The oxygen concentration in near-bottom water shapes the structure of macrozoobenthos in the bradymictic Lake Urowiec

Janusz Żbikowski* and Katarzyna Łapkiewicz
Department of Ecology and Biogeography, Faculty of Biological and Veterinary Sciences, Nicolaus Copernicus University, Toruń, Poland
Lwowska 1, 87-100 Toruń
* Corresponding author e-mail: jzbikow@umk.pl

Received: 12 February 2025 / Accepted: 19 March 2025

Abstract This research aimed to study the horizontal changes of macrozoobenthos structure and several abiotic parameters of water and bottom sediments along with increasing depth in the bradymictic Lake Urowiec. The samples were taken on six dates from April to October 2001, almost at monthly intervals, at the following depths: 2.5m, 5m, 7m, 9m, 10m, 11m, 15m, 20m and 30m. The high number of taxa and diversity (Shannon index) of bottom fauna were found only at depths of 2.5m (34 and 1.98, respectively) and 5m (27 and 2.18, respectively). From a depth of 9m, there were almost exclusively *Chaoborus* sp. larvae. The zoobenthos density decreased with depth from 2247 ind. m^{-2} at a depth of 2.5m to 200 ind. m^{-2} at 30m depth. The biomass of bottom fauna ranged from 6.51 g m^{-2} at a 2.5m depth to 0.43 g m^{-2} at a depth of 30m. A significant decrease in the diversity and, to a lesser extent, in the abundance of bottom fauna was most likely the consequence of the rapid decline in the water near bottom oxygenation with depth. Starting from a depth of 7 meters and deeper, the average oxygen concentration in the over-bottom water was very low - below 4 mg dm^{-3}.

Keywords: bottom fauna, bottom sediments, water dynamics, oxygen concentration

1. Introduction

The water dynamics in lakes have a substantial impact on their functioning. It significantly influences the abiotic parameters of the aquatic environment, especially aerobic conditions (Raczyńska and Kubiak 2003), which in turn affects the structure of its biocenosis. The intensity and range of water mixing in a water body depend primarily on its morphometric features, such as depth and area, and a lake's exposure to wind (Kajak 1998, Kubiak and Machula 2013, Bek et al. 2018).

In the temperate climate, the majority of deeper lakes are dimictic ones. In turn, some of these lakes are bradymictic, where the water mixing is hampered, prolonging thermal stratification. Consequently, in bradymictic lakes, especially eutrophic, with increasing depth, there is usually a sharp decrease in oxygen concentration in the water near the bottom.

Benthic macroinvertebrates play a vital role in the functioning of aquatic ecosystems (Graneli 1979; Svensson and Leonardson 1996; Dos Santos 2016, Nieto et al. 2017, Severiano et al. 2023, Ozkan 2024). Moreover, they can reflect the ecological conditions of the aquatic ecosystems they inhabit (Callisto et al. 2005; Behrend et al. 2012). The distribution of this group is controlled by a variety of environmental factors such as depth, water quality (Hellawell 1986), substrate type (Reynoldson et al. 1995), sediment grain size (Tolkamp 1980), organic matter content in sediments (Rodriguez et al. 2001; Ciutat et al. 2006) or contaminants (Clements and Kiffney 1993; Phipps et al. 1995), so it is difficult to specify which one plays the most crucial role. However, according to many authors, the key factors are oxygen conditions near the bottom and the quality and availability of food (Cooper and Knight 1985; Rasmussen 1988; Real and Prat 1991; Prat et al. 1992). Due to the place of living and poor mobility, the zoobenthos is more dependent on the oxygenation in over bottom water than other ecological formations.

This research aimed to study the horizontal changes of the macrozoobenthos structure along with increasing depth in the bradymictic Lake Urowiec. We hypothesize that the diverse and abundant benthic fauna will be present only in the shore zone of the lake under study.

2. Study area

Lake Urowiec is located in the Iława Lake District, the western part of the Masurian Lake District. It is a mid-forest water body surrounded by mixed forest, with a small inflow from the south side of Lake Plajtek and an outflow to the east. The basic morphometric data of the studied lake are as follows: surface area 26.1 ha, total volume 2 114 thous. m^3, maximum length 880m, maximum width 450m, mean depth 8.1m (maximum 31.8m).

Urowiec is a dimictic lake with strongly marked bradymixia features, characterised by clear, prolonged thermal stratification. This lake's very low water dynamics is a consequence of its great depth and small area, as well as the high banks covered with forest.

The shoreline is poorly developed. The lake's shores, except the northern part, are overgrown with emergent vegetation with the dominance of common reed (*Phragmites australis*). Despite the high water transparency, submerged vegetation is relatively poorly developed. In some places the lake bottom is covered with a Canadian pondweed (*Elodea canadensis*) and Hornwort (*Ceratophyllum demersum*).

In the epilimnion of Lake Urowiec, high concentrations of total phosphorus (0.28 mg · dm^{-3}) and total nitrogen (1.96 mg · dm^{-3}) were found (Kentzer 2001). The high trophy of this lake confirms also the dominance of *Rotifera* in the zooplankton (Bittel et al. 1965), while diatoms and green algae dominate the phytoplankton.

3. Materials and methods

The samples were taken on six dates from April to October 2001, almost at monthly intervals, at the following depths: 2.5m, 5m, 7m, 9m, 10m, 11m, 15m, 20m and 30m (Fig.1). The sampling site at a depth of 2.5m was located in the sandy-bottom littoral zone. The site at 5m depth was situated in the sandy-muddy bottom sublittoral zone. The other sites were located in the upper (7m, 9m and 10m), in the middle (11m and 15m) and the lower (20m and 30m) profundal zone, with muddy sediments.

We used the Ekman-Birge grab (catching area: 225cm^2, 2-4 replicate samples) to collect the bottom fauna. The samples were rinsed using a 0.5mm sieve and preserved in 4% formaldehyde. To assess the fresh biomass of the macrozoobenthos, preserved animals were dried on blotting paper and weighed to the nearest 0.0001g with an analytical scale PRL T A13 (Poland). Among the benthic fauna, a group referred to as "Littoral fauna" was distinguished, which included larvae of Ephemeroptera, Trichoptera, Odonata, Ceratopogonidae, *Sialis* sp., as well as Mollusca, Hirudinea and *Asellus aquaticus*.

Along with collecting macrozoobenthos samples, several abiotic parameters of water and bottom sediments were determined. Water transparency was measured with a Secchi disc. Temperature and oxygen concentration were measured with a Multi-Line P4 (WTW GMBH, Weilheim Germany) Universal Pocket-Sized Meter. To assess the water dynamic, these parameters were determined at the surface and near-bottom water layer (2-3cm above the sediments).

Selected parameters of the bottom sediments were measured in their surface layer (0-5cm) taken using a Kajak core sampler. We determined the water content in the bottom sediments (by their oven-drying to a constant mass at 104°C) and the organic matter content in the sediments (by igniting dried sediments at 550°C for 2 hours).

Statistical analysis

To analyse the effect of the water depth on the particular parameters (oxygen concentration, water and organic matter content in the bottom sediments, density and biomass of macrozoobenthos), we used Analysis of Variance (ANOVA). We run separate models for each parameter, with the water depth as a categorical dependent variable. The significant effect of the water depth on the parameter of interest was followed by Tukey-HSD post-hoc comparisons to investigate differences between particular groups. All analyses were performed using PAST v4.03 software (Hammer et al. 2001).

4. Results

4.1. Macrozoobenthos

Over the course of the study, 43 zoobenthic taxa were found. The relatively high number of taxa at depths of 2.5m (34) and 5m (27) were only reported (Fig.2.). At depths of more than 9m, only 1 or 2 the macrozoobenthos taxa were noted. The high diversity of bottom fauna, based on the Shannon index, was found only at depths of 2.5m (1.98) and 5m (2.18) (Fig.2.). At depths of more than 7m, these index values were very low (below 0.5).

The total zoobenthos density decreased with increasing depth from 2247 ind. m^{-2} at a depth of 2.5 to 200 ind. m^{-2} at a depth of 30m (Fig.3.). At the former, the "Littoral fauna" (45% of the zoobenthos density at this site) the Chironomidae larvae (39%) codominated. The Oligochaeta (48%) and the Chironomidae larvae (38%) were dominant at a depth of 5m, while at the deeper sites, the *Chaoborus* sp. larvae predominated (67-100%).

Among chironomids in the shallower parts of the lake, *Tanypus sp., Tanytarsus sp., and Cladotanytarsus sp*. larvae dominated, while at the larger depths, there were only *Chironomus* sp. and *Procladius* sp. larvae (Fig.4.). The Oligochaeta occurred only to a depth of 10m. At a depth of 2.5m, *Stylaria lacustris* dominated. In contrast, at the larger depths, *Potamothrix hammoniensis* was more numerous (Fig.5.). The "Littoral fauna" was practically present only at a depth of 2.5 m. The most numerous were Ephemeroptera larvae (38% of the "Littoral fauna" density at this site) and Mollusca (22%), among which small bivalves of the genus *Pisidium* predominated (Fig.6.).

The biomass of bottom fauna ranged from 6.51 g $\cdot$ m^{-2} at 2.5m depth to 0.43 g $\cdot$ m^{-2} at a depth of 30m (Fig.7.). The zoobenthos dominance structure based on this parameter was similar to that determined on the density except for a depth of 2.5m. At this depth, the *Sialis* sp. larvae predominated (31% of the total zoobenthos biomass).

In summary, the high number of taxa and diversity of the bottom fauna at depths of 2.5m and 5m were only found. Relatively rich in quality was still the macrozoobenthos at a depth of 7m. At the larger depths, there were almost exclusively *Chaoborus* sp larvae. Also, the abundance of zoobenthos was higher in the shallower zones of the lake under study.

4.2 Abiotic parameters

Water transparency based on the Secchi depth averaged 2.8m (Tab. 1). The temperature in the very surface water layer was comparable at all sampling sites. However, from a depth of 2.5m to a depth of 7m, there was a rapid decrease in the temperature (from 15.4°C to 8.9°C, respectively) in the over-bottom water. At the larger depths, the changes in these parameters were smaller. The temperature difference between the surface and over-bottom water layers increased with depth, particularly up to 7m (Fig.8.).

Oxygenation of surface water was very similar across all sampling sites (averaging approx. 11mg · dm^{-3}), showing no significant seasonal variation. In contrast, the oxygen concentration in the bottom water layer decreased markedly with increasing depth, from 7.8mg dm^{-3} at a depth of 2.5m to 1.1mg dm^{-3} at a depth of 10m, and subsequently remained at a very low level (about 1mg dm^{-3}) at greater depths (Fig.9).

The water content (WC) and the organic matter content (OC) in the bottom sediments were by far the lowest at a depth of 2.5m (23.7%, 0.8%, respectively) (Fig.10.). Significantly higher values of these parameters were found at depths of 5m (52.8%; 4.2%, respectively) and 7m (86.3%; 19.3%, respectively), while the highest and similar at the greater depths (WC from 94.5% to 97.0% and OC from 40.2% to 62.3%).

5. Discussion

The results of this study fully confirmed our hypothesis that in eutrophic, bradymictic lakes, the diversity and abundance of macrozoobenthos are limited to a relatively shallow shore zone. In Lake Urowiec, it was a depth of less than 9m because, at this depth, the bottom fauna was very poor in quality. A significant decrease in the diversity and, to a lesser extent, in the abundance of bottom fauna was most likely the consequence of the rapid decline in the water near bottom oxygenation with depth. At a depth of 7m, the average oxygen concentration in the over-bottom water was only about 4 mg · dm^{-3}, and according to Caraco and Cole (2002), water oxygen concentration of about 5mg · dm^{-3} may be a limiting factor for bottom fauna development. As previously mentioned, the bottom fauna structure is shaped by many environmental variables, but according to many authors, oxygen and food conditions play the most critical roles. However, these studies suggest that oxygen conditions play a decisive role because food availability, evaluated based on organic matter content in the bottom sediments, increased with depth.

From a depth of 9m, the presence of taxa with high resistance to unfavourable environmental conditions was almost exclusively found. These include *Chaoborus* sp. larvae, the dominant in the studied lake from a depth of 9m and the sole representative of the zoobenthos from a depth of 15m, *Chironomus* sp. and *Procladius* sp. larvae (Chironomidae), as well as *Potamothrix hammoniensis* (Oligochaeta). They are highly tolerant organisms, adaptable to poor environmental conditions, and unusually resistant to low water oxygen concentrations (Armitage et al. 1995; Petridis and Sinis 1997; Risnoveanu and Vadineanu 2002; Nyman et al. 2005). The above taxa generally dominate in a deep profundal of eutrophic lakes. Still, it should be emphasised that in Lake Urowiec, their clear dominance from a depth of 9m suggests terrible habitat conditions in the upper profundal.

At depths of 2.5 and 5m, the number of taxa and diversity of benthic fauna were relatively high. It should be noted, however, that at the latter sampling site, there were almost no organisms included in the "Littoral fauna". The main cause was not oxygen deficits, which suggest both relatively good water oxygenation over the bottom at this depth (6mg dm^{-3}), as well as numerous presence of *Tanytarsus* sp. larvae (Chironomidae), considered to be very sensitive to low oxygen concentrations. Therefore, the occurrence of the aforementioned taxa only at a depth of 2.5m could be associated with macrophytes, whose presence only in the area of this site was found. Submerged plants significantly contribute to the increased bottom fauna diversity through increased habitat heterogeneity and improved nutrient conditions (Hargeby et al. 1994; Scheffer 1998; Declerck et al. 2005; Żbikowski et al. 2010).

In contrast to the other distinguished groups of benthic fauna, the largest number of taxa and abundance of Oligochaeta at a depth of 5m were found. The limiting factor in aquatic worms development at shallower depths was likely food shortage (only 0.9% organic matter content in the sediments), while at greater depths it was to low oxygen concentration.

As stated earlier, benthic macroinvertebrates are an essential part of biocenosis of aquatic ecosystems. However, their role is mainly dependent on the taxonomic diversity and abundance. The results of this study suggest that in lakes with low water dynamics, such as Lake Urowiec, the role of benthic fauna in their functioning is lower than in other lakes due to the significant qualitative and quantitative depletion of macrozoobenthos with depth.

Acknowledgements

The Authors thank Doctor Mateusz Augustyniak for his assistance with statistical analyses and two anonymous Reviewers for valuable comments and remarks, which enabled the improvement of the previous version of the manuscript.

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Fig. 1. Location of sampling sites in Lake Urowiec

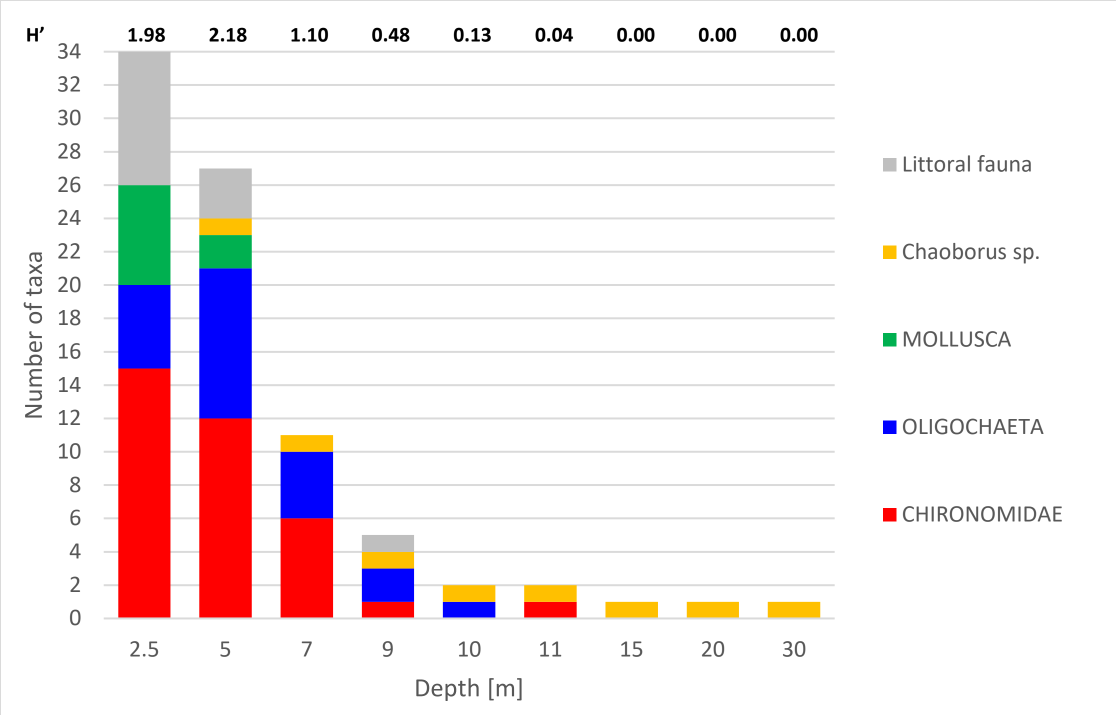

Fig.2. Number of taxa and diversity (H') of benthic fauna

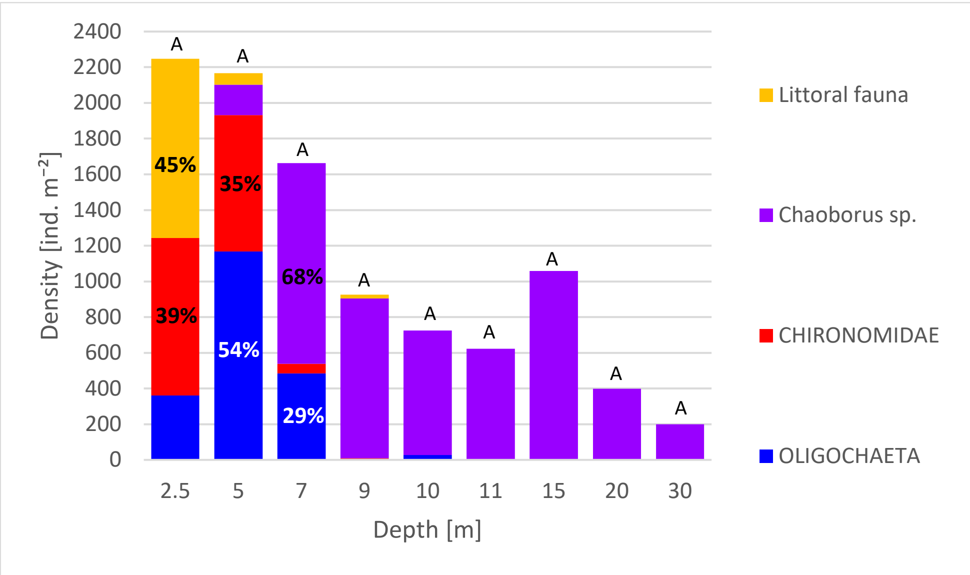

Fig.3. Density (ind. m^{-2}) and percentage share of dominant benthic fauna groups. The same letters indicate no significant differences between the corresponding values.

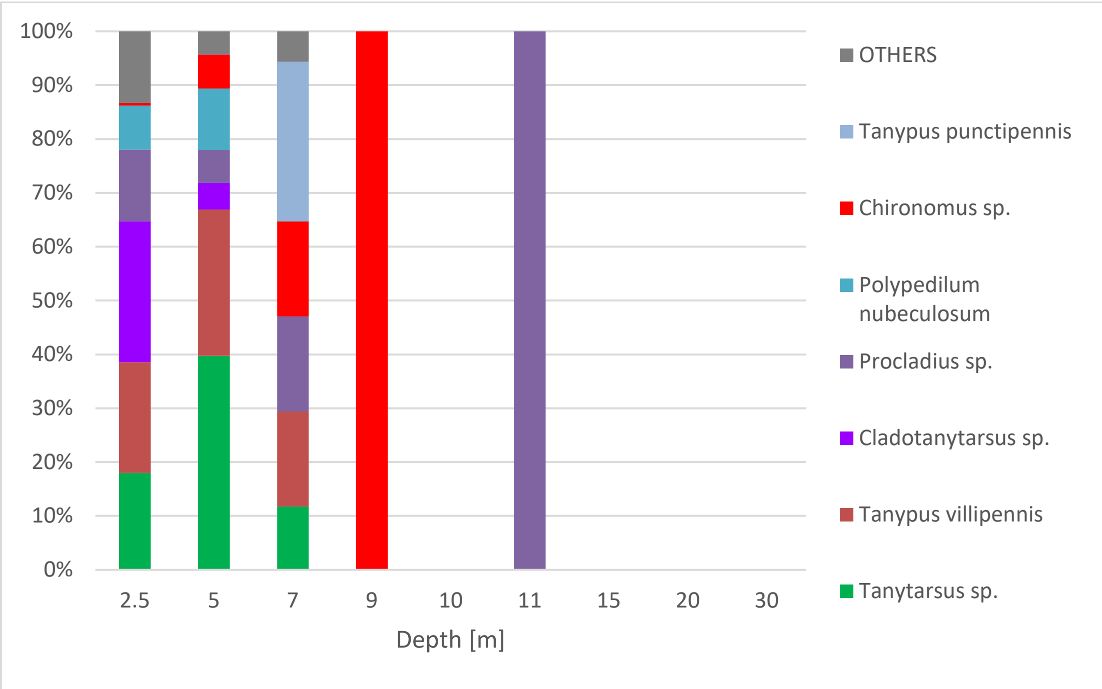

Fig.4. Dominance structure (based on density) of Chironomidae larvae

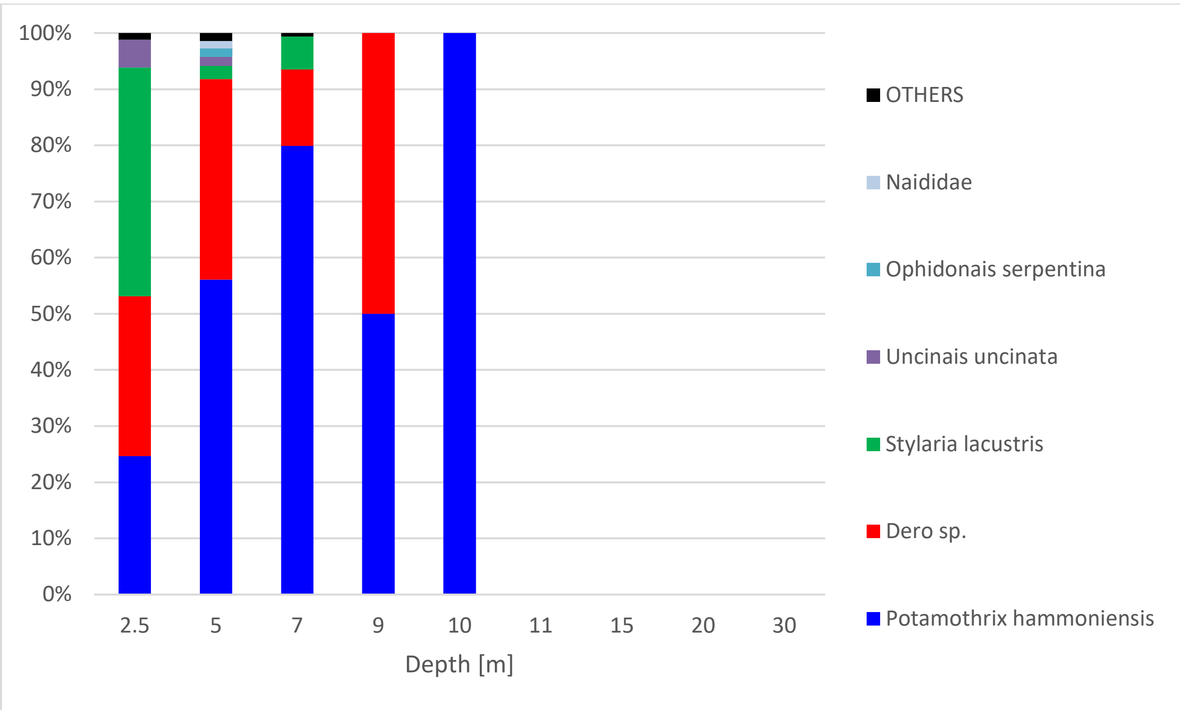

Fig.5. Dominance structure (based on density) of Oligochaeta

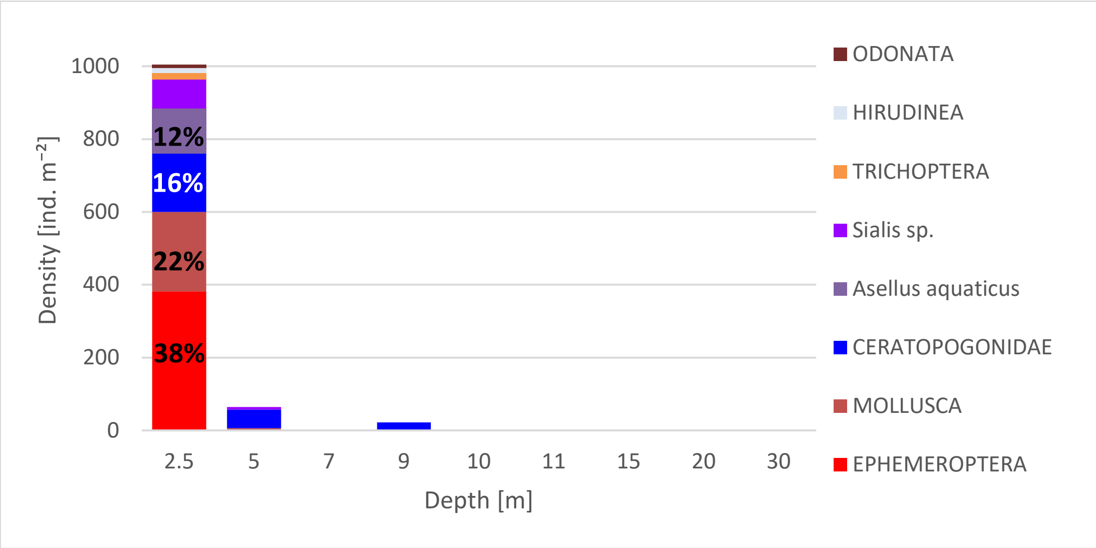

Fig.6. Density (ind. m^{-2}) and percentage share of dominant groups of "Littoral fauna"

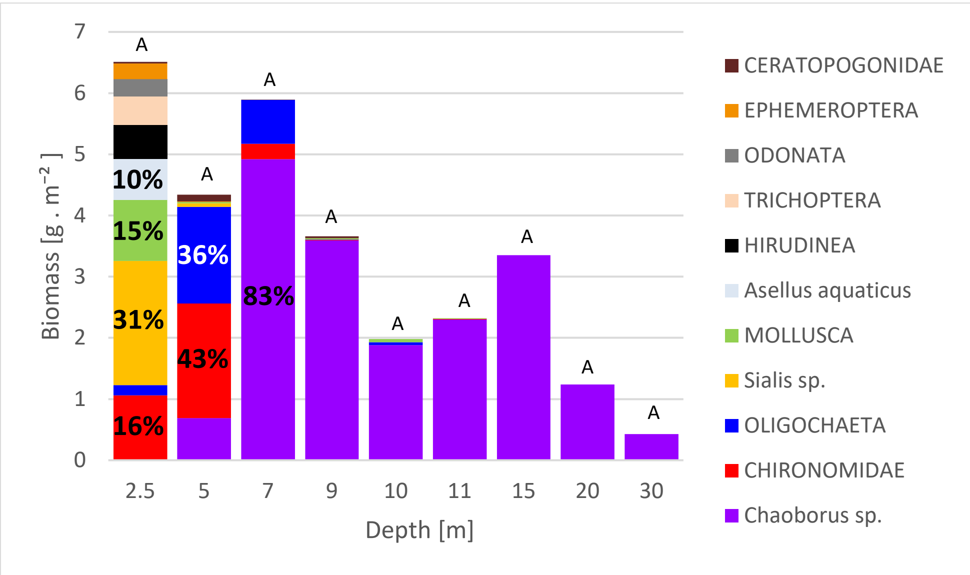

Fig.7. Biomass ($g \cdot m^{-2}$) and percentage share of dominant groups of benthic fauna. The same letters indicate no significant differences between the corresponding values.

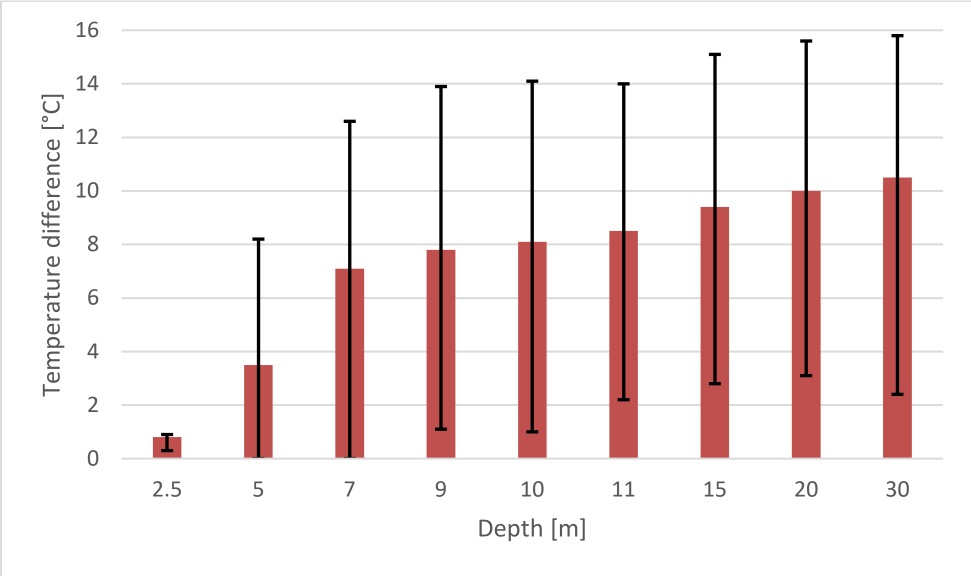

Fig.8. Difference in water temperature between the surface and near-bottom layer – mean values and range of variability.

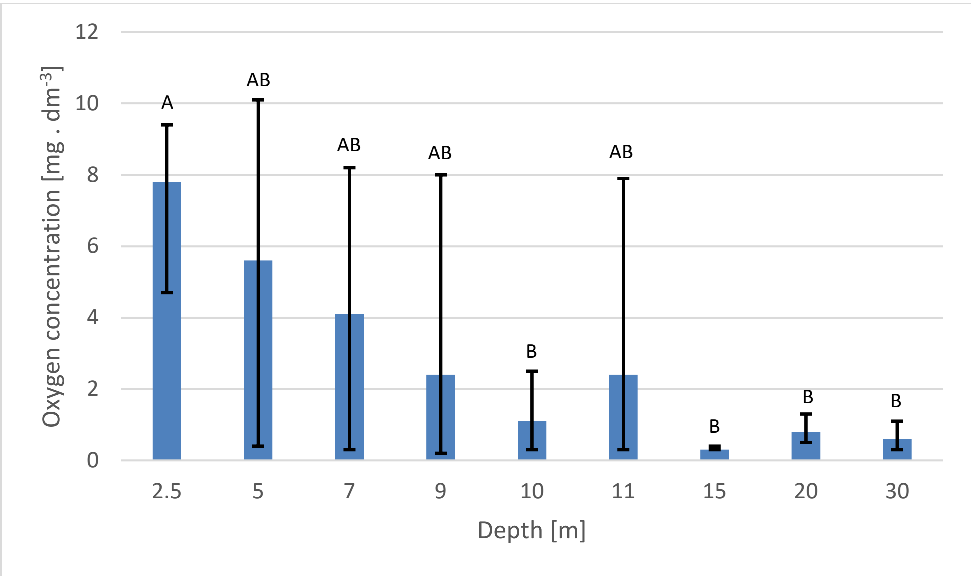

Fig.9. Oxygen concentration (mg · dm^{-3}) in near-bottom water – mean values and range of variability. The same letters indicate no significant differences between the corresponding values.

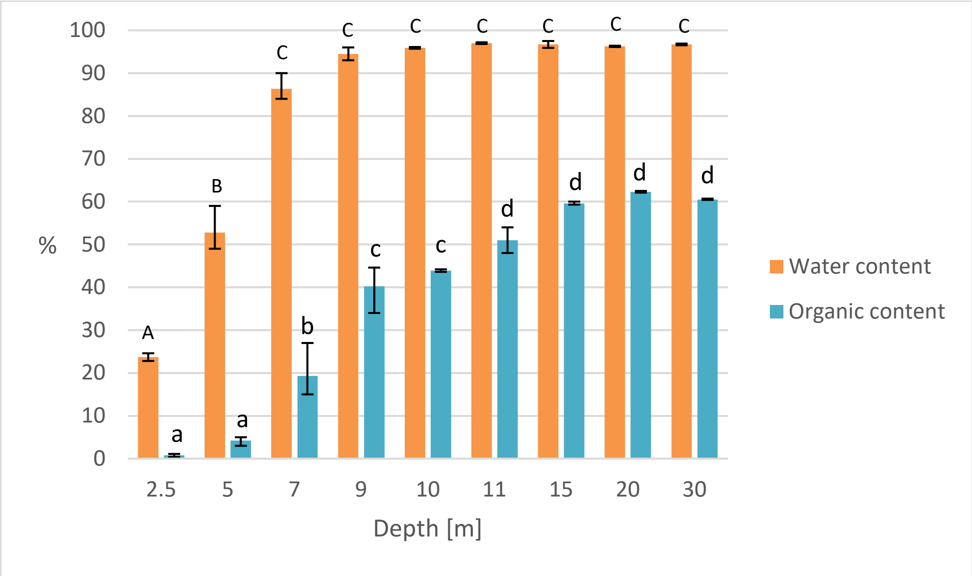

Fig.10. Water (%) and organic matter (%) content in bottom sediments – mean values and range of variability. The same letters indicate no significant differences between the corresponding values.

Table 1. Secchi disc visibility and water temperature (average values) on the particular depths of Lake Urowiec

Parameter									
Depth (m)	2.5	5	7	9	10	11	15	20	30
Secchi depth (m) - average	2.8								
Secchi depth (m) - range	1.0 - 5.1								
Temperature (°C) - surface	16.2	16.0	16.0	15.9	15.8	15.8	15.8	15.8	15.8
Temperature (°C) - bottom	15.4	12.5	8.9	8.1	7.7	7.3	6.4	5.8	5.3