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THE RELATIONSHIP BETWEEN MACROPHYTE VEGETATION AND HABITAT FACTORS ALONG A MIDDLE-SIZE EUROPEAN RIVER

ABSTRACT: The influence of habitat factors on macrophytes distribution was studied along the Hron river – one of the longest Slovakian rivers (length 298 km; average flow rate – 56 $m^3 s^{-1}$ near the outfall into the Danube) and important tributary of the Danube river. Along the river bed, 19 sections were selected according to approximately regular distances and with and without apparent industrial or agricultural influence. Each river section was 500 m in lenght, and was divided into 5 subsections with a constant length of 100 m. In each subsection, the abundance of all macrophytes was assessed using a five-level scale, from rare to very abundant (Plant Mass Estimate, PME), and habitat factors were measured or assessed. Only one side of river bed was assessed except the upper part, where plants occur across the river bed and therefore the whole river bed was assessed. PME data were transformed into "plant quantity" using the function $y = x^3$ (y – "plant quantity", x – PME; cf. Kohler and Janauer 1995) and their numerical derivatives were calculated for each river section. These are: the Relative Plant Mass – RPM (percentage of "plant quantity" of each species weighted by the river section length, formula (1) and the Mean Mass Total – MMT (index of mean PME of each species with regard to the full length of the river section, formula (2). Species richness of macrophytes (hydrophytes) is low; only 11 species were found. More than 50% of river sections contain only filamentous algae, *Rhynchostegium riparioides* (Hedw.) Cardot, and *Myriophyllum spicatum* L. According to the RPM, taxa can be ordered as follows: *Batrachium penicillatum* Dumort. (RPM ≈ 65%), *Myriophyllum spicatum* (RPM > 19%), filamentous algae (RPM ≈ 6%), *Fontinalis antipyretica* Hedw. (RPM > 5%), *Rhynchostegium riparioides* (RPM > 3%) and other species RPM ≈ 0.6%. Canonical correspondence analysis (forward selection) showed 6 habitat factors with significant effect on macrophyte vegetation pattern in the river: the distance from river outfall (river km), temperature and conductivity of water, the width of the river bed, bed material, and human land-use in the surrounding landscape. A direct impact of agricultural or industrial agglomerations was manifested more/less only in the increase of species diversity (H´ ranging from 0.99 to 1.28). Some macrophytes significantly react on habitat changes by changing the MMT. The MMT of filamentous algae, *Batrachium penicillatum* and partly *Rhynchostegium riparioides,* increased with altitude, distance from the outfall of the river, and flow velocity, but decreased with the width of the river, conductivity of water, average air and water temperature. An obviously contrasting trend was revealed for *Myriophyllum spicatum*. *Fontinalis antipyretica* slightly prefers colder water and *Batrachium penicillatum* shows a positive correlation with pH.

KEY WORDS: human effect, aquatic plant, species-habitat relationship, macrophyte vegetation, Hron river, Slovakia

1. INTRODUCTION

The recent interest in macrophytes research is associated with the expectation of using macrophytes as bioindicators (Kohler 1982, Tremp and Kohler 1995, Kelly and Whitton 1998), as well as with the effort of establishing measures for the assessment of water quality based on macrophytes (e.g. Schneider and Melzer 2003; Schaumburg *et al.* 2004).

The variability of macrophyte vegetation in rivers is associated with several factors. The most typical and frequent are the hydrological (water depth and flow velocity; e.g. Sabbatini *et al.* 1998), geographical (distance from source, river connectivity, catchment area; e.g. Demars and Harper 2005, Scarlett and O´Hare 2006) and chemical factors (water conductivity, nutrients; e.g. Schaumburg *et al.* 2004, Schneider and Melzer 2004). If nutrients are evenly distributed, physical characteristics play a more important role (Demars and Harper 2005). On the other hand, the studies in rivers under different climatic or geological conditions showed a strong influence of local chemical parameters, like both ammonia and nitrate nitrogen and both total and soluble reactive phosphorus (Dawson and Szoszkiewicz 1999, Schneider and Melzer 2004). Often, macrophyte vegetation is affected by a combination of several factors (Dodkins *et al.* 2005). This coexistence of many factors must be taken into account within the assessment of the ecological integrity of river ecosystems (Harper *et al.* 2000).

Human impact represents a specific problem, as it modifies some of the above-mentioned natural factors, chemical parameters, but also some hydrological characteristics and consequently diversity and abundance of macrophytes. The regulation of rivers, artificial protection of riverbanks, dam constructions, and several other activities are significantly reflected in the variability of macrophyte vegetation (Onaindia *et al.* 1996, Baatrup-Pedersen and Riis 1999, Bernez *et al.* 2004b, Abou-Hamdan *et al.* 2005).

Both kinds of changes, the alteration of habitat and the subsequent changes of vegetation, are usually differently manifested along the longitudinal gradient. Generally, nutrient enrichment, reduction of current velocity and increase of anthropogenic pressure affect floristic diversity and abundance of macrophytes in downstream reaches, mainly of lowland rivers. With growing distance from the source of a river, the occurrence of pollution-tolerant macrophytes increases, that can indicate the environmental condition of river (Bernez *et al.* 2004b).

Most Central European studies of the interactions between habitat factors and distribution of macrophytes in running waters were done in the part of a single river (e.g. Paal *et al.* 1996, Janauer *et al.* 2003, Hrivnák *et al.* 2006) or several rivers within one geographical region or catchment (e.g. Schaumburg *et al.* 2004, Szoszkiewicz *et al.* 2006). Less frequently, these interactions are studied along the whole river lengths (e.g. Germ *et al.* 2004).

Concerning the mentioned facts, we decided to accomplish our study along total length of one of the largest rivers in Slovakia – Hron (298 km) by sampling within successive sections. The river valley represents a long-term and important transport corridor connecting many agglomerations and industrial zones, where historical settlements existed as early as during the Palaeolithic period (Šiška 2002), and which has been crossed by important roads already since the Middle Age (Žudel 1980). In the upper parts, the river flows through natural mountain landscape (Lower Tatra Mts, Slovenské rudohorie Mts), with relatively low human impact. Along the river, the amounts of discharged agriculture waste, further also urban and industrial waste gradually increase. Therefore, data from distant points provide an optimum study material to follow several objectives: 1) which factors represent the most significant variables affecting the variability of macrophyte vegetation in a river? 2) what is the relationship between selected habitat variables and the detected macrophytes? 3) which factors and which macrophytes (their diversity and abundance) are mostly influenced by industrial or agricultural agglomerations, or human activities along the river.

Table 1. Selected habitat characteristics of the upper, middle and lower part of the Hron river (see Fig. 1) calculated from the measured values within the respective river sections during the field research in September 2005.

Part of river		Altitude m	Width of river m	Temperature of water ° C	Conductivity of water µS cm^{-1}	pH
Upper	Mean	535	15	12.9	230	8.8
	SD	.	.	2.2	27.8	0.1
Middle	Mean	246	42	16.4	336	8.7
	SD	.	.	2.6	25.4	0.1
Lower	Mean	118	80	19.5	410	8.7
	SD	.	.	1.4	20.5	0.2

2. STUDY SITE

The study was carried out at the Hron river (48° 49′ 30″ N – 19 ° 00′ 50″ E; 47 ° 49′ 08″ N – 18 ° 44′ 40″ E) which represents the second longest river (length 297.4 km; catchment area – 5464.54 km^2), and one of the most important tributaries of the Danube river in Slovakia with an average flow rate of 56 m^3 s^{-1} near its outfall into the Danube (Fig. 1). The river origins at the boundary between the Nízke Tatry and Slovenský Raj mountain ranges at 934 m a.s.l. and reaches the Danube near the village of Kamenica n/Hronom at 103 m a.s.l. From the source to the outfall, the climate along Hron changes from moderately cool region to a warm and very dry region (Faško and Šťastný 2002, Lapin *et al.* 2002). Upper part of river (Fig. 1) lies in the submontane belt, Carpathian phytogeographical region and within region from moderately cool to moderately warm and humid climate. Middle part lies in colline belt, Carpathian phytogeographical region and within region from moderately humid to moderately dry warm climate. At the end, the lower part is situated in the planare belt, Pannonian phytogeographical region and within region with dry and very dry warm climate. Selected habitat characteristics of the mentioned three parts of river are presented in Table 1.

Major part of the river was regulated and affected by strong human activities in the past and the human influences have lasted until the present time. Therefore, the Hron river belongs to the most modified and polluted rivers in Slovakia. Only the upstream reaches of the river have clean water (*www.shmu.sk*).

3. METHODS

Field research was carried out in September 2005. We selected 19 river sections (Fig. 1) with standardized length of 500 m according to: 1) more or less regular distances between sections, 2) alternating sections with and without apparent industrial or agricultural influence. Each river section was divided into 5 subsections with constant length of 100 m. In each subsection, all macrophytes (bryophytes, vascular plants and macroscopis algae) were sampled and the Plant Mass Estimate (PME) was assessed using a five-level scale (1 – rare, 2 – occasional, 3 – frequent, 4 – abundant, 5 – very abundant; Kohler *et al.* 1971, Kohler 1978, Kohler and Janauer 1995, Janauer 2003). It is an visual estimate of the amount of each macrophyte species in each subsection, which is not based on cover estimates, but takes into account the three-dimensional development of the plant stands (Janauer 2003). Only one side of river bed

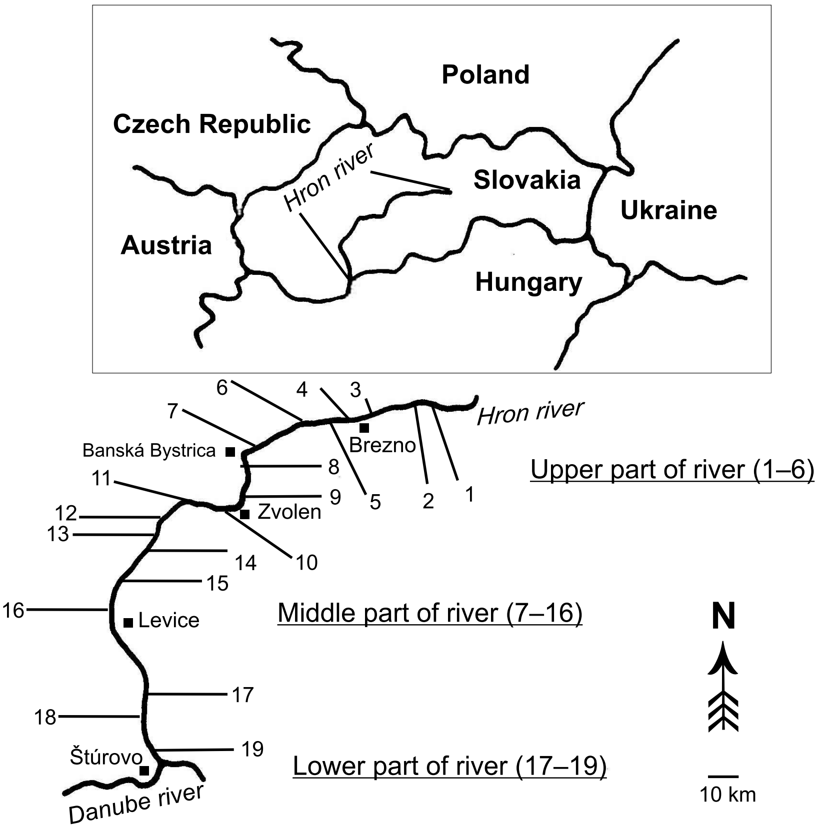

Fig. 1. Map of the study area with the localities of the sampling sites (river sections; 1–19) and different parts of river (upper, middle and lower).

was assessed except in the upper part, where plants are growing across the river bed and therefore the whole river bed was assessed. Selected habitat variables were assessed:

– altitude (mean altitude for river section in m),

– river km (distance from river outfall),

– climatic district following Lapin *et al.* (2002); 1 – moderately cool, 2 – moderately warm and humid, 3 – warm and moderately humid with cool winter, 4 – warm and moderately humid with mild winter, 5 – warm and moderately dry, 6 – warm and dry, 7 – warm and very dry,

– bank (size of substrate structures: solid rock > 6.3 cm, gravel 0.2–6.3 cm, sand – 0.063–0.2 cm, fine inorganic substrate < 0.063 cm),

– human-made bank (yes or no),

– bed material (substrate on which the plants grow – rock and large human-made material, gravel, sand or fine substrate),

– flow velocity class (stagnant, low flow velocity – from just visible to ca. 30 cm s^{-1}, medium flow velocity – ca 35–65 $cm \cdot s^{-1}$, high flow velocity – more than 70 cm s^{-1}),

– prevailing CORINE land-use type (only three basic groups were used – human transformed areas, meadows and pastures, forests and shrubs),

– width of river and depth of water (mean values for river section measured within all subsections in m and cm, respectively),

– shading (relative cover of woody vegetation growing on banks in %),

– human effect (position of river section related to industry and agricultural agglomeration),

– temperature (° C),

– pH and conductivity (µS cm^{-1} in 20°C) of water, which were measured in the field using a combined pH-meter/conductometer WTW pH/Cond 340i.

PME data were transformed into "plant

quantity” using the function $y = x^3$ (y – “plant quantity”, x – PME; cf. Kohler and Janauer 1995). Based on the transformed Plant Mass Estimate data, their numerical derivatives were calculated for each river section:

– the Relative Plant Mass (RPM; percentage of “plant quantity”of each species weighted by the river section length in the order of dominance) was calculated according to formula (1),

$$RPM[\%]_i = \frac{\sum_{j=1}^{k} M_{ij}^3 \cdot L_j \cdot 100}{\sum_{i=1}^{n}\sum_{j=1}^{k} M_{ij}^3 \cdot L_j} \quad (1)$$

where M_{ij} = estimated mass of the *i*th species in the *j*th subsection, and L_j = length of the *j*th subsection,

– the Mean Mass Total (MMT; takes into account the logarithmic nature of the PME scale and is weighted by the river section length, with regard to full length of the river section; see Kohler and Janauer 1995 for details) was calculated according to formula (2),

$$MMT_i = \sqrt[3]{\frac{\sum_{j=1}^{k} M_{ij}^3 \cdot L_j}{L}} \quad (2)$$

where M_{ij} = estimated mass of the *i*th species in the *j*th subsection, and L_j = length of the *j*th subsection, L = total length of the survey units (subsections).

The procedure for the calculation of numerical derivatives was downloaded from the web-site of project “Multifunctional integrated study Danube corridor and catchment (*www.midcc.at*). CANOCO 4.5 for Windows package (ter Braak and Šmilauer 2002) was used for running Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA). Gradient length for the first DCA axis was 3.852, indicating that the unimodal model was suitable for the analysis. Rare species (occurrence only in one river section: *Batrachium trichophyllum* (Chaix) Bosch, *Lemna gibba* L., *L. minor* L., *Potamogeton trichoides* Cham. et Schltdl. and *Spirodela polyrhiza* (L.) Schleid.) were downweighted. The MMT index was used as a species-abundance indicator for the analysis. Post hoc correlations of unconstrained axes with the variables and correlations among variables were used. CCA was used to assess the vegetation-variables relationship. Six variables best explaining the vegetation variability were identified using forward selection (conditional effect). Each of the studied variables was tested by Monte Carlo permutation test with 9999 unrestricted permutations (ter Braak and Šmilauer 2002). The relationship between the MMT values of individual species (only species with occurrence in 6 and more river sections were used) and habitat variables was assessed by Spearman’s rank correlation coefficient; the program STATISTICA (Statsoft 2001) was used for the calculations.

The index of species diversity H´ was calculated using Shannon’s formula (3) (Whittaker 1972).

$$H' = -\sum_{i=1}^{s} N_i \ln N_i \quad (3)$$

where N_i = quantity of the species *i*/total quantity of all species, *s* = total number of taxa in the community.

The nomenclature of the non-vascular and vascular plants follows Marhold and Hindák (1998).

4. RESULTS

Number of macrophytes in the whole river is obviously low – we found only 11 taxa, here in alphabetical order: *Batrachium penicillatum* Dumort., *B. trichophyllum*, *Ceratophyllum demersum* L., *Fontinalis antipyretica* Hedw., *Lemna gibba*, *L. minor*., *Myriophyllum spicatum* L., *Potamogeton pectinatus* L., *P. trichoides*, *Rhynchostegium riparioides* (Hedw.) Cardot, *Spirodela polyrhiza* and filamentous algae. The mean number of macrophyte taxa including the group “filamentous algae” per river section was 3.26 (ranging from 1 to 6). The diversity in the river sections is similarly low, H´ = 1.12. More than 50% of river sections contain only filamentous algae, *Rhynchostegium riparioides* and *Myriophyllum spicatum*. According to the Relative Plant Mass (RPM, formula 1) value, taxa can be ordered as follows: *Batrachium penicilla-*

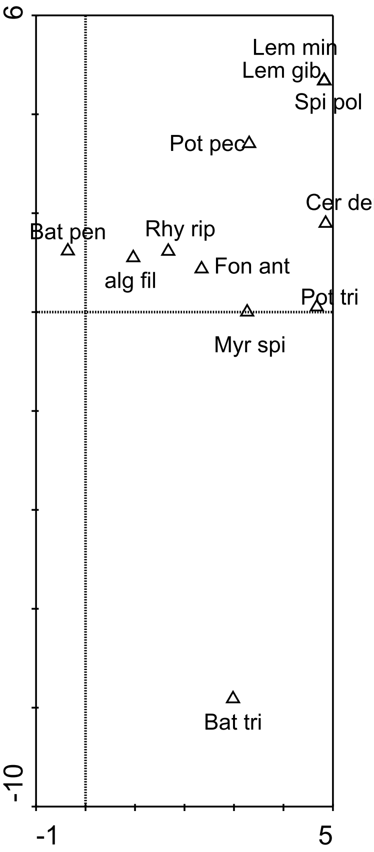

Fig. 2. Position of the macrophytes on the first two axis of DCA along the course of the Hron river (*Batrachium penicillatum – Bat pen*, *B. trichophyllum – Bat tri*, *Ceratophyllum demersum – Cer dem*, *Fontinalis antipyretica – Fon ant*, *Lemna gibba – Lem gib*, *L. minor – Lem min*, *Myriophyllum spicatum – Myr spi*, *Potamogeton pectinatus – Pot pec*, *P. trichoides – Pot tri*, *Rhynchostegium riparioides – Rhy rip*, *Spirodela polyrhiza – Spi pol* and filamentous algae – *Alg fil*).

tum (RPM almost 65%), *Myriophyllum spicatum* (RPM more than 19%), filamentous algae (RPM 6%), *Fontinalis antipyretica* (RPM more than 5%), *Rhynchostegium riparioides* (RPM more than 3%) and other species RPM 0.6%.

Along the first DCA axis, there is an apparent shift from *Batrachium penicillatum* to species like *Ceratophyllum demersum* or *Potamogeton trichoides*. There is more variation along the second axis, which is affected in this case by the position of the outlier *Batrachium trichophyllum* (Fig. 2). Cumulative percentages of variance of species data for the first two axes are 45% and 50%, respectively.

The main gradient along the first DCA axis explains 7 out of 17 habitat variables. This gradient can be considered as a complex one, since it included geographical (post-hoc correlations with the first axis: River km -0.90, Altitude -0.84, Climate district 0.83), physical and hydrological (Flow velocity class -0.84, Width of river 0.73, Temperature of water 0.72), as well as chemical (Conductivity of water 0.91) variables (Fig. 3). The second DCA axis is correlated mainly with Conductivity (-0.63), Temperature of water (-0.59) and Bed material (0.40). The sequence of river sections along the first DCA axis corresponds more or less to the order from the source to the outfall (1–19; Fig. 3).

All habitat variables explain together more than 96% of species variability (CCA analysis). Marginal effect of variables is shown in Table 2. First seven variables are statistically significant. Forward selection of variables within CCA revealed 6 variables in the dataset which are most related to vegetation variability (conditional effect; Table 2 and Fig. 4) and explain almost 54% of this variability. Other variables with a high marginal effect, such as Flow velocity class, Climate district and Altitude, did not succeed in forward selection, because of their close relationship with River km, Conductivity of water, Temperature of water and Width of river (Table 3). The first CCA axis was most correlated with distance from river outfall (River km -0.93), whereas the second CCA axis was related to human made bank (-0.34).

For six macrophyte species, we found a significant relationship with certain habitat variables (Table 4). MMT values (formula 2) of filamentous algae, *Batrachium penicillatum* and partly also *Rhynchostegium riparioides* increased with altitude, distance from the outfall of the river, and flow velocity class, but decreased with the width of the river, conductivity of water, average air temperature (Climate district) and water temperature. An evidently contrasting trend was revealed for *Myriophyllum spicatum*. The moss *Fontinalis antipyretica* slightly prefers colder water and only *Batrachium penicillatum* shows a positive correlation with pH (Table 4).

Table 2. CCA analysis – marginal and conditional effects of habitat variables to variability of macrophyte vegetation along the Hron river (for details see Methods).

Environmental variable	Marginal effect	*P*	Conditional effect	*P*
River km	0.598	***	0.598	***
Flow velocity class	0.562	***	.	.
Conductivity of water	0.562	***	0.173	**
Climatic district	0.533	***	.	.
Altitude	0.512	***	.	.
Temperature of water	0.488	***	0.130	**
Width of river	0.455	***	0.106	*
pH of water	0.186	n.s.	.	.
Human transformed areas	0.173	n.s.	0.072	*
Grassland	0.151	n.s.	.	.
Forest	0.097	n.s.	.	.
Shading	0.086	n.s.	.	.
Depth of water	0.072	n.s.	.	.
Human made bank	0.070	n.s.	.	.
Bed material	0.067	n.s.	0.128	**
Human effect	0.055	n.s.	.	.
Bank	0.049	n.s.	.	.
Total inertia	1.535	.	.	.
Explained variance by all variables	1.481	.	.	.
Explained variance by signif. variables	.	.	1.208	.

*** *P* <0.001, ** *P* <0.01, * *P* <0.05, n.s. – not significant. For an explanation of habitat variables, see Methods.

Among all selected variables, which are related to human effect on macrophyte vegetation variability, the most important was the factor Human transformed areas, as a traditional evidence of a strong exploitation (land use) of landscape along the river. The variables Human made bank and Human effect were found to be poorer predictors (see Table 2 and Fig. 4). Nevertheless, the variable Human effect partly affects species diversity, which was lower in the river sections located upstream from the largest agricultural or industrial agglomerations (H´ = 0.99), than those downstream of these sources of eutrophication (H´ = 1.28). Some other assessed variables (e. g. Temperature, pH, Conductivity of water) were changed slightly or not at all by the Human effect. In the more exploited landscape along the downstream reaches of the river, natural forests (Forest) and seminatural habitats (Grassland) become more and more rare and the average value of Shade decreased (42% *vs.* 89%).

Table 3. Post hoc correlations (from the DCA weighted correlation matrix) among habitat variables along the Hron river.

	Alt	River km	Bank	Bed	Flow	Width	Depth	Shading	Climatic	Temp	Cond	pH
Alt	1	.	.	.	.	.	.	.	.	.	.	.
River km	0.95	1	.	.	.	.	.	.	.	.	.	.
Bank	0.01	0.07	1	.	.	.	.	.	.	.	.	.
Bed	0.43	0.33	0.14	1	.	.	.	.	.	.	.	.
Flow	0.83	0.85	0.06	0.07	1	.	.	.	.	.	.	.
Width	-0.63	-0.70	-0.30	-0.24	-0.72	1		.	.	.	.	.
Depth	-0.09	0.02	0.36	0.24	0.06	-0.14	1	.	.	.	.	.
Shading	0.08	0.13	0.18	0.12	0.10	-0.41	0.23	1	.	.	.	.
Climatic	-0.91	-0.97	-0.09	-0.34	-0.78	0.69	-0.05	-0.23	1	.	.	.
Temp	-0.89	-0.91	-0.15	-0.51	-0.77	0.70	-0.12	-0.18	0.91	1	.	.
Cond	-0.84	-0.88	-0.01	-0.12	-0.84	0.52	0.03	0.09	0.80	0.66	1	.
pH	0.70	0.56	-0.21	0.48	0.44	-0.32	-0.14	0.02	-0.47	-0.49	-0.52	1

For an explanation of habitat variables, see list in Fig. 3 and Methods.

Table 4. Correlations between selected habitat variables and Mean Mass Total [MMT, formula (2)] of selected hydrophytes.

Macrophyte	Alt	River km	Flow	Width	Depth	Climatic	Temp	Cond	pH
Fon ant	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-0.57*	n.s.	n.s.
Rhy rip	0.56*	0.54*	0.56*	-0.55*	n.s.	-0.60**	-0.65**	n.s.	n.s.
Bat pen	0.70***	0.70***	0.65**	-0.69**	n.s.	-0.69**	-0.43*	-0.76***	0.53*
Myr spi	-0.69**	-0.69***	-0.74***	0.70***	n.s.	0.65**	0.66**	0.71***	n.s.
alg fil	0.82***	0.81***	0.90***	-0.83***	0.49***	-0.83***	-0.72***	-0.78***	n.s.

*** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$, n.s. – not significant. Abbreviations: Alt – Altitude; Flow – Flow velocity class; Depth – depth of water; Width – width of water; Climatic – climatic district; Cond – conductivity of water; Temp – temperature of water. For an explanation of macrophyte abbreviations and habitat characteristics, see list in Fig. 2.

5. DISCUSSION

5.1. Main habitat gradient

The specific feature of our research was investigate the vegetation changes within the whole course of one river in relation to continously changing distance from the outfall. Several variables are logically associated and frequently closely correlated, either positively or negatively (Table 3). Our study of the Hron river showed that the central gradient seems to represent a complex factor, encompassing geographical (River km, Altitude, Climatic district), physical and hydrological (Flow velocity class, Width of river, Temperature of water), and chemical (Conductivity of water) variables (Fig. 3). The most important factor within this complex proved to be the distance from the river outfall (River km), which was shown to be the most corre-

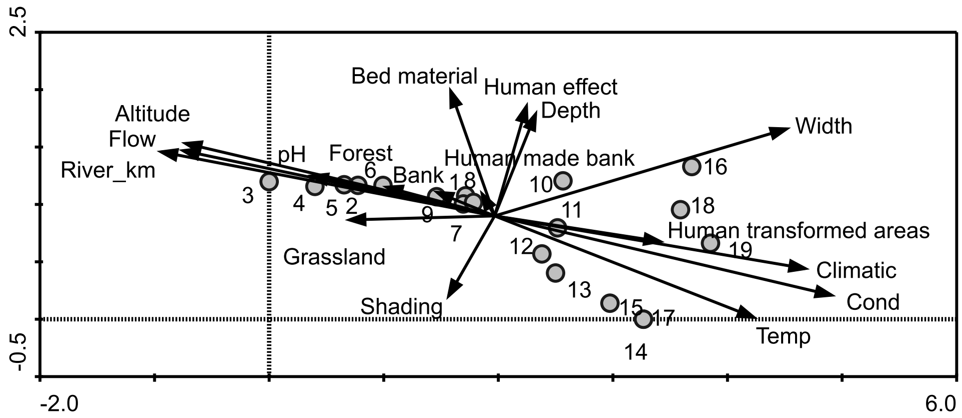

Fig. 3. DCA ordination diagram (first two axis) of river sections (1–19; Fig. 1) and post-hoc correlated habitat variables (total inertia 1.535; lenght of gradient of axis 1 – 3.852; cumulative percentage variance of species data of axis 1 – 45, axis 2 – 50). Abbreviations: Alt – Altitude; Flow – Flow velocity class; Depth – depth of water; Width – width of water; Climatic – climatic district; Cond – conductivity of water; Temp – temperature of water; land use type: Forest – forests and shrubs, Grassland – meadows and pastures, Human transformed areas. For an explanation of habitat variables, see Methods.

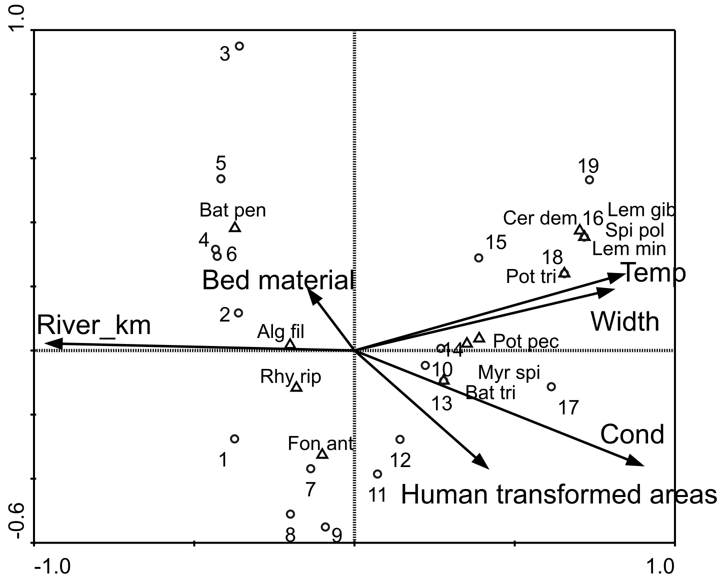

Fig. 4. CCA ordination diagram (first two axes) of both river sections (1–19; see Fig. 1) and macrophytes. Only significant variables resulting from the forward selection are shown. For the explanation of macrophyte abbreviations and habitat variables, see the list in Figs 2 and 3.

lated with the first DCA as well as CCA axis. However, several other variables were closely correlated with the distance from the outfall, such as Altitude, Flow velocity class, Width of river, Climatic district, Temperature and Conductivity of water (Table 3). Some studies (e.g. Thiébaut and Müller 1999, Bernez *et al.* 2004b, Demars and Harper 2005) demonstrated that the width of river and the amount of nutrients increase along the river, whereas altitude and flow velocity also decrease. Other studies in European rivers also revealed that main habitat gradients affecting vegetation variability in running waters are complex, whereby a combination of hydrological, geographical and chemical variables, and frequently anthropogenic changes play a major role (Onaindia *et al.* 1996, Khedr and El-Demerdash 1997, Sabbatini *et al.* 1998, Bernez *et al.* 2004b). However, in several studies, purely hydrological variables were shown to be important, e.g. flow (Janauer 2001), whereas in others it was the content of nutrients in water, which determined the abundance and distribution of macrophytes and their communities (Dawson and Szoszkiewicz 1999). In some cases, also spatial connectivity was found to be quite important (Demars and Harper 2005), but this factor was not included in our study as our research focused on one continuous river flow only.

5.2. Human impact on river vegetation

The intensity of human impact in the landscape is immediately reflected in the changes of some variables, mostly chemical and physical ones, and indirectly also in the abundance and distribution of macrophytes (e.g. Bernez *et al.* 2004b, Abou-Hamdan *et al.* 2005). Human effect is one of the factors, which weakly affect biodiversity of macrophyte vegetation in the Hron river (Table 2). The other factor connected with flow regulation (Human made bank) did not exhibit any considerable effect on the vegetation variability (Table 2), although in some cases, it may contribute to the control of macrophyte diversity and composition (cf. Baattrup-Pedersen and Riss 1999).

Human disturbances such as river regulation, dam building or water pollution generally represent a potential for changes in macrophytes' distribution (Pall *et al.* 1996; Bornette and Arens 2002; Oťaheľová and Valachovič 2002; Bernez *et al.* 2004a, b; Abou-Hamdan *et al.* 2005). Enrichment of water (e.g. nutrients) due to human impact may limit the growth and distribution of macrophytes (Cristofor *et al.* 2003, Daniel *et al.* 2005). According to our results, there is no conspicuous shift in total species variability between river sections upstream from supposed sources of pollution (e.g. agglomeration), and sections lying further downstream. Nevertheless, species diversity slightly increased in lower reaches.

5.3. Interaction between the abundance of macrophyte species and habitat variables

Filamentous algae and *Batrachium penicillatum* are the species most significantly correlated with the selected variables (Table 4). Unfortunately, in the case of filamentous algae it would be more correct to speak about group of species, which, considering its heterogeneity and indeterminacy, can hardly be taken as an indicator. The other taxon, *Batrachium penicillatum,* belongs to very rare plant species in Slovakia with unclear distribution on this territory (cf. Husák and Slavík 1982). Its occurrence in the Hron river is restricted only to the upper parts of the river (Fig. 1), where it forms a morphologically variable population with transitional tendencies into *Batrachium fluitans* (Kochjarová *et al.* 2004). Generally, within the Hron river, this species prefers higher altitudes, cooler water and also lower air temperatures, lower values of conductivity, narrower riverbeds and faster flow. Within the distribution range, it grows predominately in running waters (Cook 1966). Optimal conditions for this species are confined to waters with slow to fast flow rates in summer, with fluctuating water level, intermediate water depth, occasional biotic disturbance and oligo-meso-trophic to eutrophic trophic status (Willby *et al.* 2000). In the rivers of north-eastern Spain, *Batrachium penicillatum* had the lowest indicator values for temperature and conductivity of water among 11 other common macrophytes (Onaindia *et al.* 2005).

In the case of *Fontinalis antipyretica,* we observed only a preference of this species to cooler climatic regions (Table 4). However, the affinity of this moss to fast flowing waters and coarse substrates is known from several rivers in Europe (e.g. Dawson and Szoszkiewicz 1999; Bernez *et al.* 2004b; Hrivnák *et al.*, 2004, 2006).

The abundance of *Myriophyllum spicatum* increases with decreasing distance from river outfall, altitude and water flow velocity, and with increasing water temperature, width of river and conductivity of water (Table 4). Some of our results are supported by other studies, e.g. the affinity to the width of river (Khedr and El-Demerdash 1997), whereas other our results differed from previously published ones (e.g. absence of a significant correlation between species abundance and distance from the river source, c.f. Demars and Harper 2005; positive correlation with flow velocity, cf. Hrivnák *et al.* 2006). *Myriophyllum spicatum* overgrows mostly the middle and lower parts of the Hron river (Fig. 1) with a higher content of nutrients and pollutants. Willby *et al.* (2000) considered *Myriophyllum spicatum* to be a species with eutrophic to hypertrophic status. Similarly, numerous authors like Husák and Vořechovská (1996), Sabbatini *et al.* (1998), Kohler and Schneider (2003), Schneider and Melzer (2004), Meilinger *et al.* (2005) characterised *Myriophyllum spicatum* as a species with a wide-ranging disturbance tolerance to eutrophic waters.

For *Rhynchostegium riparioides,* optimum conditions are in the upper and middle parts of the river (Fig. 1) with a faster water flow (Table 4). Abou-Hamdan *et al.* (2005) also found a correlation between *Rhynchostegium riparioides* and upstream reaches of the river Huveaun (south-east France). Hrivnák *et al.* (2006) also documented that in the river Slatina (left tributary of Hron), the abundance of *Rhynchostegium riparioides* positively correlates with faster current velocity.

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