An acoustic study of zooplankton diel vertical migration in the Black Sea

Patryk Damian PEZACKI[1)], Natalia GORSKA[1)], Vladimir SOLOVIEV[2)]

[1)] University of Gdańsk, Institute of Oceanography
al. Marszałka Józefa Piłsudskiego 46 Gdynia, Poland
patryk.pezacki@phdstud.ug.edu.pl
natalia.gorska@ug.edu.pl

[2)] P.P. Shirshov Institute of Oceanology RAS
36, Nakhimovski prospect, Moscow, Russia, 117997
sol@ocean.ru

Reliable, rapid and non-invasive techniques are important for the monitoring of the ecosystem of the semi-enclosed Black Sea, especially sensitive to the human impact. Hydroacoustic techniques meet these requirements.

In the study, the ADCP data (volume backscattering strength and water velocities), collected in the north-east part of the Black Sea in October 2014, were used to understand some biotic and abiotic processes in the environment. The study was motivated by the fact that the used ADCP mounted on the autonomous (moving vertically) platform provided measurements with significantly higher spatial resolution that it was in the previous hydroacoustical studies of Black Sea ecosystem.

The main objective of the analysis was to determine the velocity of zooplankton diel vertical migration and understand the processes responsible for the variability of the volume backscattering strength.

Keywords: hydroacoustics, backscattering, ADCP, velocity of zooplankton

1. Introduction

The Black Sea hydrological specifics (significant anoxic water volume, strong vertical stratification, limited exchange with the ocean) and rapid industrial expansion along the Black Sea coast, require permanent observation of their impact on marine ecosystem using reliable, rapid and non-invasive techniques. Hydroacoustic techniques meet these requirements.

An Aqualog profiler was used for the first time in 2007 in the Black Sea [1,2] to study hydrodynamic processes. This carrier platform could autonomously profile a water column during several months at depths ranging from 20 m to 240 m. An ADCP Nortek Aquadopp current meter and a Seabird SBE 52MP CTD sensor, integrated with a Seabird SBE 43F oxygen sensor, were mounted at the platform. The water velocity data, combined with the temperature, salinity and oxygen data were analysed in order to study hydrodynamic processes. Accounting for the fact that the ADCP registered not only current velocity data, but also volume backscattering strength, we decided to take the opportunity and to use backscattering and the vertical velocity data for studying Black Sea zooplankton, one of the key element of its ecosystem [10]. We used the data collected using an Aqualog in October 2014 in the north-east part of the sea. Preliminary visualisation of the data demonstrated strong backscattering variability. It was curious – what processes were responsible for the variability?

What additionally motivated us to conduct this research? Diel vertical migration (DVM) of zooplankton was studied hydroacoustically mainly in southern part of the sea using the downlooking echosounders working at frequencies 120 and 200 kHz [5, 6, 7], and downlooking ADCP at the frequency 150 kHz [6, 7]. These devices, being of a longer working range, have poor spatial resolution at larger depth. In contrary, the ADCP, mounted at the Aqualog profiler worked at a higher acoustic frequency, 2 MHz and the beam patterns of its transducers are significantly narrower (transducer's beam width was 1.7^{o}) [13]. Moreover, two ADCP transducers projected their beams horizontally. At each depth the data was collected over the same range between about 0.35 m and 1.85 m from the ADCP. These features provided that the spatial resolution of the measurements of the volume backscattering strength and velocities was significantly higher than in the previous research and did not depend on the water depth.

One of the main objective of our study was the definition of zooplankton DVM velocities and features of zooplankton spatial distribution. The impact of the hydrological conditions (the vertical distributions of temperature, salinity, oxygen) on them was studied. The second objective was interpretation of the temporal and spatial variability of the volume backscattering strength and understanding what factors are responsible for it. The influence of: zooplankton diel vertical migration, presence of the biological layers, horizontal currents transporting sediments and vertical distributions of environmental parameters, was considered.

2. Material and Methods

Analyzed data was collected using an Aqualog profiler from 7 – 31 October 2014 at a location near the Gelendzhik Bay within the upper part of the continental slope (Fig. 1).

The Aqualog profiler moved vertically in the water column, the profiling cycles started at 03:00, 09:00, 15:00, 21:00 local time. During each cycle, firstly it moved from the depth of about 95 m up to the depth about 25 m. Next, it moved down to the depth about 215 m. At the end it returned to the depth of about 95 m, where it was parked till the next start. Velocity of the Aqualog varied over the range 20-25 cm/s.

The data on the volume backscattering strength, zooplankton DVM velocity and the horizontal water current velocity were acquired using an ADCP Nortek Aquadopp current meter, which was described above in the Introduction [13]. Environmental data on water temperature, salinity and dissolved oxygen content was collected using Probe CTD Seabird SBE 52MP and the oxygen sensor Seabird SBE 43F, also mounted on the Aqualog profiler.

Net sampling confirmed presence of migrating and non-migrating zooplankton at the study location [3].

The collected data were analyzed using software MATLAB (scripts developed by authors) and STATISTICA.

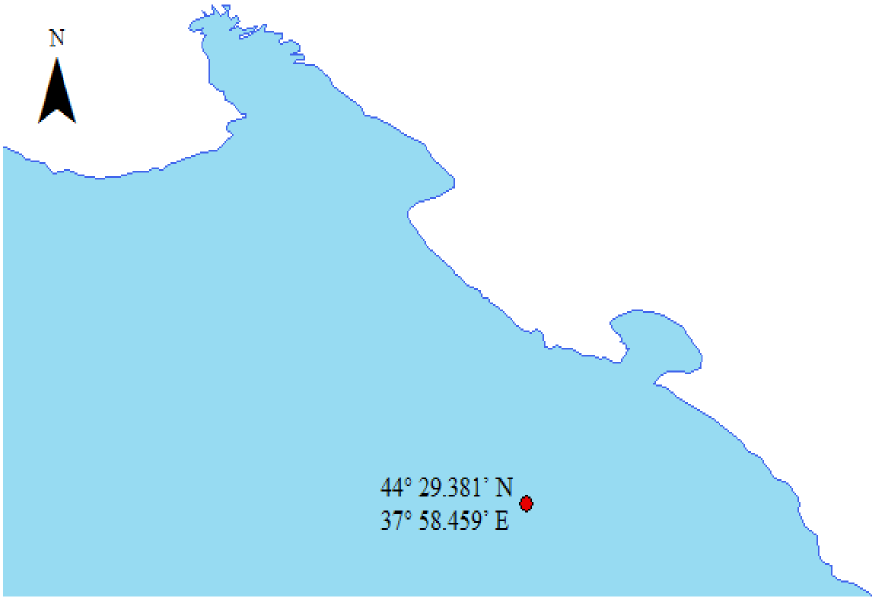

Fig.1. Study area [9].

The consideration of zooplankton DVM was justified by the previous studies in which the zooplankton DVM was observed in October in the Black Sea [2, 6]. The profiling cycles were made by Aqualog with the relatively small frequency one per six hours, so it was important to define criteria for choosing time and space for the analysis of DVM velocity.

To define the time and space for the migration velocity analysis; firstly, the profiling cycles, during which the migration was present, were identified. We accounted for the fact that, according to [6], twilight and dawn migrations began respectively three and two hours before sunset and sunrise and the migration was completed in about 2.5-4 h. We took into account the time of sunset (19:00 and 18:21 at local time in the first and last observation days respectively), and sunrise (07:31 and 08:02 at local time in the first and last days respectively) in our study area. Then we defined the possible time intervals of the migration and compared them with the intervals in which the Aqualog profiled the water column. The comparison demonstrated that we had chance to observe the twilight migrations only during the Aqualog movement started at 15.00. It was also shown that the observation of dawn migrations was not possible.

At the next step, in order to define the velocities of the upward migration, only the data, collected during the Aqualog profiling cycle at 15.00, was used. The analysis was done for the entire 25 days of observations. This collected vertical velocity data was analyzed in sequential short time representative intervals over the entire depth profiled by the Aqualog during the cycle. For the each interval, a histogram of the measured vertical velocities was developed. Analyzing the histograms, the time intervals with significant dominance of upward velocities were qualified as corresponding to the twilight vertical migration. The mean DVM velocities were defined for the each selected interval.

It was also taken into account that velocities recorded by the ADCP ($\vec{V}_{za}$) were defined relative to a moving coordinate system associated with the Aqualog, while we were interested in the vertical velocities $\vec{V}_z$ relative to a fixed coordinate system. These velocities were calculated from the following relationship:

$$\vec{V}_z = \vec{V}_a + \vec{V}_{za} \quad (1)$$

where $\vec{V}_a$ - Aqualog profiler velocity (determined based on the temporal changes in pressure measured by a CTD sensor mounted on the vertically moving carrier).

3. Results and discussion

Volume backscattering strength variability

The results of the 25-days measurements were demonstrated in the echogram (Fig. 2). The colour scale bar presents volume backscattering strength in dB. Dark red colour corresponds to the maximum values. Time of the measurements and the pressure were presented in the horizontal and vertical axes respectively.

The reasons for the volume backscattering strength variations, visible in the echogram (Fig. 2) are discussed below including: (i) zooplankton diel vertical migration, (ii) backscattering by sediment particles, suspended in water and transported by the horizontal current directed from the near-shore zone, (iii) presence of the biological layers, (iv) impact of the temporal and spatial variability of temperature, salinity and oxygen profiles.

Firstly, the ten fragments qualified as corresponding to the DVM were marked by red frames in the echogram. The backscattering pattern in these fragments could be interpreted as result of backscattering by upward migrating zooplankton. It is visible that because of

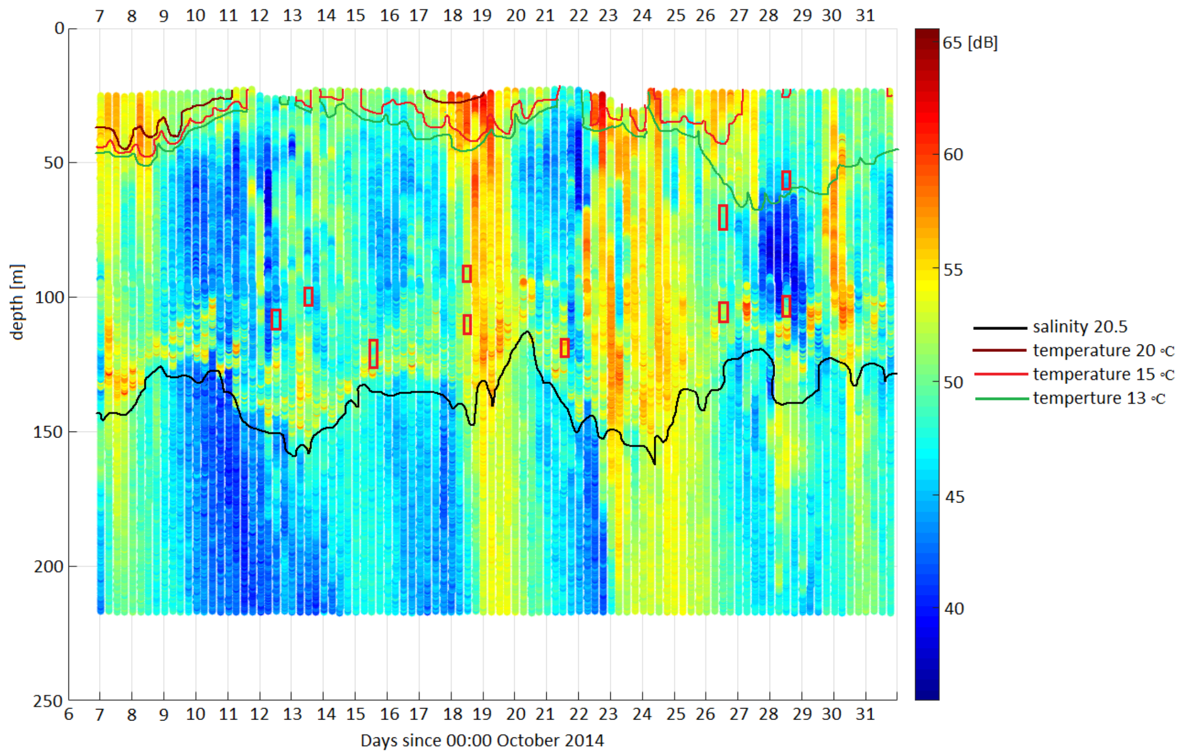

Fig. 2. Echogram (backscattering data collected using ADCP in October 2014).

the specifics of the experiment (the low frequency of profiling cycles - one time per six hours) the impact of the migration on the backscattering variability could not be demonstrated.

The second feature of the backscattering pattern in Fig. 2 is the higher volume backscattering strength (marked by yellow and red colors) in the upper layer (the top part of the echogram). The detailed analysis conducted showed that it is observed not only during the nights, when the migrating zooplankton was closer the surface, but also during the day. It can be speculated that a possible reason is connected with the thermocline located in this layer.

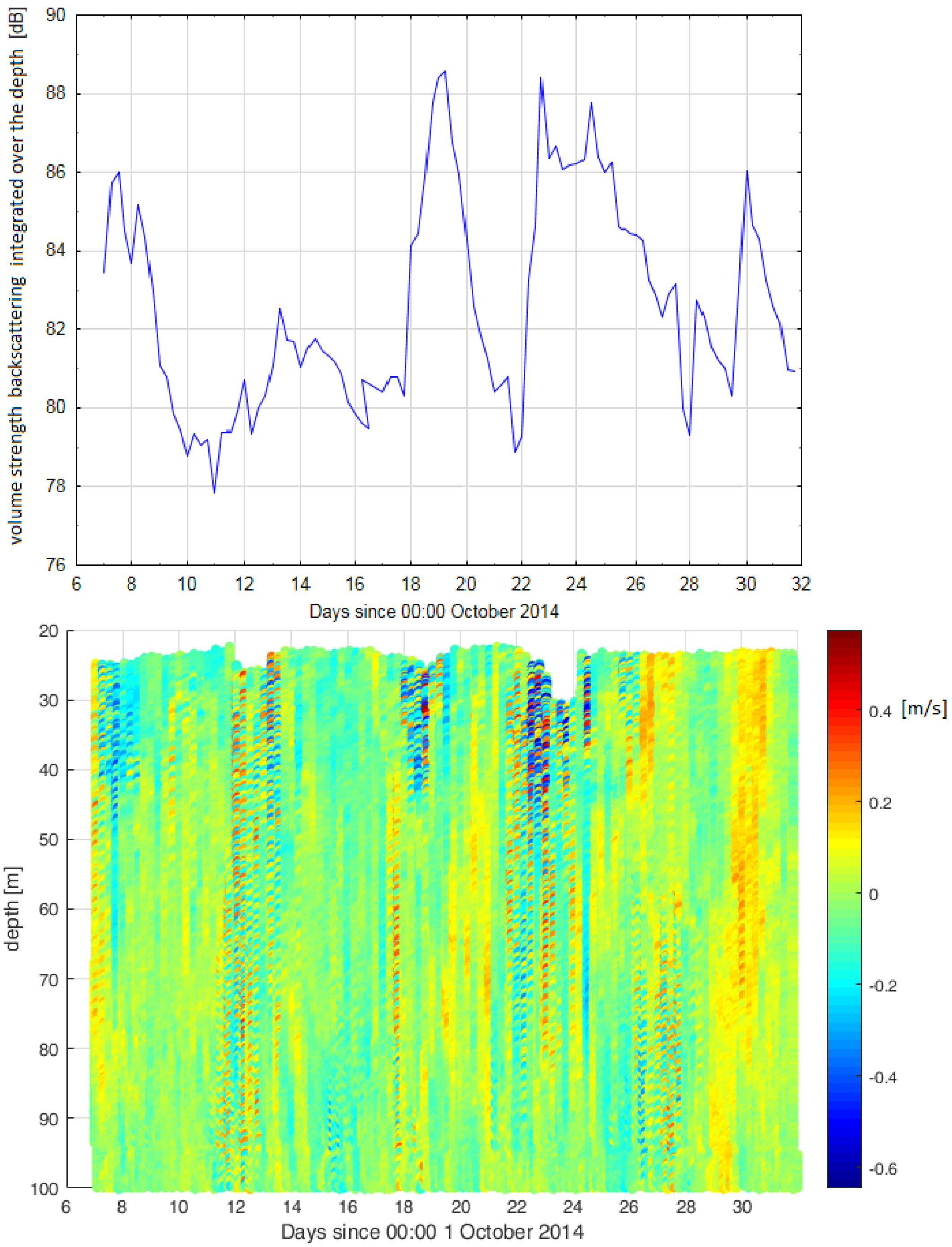

Fig. 3. Impact of the horizontal currents on the backscattering. Upper plot – time variability of volume backscattering strength integrated over the entire depth interval. Bottom plot – variability of the north-east component of horizontal current.

The isotherms are presented in the echogram (Fig. 2). The temperature gradient resulted in the density gradient, which was accompanied by the accumulation of the organic and non-organic material within the gradient area. The small scatterers (e.g. suspended sediment particles, phytoplankton) could be present within the area. Accounting for the fact that the 2-MHz ADCP signal is sensitive to small scattering targets (till 0.05–2 mm), the accumulation could be one of the reason for the higher backscattering during the day. It is also interesting to note that on October 12 and 23, when the thermocline was not visible (likelihood that the isotherms moved upward), the backscattering pattern also was weak (blue color).

The echogram (Fig. 2) demonstrates also volume backscattering strength increase in the days: 7 – 8, 18 – 19, 23 – 25 and 30 October, 2014, in the upper sea layer, or in the whole water column. It also was confirmed by the variability of the volume backscattering strength integrated over the entire depth interval (upper plot in Fig. 3). Comparing these results with the results of the measurements of the north-east component of horizontal current, it was concluded that the variation in the backscattering energy correlates with the variation of the component direction. Backscattering was strong in the days in which the north-east component of horizontal current was directed from the near-shore zone (blue color). Such currents could carry suspended sediment particles, presence of which resulted in the backscattering growth.

On the echogram (Fig. 2) the non-migrating zooplankton layer [3] is observed between 100 m and 150 m depth. To understand the oscillation of the depth of the layer location, the temporal variations of vertical distribution of salinity and dissolved oxygen content were visualised. The salinity distribution is demonstrated in Figure 4. The colour scale bar presents salinity values. Dark red colours refer to the largest salinity. Time of measurements (days of October) and the depth were presented in the horizontal and vertical axes respectively.

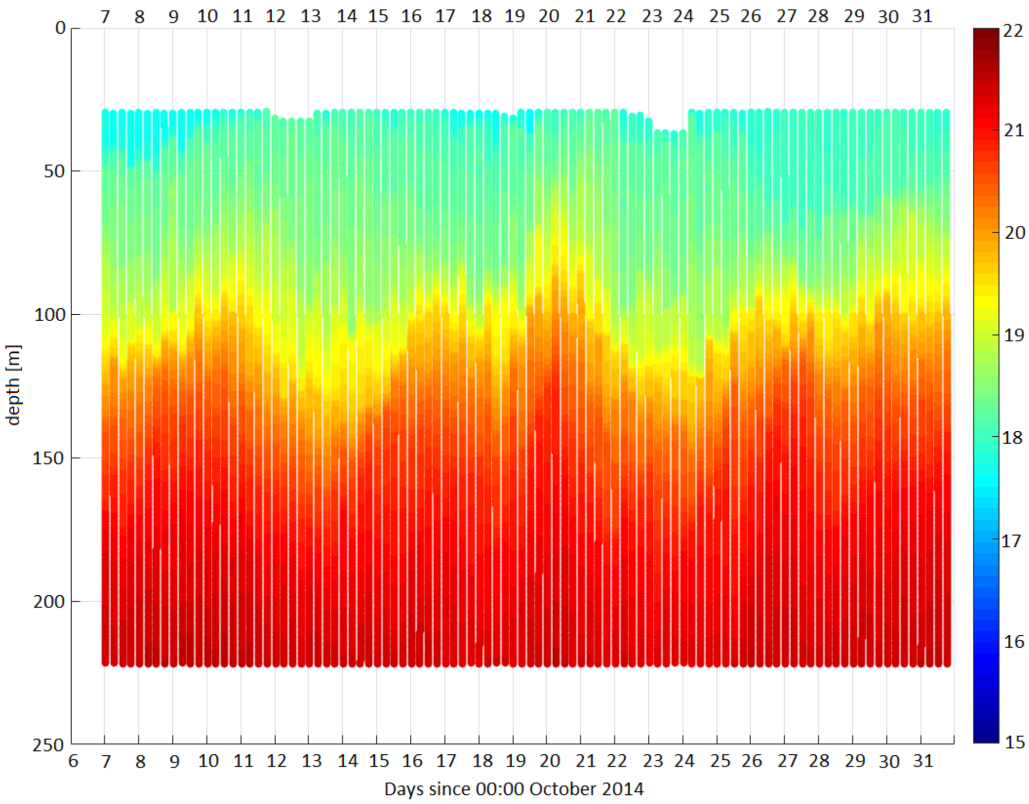

Fig. 4 Vertical salinity distribution (data collected by CTD probe in October 2014).

The temporal-spatial dependence of the dissolved oxygen content is presented in Figure 5. The colour scale bar demonstrates the values of the dissolved oxygen content in mg/l. Dark red colour corresponds to the highest content. The time of measurement (days of October) and the depth are presented in the horizontal and vertical axes respectively.

Comparison of Figs. 4 and 5 demonstrates the similar variation in the location depth of the isohalines and isooxylines. As the halocline water did not mix vertically, it resulted in the thin oxygen layer (see also [8,12]).

Comparison of:

- Figs. 4 and 5 with the echogram (Fig. 2),
- the positions of the isohaline (20.5 salinity), presented in the echogram (Fig. 2), and non-migrating layer,

demonstrates that this isohaline “indicated” the layer position. Within the layer the dissolved oxygen content is about 0.85 mg/l. The calculations demonstrated that non-migrating zooplankton was located at water layer with potential density anomaly σ_{θ}=15.9 [2, 3] i.e., above the hydrogen sulfide zone in which zooplankton surviving is not possible.

It also means that below the layer only suspended sediment particles, which were brought by the north-east flow from the near-shore zone, could be responsible for the backscattering pattern.

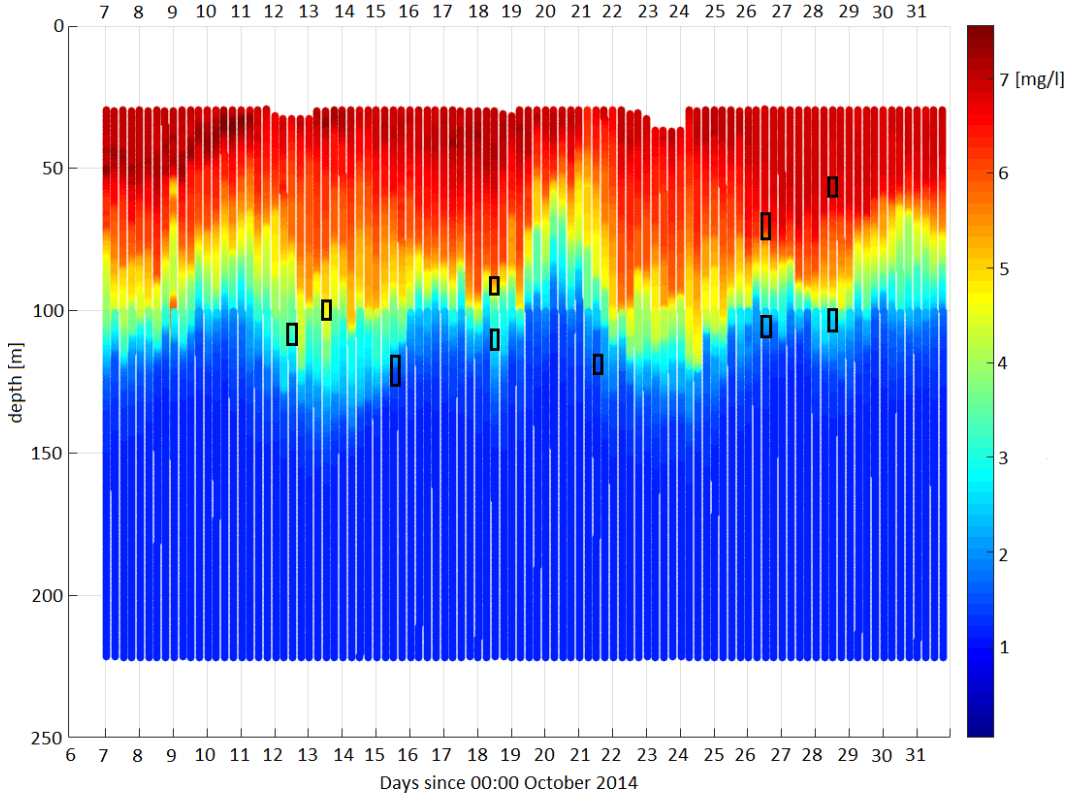

Fig.5. Vertical dissolved oxygen content distribution (data collected by oxygen sensor in October 2014).

The diel vertical migration velocities.

The results of the measurements of zooplankton upward DVM velocities (within the marked windows in Fig. 2) are presented in Fig. 6 (vertical axis). The variability range of the mean velocities between 2.3 cm/s and 3.9 cm/s were defined.

The migrators velocities could be affected by a series of factors e.g. dissolved oxygen content, temperature, illumination, presence of phytoplankton, avoiding predation. However, being limited by the oxygen, as the only factor which changed over the depth intervals, in which the migrators velocities were measured (see the windows presented in Fig. 5), we consider the only correlation between the migrator velocity and the dissolved oxygen content.

The study of the correlation between zooplankton velocities and the dissolved oxygen content was also encouraged by the results of the laboratory research of the oxygen impact on the locomotion activity of zooplankton [10] and by the results obtained by Mutlu in southern Black Sea [5]. It was demonstrated that the velocity increased when zooplankton moved within the area with higher dissolved oxygen content.

The relationship between the mean velocity and the dissolved oxygen content is demonstrated in Fig. 6. The regression curve and the 95% confidence interval curves are indicated by red solid and dashed lines respectively. The results, presented in the plot, confirmed that the higher dissolved oxygen content, the higher the velocity of the diel vertical migration. However, the correlation coefficient was not large, and is equal to 0.4066. It is interesting to note that the lower velocities were not observed for the dissolved oxygen content higher than 3.0 mg/l.

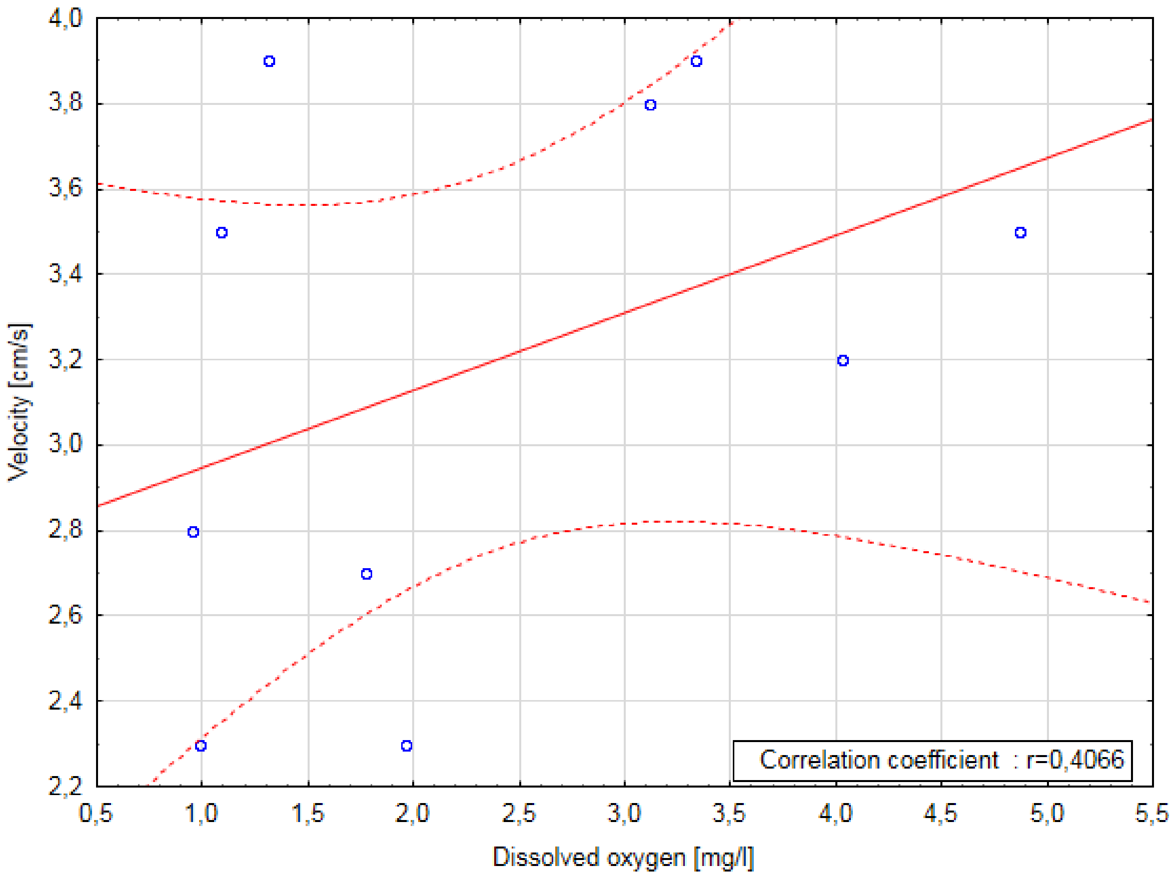

Fig. 5. Relationship between the velocity of upward diel vertical migration and the dissolved oxygen content. Red line: regression curve. Red dashed lines: boundaries of the 95% confidence interval.

4. Conclusions

Using a mobile autonomous Aqualog profiler equipped with ADCP, backscattering strength and water current velocities were measured with the same high resolution in the whole water column.

The mean velocities of upward DVM varied within the range between 2.3 cm/s and 3.9 cm/s. Contrary to the previous studies, the slight correlation between the velocity and dissolved oxygen content was demonstrated, that could be connected with the small amount of the measured mean velocity data.

The reasons for the volume backscattering strength variability at different depths have been discussed and it was shown that:

1. In anoxic layer, the backscattering could be caused only by the suspended sediment particles and its variability is correlated with the changes of the direction of the north-east component of the horizontal current. Backscattering was stronger in the days in which the north-east component of horizontal current was directed from the near-shore zone.
2. The non-migrating zooplankton layer was observed between 100 m and 150 m depth. The isohaline (20.5 salinity) and the level of the dissolved oxygen content 0.85 mg/l indicated the layer position.
3. Above the layer, the presence of the suspended sediment particles transported by the north-east component of horizontal current directed from the near-shore zone is also responsible for the backscattering pattern variability
4. The accumulation of the scatterers within the thermocline could be responsible for the backscattering pattern variability in this near-surface layer.

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