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Small scale macrophyte–environment relationship in an oxbow-lake of the Upper-Tisza valley (Hungary)

B. A. Lukács[1,4], Gy. Dévai[2] and B. Tóthmérész[3]

[1] *Department of Tisza Research, Balaton Limnological Research Institute of the Hungarian Academy of Sciences, Debrecen, Bem sq. 18/c, H-4026 Hungary*
[2] *Department of Hydrobiology, University of Debrecen, POB. 57, H-4010 Debrecen, Hungary*
[3] *Department of Ecology, University of Debrecen, POB. 71, H-4010 Debrecen, Hungary. E-mail: tothmerb@science.unideb.hu*
[4] *Corresponding author. E-mail: marsilea@freemail.hu*

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Abstract: We tested the relationship between water chemical variables and macrophyte vegetation in an oxbow-lake of the Upper-Tisza, Hungary. There were 42 relevés in random plots of 2 m by 2 m and 20 chemical variables (Ca, Fe, Hydrogen-carbonate, K, carbonate, Kjeldahl-nitrogen, chloride, COD(Cr), Mg, m-alkalinity, Mn, Na, NH_4, NO_2, NO_3, dissolved ortho-phosphate-P, total phosphorus, pH, sulphate and conductivity) and a biological one (chlorophyll a) were measured. Detrended canonical correspondence analysis was used to explore the species-vegetation-water chemical variables relationship. Our results revealed that there were pronounced differences both in the vegetation and the chemical variables among the different kinds of vegetation patches. According to the DCCA, Trapetum natantis, Glycerietum maximae, Ceratophyllo-Nymphaeetum albae and Typhetum angustifoliae associations could be separated based on the relevés and environmental variables. Kjeldahl nitrogen and carbonate were found to be the most important variables. Our results suggest that water chemical variables had strong influence on vegetation development. The groups of relevés identified by the DCCA were coherent with classical phytosociological categories.

Abbreviations: COD – Chemical Oxygen Demand, DCCA – Detrended Canonical Correspondence Analysis.

Nomenclature follows: Simon (2000) for taxa; Borhidi (2003) for syntaxa.

Introduction

The essential role of macrophytes in the metabolism of freshwater bodies is emphasized in the literature (Wetzel 1975, Wiegleb 1984). Aquatic macrophytes are recognized as having important influence on a lake's physical and chemical environment and there is mounting evidence that they can dramatically alter lakes material and energy flows. Many papers (Frodge et al. 1990, Barendregt and Bio 2003) deal with the issue how macrophytes influence water chemistry on macro-scale. We also have information on how does it work on fine-scale (m^2) but from oligotrophic lakes (Tóth and Braun 1995, Lee and McNaughton 2004, Somodi and Botta-Dukát 2004). These studies have shown that the dominant vegetation has a significant effect on the overall water quality of a lake. The vegetation of oxbow-lakes depends on the age of the oxbow-lake and/or successional state. Oxbow-lakes in different successional state have their own characteristic vegetation and water chemistry features (Lukács et al 2009). Dévai et al. (1992) classified oxbow-lakes based on their geo-morphological features as deep-pond, pond, and marsh. The most species rich type of them is the deep-pond which is characterized by deep water, relatively small area, and diverse marshy and aquatic vegetation. It is also characterized by many different kinds of micro-habitats. Surveying these micro-habitats, we can find all kinds of habitats from the deep water to the marshy vegetation.

Vegetation and water chemistry are closely related (Barendregt and Bio 2003, Heegaard et al. 2001, Kłosowski 2006). However, their relationships at the scale of micro-habitats are largely unexplored. Hence we chose a deep-pond type oxbow-lake in the Upper-Tisza valley, which was characterised by mosaic vegetation structure, and where most of micro-habitats were in good ecological condition (Wittner et al. 2004) to examine the vegetation of a species rich, eutrophic oxbow-lake and to explore the relationship between water chemistry and aquatic and marshy vegetation.

There is an association between the abiotic environment and the vegetation type in an oxbow-lake. In this paper, we tested the mutual influence between the abiotic factors and vegetation in such a habitat. Our study may provide useful information for the nature management and protection of these rare, diverse habitats and also may be useful during the implementation of Water Framework Directive of the European Union.

Table 1. Classes and groups of associations, and the studied associations of Boroszló-kerti-Holt-Tisza oxbow-lake with the identification numbers of water samples referring to Table 2.

Association classes	Alliances	Associations	No. of relevés	Water sample id.
Phragmiti-Magnocaricetea	I. Phragmitetalia	Glycerietum maximae Hueck 1931	5	8
Reed beds		Typhetum angustifoliae (Soó 1927) Pignatti 1953	4	2
		Sparganietum erecti Roll 1938	4	11
	II. Oenanthetalia aquaticae	Oenantho aquaticae-Rorippetum amphibiae Lohmayer 1950	3	10
Potametea	III. Potametalia	Trapetum natantis V. Kárpáti 1963	9	1
Rooted submerged and floating vegetation		Ceratophyllo-Nymphaeetum albae (V. Kárpáti 1963) Borhidi 2001	5	5
		Myriophylletum verticillati Gaudet 1924	3	7
		Myriophyllo verticillati-Nupharetum luteae W. Koch 1926	3	9
Lemnetea	IV. Hydrocharetalia	Ceratophylletum demersi Hild 1956	3	4
Free-floating vegetation		Hydrocharitetum morsus-ranae van Langendonck 1935	2	6
		Stratiotetum aloidis Nowinski 1930	1	3

Materials and methods

Study site

The studied oxbow-lake (Boroszló-kerti-Holt-Tisza) is in the Carpathian Basin, at the Hungarian part of the Upper-Tisza region (NE Hungary) (Fig. 1). It is a naturally detached oxbow-lake (Dévai et al. 1998), with a nonlinear, curved shape. The studied oxbow-lake showed unusual zonation of vegetation compared to ponds, because the bed showed the morphology of a river. The point where the oxbow-lake was detached was the shallowest part of the pond bed. Hence, extensive marshy vegetation did not encompass all around the oxbow-lake, only the upper and lower part of the oxbow-lake was covered with *Glyceria* and *Typha* stands. The center area of the oxbow-lake was covered with different kinds of aquatic weed vegetation such as *Potamogeton*, *Nymphaea* and *Trapa* stands. Aquatic and shoreline vegetation were surveyed using random plots of 2m by 2m based on a GIS map and computerized randomization. Altogether there were 42 relevés in the 11 associations (Table 1); we registered percentage cover of macrophytes according to Braun-Blanquet (1951).

Geoprocessed aerial photographs and Arc GIS 9.0 were used to determine the main attributes of the oxbow-lake. The area was 134 036 m^2. Cover of the marshy vegetation was 31%, and the cover of aquatic vegetation was 33%. The depth of water ranged between 4.9-0.6 m.

Figure 1. Location of the study site. The Hungarian part of the Upper-Tisza region is indicated by a rectangle. The location of the study site is denoted by an asterisk.

Water samples and laboratory procedures

There was a five litre water sample collected in each association. Water samples were analysed in the laboratory (Table 2). Chemical- and biological variables of the water samples (Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, NH_4^{+}, NO_2^{-}, NO_3^{-}, a-chlorophyll, hydrogen-carbonate, carbonate, Kjeldahl-N, chloride, COD-Cr, conductivity, pH and total-phosphorus, dissolved orto-PO_4, SO_4^{2-}, m-alkalinity) were analyzed within 4 hours after sampling. In situ measurements (conductivity and pH) were also carried out by a water quality multiprobe (Hydrolab 4a, Hach LDO™). These field surveys provided the same results as laboratory measurements.

Statistical analysis

Detrended canonical correspondence analysis (DCCA, Lepš and Šmilauer 2003) was used to assess the relationships between the relevés of the studied plant association and the measured water chemical variables. Percentage cover was square root transformed to decrease the influence of highly dominant species. Environmental variables were not transformed. The result of DCCA was displayed as triplot; CANOCO package was used during the calculations (Lepš and Šmilauer 2003). Significance of these relationships was tested by Monte-Carlo method (Cade and Richards 1996, Ter Braak and Šmilauer 1998).

Results

There were 32 species altogether, and the average number of species in the relevés was 4.9. According to the DCCA (Fig. 2), lesser reed-mace (Typhetum angustifoliae) and sweetgrass (Glycerietum maximae) associations were clearly separated from the other associations in the DCCA scatterplot. Water chestnut carpets (Trapetum natantis), and northern *Nymphaea* beds (Ceratophyllo-Nymphaeetum albae) were also separated. There was a mesh of medium-tall waterside associations (Oenenthetalia aquaticae) and eu-hy-

Table 2. Water chemical variables of the Boroszló-kerti-Holt-Tisza oxbow-lake. Names of the associations 1-11 are listed in Table 1.

Associations		1	2	3	4	5	6	7	8	9	10	11
a-chlorophyll	µg/L	7.1	6.3	4.4	8.2	0.8	5.5	44	130.2	0.8	18.9	15.2
Ca	mg/L	32	30	31	29	27	31	37	27	27	32	37
Fe	mg/L	0.21	0.26	0.20	0.15	0.16	0.21	0.35	0.50	0.16	0.22	0.35
Hydrogen-carbonate	mg/L	118	126	124	123	123	121	155	138	123	140	154
K	mg/L	2.0	2.0	2.0	1.9	2.0	2.1	1.6	1.7	2.0	2.0	1.7
carbonate	mg/L	0.0	0.0	0.0	6.0	8.4	0.0	9.6	6.0	8.4	0.0	0.0
Kjeldahl-nitrogen	mg/L	3.3	2.8	2.8	3.9	4.4	3.9	3.9	5.0	4.4	3.9	3.3
chloride	mg/L	8	9	10	8	9	9	8	9	9	8	7
COD(Cr)	mg/L	16.0	17.9	15.0	17.0	15.1	16.9	34.0	205.0	15.1	14.1	17.9
Mg	mg/L	4.4	4.1	4.2	4.0	3.9	4.4	4.9	4.2	3.9	4.3	5.1
m-alkalinity	mg/L	1.9	2.1	2.0	2.0	2.0	2.0	2.5	2.3	2.0	2.3	2.5
Mn	mg/L	0.09	0.11	0.06	0.01	0.01	0.01	0.15	0.25	0.01	0.03	0.22
Na	mg/L	7	7	7	7	8	8	7	9	8	7	8
NH_4	mg/L	0.07	0.06	0.06	0.07	0.08	0.06	0.06	0.10	0.08	0.11	0.07
NO_2	mg/L	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.03	0.01	0.02	0.01
NO_3	mg/L	0.15	0.16	0.12	0.09	0.08	0.39	0.16	0.22	0.08	0.13	0.19
Diss. orthophosphate-P	mg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.01	0.02	0.01
Total phosphorus	mg/L	0.10	0.10	0.10	0.13	0.09	0.11	0.25	2.89	0.09	0.07	0.08
pH	mg/L	7.86	7.84	7.87	8.46	7.95	7.83	7.73	7.32	7.95	7.91	7.77
sulphate	mg/L	7	7	8	8	5	4	10	9	4	9	8
conductivity	µS	176	175.8	175.6	172.3	172	171.5	204.5	178.7	172	176.3	207.4

Table 3. Correlation coefficients between environmental variables and canonical correspondence axes (see Fig. 2). *: p<0.05.

	Kjeldahl nitrogen	carbonate	Plant nutrients (*Total-P, COD*)	pH	NO3	sulphate
Axis 1	0.2215*	–0.3730	0.1041	0.3406	0.8767	–0.0334
Axis 2	0.5551	0.2240*	–0.3709	0.2058	0.3493	0.4085

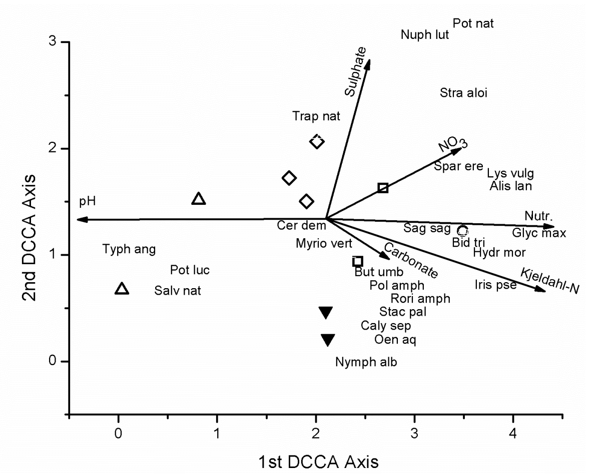

Figure 2. DCCA ordination triplot with environmental variables represented by arrows and the 42 relevés by the indication of the groups of relevés and species by numerical figures. Eigenvalues: λ_1=0.62, λ_2= 0.26, λ_3=0.03, λ_4=0.002. Notations: ▼ – Ceratophyllo-Nymphaeetum albae, △ – Typhetum angustifoliae, ◇ – Trapetum natantis, O – Glycerietum maximae, □ – Mixed vegetation (Oenantho aquaticae-Rorippetum amphibiae and associations from Hydrocharetalia group). The species names are as follows: Alis lan - *Alisma lanceolata,* Bid tri - *Bidens tripartitus,* But umb - *Butomus umbellatus,* Caly sep - *Calystegia sepium,* Cer dem - *Ceratophyllum demersum,* Glyc max - *Glyceria maxima,* Hydr mor- *Hydrocharis morsus-ranae,* Iris pse - *Iris pseudacorus,* Lys vul - *Lysimachia vulgaris,* Myrio vert - *Myriophyllum verticillatum, Nuph lut - Nuphar lutea, Nymh alb - Nymphaea alba,* Oen aq - *Oenanthe aquatica,* Pol amph - *Polygonum amphibium,* Pot luc - *Potamogeton lucens,* Pot nat - *Potamogeton natans,* Rori amph - *Rorippa amphibia,* Sag sag - *Sagittaria sagittifolia,* Salv nat - *Salvinia natans,* Spar ere - *Sparganium erectum,* Stac pal - *Stachys palustris,* Stra aloi - *Stratiotes aloides,* Trap nat - *Trapa natans,* Typh ang - *Typha angustifolia.*

drophyte associations (Hydrocharetalia) in the bottom of the ordination scatterplot.

We found by forward selection of variables that Kjeldahl-nitrogen and carbonate were the most significant variables to determine the occurrence of vegetation (Table 3). The first two axes of canonical correspondence analysis explained the 25.9% and 43% of the variance of species-environment relations (explainable inertia), so we consider these results informative. Kjeldahl nitrogen was significantly correlated ($P < 0.05$) with axis 1, while carbonate was significantly correlated with axis 2 (Table 3).

Kjeldahl nitrogen was correlated with reed-beds. Together with nutrients the high values of Kjeldahl nitrogen were mainly determined the position of *Glycerietum maximae* association, and correlated negatively with *Typhetum angustifoliae* association.

High amount of carbonate and low amount of sulphate together with the different amount of Kjeldahl nitrogen were correlated with the floating broad-leaved carpets. Northern Water lily beds (Ceratophyllo-Nymphaeetum albae) created a quite distinct group in the positive part of Kjeldahl nitrogen gradient. Low amounts of sulphate and nitrate were also characterising them. Their cognate association, *Nuphar* beds (Myriophyllo verticillati-Nupharetum luteae) separated from them and faded into a group of medium tall waterside associations (mixed vegetation); characterised with lower amount of carbonate and Kjeldahl nitrogen. The floating plant association represented in the present study was water chestnut carpets (Trapetum natantis) and characterized with medium amount of carbonate and low amount of Kjeldahl nitrogen.

The "mixture group" consists of marshy and aquatic vegetation types. These stands are mainly characterized by short size, and mosaic structure. The relevés were in the centre of the DCCA scatterplot (Fig. 2). Neither of the water chemical variables was characteristic to that kind of vegetation.

Characteristic species of Typhetum angustifoliae association were *Typha angustifolia*, and *Salvinia natans* (Fig. 2). Characteristic species of reed sweetgrass beds (Glycerietum maximae ass.) were the following: *Hydrocharis morsus-ranae*, *Lysimachia vulgaris*, *Bidens tripartitus*, *Alisma lanceolata*, *Iris pseudacorus*, *Sagittaria sagittifolia*, *Sparganium erectum* and *Stratiotes aloides*. Characteristic species of water chestnut carpets were *Trapa natans* and *Ceratophyllum demersum* and for northern Water lily beds *Nymphaea alba* was a characteristic species. High concentration of carbonate was characteristic to the broad-leaved pondweed carpets.

Discussion

The relevés spread along a continuum in the ordination space with high overlaps, although there were differences among their floristic composition. Our results suggest that macrophyte associations in a eutrophic oxbow-lake were well defined, both in floristic composition and percentage cover and in water chemical demands. Moreover, the group of relevés revealed by DCCA triplot (see Fig. 2) were in a good agreement with the traditional phytosociological associations. The "mixture vegetation" group was comprised by marshy and aquatic vegetation types. They usually situated at the transitional zone of the high marshy vegetation, forming a transition between the eu-hydrophyte associations (Lemnetea, Potametea phytocoenoses) and reed-beds (Phragmiti-Magnocaricetea phytocoenoses). The species of the Phragmitetalia and Potametalia groups were also frequently occurring in this group. Water chemical features showed the same transitional behaviour.

Nitrogen forms and carbonate were the variables that exactly reflected the structure of the associations provided by the ordination scatterplot and the categorization according to classical phytosociology. Since these variables were strongly correlated with sulphur, phosphorous and calcium-hydrocarbonate content as well, general nutrient availability appeared to be important. This corroborates the results of Barendregt and Bio (2003) for macrophyte associations in running waters and also the results of Toivonen and Huttunen (1995), Heegaard et al. (2001) and Kłosowski (2006) from oligotrophic lakes in Finland, Northern Ireland and Poland, respectively. Our findings also indicated the importance of Kjeldahl nitrogen in determining the occurrence of plant associations. Similar studies from Central Europe were reported from oligotrophic lakes and fens (Hájková et al. 2004, Navrátilová and Navrátil 2005, Kłosowski 2006).

Our findings were in agreement with the data reported from numerous works of other authors (Toivonen and Huttunen 1995, Vastergaard and Sand-Jensen 2000, Heegaard et al. 2001); they pointed out the importance of the carbonate complex in influencing the distribution of submerged plants. Our results also confirm the findings of Kłosowski (2006) for the calcium-hydrocarbonate and nitrogen complexes demands of *Potamogeton lucens*, and *Myriophyllum verticillatum*.

Extensive *Typha* and *Glyceria* stands were correlated with high conductivity; COD, total-phosphorous and low pH conditions due to high oxidization of organic components may represent a possible route towards neutral marshes (or fens perhaps) (Somodi and Botta-Dukát 2004).

The coherence of a standing water morphology and vegetation is well known in large-scale studies (geographical scale). However, the relationship of fine-scale vegetation pattern and physico-chemical variables is not explored in details especially in eutrophic waters. Similar fine-scale surveys were only made in oligotrophic ponds (Barendregt and Bio 2003, Heegaard et al. 2001, Kłosowski 2006). Our fine-scale findings together with similar surveys at other scale (between ponds; Lukács et al. 2009) revealed a new aspect of macrophyte based water qualification. In conclusion, we underline that this is one of the first studies dealing with the relationship of the vegetation and environmental variables in a eutrophic standing water. The present data and those obtained by other authors show that in spite of the high ecological plasticity of aquatic plants (Wiegleb 1984) as well as the typological and geographical diversity of water habitats (Murphy 2002), many phytocoenoses-habitat relationships have not only regional but also general character. Being dominated by specific submerged aquatic species, the phytocoenoses could be good indicators of various micro-habitat conditions in pond ecosystems. The macrophyte assessments in the European countries show that macrophytes can be used for an ecological state assessment at a local scale (Tóth et al. 2008, Penning et al. 2008, Schaumburg et al. 2004). Our results may be useful for the ecological status classification and monitoring of surface water bodies in Water Framework Directives (WFD 2000).

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