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DISTRIBUTION OF CLADOCERA COMMUNITIES ACROSS A CLIMATE GRADIENT IN SHALLOW LAKES FROM CROATIA TO HUNGARY: A PRELIMINARY STUDY

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Abstract

Cladocera communities in surface sediments of seven lakes were sampled from the Mediterranean to north Hungary. Conductivity, pH, primary ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, CO_3^{2-}) and macrophyte coverage were measured as contributed environmental parameters for the distribution of cladoceran communities across the lakes. Thirty-two cladoceran species were found in the seven lakes. The recorded species have wide tolerance spectra, and are able to colonize very different kind of habitats. The most common and abundant species were *Chydorus sphaericus*, *Alona rectangula* and *Bosmina longirostris*. Lake area, latitude, macrophyte coverage, pH, conductivity and hardness were found to be the most determinant environmental variables in the distribution of cladoceran species. This study revealed that although the lakes show a clear separation in environmental parameters the composition and distribution of Cladoceran communities differ only slightly across the investigated geographical gradient.

Key words: Subfossil Cladocera, climate change, training set

INTRODUCTION

Cladocerans are key species in aquatic food-webs, while being nutrient resources to other organisms and being consumers of other organisms (Eggermont, Martens 2011). Due to this central position in food-webs and to their high representation between benthic and pelagic taxa, their communities respond rapidly to changes in predation pressure and availability of nutrient resources (Jeppesen *et al.* 2011).

Following the pioneer works of Frey (1955, 1958, 1959), numerous paleoenvironmental surveys are based on Cladocera. Their remains are well preserved in the sediment with a bias to the strongly chitinized species (i.e. bosminids and chydorids) (Korhola, Rautio 2001; Kattel *et al.* 2006). Thus, these remains can be used to reconstruct former cladoceran communities especially those of chydorids. The community responses of Cladocerans to changes in the physical environment are generally expressed as changes in species diversity measurements (Hofmann 1987). Moreover, several studies have documented the general importance of temperature and other climate factors to Cladocera community (Korhola, Rautio 2001; Bjerring 2007, Korponai *et al.* 2011).

Facing a global climate change, extreme warming is expected with increased dry periods in the Carpathian basin (Gálos *et al.* 2007). Two scenarios were constructed for the predictions of the possible effect of the climate change. Scenario A2 predicted a greater temperature increase in the Carpathian basin than scenario B2. The largest temperature increase is expected in the summer, whilst the smallest in spring. In case of the summer daily mean temperature the expected increase is 4.5–5.1°C (A2) and 3.7–4.2°C (B2). For spring, the expected temperature increase in Hungary is 2.8–3.3°C (A2) and 2.3–2.7°C (B2). These predictions suggest that an increasing Mediterranean effect on the Hungarian climate is highly probable.

Due to climatic differences, the summer temperatures in the Mediterranean lakes exhibit higher summer values than those in Hungary. Thus, we assumed that the differences among cladoceran communities can be addressed to climate. In this study we compared cladoceran communities across a climatic gradient from the Mediterranean to the Carpathian Basin. We selected lakes from the South (Croatia and Bosnia and Herzegovina) to the North (Aggtelek National Park in Northern Hungary) covering the broadest spectrum of heterogeneity in water chemistry and habitats. This collection of lakes also provides the fundaments for building the "Cladocera Training-Set" for the Carpathian Basin.

MATERIAL AND METHODS

Survey area

The surveys of the seven lakes and ponds (Fig. 1) were conducted between April and August, 2011. Two small lakes were selected in Northern Hungary. Lake Aggtelek is relatively small (1.13 ha) and shallow (average depth is 1 m)

Fig. 1. Map of the study lakes.

lake, on the border of karstic and non-karstic bedrocks in the village of Aggtelek. Due to human impact the lake became eutrophic with dense submersed vegetation. Lake Vörös is also a small (1 ha), shallow (average depth is 1 m) lake near to Lake Aggtelek. Its water is eutrophic and turbid, due to the colloidal clay fraction (Samu, Bárány-Kevei 2010).

Lake Velence is larger but also a shallow lake with an average depth of 1.89 m, and it is considered as a eutrophic, saline and alkaline lake. Its water is dark because of the humic substances. Two main habitat types include open water and reed beds. The lake suffers from a strong human impact since its coupling with Lake Balaton, as a main target for tourism (Ács *et al.* 1994).

Lake Ferto is a large and also a saline lake, situated between Hungary and Austria in the west part of Hungary. Its trophic state is mesotrophic. Its water is turbid, because even small winds (2 m s^{-1}) can mix the shallow water column and stir up the sediment (Löffler 1979). Two main habitats can be identified in the lake, the reedbelt (Hungarian part) and the open water area (Austrian part). Samples were taken in the Hungarian part of the lake.

Lake Baláta is considered as an endorheic peatbog lake far from inhabited areas with an average depth of 1.6 m. This lake is eutrophic with dense vegetation (Majer *et al.* 2002).

Lake Vrana is a shallow lake (average depth of 2.8 m) with dense, submerged macrophytes, located in Croatia. The water is brackish in this lake partially due to the narrow, limestone-dolomite sedimentary rock barrier separating it from the sea, that are partially permeable to salt water. Moreover, in the southeastern part of the lake, an 800 m long artificial channel connects it to the sea (Katalinic *et al.* 2008).

Lake Svitavsko is in Bosnia and Herzegovina, a large expanse of moorland, located in the Hutovo Blato National Park. This lake had been a swamp until 1979, but followed by the construction of a hydroelectric power station the swamp was flooded and expanded to a 1,300 ha lake. This is a shallow lake with dense submerged macrophyte vegetation connected to the River Neretva, Hutovo Blato and other lakes through the Krupa River.

Environmental and chemical variables

Measurements were taken from a boat at five sampling points at each lake. Physical parameters suchlike conductivity, temperature and pH were measured in the field using a WQC-24 Multiparameter Water Quality Meter. Macrophyte cover (emerse and submerse) was estimated during walks around the lake by screening the lake bottom in transects with water glass. Water depth and transparency were measured using a Secchi disk. Concentration of Na^+ and K^+ were measured in the lab using a flame spectrophotometer (Flapho 41 , Zeiss Inc.). SO_4^- was determined by UV/VIS spectrophotometer (Specol, Zeiss Inc.), major ions (Ca^{2+}, Mg^{2+}, Cl^-, CO_3^{2-} and HCO_3^-) were measured by titrimetry. Furthermore, chlorophyll-a content was determined spectrophotometrically after an extraction with methanol (Wetzel & Likens, 1991). All measuring were conducted following ISO protocols. The mean value characteristic to each lake was calculated from data recorded at five sampling points.

Surface sediment sampling and cladoceran analysis

Sediment samples were taken from a boat using a gravity corer at five points from each lake. The top two centimetres of the core was utilized for further analyses. Subsamples (1 cm^3) for the Cladoceran analyses were treated with 10% KOH, 10% HCl, and concentrated HF solutions and were then sieved through a 35-µm mesh (Frey 1986), and diluted in 10 cm^3 of distilled water. Slides were prepared from 0.1 ml of each sample, and examined under a microscope (100, 200, and 400 magnifications). The composition of the Cladoceran community was estimated on the basis of determination of at least 300 individuals in each subsample (Korhola & Rautio 2001). Two to six slides from each sample were scanned. In cases where less than 300 individuals were counted, the entire sample was assessed. To determine the density of Cladocerans only well preserved chitinous remains were taken into consideration (headshields, carapaces, postabdomens, postabdominal claws, and ephippia; fragments were counted only if unambiguous diagnostic marks were found). Body parts found most frequently in the samples were used to estimate the abundance of each taxa per unit volume (density: individuals cm^{-3}). Relative abundance were calculated using this raw dataset. Identification was carried out using the keys and descriptions of Frey (1950, 1962, 1988, 1991), Goulden & Frey (1963), Gulyás & Forró (1999), Sebestyén (1965, 1969, 1970, 1971), Szeroczyńska & Sarmaja-Korjonen (2007) and Whiteside *et al.* (1978). The five samples from

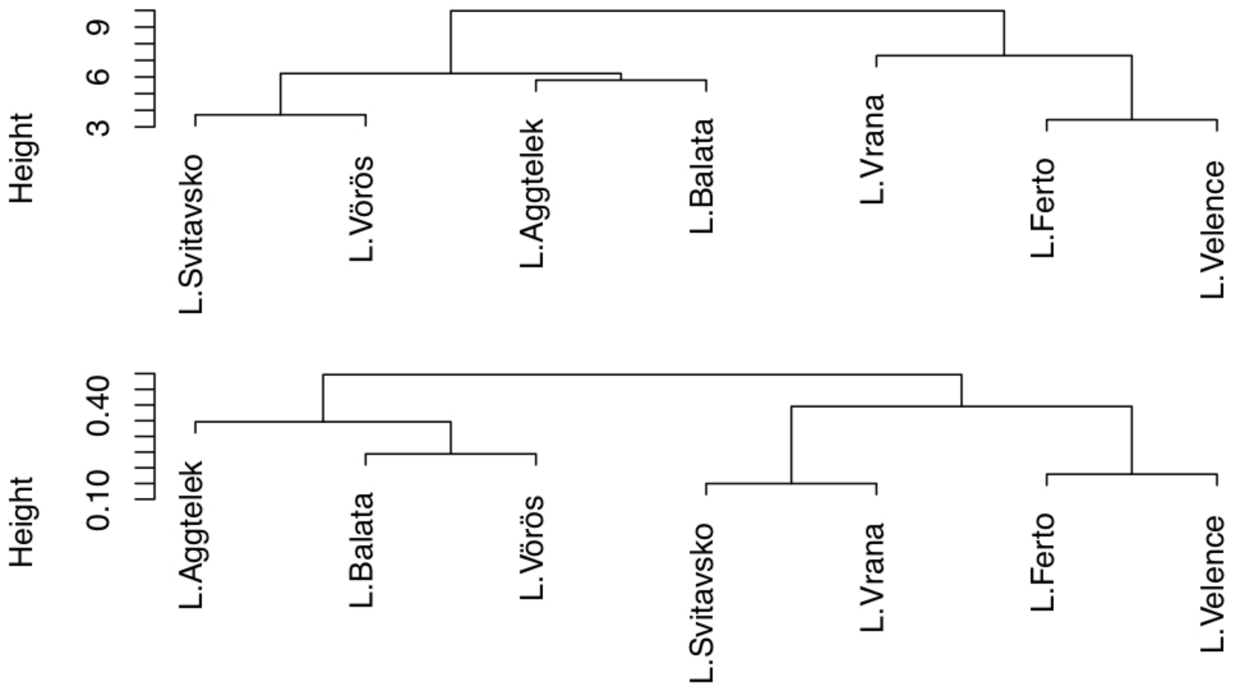

Fig. 2. Cluster diagram of lakes by the environmental parameter (Eucledian distance with Ward methods: supper panel), and by cladoceran species (Bray-Curtis dissimilarity with Ward methods: lower panel).

each lake were counted separately, and then a mean value was calculated for each lake for further analysis.

Statistical analysis

Statistical analyses were carried out on the Cladocera relative abundance data. The Hill's N2 numbers were calculated for each sample and species (Hill 1973; Korponai *et al.* 2011). Species having a N2 <2 were excluded from the analysis, the removed species accounting for less than 20% of all the individuals recorded from the samples. The relative abundance of each species was calculated and values were arcsine square root transformed. The environmental parameters were used as a concentration value, hence pH was converted to H^+-ion concentration, then all concentrations were standardized.

To characterize lake groups constrained hierarchical cluster analysis (Ward's method) was applied on Bray-Curtis dissimilarities of cladoceran relative abundances. The same method was used for environmental parameters based on their euclidean distances. Similarity Percentage (SIMPER) analysis, with a Bray-Curtis measure, was performed to assess which taxa are primarily responsible for the observed differences between the lakes groups. Constrained redundancy analysis (RDA), cluster and simper analyses were carried out on the transformed data, using R (R Development Core Team, 2010) with vegan package (Oksanen *et al.* 2010).

RESULTS AND DISCUSSION

Lakes showed a strong differentiation in size and in the amount of macrophyte-covered area, since the lakes with high macrophyte cover or small in size grouped in one cluster, while the large lakes with less macrophyte cover grouped in the other cluster (Fig. 2 upper panel). The pH varied between 5.4 and 8.6, the conductivity distributed in wide range and it varied between 73 $\mu S\ cm^{-1}$ and 3860 $\mu S\ cm^{-1}$ (Table 1). Ion composition suggested two main lake groups. One group, including Lake Aggtelek, Lake Vörös and Lake Svitavsko, was characterized by a dominance of calcium-hydrogen-carbonate ion, whilst the second group, incorporating Lake Ferto and Lake Velence, could be characterized with a sodium-hydrogen-carbonate water. Due to wetland environment the water chemistry of Lake Baláta was characterized by calcium-sulphate ion dominance. Lake Vrana had sodium-chloride type brackish water (Fig. 3).

Thirty-two cladoceran species were found in the seven lakes (Table 2). Recorded species have wide tolerance spectra, and are able to colonize very different kinds of habitats (Korhola & Rautio 2001). The most common and most abundant species were *Chydorus sphaericus*, *Alona rectangula* and *Bosmina longirostris*. The Cladocera communities of Lake Vörös and Lake Aggtelek can be characterized by the presence of *Dunhevedia crassa*. In Lake Baláta, besides the most abundant species mentioned above, *Alonella excisa* occurred in high number. Although Lake Ferto and Lake Velence were characterized by the high amount of the most common species, the occurrence of *Oxyurella tenuicaudis* was also remarkable. The Mediterranean lakes had dense submerged macrophyte cover supporting abundant populations of *Acroperus harpae* and *Alona affinis* (Table 2).

Cladocera data yielded DCA gradient lengths of 1.1927 and 0.71347 SD for axes 1 and 2, which favours for the use of redundancy analysis (constrained RDA). The set currently have more environmental parameters than lakes, and in the RDA environmental data accounted for 100% of the variance

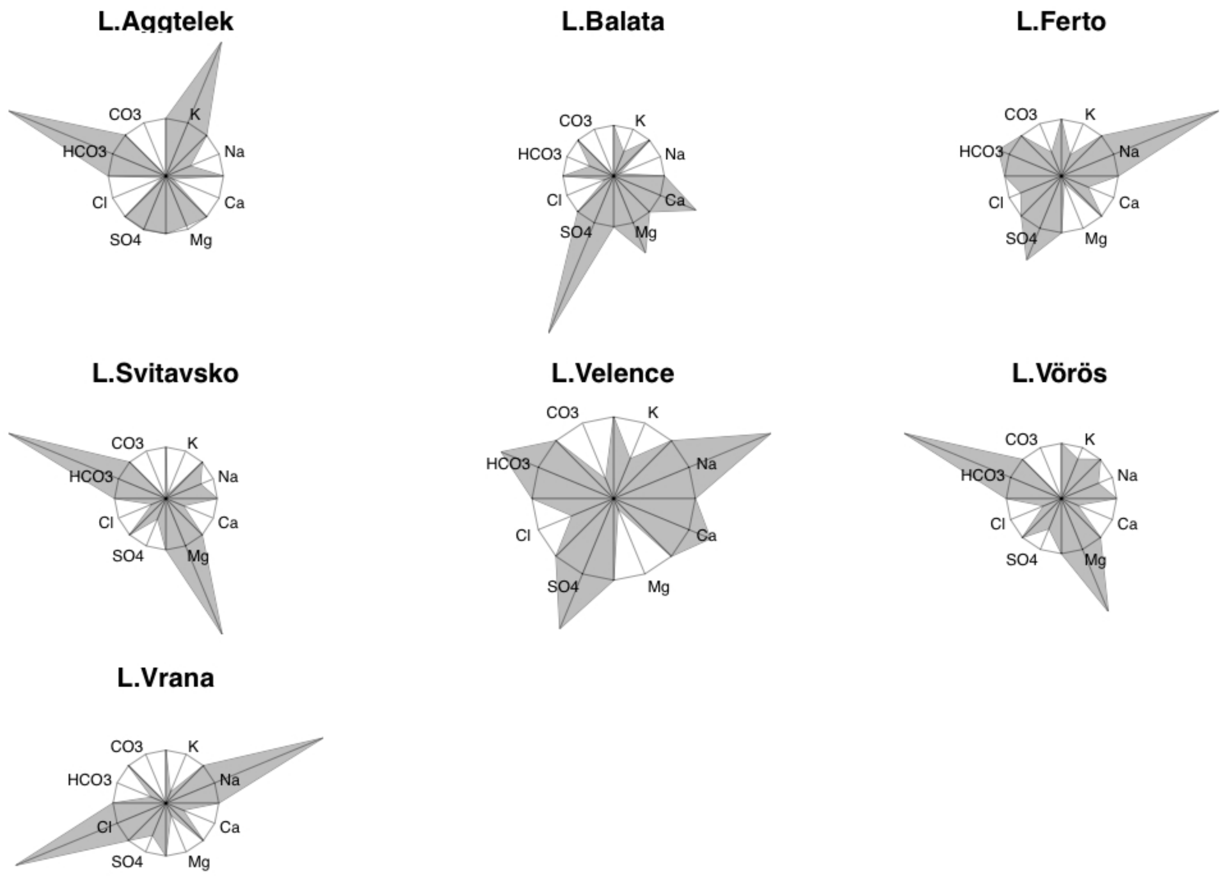

Fig. 3. Maucha diagram of the major ions.

Table 1

Lake characteristics and chemical parameters

	L. Aggtelek	L. Vörös	L. Baláta	L. Fertő	L. Velence	L. Vrana	L. Svitavsko
Latitude (°)	48.47002	48.47311	46.31494	47.73612	47.21514	43.90956	43.021859
Longitude(°)	20.51118	20.54277	17.20676	16.71889	18.61295	15.55744	17.784334
Area (ha)	1.13	1	174	7500*	2800	3000	1300
Macrophyte cover (%)	100	30	100	70	30	70	100
pH	7.5	7.6	5.4	8.6	8.1	8.3	7.1
Conductivity (µS/cm)	616	179	73.8	2072	1855	3860	259
Chlorophyll-a (mg/m^3)	56	19	7	12	21	<1	<1
TP (mg/l)	0.349	0.045	0.297	0.051	0.641	0.013	0.026
TN (mg/l)	2.160	0.610	2.900	2.060	2.073	0.1	0.2
Ca^{++} (mg/l)	92	36	27	38	36	97	53.5
Mg^{++} (mg/l)	7	3	17	88	203	83	4
Na^{+} (mg/l)	23	6	1	459	287	660	7
K^{+} (mg/l)	77	3.9	2.6	37	44	27	0.4
Cl^{-} (mg/l)	5.1	10	8	244	229	1143	11.5
SO_4^{--} (mg/l)	62	<25	117	372	529	181	0
HCO_3^{-} (mg/l)	311	112	30	481	786	137	166
CO_3^{-} (mg/l)	0	0	0	88	66	0	0

* – Hungarian part only

Table 2

Relative abundance of Cladocera species

	L. Aggtelek	L. Vörös	L. Baláta	L. Fertő	L.Velence	L. Vrana	L. Svitavsko
Acroperus harpae	0.09	4.81	3.45	0.58		2.64	7.66
Alona affinis	0.09		3.45	1.26	0.002	8.02	8.82
Alona costata	0.35			0.16			
Alona guttata	5.24	0.96	5.84	0.92	0.15	3.29	17.46
Alona quadrangularis	0.17		0.53			2.54	2.97
Alona rectangula	34.47	8.65	30.5	15.51	47.28	24.07	18.2
Alona sp.							0.35
Alonella excisa	0.96	0.96	10.08	0.04	0.14	3.61	0.06
Alonella exigua			4.77	0.07	0.07	0.09	
Alonella nana			2.12	0.27	0.03		8.72
Bosmina longirostris		0.96	2.65	13.14	12.73	34.26	18.64
Camptocercus rectirostris			1.86	0.36			0.35
Ceriodaphnia ephippium	1.48	0.96	0.53	0.06	0.26		0.09
Chydorus sphaericus	32.55	16.35	25.46	39.71	34.18	12.54	10.52
Daphnia longispina-group		0.96					
Daphnia magna	1.13						
Daphnia pulex-group	7.07	0.96					0.03
Daphnia sp.	0.17	0.96			0.17		0.04
Diaphanosoma sp.				2.8	0.04		
Disparalona rostrata		0.96	1.06	0.17	0.02	0.03	0.48
Dunhevedia crassa	14.83	0.96					
Eurycercus lamellatus	0.09			0.32	0.09	0.24	0.96
Graptoleberis testudinaria			2.92	0.09		0.29	0.47
Leptodora sp.				0.06			
Leydigia acanthocercoides				6.71	1.34	6.43	0.82
Leydigia leydigi			1.59	2.34	0.42	1.4	0.68
Monospilus dispar				0.1	0.002	0.02	0.38
Oxyurella tenuicaudis	0.26	21.15	0.53	14.37	1.82		
Pleuroxus laevis		2.88	1.33		0.05		0.1
Pleuroxus trigonellus	0.87	4.81	0.53	0.57	1.12	0.52	1.95
Pleuroxus truncatus	0.17	31.73	0.27				0.01
Pleuroxus unicatus							0.2
Sida crystallina				0.11			
Simocephalus sp.		0.96	0.53	0.26	0.09		0.02

in Cladocera data. The eigenvalue of the first two RDA axes were 0.07354 and 0.04938, accounting for 72% of the cumulative variance in the cladoceran data. Lake area, latitude, macrophyte cover, pH, conductivity and hardness had the lowest multicollinearity ([Variance Inflation Factor (VIFs)] < 10). It revealed that they were the most determinant environmental variables in the distribution of cladoceran species (Table 3, Fig. 4).

The separation of small lakes was confirmed by cluster analysis. Since these small lakes are situated in the northernmost area, the latitude effect obtrudes size in the RDA analysis (Fig. 4). The second group consisted of large lakes (Lake Ferto, Lake Velence, Lake Vrana and Lake Svitavsko) and this group can be divided into further groups such as Hungarian (Lake Ferto, Lake Velence) and Mediterranean (Lake Vrana and Lake Svitavsko) large lakes. Although characteristic of Lake Vrana is similar to Hungarian large lakes (Lake Velence and Lake Ferto, Fig. 2 upper panel) its Cladocera community is closer to Lake Svitavsko (Fig. 2 lower panel, Fig. 4). Abundances of *A. rectangula*, *C. sphaericus*, *B. longirostris* populations were greater in large lakes than in small ones, thus playing a significant role in the separation of these groups. Moreover, greater population sizes of *A. rectangula* and *C. sphaericus* were recorded in Hungarian large lakes, whilst *B. longirostris* and *A. guttata* were more abundant in the Croatian lakes.

We conducted a similarity percentage (SIMPER) analysis with Bray-Curtis similarity indices to indicate the taxa responsible for the faunal differences between lakes. Macrophyte cover, chlorophyll-a and conductivity were selected as

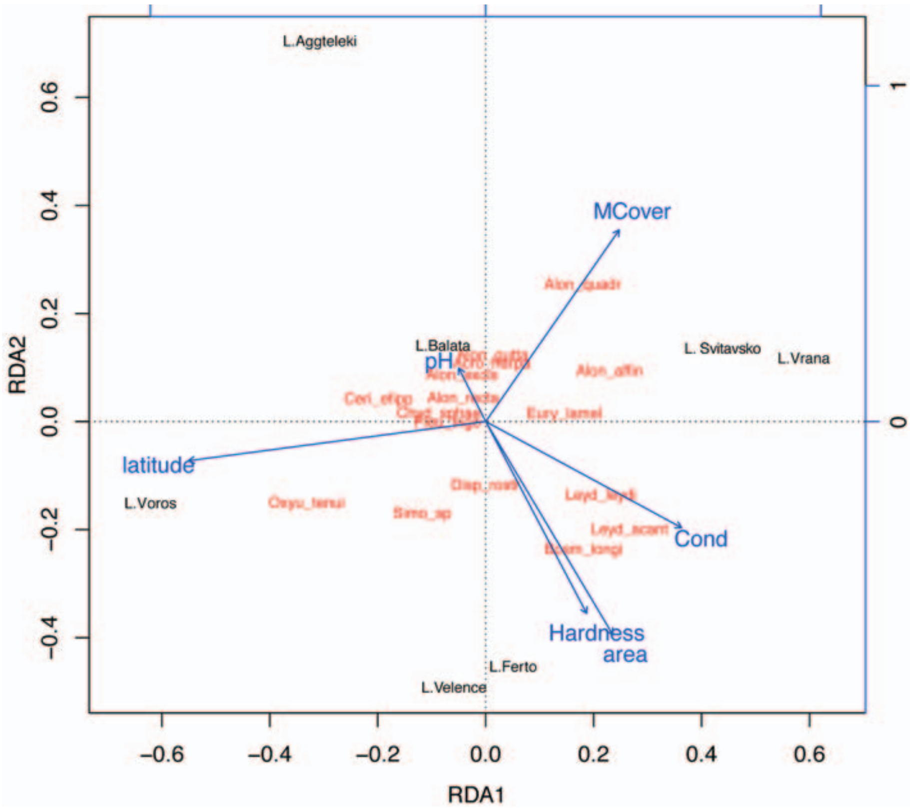

Fig. 4. Redundancy analysis (RDA) biplot of zooplankton species and environmental scores. (*Acroperus harpae*: Acro_harpa, *Alona affinis*: Alon_affin, *A. guttata*: Alon_gutta, *A. quadrangularis*: Alon_quadr, *A. rectangula*: Alon_recta, *Alonella excisa*: Alon_excis, *Bosmina longirostris*: Bosm_longi, *Ceriodaphnia ephippium*: Ceri_efipp, *Chydorus sphaericus*: Chyd_sphae, *Disparalona rostrata*: Disp_rostr, *Eurycercus lamellatus*: Eury_lamel, *Leydigia acanthocercoides*: Leyd_acant, *L. leydigi*: Leyd_leydi, *Oxyurella tenuicaudis*: Oxyu_tenui, *Pleuroxus trigonelus*: Pleu_trigo, *Simpocephalus* sp.: Simo_sp.).

Table 3

Variance Inflation Factor of explanatory environmental variables

Area	Latitude	Macro-phyte cover	pH	Conducti-vity	Hardness
2.488046	1.572175	1.817284	3.568177	4.209104	3.351000

environmental factors into SIMPER analysis. SIMPER revealed that the abundance of *A. rectangula* and *C. sphaericus* increased, while that of *B. longirostris* and *A. guttata* decreased with increasing macrophyte cover. With the increase of chlorophyll-a content the abundance of *A. rectangula* and *C. sphaericus* decreased while that of *B. longirostris*, *A. guttata* and *A. affinis* increased. These species were regarded as indicators of moderate and high trophic status (Chen *et al.* 2010; Korponai *et al.* 2010), which is in line with the measured high chlorophyll content in these lakes. Beside latitude, conductivity also had an effect on the abundance of *A. rectangula*, *C. sphaericus*, *B. longirostris* and *Leydigia acanthocercoides*.

Our surveys revealed that the composition and distribution of Cladoceran communities only slightly differ across the investigated geographical gradient, even though the lakes show clear separation in environmental parameters. Shallow lakes usually have extended littoral zone, thus phytophilous species can be found in high number (Korponai *et al.* 2010). Although in our lake set the macrophyte cover was high, *A. harpae*, *Pleuroxus* sp. and *E. lamellatus* occurred in high abundances in Lake Svitavsko only. The bottom of Lake Svitavsko was totally covered by submerse pondweed among reed patches, while the coverage on the bottom of Lake Vrana was lower (70%). Although *A. quadrangularis* is regarded as a mud-living species (Korhola & Rautio 2001, Nykänen *et al.* 2010), it shows a clear relationships with macrophytes as, in our samples, it was found in lakes with high macrophyte cover. We found high abundances of *Oxyurella tenuicaudis* in Lake Vörös, which is a small lake, and Lake Ferto. This species occurs in eutrophic small ponds (Boix *et al.* 2007, Bjerring *et al.* 2009, Nykänen *et al.* 2010, Kattel 2011). Although these lakes were highly different in most of environmental variables (Table 1, Fig. 2 upper panel), the common characteristic was the high turbidity.

In contrast with our expectation the Cladocera communities of the studied lakes were very similar, consisting of common species. These lakes were inhabited by Cladocera species with wide tolerance indicating a narrow ecological gradient length (eigenvalue of first two DCA axes). Due to the high proportion of generalist species in our samples along with the higher sensitivity of multivariate ordinations to specialist species the power of discrimination process in our analysis was limited. The main ecological drivers could not be identified and still are to be analysed using a greater sample set and statistical methods more sensitive to generalist species. For studying the effect of climate change, incorporating other environmental parameters into the analysis and the extension of the data set with other shallow lakes across the entire climatic gradient have to be seriously considered.

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