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Environmental effects on species richness of macrophytes in Slovak streams

Research Article

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Abstract: The effect of 19 environmental variables on species richness of macrophytes was studied in 39 Slovak streams. The studied streams were poor in species; in total, 88 macrophyte taxa were found and the average number of macrophytes per sampling site was 4, ranging from 0 to15. The most frequently occurring macrophytes were filamentous algae (occurrence at 38.6% of sampling sites), followed by *Rhynchostegium riparioides* (28.4%) and *Phalaris arundinacea* (19.3%). The strongest environmental gradient in the sampling site detected by factor analysis (factor 1 explains more than 32% variability) is related to the portion of artificial banks, shading by woody vegetation along banks, flexuosity of stream course and the portion of natural land cover in the contact zone of the stream, and can be interpreted as a natural-anthropogenic gradient. The following variables had the highest correlations with species richness of macrophytes: shading by woody vegetation (r=-0.507), portions of artificial bank (r=0.488), flexuosity (r=-0.457) and distance from stream source (r=0.388).

Keywords: *Alpha diversity • Danube catchment • Vascular plants • Bryophyte • Environmental characteristics • Factor analysis*

1. Introduction

Aquatic macrophyte assemblages in both lentic and lotic habitats are characterized by a high spatial and temporal variation of species composition, richness and environmental conditions. Streams in Europe are dynamic ecosystems hosting a diverse but relatively species-poor macrophyte vegetation compared to other aquatic habitats, [1,2]. While in ponds, rivers or ditches and also in lowland streams vascular plants prevail, bryophytes represent an important group growing in fast-flowing (sub)mountain streams [3,4]. The effort of detecting causes of differences in the macrophyte composition resulted in numerous studies of macrophyte-environment relationship. Several papers have focused on species composition in streams in relation to ecological variables [5-9] or human impact and management [10]. The acquired knowledge is applicable under the Water Framework Directive [11] where macrophytes are used as one group of the indicators of ecological status in different types of surface waters [cf. 4]. Several studies have paid attention to macrophyte changes over time [12,13] or to seasonal dynamics in relation to environmental influences [14]. On the other hand, studies focusing on the relationship between species richness and environmental conditions in streams are relatively rare [15]. The lack of information about species richness-habitat relationship in streams was the incentive for the study of this relationship in Slovak streams. Moreover, because Slovakia has 96% of its territory within the Danube catchment area, it belongs to a group of countries that have diverse ecological conditions that can affect macrophyte vegetation in streams [16].

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Accordingly, the main objectives of this study were to detect i) the species richness of macrophytes in streams and ii) which environmental variables influence species richness of macrophytes.

2. Experimental Procedures

2.1. Field sampling and laboratory analyses

Field sampling was carried out between July and August of 2006. Thirty-nine streams distributed over the whole territory of Slovakia were selected with respect to both geographical and phytogeographical regions and diversity of site conditions. Within each stream, two 100-m-long sections were selected (denoted further as sampling sites) reflecting the difference of human impact and land use. The first sampling site was situated in the upper part of a stream with relatively natural conditions, whereas the second was located in the lower part of a stream affected by human activities and with predominantly artificial land use. All macrophytes including bryophytes, vascular plants and macroscopic filamentous algae (treated as a single taxon) as well as 19 environmental variables were recorded or assessed within each sampling site (Table 1). Most variables were measured or evaluated in the field, and only selected chemical properties of water were measured in the laboratory. For these analyses, water samples were collected from each sampling site, quickly frozen and maintained at –18°C until the ammonia, nitrite, nitrate and phosphate contents were measured. Ammonia content was determined

Variable	Abbreviation	Variable characteristics	Mean	St. dev.	Min	Max
Width of water-course	Width	Average width of water-course measured in 5 sites (m)	4.088	3.042	0.5	15.2
Depth of water	Depth	Average depth of water measured in 5 sites (cm)	30.569	24.139	1.3	150.0
Artificial bank	Art_bank	Relative ratio of artificial bank in sampling site (%)	42.821	48.059	0.0	100.0
Bed material	Sediment	Prevailing bed material in sampling site[1]	2.241	1.060	1.0	4.0
Artificial bed material	Art_sed	Presence of artificial bed material (%)	5.528	16.245	0.0	80.0
Depth of bed material	Sed_Depth	Average depth of bed material measured in 5 sites (cm)	4.032	9.168	0.0	62.0
Flow velocity	F_vel	Flow velocity class[2]	1.882	0.660	1.0	3.0
Shading	Shading	Shading by woody vegetation along banks (%)	46.390	37.231	0.0	100.0
Flexuosity	Flexuosity	Shape of the stream-course[3]	2.667	1.213	1.0	5.0
Land cover	Nat_Land	Portion of natural land cover (wetlands, woody vegetation) in contact zone of sampling site (%)	38.808	42.491	0.0	100.0
Altitude	Alt	Altitude measured by GPS at the central point of a sampling site (m)	329.179	182.413	103.0	831.0
Stream source	Str_source	Distance from the stream source obtained from map (km)	14.542	10.830	1.0	46.5
Water temperature	W_Temp	Average water temperature (ºC) measured in the field	17.403	4.654	8.2	35.9
Water pH	W_pH	Water reaction (pH) measured in the field by *pH-meter/ conductometer WTW pH/Cond 340i	8.204	0.508	6.9	9.5
Water conductivity	W_Cond	Water conductivity (μS/cm; corrected to 25 ºC) measured in the field by *	348.360	217.667	35.0	1119.0
Ammonium content	NH_4^+	Ammonium content in water measured in laboratory (mg/l)	0.517	2.354	0.0	20.7
Nitrate	NO_3^-	Nitrate content in water measured in laboratory (mg/l)	1.491	1.582	0.1	9.2
Nitrite	NO_2^-	Nitrite content in water measured in laboratory (mg/l)	0.299	1.301	0.0	9.7
Phosphate content	PO_4^{3-}	Phosphate content in water measured in laboratory (mg/l)	0.342	0.884	0.0	5.2

Table 1. Basic statistics of the studied environmental variables.

[1]1 = rock and large artificial bed material, 2 = gravel, 3 = sand, 4 = fine bed material; for details see [28]; [2]1 = 0–30 cm/s, 2 = 35–65 cm/s, 3 > 70 cm/s; for details see [28]; [3]1 = absolute straight channel, 2 = straight channel, 3 = slightly sinuous channel, 4 = moderately sinuous channel, 5 = meandering channel

by ion-selective electrode at 20°C. Nitrite content was determined spectrophotometrically at λ=540 nm, after diazotation with 40 g/l sulfanilamide and 2 g/l *N*-(1-naphthyl)-ethylenediamine dihydrochloride in 10% H_3PO_4. Nitrate plus nitrite level were measured by the same method except that the samples were reduced by 1.4 g/l hydrazinsulphate, 7.5 g/l $CuSO_4$ and then neutralized adding 3 g/l NaOH prior to the diazotation. The nitrate content was then calculated as the difference in the absorbance of the same sample with and without reduction. If the nitrate content in the sample was above 0.1 mg/l, its level was controlled using ion-selective electrode at 20°C. The phosphate content in the samples was analyzed spectrophotometrically employing a modification of the method of [17], measuring the absorbance of the samples at λ=720 nm, after derivatization with ammonium-molybdate reagent containing 0.1 M sulfamic acid, 0.01 M ammonium molybdate, 0.1 M potassium antimonyl oxide tartarate and 0.1 M ascorbic acid.

2.2. Data analysis

To avoid potential bias caused by the area-richness relationship, we first tested the correlation between the area of sampling sites (length × width) and the number of detected macrophytes. The Pearson correlation was weak (r=0.17) and statistically non-significant (P=0.131). Considering this outcome, we compared α-diversity (species richness) of macrophytes within sampling sites without regard to the sampling area.

We studied primary multivariate relationships among the environmental variables using factor analysis [18,19]. Analyses were run with the number of factors increasing from two to seven. Factors were extracted using principal component analysis with the squared multiple correlations of each variable with all other variables used as a prior communality estimate. Axis rotation was done using the varimax criterion (SAS procedure FACTOR) [20], preserving orthogonality of axes. The solution with the lowest interpretable number of factors was accepted as the most parsimonious outcome.

Finally, the relationships between environmental variables and species richness of macrophytes were assessed by Pearson correlation coefficients using the Statistica software [21].

2.3. Nomenclature

The names of bryophytes and vascular plants are presented according to the Checklist of Non-Vascular and Vascular Plants of Slovakia [22]. Although most bryophytes were identified at the species level, unidentifiable specimens were pooled (only 8 specimens from 87) into either *Marchantiophyta* or *Bryophyta*. Similarly, no macroscopic filamentous algae (except *Phormidium formosum*) were determined. Therefore, they were treated collectively as filamentous algae.

3. Results

3.1. Species richness of macrophytes

In total, 88 macrophyte taxa (including the three broad groups of filamentous algae, *Marchantiophyta* and *Bryophyta*; see Appendix 1) were found at the sampling sites in Slovak streams. The studied streams were poor in species; the average number of macrophytes per sampling site was 4, ranging from 0 to 15. The most and the least frequent number of macrophytes per sampling site was 1 and 12, respectively. The most frequently occurring macrophytes were filamentous algae (occurrence at 38.6% of sampling sites), followed by *Rhynchostegium riparioides* (28.4%) and *Phalaris arundinacea* (19.3%). In addition to the above-mentioned taxa, the following four macrophytes were found at more than 10% sampling sites: *Lemna minor*, *Sparganium erectum*, *Butomus umbellatus* and *Agrostis stolonifera*.

3.2. Environmental patterns

The basic statistics for environmental variables are shown in Table 1; variation levels clearly differed among environmental characteristics.

Among factor analyses employing different numbers of factors, the best results were achieved using three factors which explained >80% of total variance while providing the lowest interpretable number of factors (the first two factors explained >60% of total variance) (Table 2). The strongest environmental gradient in the sampling site variable set seems to be dominated by decreasingly artificial character of the streams with the distance from the stream source (factor 1 explains more than 32% variability; Table 2): increasing portion of artificial banks on one hand, lower shading by woody vegetation along banks, flexuosity of stream course and portion of natural land cover in the contact zone of stream on the other hand. The second gradient (factor 2 ~30% of variance; Table 2) was related to bed material characteristics (positive correlation with both type and depth of bed material) and water chemical properties (water reaction and conductivity, as well as nitrite content in water). The weakest gradient (factor 3 ~20% of variance; Table 2) was associated with the depth of water (positive correlation), flow velocity and altitude (negative correlation).

3.3. Relationships between environmental variables and species richness of macrophytes

Taking the outcomes of the factor analysis into account, ordination plots showed that natural habitats are poor for macrophyte species in comparison to sites under human impact. The portion of artificial bank, distance from stream source, flexuosity and shading by woody vegetation best explain the variability along the first ordination axis (Figure 1). The bivariate correlation analysis confirmed this observation; the highest correlations were found between species richness and the variables associated with factor 1: shading by woody vegetation (r=-0.507), the portion of artificial bank (r=0.488), flexuosity (r=-0.457) and the distance from stream source (r=0.388). The other variables exhibited weaker correlations with species richness (ammonium content in water r=0.382, portion of natural land cover in the stream contact zone r=-0.320, depth of water r=0.315, water conductivity r=0.269 and flow velocity class r=-0.246) or correlations were non-significant.

4. Discussion

Species richness of macrophytes in Slovak streams is very low; only 4 taxa per sampling site were detected on average, ranging from 0 to 15. Considering differences in sampling area, comparable species richness has been reported in European mountain streams without human impact [1,2,4,8,23] including Slovak streams [16]. A slightly higher richness was recorded in Western Europe whereas the lowest species number per sampling site was detected in the Carpathian streams [2,4]. Generally, much higher numbers of macrophytes were observed in lowland streams [4].

Addressing the potential causes of detected species richness, our study indicates that the most important ecological variables affecting species richness of macrophytes are those associated with the natural-anthropogenic gradient. Most environmental variables significantly correlated with richness are directly associated with this gradient. The parts of streams more distant from the source (naturally, deeper and richer in accumulated bed material) are more affected by human activities. Consequently, the portion of artificial banks and pollution by nitrogen compounds and phosphates increase, whereas shading by woody vegetation on banks, flexuosity of stream course, flow velocity, and portion of natural land cover in the contact zone of streams decrease in these parts of the streams. Similar effects of natural-anthropogenic gradient or the above-mentioned environmental variables on macrophytes in

Variable	Factor 1	Factor 2	Factor 3	*Communality
Shading	**0.821**	-0.203	-0.149	0.737
Art_bank	**-0.816**	0.367	0.148	0.822
Flexuosity	**0.760**	-0.180	-0.110	0.621
Nat_Land	**0.746**	-0.191	-0.138	0.612
Str_source	**-0.685**	-0.030	**0.554**	0.777
W_Temp	-0.295	**0.811**	0.231	0.798
W_Cond	-0.257	**0.717**	0.059	0.584
NO_2^-	-0.030	**0.628**	-0.150	0.418
Sediment	-0.056	**0.608**	0.498	0.621
Sed_Depth	-0.127	**0.531**	0.062	0.302
Alt	0.230	**-0.599**	**-0.509**	0.670
F_vel	0.088	**-0.567**	**-0.508**	0.587
Depth	-0.345	-0.050	**0.680**	0.584
W_pH	-0.118	0.007	-0.442	0.209
Width	-0.464	-0.349	0.403	0.499
PO_4^{3-}	-0.061	0.334	0.338	0.229
NH_4^+	-0.130	0.142	0.209	0.080
Art_sed	-0.344	0.067	-0.130	0.139
NO_3^-	-0.016	0.044	0.081	0.009
Proportion of variance explained	0.324	0.301	0.197	

Table 2. Correlation between extracted factors and the environmental variables related to species richness of macrophytes in the studied streams.

*Loadings >0.5 are in bold. *Portion of the variance of the variables explained by the factors. Abbreviations are explained in Table 1.*

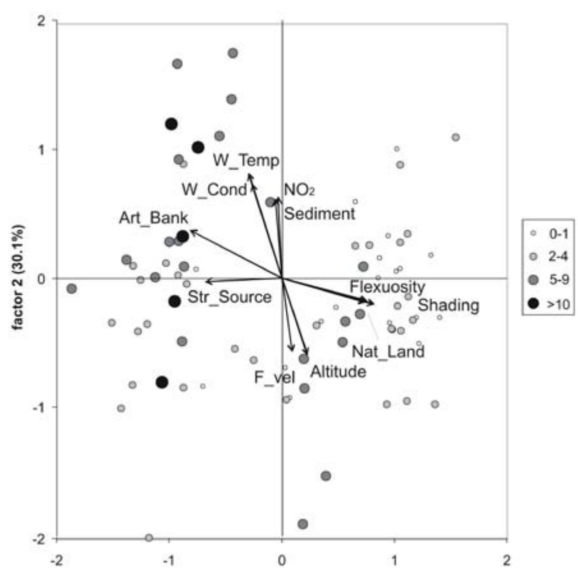

Figure 1. Ordination of sampling sites relative to the main factors and environmental variables.

streams are known from studied focusing on species composition [5,8,16,24]. Relationships between species diversity and environment are less frequent studied; for example, data from comparative biodiversity studies of various aquatic habitats in England are known [1].

Among environmental variables, shading by woody vegetation on banks and portion of artificial banks were found to be the most strongly correlated with species richness of macrophytes. Shading by woody vegetation is directly linked to the light availability for macrophytes, and consequently with several other variables such as water transparency and depth [25,26]. Our results showed that species richness of macrophytes decreased with higher portion of woody vegetation in the bank; the correlation was the strongest among the studied ecological variables. Although this specific relationship has not previously been studied in streams, studies correlating the effect of shade on species richness of macrophytes in aquatic habitats including streams provide supporting evidence for our results [1]. Another important ecological variable influencing macrophyte diversity in Slovak streams is the extent of artificial banks, where a positive correlation was found. This may be noteworthy as artificial banks exert a strong effect on biota (including macrophytes) in running waters. Artificial banks were eith uncovered or only slightly covered by woody vegetation, while natural banks had a higher portion of shrubs and trees (r=-0.825, P<0.001). In addition, artificial banks were collinear with other environmental variables, such as altitude (r=-0.467, P<0.001), flow velocity (r=-0.326, P<0.01), water depth (r=0.409, P<0.001) and bed material (r=0.349, P<0.01), which influenced species richness of macrophytes as well. It is likely that, sufficient amount of light and appropriate hydrological conditions for macrophytes are partially responsible for a positive correlation between species richness of macrophytes and portion of artificial banks. The other ecological variables such as the distance from stream source, ammonium content in water, depth of water, water conductivity, flexuosity, portion of natural land cover in stream contact zone and flow velocity class were shown to influence both species composition and richness of macrophytes in streams by earlier studies [5,8,15,27], demonstrating a comprehensive effect of several ecological variables on species richness of macrophytes in streams.

In general, previous studies of the variability of assemblage patterns, and the abundance and diversity of macrophytes in European streams have revealed a shift from species-poor, shallow and small-sized mountain streams with bryophytes to more species-rich, medium-sized lowland streams dominated by vascular plants [4]. Macrophytes in European streams showed a significant response to eutrophication/organic pollution gradients as well [24]. Similar shifts in species composition were also recorded in Slovak streams [16]. The species richness pattern found in our study indicates a natural-anthropogenic gradient, which is partially related to a number of variables and gradients.

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Appendix 1

List of the macrophytes recorded in the Slovak streams in alphabetical order.

Acorus calamus, *Agrostis stolonifera*, *Algae* filamentosae, *Alisma lanceolataum*, *Alisma plantago-aquatica*, *Alopecurus geniculatus*, *Amblystegium* sp., *Amblystegium tenax*, *Armoratia rusticana*, *Batrachium aquatile*, *Berula erecta*, *Bolboschoenus maritimus* agg., *Brachythecium rivulare*, *Brachythecium rutabulum*, *Bryophyta*, *Bryum pseudotriquetrum*, *Butomus umbellatus*, *Caltha palustris*, *Calystegia sepium*, *Callitriche* sp., *Campylium stellatum*, *Caradmine amara*, *Carex acuta*, *Carex acutiformis*, *Carex paniculata*, *Ceratophyllum demersum*, *Chiloscyphus pallescens*, *Chiloscyphus polyanthos*, *Conocephalum conicum*, *Cratoneuron filicinum*, *Eleocharis acicularis*, *Epilobium hirsutum*, *Eurhynchium speciosum*, *Fontinalis antipyretica*, *Glyceria fluitans*, *Glyceria maxima*, *G. notata*, *Hygrohypnum ochraceum*, *Hygrohypnum* sp., *Iris pseudacorus*, *Juncus effusus*, *Leersia oryzoides*, *Lemna gibba*, *Lemna minor*, *Lophocolea heterophylla*, *Lycopus europaeus*, *Lysimachia nummularia*, *Lythrum salicaria*, *Marchantia polymorpha*, *Marchantiophyta*, *Mentha aquatica*, *Mentha longifolia*, *Mentha spicata*, *Myosotis scorpioides* agg., *Myriophyllum spicatum*, *Nuphar lueta*, *Palustriella commutata*, *Pellia* sp., *Persicaria amphibia*, *Persicaria hydropiper*, *Petasites hybridus*, *Phalaroides arundinacea*, *Phormidium formosum*, *Phragmites australis*, *Potamogeton nodosus*, *Potamogeton pectinatus*, *Potamogeton perfoliatus*, *Potamogeton pusillus* agg., *Ranunculus repens*, *Ranunculus sceleratus*, *Rhynchostegium riparioides*, *Rumex hydrolapathus*, *Rumex maritimus*, *Sagittaria sagittifolia*, *Scapania* sp., *Scapania undulata*, *Scirpus sylvaticus*, *Scrophularia* sp., *Scrophularia umbrosa*, *Solanum dulcamara*, *Sparganium emersum*, *Sparganium erectum*, *Spirodella polyrhiza*, *Symphytum officinale*, *Typha latifolia*, *Urtica dioica*, *Veronica anagallis-aquatica*, *Veronica beccabunga*.