgal photosynthetic activity.

Five multiday laboratory experiments, different in hydrophysical or biological conditions, were conducted. During each measurement series, the "day" (illumination) and "night" (darkness) conditions (L:D cycle) were simulated and the diel variations of the echo energy of the backscattered signal were analyzed. The hydroacoustic data were acquired along with measuring biological and biooptical parameters and oxygen concentration. The study demonstrated the impact of microphytobenthos photosynthesis on the backscattering properties of the marine sediment which is sensitive to the illumination level, benthic microalgal biomass and macrozoobenthos bioturbation.

## 1. Introduction

Hydroacoustic techniques have been actively developed in order to classify and map benthic habitats in different marine areas (Kenny et al., 2003; Van Walree et al., 2005; ICES, 2007; Jackson and Richardson, 2007; Brown and Blondel, 2009; Blondel and Sichi, 2009; Brown et al., 2011; Lamarche et al., 2011; Snellen et al., 2011; Micallef et al., 2012; Snellen et al., 2013; Buscombe et al., 2014a,b; Eleftherakis et al., 2014; Tang et al., 2015). Being non-invasive and permitting the synoptic coverage of a large area, the techniques are highly important for a large number of applications, including e.g. marine biology and geology, exploitation and exploration of marine resources, marine area protection, planning and management.

The rapid evolution of hydroacoustic methods requires understanding of variability in backscattering from the seabed due to the presence of benthic biological entities and their activities as well as geological and physical processes (Jackson et al., 1996; Jumars et al., 1996; Richardson et al., 2001; Self et al., 2001; Hermand, 2003; Klusek et al., 2003; Kringel et al., 2003; Tęgowski et al., 2003; Faghani et al., 2004; Holliday et al., 2004; ICES, 2007; Jackson and Richardson, 2007; Borg et al., 2009; Greenstreet et al., 2010; Gorska and Kowalska, 2012; Wildman Jr and Huettel, 2012; Gorska et al., 2015; Gutperlet et al., 2017).

The paper addresses only one out of a large number of biological factors that could potentially change the seabed backscattering properties - photosynthesis of benthic microalgae. Shallow waters are often sufficiently illuminated so as to support populations of marine benthic plants and microalgae and their photosynthetic activity. Benthic photosynthesis is responsible for the oxygen supersaturation in pore waters and waters overlying the sediment surface, and thus, the formation of numerous bubbles (Gattuso et al., 2006). Wildman Jr and Huettel (2012) investigating the impact of benthic microalgal photosynthesis on the signal backscattered by the seafloor in St. Joseph Bay, Florida, observed approximately 50,000 bubbles per square meter. Gas bubbles, even in small numbers, could strongly modify scattering of sound (Leighton, 1997; Fonseca et al., 2002; Holliday et al., 2004; Medwin, 2005; Ainslie and Leighton, 2011). It means that photosynthesis of benthic plants and microalgae can affect seabed backscattering properties (Hermand, 2003; Holliday et al., 2004, 2012; Wildman Jr and Huettel, 2012; Gorska et al., 2015).

The impact of microphytobenthos photosynthesis on the interaction between high-frequency acoustic waves and sandy sediment was studied both in the laboratory (Holliday et al., 2004; Wildman Jr and Huettel, 2012; Gorska et al., 2015) and in situ (Hermand, 2003;

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Holliday et al., 2010, 2012; Wildman Jr and Huettel, 2012). Most of the investigations were conducted in warm southern marine waters of relatively high salinity (near Florida beach) (Holliday et al., 2004, 2010, 2012; Wildman Jr and Huettel, 2012). The number of bubbles, generated due to the photosynthesis (during the light period), depends on the oxygen solubility, which is sensitive to temperature and salinity (Benson and Krause, 1984). This motivated us (Gorska et al., 2015) to study how the microphytobenthos photosynthesis affects the acoustic backscattering from the sandy sediments of the southern Baltic Sea, an area of lower temperature and salinity. This laboratory study confirmed the importance of the phenomenon under Baltic hydrophysical conditions. However, as compared to warmer marine waters (Holliday et al., 2004, 2012; Wildman Jr and Huettel, 2012) weaker diel variations in the backscattering were demonstrated.

The development and adjustment of hydroacoustical characterization techniques to study and monitor the environment of the Baltic Sea, particularly sensitive to the human impact, is of utmost importance. Therefore, this study aims to further investigate the effect of microphytobenthos photosynthesis on the backscattering properties of the southern Baltic sandy sediments. This research was also encouraged by the recommendations of Holliday et al. (2010, 2012) to deepen the knowledge on the impact of the physical and biological factors on diel variations of the backscattered signal due to microphytobenthos photosynthesis.

The main objective of the research was to understand the effect of the biotic and abiotic factors on the diel variation of the backscattering properties due to the microphytobenthos photosynthetic activity which the previous research (Gorska et al., 2015) did not consider. The impact of the light conditions, microphytobenthos biomass and a benthic macrofauna activity was analyzed. Five multiday laboratory experiments differing in hydrophysical or biological conditions were conducted. The backscattering data were collected in the aquarium with sandy bottom under controlled constant temperature and salinity with changing light conditions (light/dark (L/D) photocycles). The oxygen content in the water column was recorded and chlorophyll *a* variable fluorescence as a measure of microphytobenthos photosynthetic activity was monitored. Additionally, chlorophyll *a* concentration as a microphytobenthos biomass estimate was calculated.

The research methodology is presented in details in the Materials and Methods section. The results of hydroacoustic, hydrophysical, biological and biooptical measurements are shown in the Results section. The impact of the biotic and abiotic factors on the diel variation of the backscattering properties due to the microphytobenthos photosynthesis is discussed in the Discussion section. The summary is in the Conclusions part.

## 2. Materials and methods

### 2.1. Experimental design

In order to understand the impact of the benthic microalgal photosynthesis on the backscattering properties of the Baltic sandy sediment and the importance of the abiotic (light intensity) and biotic factors (microphytobenthos biomass, macrozoobenthos activity) five multiday laboratory experiments were conducted from July to October period.

Hydroacoustical, biooptical, biological (i.e. chlorophyll *a* fluorescence) and oxygen concentration measurements were carried out in an aquarium (size: 50 × 50 × 50 cm) with sandy layer at the bottom under controlled constant light, temperature and salinity conditions (Fig. 1). A temperature logger and a sensor for photosynthetically active radiation (PAR) measurements can be seen respectively on the right back and front bottom corners of the tank. Three oxygen sensors, mounted at different depths, and a salinometer were placed in the left and right parts of the tank respectively. A fluorometer was located near the tank floor (left back bottom corner). The equipment was sufficiently away from the acoustically sampled area.

The tank was filled with artificial sea water of 6.7 salinity (which is the value characteristic for the waters of the Gulf of Gdańsk). Each of the experiments was conducted at

the stable temperature and photosynthetically active radiation (PAR) intensity. The parameter values are presented in Table 1, in which the experiment conditions are summarized.

During each measurement series, the "day" (illumination) and "night" (darkness) conditions (L:D cycle) were arranged. The photoperiod (L:D cycle, duration of light and dark periods in hours) was 10:14 in the first two experiments and 9:15 in the next three measurement series. The experiments were carried out in a darkened air-conditioned laboratory. As a source of photosynthetically active radiation a Philips 400 W sodium lamp located above the aquarium was used.

For all five measurement series, sandy sediment samples, containing the natural flora and fauna, were collected in the vicinity of Władysławowo (45° 50′ 2″ N, 18° 18′ 56″ W), which is situated in the western internal part of Puck Bay (the Gulf of Gdańsk, southern part of the Baltic Sea, Poland). The details of the sampling were discussed by Gorska et al. (2015). In the laboratory, the sand was mixed in order to obtain equally distributed algal biomass, placed in the aquarium forming a seven-cm thick sand bed and the sediment surface was carefully flattened.

Before Exp. 1, macrozoobenthos organisms, present in the sediment, were manually removed. However, during this measurement series, their presence became evident and slight irregularities of the sediment surface were noticed. The organisms became more active during the second measurement series (Exp. 2). The roughness of the surface of sandy layer and its volume heterogeneity were more pronounced. The impact of the macrozoobenthos activity on the diel variability of the sediment backscattering properties due to the photosynthesis, was studied in this experiment. In order to avoid its impact in the next measurement series (Exp. 3 - Exp. 5), after the second experiment the sand from the aquarium was wet sieved through a 2 mm sieve. It is also important to note that before each experiment microphytobenthos community was given time to adapt to particular laboratory conditions (including: photoperiod, illumination and temperature) for 3 days.

Exp. 1 was conducted at lower PAR intensity. In order to understand the illumination impact, its results were compared with the results of the third measurement series (Exp. 3) in which higher PAR intensity was applied (Table 1.) In the second measurement series (Exp. 2) the benthic macrofauna was characterized by high level of activity. In order to understand the macrozoobenthos effect the results of this experiment were compared with the results of the third measurement series (Exp. 3). The presence of macrozoobenthos was the only distinguishing factor for these two measurement series. Exp. 4 and Exp. 5 were different in microphytobenthos biomass. Their results were compared for better recognition of the impact.

### 2.2. Hydroacoustic measurements and analysis of the backscattered data

The acquisition of hydroacoustic data and its subsequent analysis were carried out using procedures as previously described by Gorska et al. (2015). It is worth reminding that the vertically down-looking transducer was mounted 29 cm above the sand surface (Fig. 1) and operated consecutively at the frequencies from 200 to 700 kHz with the step of 10 kHz. Over the entire frequency range, at each individual frequency, 64 pulses were emitted (one measurement series lasted about 11–12 min) and then averaged and archived for the subsequent analysis. Over the entire frequency range, at each frequency *f*, the pulse length was equal to *10/f* (ten periods). The transducer directivity pattern was narrow enough to create proper conditions excluding the impact of the multi reverberation effect typically disturbing the hydroacoustic measurements in a small tank/aquarium. The half of "-3 dB" - beam width of the echosounder main lobe decreases from