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BIODIVERSITY AND INDICATIVE ROLE OF ZOOPLANKTON IN THE SHALLOW MACROPHYTE-DOMINATED LAKE ŁUKNAJNO

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Key words: Lake Łuknajno, macrophyte-dominated lake, zooplankton biodiversity, biocoenotic indices.

Abstract

The biological diversity of zooplankton communities was studied in August 2006 and 2007 in Lake Łuknajno (Masurian Lakeland, NE Poland), a shallow, macrophyte-dominated water body. An analysis of the species composition, abundance, biomass and the values of biocoenotic indices revealed significant differences between the analyzed zooplankton groups. The noted differences were related to trophic levels, the presence of macrophytes and environmental conditions. A total of 20 zooplankton species were reported in 2006 and 2007. The average abundance and biomass of zooplankton in 2006 and 2007 reached 546 indiv./dm^3 and 0.3085 mg/dm^3, and 385 indiv./dm^3 and 0.6113 mg/dm^3, respectively. Rotifers dominated in terms of abundance (75% in 2006 and 70% in 2007), while crustaceans in terms of biomass (approx. 80% in 2006 and over 70% in 2007). In 2006 and 2007, indicator species of high trophicity accounted for 41% and 24%, respectively, of the total zooplankton abundance in Lake Łuknajno. The values of biocoenotic indices did not point to the predominance of any zooplankton group. There were no significant differences in biodiversity between sites with and without macrophyte cover, whereas such differences ($p < 0.05$) were observed between sampling sites.

RÓŻNORODNOŚĆ BIOLOGICZNA I INDYKACYJNA ROLA ZOOPLANKTONU W PŁYTKIM MAKROFITOWYM JEZIORZE ŁUKNAJNO

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Słowa kluczowe: jezioro Łuknajno, jezioro makrofitowe, bioróżnorodność zooplanktonu, wskaźniki biocenotyczne.

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Abstrakt

Badania różnorodności biologicznej zooplanktonu przeprowadzono w płytkim, makrofitowym jeziorze Łuknajno (Pojezierze Mazurskie) w sierpniu 2006 i 2007 r. Na podstawie składu gatunkowego, liczebności, biomasy i wskaźników biocenotycznych stwierdzono duże zróżnicowanie grup zooplanktonu, zależne od trofi siedliska, makrofitów i warunków środowiskowych. Zarówno w 2006, jak i 2007 r. zaobserwowano po 20 gatunków zwierząt planktonowych. Średnia liczebność i biomasa w roku 2006 i 2007 wynosiły odpowiednio: 546 osobn./dm^3, 0.3085 mg/dm^3 oraz 385 osobn./dm^3 i 0.6113 mg/dm^3. Wrotki decydowały o liczebności zooplanktonu (75% w 2006 i 70% w 2007 r.), a biomasę kształtowały skorupiaki (około 80% w 2006 i ponad 70% w 2007 r.). Podczas badań odnotowano gatunki wskaźnikowe wysokiej trofii wód. W roku 2006 stanowiły one 41% udziału w ogólnej liczebności zooplanktonu jeziora Łuknajno, natomiast w roku kolejnym – 24%. Wskaźniki biocenotyczne nie wskazywały na dominację jakiejkolwiek z grup zooplanktonu. Między siedliskami porośniętymi makrofitami a siedliskami bez pokrywy roślinnej nie wykazano istotnych statystycznie różnic w różnorodności biologicznej. Różnice ($p < 0.05$) te stwierdzono natomiast między stanowiskami badawczymi.

Introduction

Biological diversity, or biodiversity, is defined as the variety of life forms at various levels. An analysis of biodiversity in a given environment enables to determine the species composition of the studied communities and the effects of external and internal factors, in both quantitative and qualitative terms. Biodiversity studies often focus on shallow water bodies where the composition of flora and fauna is considerably affected by environmental conditions. The specific character and ecological significance of shallow water bodies result from their morphology. Due to their relatively low depth, wind blowing over their entire surface thoroughly mixes the waters, thus preventing stratification (KUFEL and KUFEL 1997). Another distinct feature of shallow water bodies is the presence of macrophytes, with floating leaves or growing on the bottom. Macrophytes create specific habitats that support zooplankton development (CELEWICZ et al. 2001). Lake Łuknajno, a shallow water body located in the Masurian Lakeland (NE Poland), is overgrown with charophytes in 50%, which creates a suitable habitat for zooplankton development (BOWSZYS et al. 2006).

The objective of this study was to determine the effects of selected abiotic factors and the presence of macrophytes on zooplankton structure, and to analyze differences in biodiversity between habitats and sampling sites.

Materials and Methods

The study was conducted on the shallow, macrophyte-dominated Lake Łuknajno which – according to the typology proposed by KONDRACKI (2001) – is

located in the macroregion of Masurian Lakeland (NE Poland). This kettle, oval-shaped lake, elongated in the N-S direction, is connected to the moraine Lake Śniardwy by a narrow (approx. 500 m wide) inlet. Lake Łuknajno has a total surface area of 623 ha and a maximum depth of 3.0 m. The lake bottom is covered by a thick (approx. 15 m) layer of gyttja. Since the local climate is controlled by Arctic air masses, the growing season is short and the mean annual temperature is as low as + 6.5°C (DENISIUK and PROFUS 1990, BREYMEYER 1997, BOWSZYS et al. 2006). The lake has flat shores overgrown with dense rushes (a 30–150 m wide belt) comprising mostly the common reed (*Phragmites australis*) and the bulrush (*Typha latifolia*). Along the rush belt there is a sedge (*Carex* sp.) belt on the land side and a pondweed (*Potamogeton* sp.) belt on the water side. The lake bottom is covered by charophyte meadows, with *Chara aculeolata* and *Chara aspera* as predominant species (KRÓLIKOWSKA 1997). The littoral zone on the northern, western and southern side is swampy and marshy, with peat deposits. An alder forest stretches along the eastern side of the lake. The area is flat and morphologically uniform (BREYMEYER 1997). The lake's catchment area of 48.4 km2 comprises arable land (55%), grassland (26%) and forests (18%), (KUFEL and KUFEL 1997). Drainage reclamation works carried out in the catchment area of Lake Łuknajno during the late 1920s, including an artificial lowering of the water-table to 2.5 m, contributed to the eutrophication and shallowing of the lake (DENISIUK and PROFUS 1990).

An analysis of zooplankton communities (Rotifera, Crustacea) in Lake Łuknajno was based on materials collected at 20 sites in the water column (Figure 1), in August 2006 and 2007. Water samples were collected with a five-liter Patallas sampler, in the water column, from the surface to the bottom. A total of 25 liters of water was collected. Zooplankton samples were concentrated using an Apstein plankton net (30 μm), and they were fixed in Lugol's solution followed by 2–4% formalin. Water temperature and dissolved oxygen concentrations were determined with the use of the HACH HQd Field Case probe (RUGGED). Water transparency was measured with the Secchi disk (real-time assessment).

Plant communities were first identified based on previous studies (CIECIERSKA et. al. 2009), and next the sites were surveyed by boat during the growing season. A special anchor was used to collect macrophyte samples at deeper sites.

The species characteristic of high trophic levels were determined according to the procedure proposed by KARABIN (1985 a,b). A quantitative analysis of zooplankton was performed as described by STARMACH (1955), HILLBRICHT-ILKOWSKA and PATALAS (1967), BOTTRELL et al. (1976), and EJSMONT-KARABIN (1998). The values of biodiversity indicators (the Shannon-Weaver index based

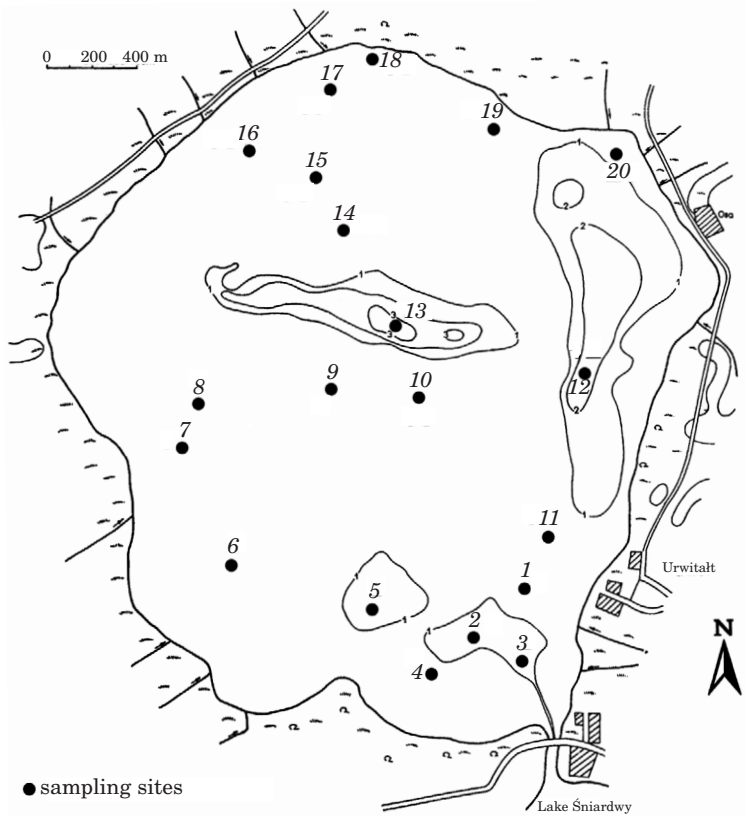

Fig. 1. Location of sampling sites on Lake Łuknajno

on abundance and biomass, the Simpson index based on abundance and biomass, Pielou's evenness index, species richness and density) were determined as recommended by ODUM (1982) and KREBS (1996).

The obtained results, in the form of measurable indices, were processed statistically using the Statistica PL 10.0 software package. The effects of abiotic environmental factors (temperature, oxygen saturation, water transparency) on the average abundance and biomass of zooplankton were determined by the Pearson correlation coefficient. The correlation between the average abundance and biomass of zooplankton and the presence of macrophytes was determined using Spearman's rank correlation coefficient.

In order to compare zooplankton biodiversity between sites with and without macrophyte cover, a *t*-test for two independent samples was performed. The following parameters were compared: the number, abundance and biomass of species, Shannon-Weaver index calculated based on abundance

and biomass, and the percentage share of indicator species in total zooplankton abundance. The data on biodiversity at different sampling sites, measured using the Shanonn-Weaver index based on abundance (HA), were subjected to a statistical analysis (*t*-test for two independent samples).

Results

A total of 25 Rotifera, Cladocera and Copepoda species were recorded in the zooplankton communities of Lake Łuknajno in August 2006 and 2007. In 2006, 20 zooplankton species were determined in water samples, including 11 Rotifera taxa, six Cladocera taxa and three Copepoda taxa. In 2007, also 20 species were identified, including seven Rotifera taxa, seven Cladocera taxa and six Copepoda taxa (Table 1).

Table 1

Species composition of zooplankton in Lake Łuknajno in August 2006 and 2007

2006	2007
ROTIFERA	ROTIFERA
Asplanchna priodonta priodonta (Gosse, 1850)	*Anuraeopsis fissa** (Gosse, 1851)
*Anuraeopsis fissa** (Gosse, 1851)	*Keratella cochlearis cochlearis* (Gosse, 1851)
*Brachionus angularis angularis** (Gosse, 1851)	*Keratella cochlearis tecta** (Gosse, 1886)
Keratella cochlearis cochlearis (Gosse, 1851)	*Keratella quadrata quadrata** (O.F. Müller, 1786)
*Keratella cochlearis tecta** (Gosse, 1886)	*Lecane luna luna* (O.F. Müller, 1776)
*Keratella quadrata quadrata** (O.F. Müller, 1786)	*Polyarthra dolichoptera dolichoptera* (Idelson, 1925)
Kellicottia longispina (Kellicott, 1879)	*Polyartha euryptera* (Wierzejski, 1891)
Lecane luna luna (O.F. Müller, 1776)	*Trichocerca capucina capucina* (Wierzejski & Zacharias, 1893)
Polyarthra dolichoptera dolichoptera (Idelson, 1925)	CRUSTACEA
Polyartha euryptera (Wierzejski, 1891)	Cladocera
Trichocerca capucina capucina (Wierzejski & Zacharias, 1893)	*Alona quadrangularis* (O.F. Müller, 1785)
Trichocerca similis (Wierzejski, 1893)	*Bosmina coregoni* (Baird, 1857)
CRUSTACEA	*Bosmina longirostris** (O.F. Müller, 1785)
Cladocera	*Bosmina longispina* (Leydig, 1860)
Alona quadrangularis (O.F. Müller, 1785)	*Chydorus sphaericus* * (O.F. Müller, 1785)
*Bosmina longirostris** (O.F. Müller, 1785)	*Diaphanosoma brachyurum** (Liévin, 1848)
*Chydorus sphaericus** (O.F. Müller, 1785)	*Leptodora kindti* (Focke, 1844)
Daphnia pulex (Leydig, 1860)	Copepoda
*Diaphanosoma brachyurum** (Liévin, 1848)	*Cyclops bohater* (Koźmiński, 1933)
Leptodora kindti (Focke, 1844)	*Cyclops kolensis* (Lilljeborg, 1901)
Copepoda	*Cyclops vicinus* (Uljanin, 1875)
Cyclops bohater (Koźmiński, 1933)	*Heterocope appendiculata* kop. (Sars, 1863)
Eurytemora lacustris (Poppe,1887)	*Mesocyclops leuckarti** (Claus, 1857)
*Mesocyclops leuckarti** (Claus, 1857)	*Mesocyclops oithonoides** (Sars,1863)

* indicator species of water bodies with high trophic levels (Karabin 1985a,b)

Indicator species of high trophicity were noted in both years of the study. A total of nine indicator species were identified, including: Rotifera – *Anuraeopsis fissa, Brachionus angularis angularis, Keratella cochlearis tecta, Keratella quadrata quadrata*, Cladocera – *Bosmina longirostris, Chydorus sphaericus, Diaphanosoma brachyurum*, and Copepoda – *Mesocyclops leuckarti, Mesocyclops oithonoides*. *B. angularis angularis* was present also in 2006, while *M. oithonoides* was noted only in 2007. In 2006 and 2007, taxa characteristic of high trophicity accounted for 41% and 24%, respectively, of the total zooplankton abundance in Lake Łuknajno.

The horizontal distribution patterns of zooplankton abundance and biomass in Lake Łuknajno were similar in 2006 and 2007. Single forms dominated in terms of abundance (Figure 2), whereas biomass varied over a wider range (Figure 3). In 2006 and 2007, Rotifera accounted for 75% and

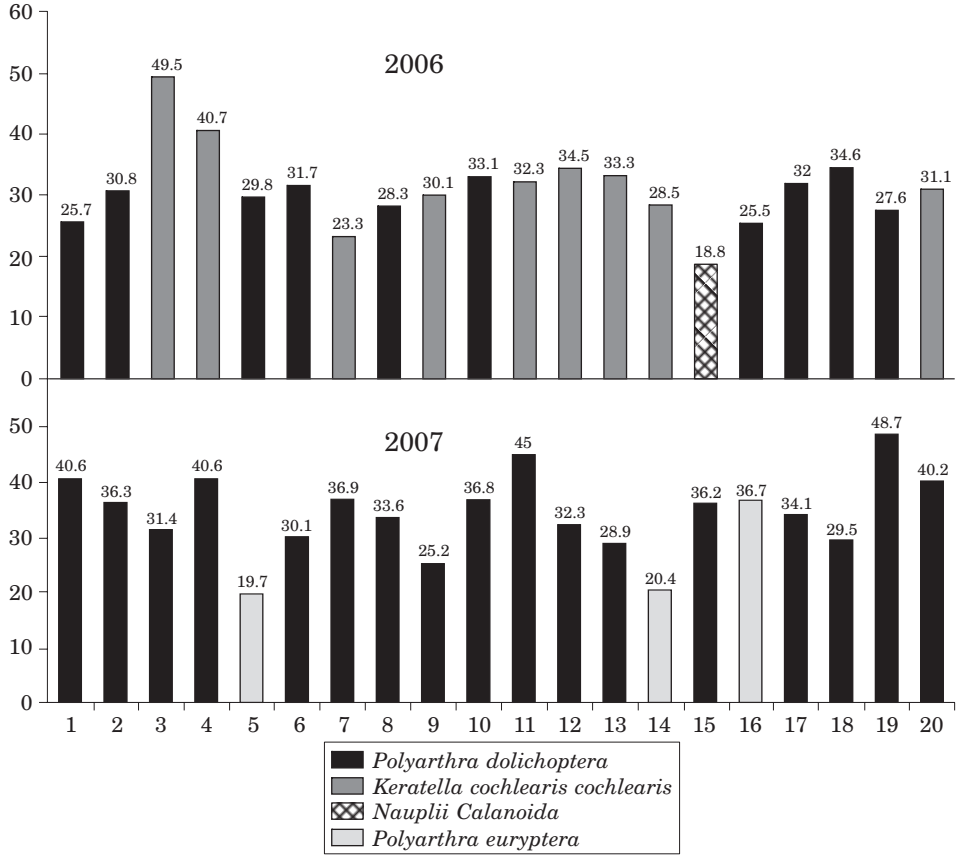

Fig. 2. Share (%) of predominant species in total zooplankton abundance at sampling sites on Lake Łuknajno in August 2006 and 2007

70%, respectively, of total zooplankton abundance. Several rotifer species (*Polyarthra dolichoptera* and *Keratella cochlearis cochlearis* in 2006, and *Polyarthra dolichoptera* and *Polyarthra euryptera* in 2007) formed large populations. Crustaceans accounted for 79% and 80% of total zooplankton biomass in 2006 and 2007, respectively. The predominant species were *Bosmina longirostris, Diaphanosmoma brachyurum* and *Mesocyclops leuckarti*. Juvenile crustaceans also had a high share of total zooplankton abundance and biomass.

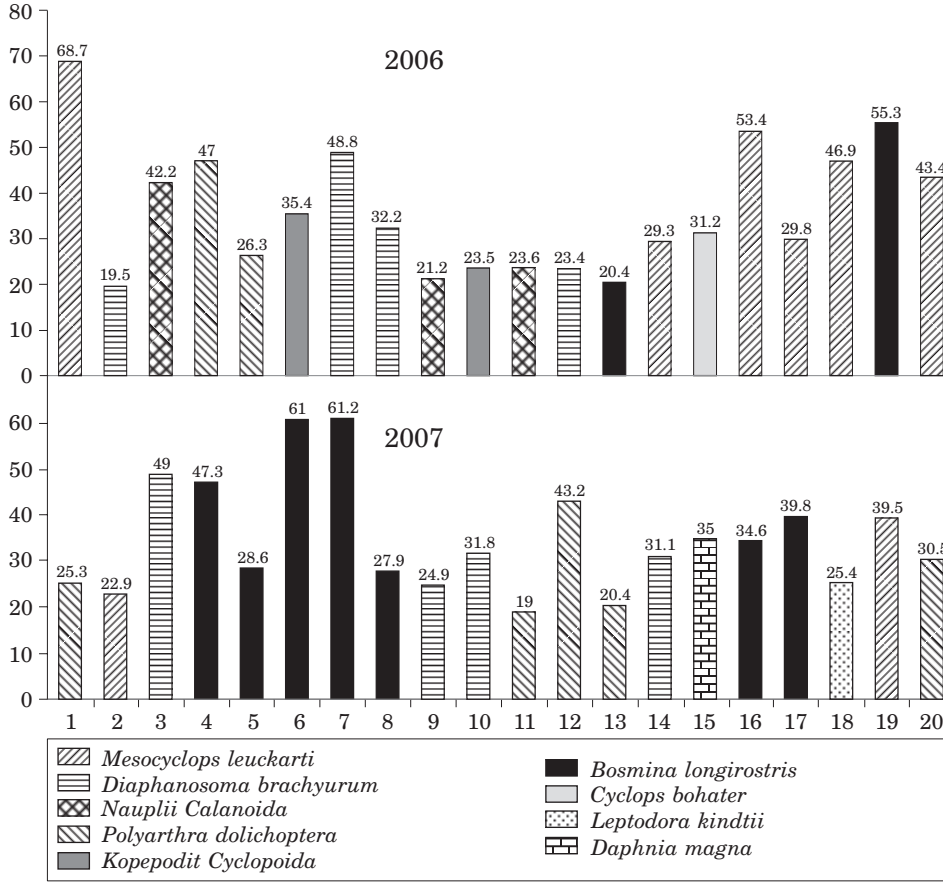

Figure 3. Share (%) of predominant species in total zooplankton biomass at sampling sites on Lake Łuknajno in August 2006 and 2007

Vegetation at the sampling sites showed low diversity levels. No vegetation cover was found at four sites: 2, 6, 9 and 15. The remaining sites were dominated by species of the genus *Chara* and *Stratiotes aloides*, as well as *Ceratophyllum demersum* at site 12, which partly or entirely covered the lake bottom (Table 2).

Table 2

Abiotic parameters of water and bottom cover in Lake Łuknajno in August 2006 and 2007

Sites	Depth [m]	Bottom cover	2006			2007		
			Temp. [°C]	Oxygen [mg O_2 dm^{-3}]	SDV [m]	Temp. [°C]	Oxygen [mg O_2 dm^{-3}]	SDV [m]
Sites with vegetation cover								
1.	0.5	*Chara (sand)*	21	9.42	1.8	22	9.23	1.7
3.	1.0	*S. aloides*	21	9.26	0.3	23	8.96	0.3
4.	1.2	*S. aloides (sand)*	21.5	8.78	1.4	23	9.04	1.3
5.	1.0	*sand (S. aloides)*	22	8.08	1.8	22.5	8.23	1.8
7.	0.3	*Chara (sand)*	22	9.98	0.6	22	9.90	0.6
8.	0.5	*sand (Chara)*	22	9.50	0.5	22	9.87	0.4
10.	0.8	*Chara*	21.5	9.35	0.8	22.5	9.23	0.7
11.	0.6	*Chara*	23	9.46	1.0	23	9.37	1.0
12.	0.8	*Chara (C. demersum)*	23	8.94	0.6	23	9.03	0.55
13.	0.85	*S. aloides*	21.5	8.01	1.0	22	8.12	1.0
14.	1.5	*S. aloides (sand)*	21	8.74	0.3	22.5	8.63	0.25
16.	0.5	*Chara*	21.5	9.52	0.5	22	9.48	0.5
17.	0.4	*Chara (sand)*	22	10.2	0.3	22	9.93	0.25
18.	0.5	*Chara (sand)*	22	9.44	0.2	23	9.37	0.2
19.	0.5	*S. aloides (Chara)*	22	9.17	0.5	23.1	9.15	0.4
20.	0.5	*S. aloides*	22.5	7.93	1.0	22.6	7.89	1.0
Sites without vegetation cover								
2.	0.5	*sand*	21.5	8.58	1.1	22.5	8.61	1.0
6.	0.4	*sand*	22	8.48	0.6	22.5	8.59	0.6
9.	0.9	*sand*	22	9.24	1.0	22	9.11	1.0
15.	2.5	*sand*	21	7.81	0.3	22.5	7.93	0.25

The abiotic factors affecting the environment of Lake Łuknajno were also studied (Table 2). In both study periods, water temperature remained relatively stable, in the 21.0–23.1°C range, oxygen saturation did not drop below 7.81 mg dm^{-3}, and water transparency varied from 0.2 m to 1.8 m. An analysis of the correlation between the average zooplankton abundance and biomass and abiotic environmental factors with the use of the Pearson correlation coefficient did not reveal significant differences between zooplankton abundance and biomass and temperature ($p=0.195$ and $p=0.172$, respectively), oxygen saturation ($p=0.819$ and $p=0.730$) and water transparency ($p=0.162$ and $p=0.688$) in Lake Łuknajno. The values of Spearman's rank correlation coefficient did not show relationships between zooplankton abundance ($p=0.3$) and biomass ($p=0.715$) and the presence or absence of vegetation at the sampling sites.

Table 3

Bioconotic indices of zooplankton communities at sampling sites on Lake Łuknajno in August 2006 and 2007

Sites	Biocoenotic indices													
	2006							2007						
	H_A	H_B	S_A	S_B	e	d	A_g	H_A	H_B	S_A	S_B	e	d	A_g
Sites with vegetation cover														
1.	1.98	1.2	0.83	0.51	0.83	1.62	1.1	1.9	2.1	0.76	0.84	0.79	1.6	1.1
3.	1.22	1.35	0.65	0.71	0.63	1.05	0.7	2.3	1.7	0.85	0.72	0.93	1.85	1.2
4.	1.34	1.47	0.67	0.82	0.69	1.05	0.7	1.98	1.8	0.78	0.73	0.77	1.9	1.3
5.	1.8	1.94	0.79	0.83	0.93	0.89	0.7	2.45	1.8	0.9	0.85	0.96	2.22	1.3
7.	2.24	1.71	0.86	0.7	0.87	1.8	1.3	1.93	1.41	0.79	0.6	0.84	1.48	1.0
8.	1.28	1.92	0.96	0.82	0.58	1.35	0.9	2.15	1.85	0.87	0.81	0.86	1.81	1.2
10.	2.0	2.34	0.81	0.88	0.78	1.87	1.3	1.98	2.0	0.8	0.83	0.8	1.83	1.2
11.	2.0	2.11	0.82	0.85	0.83	1.56	1.1	1.9	2.2	0.75	0.86	0.76	1.76	1.2
12.	2.1	2.0	0.82	0.84	0.91	1.49	1.0	2.05	1.6	0.82	0.72	0.82	1.72	1.2
13.	1.93	2.28	0.98	0.88	0.80	1.47	1.1	2.15	2.1	0.84	0.85	0.81	2.22	1.4
14.	2.13	2.1	0.85	0.84	0.93	1.44	1.0	2.4	2.1	0.88	0.84	0.91	2.3	1.4
16.	2.17	1.62	0.86	0.68	0.94	1.52	1.0	2.1	1.8	0.82	0.79	0.84	1.93	1.2
17.	1.95	2.1	0.82	0.83	0.89	1.24	0.9	2.1	1.7	0.83	0.75	0.91	1.52	1.0
18.	1.9	1.64	0.81	0.72	0.91	1.2	0.8	2.05	1.9	0.84	0.81	0.82	1.94	1.2
19.	1.94	1.54	0.81	0.66	0.93	1.14	0.8	1.6	1.5	0.71	0.73	0.77	1.28	0.8
20.	2.1	1.82	0.84	0.78	0.96	1.39	0.9	1.8	1.7	0.78	0.79	0.78	1.66	1.0
Sites without vegetation cover														
2.	1.96	2.17	0.81	0.87	0.82	1.5	1.1	1.8	2.0	0.78	0.84	0.78	1.52	1.0
6.	1.88	2.1	0.79	0.82	0.76	1.68	1.2	2.2	1.25	0.85	0.57	0.83	2.1	1.4
9.	1.9	2.33	0.82	0.89	0.83	1.4	1.0	2.1	1.9	0.84	0.83	0.91	1.55	1.0
15.	2.15	1.74	0.87	0.78	0.98	1.31	0.9	1.99	1.7	0.81	0.76	0.86	1.6	1.0

H_A – Shannon-Weaver index of species diversity based on abundance, H_B – Shannon-Weaver index of species diversity based on biomass, S_A – Simpson index based on abundance, S_B – Simpson index based on biomass, e – Pielou's evenness index, d – species richness index (species diversity), A_g – species density index

The biodiversity of zooplankton in Lake Łuknajno was evaluated using biocoenotic indices (Table 3). As regards zooplankton abundance, the Shannon-Weaver index ranged from 1.22 to 2.24 in 2006, and from 1.6 to 2.45 in 2007, and its value reached or exceeded 2.00 at many sites. Predomination of a single species was observed at the lowest values of the Shannon-Weaver index, e.g. *Keratella cochlearis cochlearis* dominated at site 3 in 2006. This taxon accounted for 50% of total zooplankton abundance and therefore the Shannon-Weaver index was as low as 1.22. In 2007, a similar situation was observed at site 19 where the predominant species was *Polyarthra dolichoptera*

(49%), and the studied index reached 1.6. There were significant ($p < 0.05$) differences in zooplankton abundance between the sampling sites (63% in 2006 and 64% in 2007). The Shannon-Weaver index based on zooplankton biomass was in the range of 1.2 – 2.34 in 2006 and 1.25 – 2.2 in 2007. The values of this index exceeded 2.00 at many sites. Similarly as with abundance, lower values of the studied index were correlated with the predomination of a single species at sampling sites – e.g. in 2006 *Mesocyclops leuckarti* dominated (69%) in terms of biomass at site 1. The Simpson index, calculated for zooplankton abundance and biomass, reached relatively high values (0.65 – 0.98 and 0.51 – 0.88, respectively). The values of species richness ranged from 0.89 to 1.87 in 2006 and from 1.48 to 2.22 in 2007. Pielou's evenness index varied between 0.58 and 0.98, indicating relatively high species evenness within the analyzed zoocoenosis. The density of zooplankton per unit volume ranged from 0.7 to 1.3. High values of this index were noted at sites 7 and 10, while low values – at sites 3, 4 and 5 where the number of planktonic animals was lower.

An analysis of biodiversity at sites with and without macrophyte cover revealed no significant differences with respect to the number of species ($p=0.8731$), abundance ($p=0.2994$), biomass ($p=0.3519$), values of the Shannon-Weaver index calculated based on abundance ($p=0.7640$) and biomass ($p=0.5272$), and the percentage share of indicator species in the total zooplankton abundance ($p=0.6513$). Differences in zooplankton biodiversity, measured using the Shanonn-Weaver index calculated based on abundance (H_A), were noted between sampling sites. Such differences were recorded at 64% of the sites in 2006, and at 66% of the sites in 2007.

Discussion

Shallow water bodies overgrown with vegetation, such as Lake Łuknajno, are of high ecological importance with regard to the preservation of high biodiversity of zooplankton communities, affected by both biotic and abiotic factors.

The effect of macrophytes on zooplankton abundance and biomass has been widely discussed in literature. Dense vegetation cover provides shelter and food for planktonic animals (BOWSZYS et al. 2006). According to KUCZYŃSKA-KIPPEN (2007), the presence of macrophytes has a direct influence on zooplankton biodiversity. The cited author studied the distribution of rotifers among emergent macrophytes (*Typha latifolia*), submerged macrophytes (*Chara tomentosa*) and in the open water area. The highest zooplankton biodiversity was noted in habitats with *Chara* beds, while the lowest biodiversity was observed at open water sites. The higher biodiversity of zooplankton

in charophyte meadows, compared with *Typha* sp. communities, is due to the more complex morphological and spatial structure of the former, which offers a more effective refuge and access to multiple food sources. Similar results were reported by KUCZYŃSKA-KIPPEN and NAGENGAST (2006a) who studied the shallow, macrophyte-dominated Lake Wielkowiejskie. The values of the Shannon-Weaver index determined for vegetation cover were generally high, and they were lowest in the open water area. Among the analyzed plant communities, the lowest biodiversity was noted at localities with *Utricularia vulgaris* for cladoceran species, and in habitats with *Nymphaea alba* for rotifer species. The highest biodiversity was recorded at localities with *Myriophyllum verticillatum* for Rotifera, and in habitats with *Nymphaea alba* for Cladocera. A trend towards higher zooplankton biodiversity in plant communities than in open water habitats was also reported by other authors (KUCZYŃSKA-KIPPEN and NAGENGAST 2006b, KUCZYŃSKA-KIPPEN and BASIŃSKA 2008, CELEWICZ-GOŁDYN et al. 2010, KUCZYŃSKA-KIPPEN and JONIAK 2010), which suggests that the species richness of planktonic animals increases along with an increase in habitat heterogeneity.

During the current study, conducted in August 2006 and 2007 on Lake Łuknajno, the absence of vegetation cover was reported at four sites only. No significant correlation was found between zooplankton abundance and biomass, and the presence or absence of vegetation, most probably due to a too small number of measurements. Further investigations are therefore required to determine whether such a relationship exists.

In shallow water bodies overgrown with vegetation, zooplankton biodiversity cannot be analyzed in view of a single factor (the presence of macrophytes), since the problem is much more complicated. Plant communities differ considerably with respect to environmental conditions including the physicochemical parameters of water (temperature, dissolved oxygen content, the concentrations of biogenic elements). KUCZYŃSKA-KIPPEN and KLIMASZYK (2007) investigated the effect of oxygen saturation on zooplankton in charophyte beds and found that only rotifers were significantly affected by this factor. The oxygen concentrations were lowest in the middle of charophyte mats (30% lower than at the remaining sites), mostly due to high vegetation density which hindered the flow of oxygen-carrying water. The above resulted in worse light conditions, a slower rate of photosynthesis and a faster rate of organic matter decomposition. The lowest abundance of Rotifera was also noted in the middle of charophyte meadows, which indicates that the density of rotifers decreases along with a drop in oxygen levels. Such a relationship was not observed in the present study since zooplankton samples were collected only in August. However, the effect of temperature on zooplankton abundance in Lake Łuknajno was reported by KARABIN et al. (1997) who noted that

cold-water, oxygen-loving rotifer species, such as *Polyarthra dolichoptera*, *Filinia terminalis* and *Synchaeta pectinata*, dominated at low temperatures (ca. 7°C), accompanied by juvenile crustaceans (Cyclopoida), while cladocerans were nearly absent. A rapid increase in water temperature was followed by an unexpected appearance of large populations of *Bosmina longirostris* and the disappearance of species which prefer lower temperatures. DAR et al. (2009) also observed a positive correlation between temperature rise and the abundance of Copepoda, which suggests that copepods, in contrast to rotifers, develop better at higher temperatures.

The present study was conducted on Lake Łuknajno only in August, in 2006 and 2007, when water temperature and dissolved oxygen concentrations remain relatively constant. Therefore, no significant effect of the examined abiotic environmental factors on zooplankton abundance was noted. A more detailed analysis should be performed, preferably over an annual cycle, to determine the impact of temperature and oxygen availability on the growth of planktonic animals.

Zooplankton biodiversity can also be evaluated in view of trophic conditions. Numerous researchers (KUCZYŃSKA-KIPPEN et al. 2004, PINTO-COELHO et al. 2005, PATUREJ 2006, WANG et al. 2007) found a close correlation between the trophic status of a water body and the abundance of planktonic animals. As demonstrated by PACE (1986), the taxonomic structure of zooplankton changes along with changes in the trophic state of a water body. Oligotrophic waters are usually dominated by copepods of the order Calanoida, whereas smaller copepods of the order Cyclopoida, rotifers and cladocerans predominate in eutrophic waters. Certain zooplankton species may act as bioindicators of the trophic state of a water body (KARABIN 1985a,b). Such a relationship was observed in many lakes (PATUREJ 2006, ČEIRĀNS 2007, PIASECKI and WOLSKA 2007, PATUREJ 2008), including in Lake Łuknajno where species typical of high trophicity were present. Yet the bioindicative role of zooplankton in Lake Łuknajno could be minimized by the effects of other factors. EJSMONT-KARABIN et al. (1996) reported that bacteria and macrophytes, which have the capacity to accumulate phosphorus, may decrease the amount of this element in the water column, thus maintaining lower trophicity. KUFEL and OZIMEK (1994) also demonstrated that owing to their specific ecological and physiological properties (relatively slow decomposition rates and the ability to grow during the winter season), stable *Chara* populations contribute to maintaining mesotrophic conditions in Lake Łuknajno through phosphorus uptake and storage in their biomass. Thus, the presence of bioindicator zooplankton species could not reflect the actual trophic state of the analyzed water body. Further studies are required to determine whether this is a general trend characteristic of all shallow lakes.

Statistical analyses showed no significant correlation between zooplankton abundance and biomass in Lake Łuknajno, and the abiotic parameters of the environment. There were no significant differences in biodiversity between sites with and without macrophyte cover, whereas such differences were observed between sampling sites. According to the findings of other authors, zooplankton biodiversity in Lake Łuknajno is affected by a variety of abiotic environmental factors and the presence of macrophytes. The fact that no such relationships were noted in this study suggests scarcity of data and the need for further investigations.

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