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Original Research

Influence of Abiotic Factors on Species Spectrum of Zoopleuston in Different Types of Peatlands

Wojciech Płaska*, Monika Tarkowska-Kukuryk

Department of Hydrobiology, University of Life Sciences,
Dobrzańskiego 37, 20-262 Lublin, Poland

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Abstract

This study aimed to determine the species spectrum and abundance of zoopleuston in five small water bodies in different types of peatlands in Roztocze National Park in 2012. The highest number of taxa and density occurred in transitional bogs. The results of DCA analysis showed distinct grouping of zoopleuston communities, depending on bog type. The studied group of organisms had a strong gradient depending on the bog type correlated with the concentration of chlorophyll-*a*, suspension, and concentrations of inorganic nutrients in the habitat.

Keywords: zoopleuston, Heteroptera, peatlands, abiotic factors

Introduction

A zoopleuston is a group of organisms living on or near the surface of water, typically in small water bodies [1]. The presence of predatory species in this ecological group can be a factor determining the abundance of other organisms in small and shallow water bodies. Thanks to an ability to fly, it also has a high capacity of dispersion, which is used in settling periodically dry reservoirs. It often makes use of the ability of imago to move actively in the air. This can be done in deteriorating habitat conditions or when food resources are depleted or there is a threat of predators. However, in the first place, the habitat conditions in small bodies of water determine the spectrum and structure of zoopleuston species [2, 3]. The study of the diversity and quantitative structure of zoopleuston's aquatic habitats is important for better understanding the relationships between organisms in such systems. Bogs are usually characterized by rich biodiversity and they play a key role in maintaining the stability of ecological interactions in respective regions [4, 5]. At the same time, they form part of the most quickly disappearing and most endangered ecosystems in Europe. This is particularly essential in connection with the distressing global warming [6]. In bogs dominated by *Sphagnum*, animal communities, especially invertebrates, are relatively well known [4, 7]. However, little or no attention is paid to the density of zoopleustons and their links with environmental parameters [8]. Bog waters have specific physical and chemical properties. Their specific character is closely related with the genetic and eco-

*e-mail: wojciech.plaska@up.lublin.pl

Table 1. Physical and chemical characteristics of water in investigated peatbog (values for the May-October period 2012), n=15.

Parameters/sites	Fens I	Fens II	Kosobudy Bog	Tittenbrun Bog	Międzyrzeki Bog
Temp. (ºC)	15.8	15.2	15.6	15.3	19.6
pH	7.9	8.1	4.6	4.7	4.4
Conductiv. ($\mu S \cdot cm^{-1}$)	276	221	31.6	76	61
N-NO_3 (mg $NO_3 \cdot l^{-1}$)	0.393	0.608	0.771	1.146	0.763
PO_4 (mg $PO_4 \cdot l^{-1}$)	0.035	0.047	0.321	0.592	0.043
P_{tot} (mg $P \cdot l^{-1}$)	0.254	0.086	0.537	0.805	0.101
Chlorophyl-*a* (mg$\cdot l^{-1}$)	9.12	10.52	212.3	260.3	25,32
TOC (mg $C \cdot l^{-1}$)	13.1	20.2	38.3	63,3	29.5
COD (mg $O_2 \cdot l^{-1}$)	28.7	45.3	86.6	146.6	67.3
BOD (mg $O_2 \cdot l^{-1}$)	17.3	27.4	50.3	85.2	37.3

logical type of bog. They differ in terms of certain abiotic factors and display various stages of ecological succession. They have clearly different water pH and conductivity.

With regard to a clear diversity of biological and chemical water conditions in the studied types of bogs, it appears that a similar diversity should occur in the case of macroinvertebrates appearing in them. The aim of this study was to determine the taxonomic and quantitative composition of the zoopleuston in three kinds of bogs (fens, transitional bogs, and raised bogs) in Roztocze National Park. In addition, we tried to determine the influence of environmental factors on the zoopleuston spectrum.

Material and Methods

The material was collected during three seasons: spring (May), summer (July), and autumn (October) in 2012. Each season three replicate samples were taken per site. Zoopleuston samples were taken from an area of 0.25 m^{-2}. They were collected with the use of a metal frame and a hand net. The samples were immediately preserved in 80% alcohol. The morphological identifications of the zoopleuston were mainly based on the work by Savage [9]. During the three seasons water was sampled (500 ml) to perform chemical analyses. The temperature, conductivity, and pH were determined *in situ* with a multiparametric probe; TOC, BOD, and COD were measured using a PASTEL UV spectrophotometer. Other factors (P_{tot} – total phosphorus, P-PO_4-NO_3, chlorophyll-*a*) were analyzed in a laboratory [10].

Study Sites

Fens: They are located in the central part of Roztocze National Park near a railway line: fen I (50º 34.48' 37 N, 22º 59.36 'E), fen II (50º 34.37' 84 N, 22º 59.24 'E). They are surrounded by mixed forest. The open backwater has a variable surface and a maximum depth of 0.9 m. It was created by flooding of alder stands as a result of beaver activity. *Lemna trisulca* L. occurs on the entire surface. The banks and shoals are covered by beaked sedge *Carex rostrata* Stokes, *Glyceria maxima* (Hartm.), *Juncus conglomeratus* L. The backwater is brown in colour, has low pH, and is poorly mineralized. In the period of the study, the measured average levels of physical and chemical factors for the water were: conductivity 174-359 $\mu S \cdot cm^{-1}$, dissolved oxygen 3.0-11.5 $mg \cdot dm^{-3}$, and pH 7.0-8.7 (Table 1).

Transitional bogs: They are located in the northwestern part of Roztocze National Park near the village of Kosobudy: the Kosobudy bog (50º 37.663 '663 N, 23º 03.147 'E), and the Tittenbrun bog (50º 37.12 '81 N, 23º 03.997 'E). The vegetation of the reservoir is quite well developed. A *Sphagnum* mat floats on the water surface, along the shoreline. The edge of the reservoirs is overgrown with a fairly dense reed bed created by *Carex rostrata* Stokes. The bottom of the reservoirs is covered with a layer of silt and peat. There also is sparse shoreline vegetation, including: *Utricularia vulgaris* L., *Potemogeton natans* L., *Schoenoplectus lacustris* (L.), *Calla palustris* L., and *Eriophorum vaginatum* L. The measured average levels of physical and chemical factors for the water were: conductivity 26-135 $\mu S \cdot cm^{-1}$, dissolved oxygen 32-147 $mg \cdot dm^{-3}$, and pH 3.8-5.5.

Raised bogs. The Międzyrzeki peatland (50º 31.44' 43 N, 23º 1.69 'E) is the largest complex of raised bogs located in the southern part of Roztocze National Park. Local plant communities are to a great extent natural. Samples were collected from small reservoirs overgrown with *Sphagnum* in an open bog. The water bodies were of a temporary nature and, in summer, their area was significantly reduced. The average levels of physical and chemical factors for the bog water were: conductivity 54-76 $\mu S \cdot cm^{-1}$, dissolved oxygen 3.7-6.2 $mg \cdot dm^{-3}$, and pH 4.0-5.7 (Table 1).

Data Processing

Detrended correspondence analysis (DCA) was used to measure and illustrate the variability of the gradient shown by the zoopleuston in order to specify the separation between studied habitats [11]. An automatic forward selec-

Table 2. Results of the Monte Carlo permutation test (CCA) for three types of peatbog ecosystems.

Variable/Habitat	Fens			Transitional bogs			Raised bog		
	λ	F	p	λ	F	p	λ	F	p
WL	**0.62**	**4.22**	**0.002**	0.01	0.00	1.000	0.00	0.00	1.000
Temperature	0.01	1.55	0.523	0.00	4.36	0.096	0.00	0.00	1.000
pH	0.01	1.50	0.278	0.01	1.58	0.256	0.00	0.00	1.000
Total suspension	**0.04**	**8.57**	**0.002**	0.03	3.67	0.076	0.00	0.00	1.000
Conductivity	**0.31**	**9.74**	**0.002**	**0.59**	**4.38**	**0.004**	0.00	0.00	1.000
Dissolved oxygen	0.01	0.96	0.432	0.01	1.70	0.194	0.00	0.00	1.000
$N\text{-}NO_3$	**0.14**	**11.28**	**0.006**	0.00	0.00	1.000	0.00	0.00	1.000
$P\text{-}PO_4$	0.00	0.00	1.000	0.00	0.00	1.000	0.02	2.59	0.224
Ptot	**0.38**	**5.91**	**0.006**	**0.19**	**13.44**	**0.002**	0.00	0.00	1.000
Chl-*a*	**0.58**	**5.74**	**0.002**	**0.46**	**4.61**	**0.020**	**0.26**	**8.20**	**0.026**
TOC	0.01	1.70	0.212	0.01	1.69	0.252	0.00	0.00	1.000
TSS	**0.02**	**3.08**	**0.046**	0.03	3.67	0.076	**0.83**	**9.58**	**0.004**
BOD	0.00	0.00	1.000	**0.60**	**15.86**	**0.002**	0.07	7.73	0.080
COD	0.00	0.00	1.000	**0.04**	**2.86**	**0.044**	0.00	0.00	1.000
SUR	0.00	0.00	1.000	0.00	0.00	1.000	0.00	0.00	1.000

Environmental variables at $p<0.05$ are statistically significant and given in bold

tion Monte Carlo permutation test (999 permutations) was used to determine the most important variables [12]. Variables whose level of significance exceeded 0.05 were passively plotted onto diagrams. Ordination analyses were performed using CANOCO 4.5 software for Windows.

Results

Abiotic Variables

The level of water in the studied peat bogs showed high variability, depending on the peat bog type and season. The highest fluctuations appeared in fens where the level of water was regulated by beaver dams. Significant differences in the values of analyzed factors were found for conductivity, P_{tot}, PO_4, and the concentration of chlorophyll-*a* (ANOVA, F = 25.11-28.31, P = 0.001). The pH of water varied from 4.0 in a raised bog to 8.7 in a fen. Conductivity varied significantly, ranging from 26 $\mu S \cdot cm^{-1}$ in a transitional bog to 359 $\mu S \cdot cm^{-1}$ in a fen. The highest conductivity usually appeared in summer or autumn, while it was lower in spring. The highest concentrations of TOC, COD, and BOD occurred in transitional and raised bogs (> 86 $mgC \cdot l^{-1}$, 206 $mgO_2 \cdot l^{-1}$, and 115 $mgO_2 \cdot l^{-1}$), with the lowest found in fens (> 27.6 $mgC \cdot l^{-1}$, 42 $mgO_2 \cdot l^{-1}$, 36.3 $mgO_2 \cdot l^{-1}$, respectively). Inorganic nutrients were the most abundant in transitional bogs, reaching their peak in summer and autumn (Table 1).

Ordination Analysis

The DCA allowed us to clearly isolate different zoopleuston formations, typical of the studied types of peat bogs (Fig. 1). All environmental variables accounted for 66% of the total variability. The Monte Carlo permutation test at P <0.05 showed the significance of seven variables:

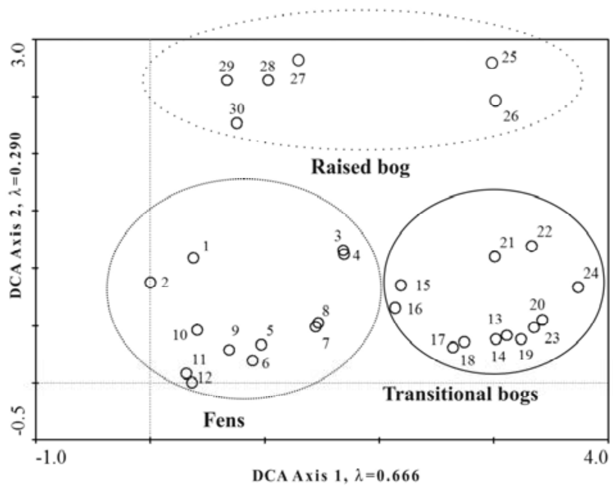

Fig. 1. Scatter plot for detrended correspondence analysis (DCA) for samples collected in different types of peatbogs. Samples collected in studied habitats are marked with an Arabic numeral: 1-12 fens, 13-24 transitional bogs, 25-30 raised bog.

WL, chlorophyll-*a*, P_{tot}, conductivity, N-NO_3, total suspension, and TSS in explaining the variability of zoopleuston in two studied fens (Table 2). On the CCA biplots of zoopleuston communities of the studied habitats, the presence of Gerridae larv., *Gerris. lacustris* (L.), *Gerris. lateralis* Schumm., *Gerris. argentatus* Schumm., Lepidoptera and *Notonecta glauca* L. positively corresponds with the rising gradient of chlorophyll-*a* and N-NO_3. The taxa: *Gerris rufosculellatus* (Lat.), *Hesperocorixa sahlbergi* (Fieb.), *Cymatia bonsdorffi* (Sahlb.), *Plea minutissima* Leach, and Dytyscidae showed a positive relation with the decreasing gradient of P_{tot} and conductivity. Culicidae, Stratiomyidae, *Microvelia reticulata* (Burm.) and Corixidae larv. positively corresponded with the decreasing gradient of conductivity, total suspension, and water level. *Hydrometra gracilenta* Hor. and Coleoptera larv. showed a positive relationship with the rising gradient of TSS (Fig. 2A).

The CCA indicated that all environmental variables accounted for 72.8% of the total variance of zoopleuston taxa in the studied habitats. Five environmental variables (chlorophyll-*a*, conductivity, COD, BOD, and P_{tot}) showed significant importance in a Monte Carlo permutation test at $P<0.05$ (Table 2). In a transitory bog habitat, zoopleuston species (*Gerris lacustris*, *G. lateralis*, Gerridae larv., *Podura aquatica* L., *Cymatia bonsdorffi*, *Hesperocorixa sahlbergi*) correspond with the rising gradient of chlorophyll-*a* and P_{tot}, COD, BOD, and conductivity. Species such as: *Microvelia reticulata*, *Notonecta glauca*, *G. argentatus,* and Dytysciadae showed a negative relationship with these factors (Fig. 2B).

The CCA revealed that all environmental variables accounted for 90.2% of the total variance of zoopleuston taxa in the studied habitats. Two environmental variables (chlorophyll-*a*, and TSS) showed significant importance in a Monte Carlo permutation test at $P<0.05$ (Table 2). In a raised bog habitat, zoopleuston species (*Notonecta glauca*, *Cymatia bonsdorffi,* and *Hesperocorixa sahlbergi*) corresponded with the rising gradient of chlorophyll-*a*, and showed a negative relationship with the decreasing TSS. Taxa such as Dytyscidae and Culicidae showed a negative relationship with the rising gradient of chlorophyll-*a*, and a positive relationship with the decreasing gradient of TSS (Fig. 2C).

The Composition of Macrofauna

21 zoopleuston taxa were identified in the studied peat bogs. These included four species of Heteroptera which are rare to Polish fauna: *Hydrometra gracilenta*, *Hebrus ruficeps* (Th.), *Coroxa punctata* (Illig.), and *Microvelia buenoi* Drake.

The number of taxa varied between 15 in transitional bogs – Tittenbrun Bog and 6 taxa (raised bog in the peatland "Międzyrzeki"). Numerous species occurred during summertime. An exception was a fen at an early stage of colonization.

The density of zoopleuston reached the culmination point in transitional bogs and was 57 ind·m^{-2} for the Kosobudy peat bog and 33 ind·m^{-2} for the Tittenbrun peat bog. In fens, the densities were lower and reached 12 ind m-2 in fen I and 20 ind·m^{-2} in fen II. In the Międzyrzeki raised bog the density was on average 5 ind·m^{-2}. The highest density of zoopleuston was in the summertime. An exception was a newly colonized backwater of fen II, where the peak population occurred in autumn.

In transitional bogs, the group of dominants included *M. reticulata*, *G. argentatus,* and Coleoptera lrv. In the Kosobudy peat bog, they were *M. buenoi*, and Coleoptera lrv., and in the Tittenbrun Bog – *H. gracilenta*. Dominants occurring in fens were: *H. gracilenta* and *M. reticulata* in fen I; and Culicidae, *G. lateralis*, and *G. argentatus* in fen II. In the Międzyrzeki raised bog, *H. sahlbergi* and *M. reticulata* were the predominant species (Fig. 3).

Discussion

The species diversity of macroinvertebrates in the studied peat bogs was typical of such habitats. A similar spectrum of species was observed in peat bogs in the region of Polesie Lubelskie [7, 8]. The littoral zone of the lakes and eutrophic reservoirs is usually characterized by higher abundance and diversity of macrofauna. The results of the study as well as works by other authors indicate that this is probably caused by less favorable habitat conditions than those in the littoral zone of a lake. Usually, Corixidae and other Nepomorpha had a significant percentage share in littoral fauna [13-16]. Possibly factors corresponding with numerous species in peat bogs constitute the key limiting factor [17-20]. Perhaps the lack of predatory fish in the studied peat bogs enables the development of a different species structure than in lakes [14, 15]. Frequently, in such patterns the role of the main predator is taken over by predatory macroinvertebrates such as Notonectidae or Gerromorpha, which significantly modify a number of other representatives of macrofauna, e.g. Culicidae [21]. In the studied peat bogs, the course of seasonal dynamics of the number of taxa evidences a stable population and inconsiderable migrations from the nearby habitats. The exceptions are temporary backwaters in fens [22, 23].

The dominant taxa, studied in the research sites, are characteristic of such habitats and were also present in other peat bogs in the region of Polesie Lubelskie [7, 8]. Most dominant taxa are species connected with peat bogs and reservoirs with rush vegetation [24]. On the other hand, an atypically low number of Culicidae is probably caused by the strong pressure of predatory Heteroptera, which dominated the studied habitats [21]. In addition, such habitats are characterized by a very low share of *Podura aquatica* typically occurring on shorelands of lakes. This is due to the specific morphometry of the studied reservoirs and the surroundings of the peat bogs. Similarly, a low abundance of Collembola was observed in peatlands in Polesie National Park [7, 8].

The DCA allowed us to clearly identify different macrofauna formations typical of the studied kinds of peat bogs. Particularly low species diversity and their low abundance in raised bogs probably result from the small size of reser-

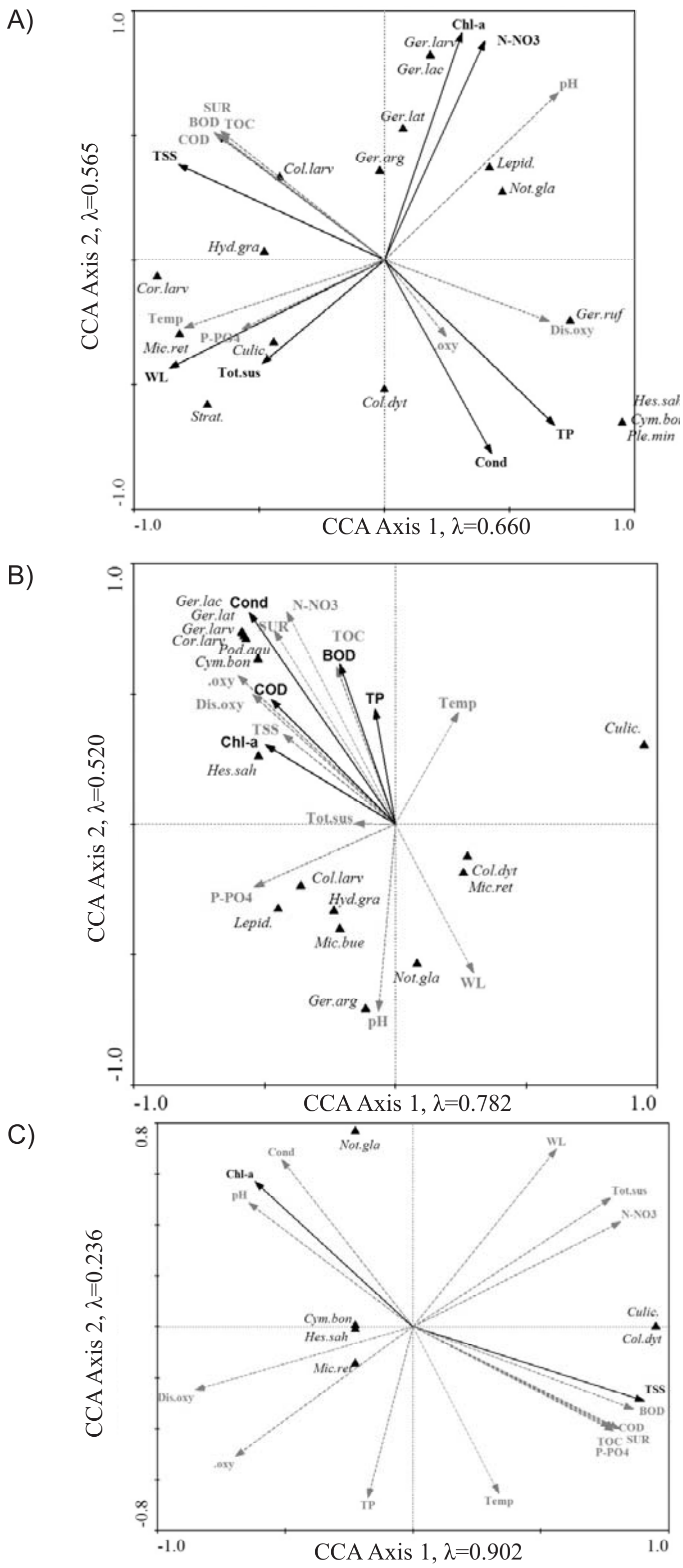

Fig. 2. Biplots for canonical correspondence analysis (CCA) for environmental variables and zoopleuston taxa in A) fens, B) transitional bogs, C) raised bog.

Arrows marked as bolded indicate significant parameters in Monte Carlo permutation test at $p<0.05$. WL – water level; Temp – water temperature; Tol.sus – total suspension; Cond – conductivity; Dis.oxy – dissolved oxygen; Chl-a – chlorophyll-a; N-NO, – nitrate nitrogen; Ptot – total phosphorous; P-PO_4 – dissolved orthophosphates; TOC – total organic carbon; TSS – total suspended solids

Taxa codes: *Mic.ret – Microvelia reticulata*, *Mic.bue – Microvelia Buenoi*, *Ger.lac – Gerris lacustris*, *Ger.lat – Gerris lateralis*, *Ger.arg – Gerris argntatus*, *Ger.ruf – Gerris rufoscutellatus*, *Ger.odo – Gerris odontogaster*, *Ger.larv – Gerridae larv*., *Heb.ruf – Hebrus ruficeps*, *Hyd.gra – Hydrometra gracilenta*, *Not.gla – Notonecta glauca*, *Not.lut – Notonecta lutea*, *Nep.cin – Nepa cinerea*, *Cym.bon – Cymatia bonsdorffi*, *Hes.sah – Hesperocorixa sahlbergi*, *Cor.pun – Corixa punctata*, *Cor.larv – Corixidae larv*., *Ple.min – Plea minutissima*, *Col.dyt – Coleoptera dytiscidae*, *Col.larv – Coleoptera larv*., *Pod.aqu – Podura aquatica*, *Culic – Culicidae*, *Strat – Stratiomyidae*, *Lepid – Lepidoptera*

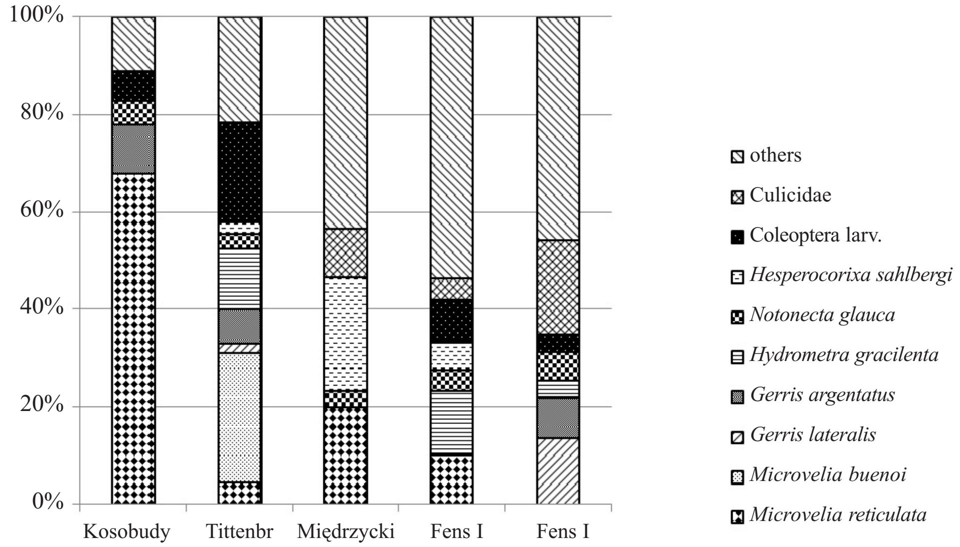

Fig. 3. Domination taxa of zoopleuston in investigated peatbogs.

voirs, which sometimes do not provide enough spatial diversity of micro habitat compared to a raised bog. The DCA shows that the zoopleuston in transitional bogs can have the best conditions for development, and there achieves the highest density and diversity. In fens habitat conditions get worse over time as seen in the structure of macrofauna species. In the raised bog habitat conditions were unfavorable, imposing a limitation on the number of zoopleuston species and their density.

There are well-known works indicating the correlation between macrofauna and abiotic factors [20, 25-27]. The relationships revealed in CCA show an increasing gradient of inorganic nutrients corresponding with numerous zoopleustonic taxa in the peat bogs. The concentration of chlorophyll-*a*, rising in the conditions of increased habitat fertility, rises analogously to the growth of inorganic nutrients gradient and creates good habitat for zoopleustonic fauna. This was particularly significant in all peat bogs for the dominant species of Gerromorpha and *Notonecta glauca*. Similar observations were made by other authors who analyzed temporary reservoirs appearing during high water levels in the river valley. They described the importance of the increasing gradient of inorganic nutrients and water levels on the density of macrofauna in small water bodies [26-28]. It was shown that many Heteroptera taxa can be found in low pH conditions. In the present study, pH was not the key limiting factor for the zoopleuston abundance. In the fens dependent on the level of water, significant relationships with those variables were also found. Other authors also highlight the role of this factor, which has a varied impact on the macrofauna [26] depending on the kind of reservoir, while its influence on different taxa turned out to be varied. Usually it is of vital importance in storage reservoirs [26] where a sudden increase of the water surface results, in the first place, in a strong dispersion of the macrofauna. In the studied peat bogs similar conditions were periodically present in the fens, and the water level had a significant influence on the decline in the density of species moving on the surface of the water. The degree of vegetation coverage of fens could also have been of considerable significance to the course of the observed colonization of fen backwaters [29, 31].

Conclusions

1. The zoopleuston of the studied peatlands was dominated by species typical for such habitats. Four of them were species rarely found in the fauna of Poland.
2. The highest species richness and abundance were observed in transitional bogs.
3. DCA analysis clearly separated studied peat bogs, which shows that zoopleuston display significant differences between the studied habitats.
4. On the basis of the CCA analysis (Monte Carlo test) a significant influence of conductivity, chlorophyll-*a*, and inorganic nutrients on the zoopleuston abundance was demonstrated. Generally, species moving on the surface of the water (*Gerris lacustris*, *Gerris lateralis*, *Gerris argentatus*) and under the water surface (*Notonecta glauca*) positively corresponded to those factors.
5. Unstable water levels in fens caused the reconstruction of the zoopleuston community and significantly affected the course of colonization of temporary water bodies.

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