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Vegetation of Estonian watercourses, II. Drainage basin of lakes Peipsi and Võrtsjärv

Jaanus Paal[1] & Tiiu Trei[2]

[1)] *Institute of Botany and Ecology, University of Tartu, Lai St. 40, 51005 Tartu, Estonia (e-mail: jaanus.paal@ut.ee)*
[2)] *Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Riia St. 181, 51014 Tartu, Estonia (e-mail: treit@zbi.ee)*

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The general aims of the current study were (i) to continue analyses of the aquatic macrophyte vegetation in the Estonian watercourses, (ii) to develop a classification of the plant communities of the watercourses connected with the two largest lakes in Estonia, Peipsi and Võrtsjärv, (iii) to distinguish the main ecological variables which determine the occurrence of the dominating species and discriminate between the community types and, (iv) to establish a classification of the river reaches (habitats) and to identify the parameters distinguishing them. The data were clustered into 29 vegetation types of which 23 were dominated by vascular plant species, while six clusters included communities of cryptogams. Total N content in water, river width, current velocity and riverbed material proved to be the variables separating the clusters most reliably. The river reaches clustered into three habitat types and were significantly separated by river width and riverbed substrate. In comparison with the drainage basin of the Gulf of Finland several differences arise between the composition of the vegetation types. Comparison of the physical environmental parameters significantly influencing the occurrence of dominating species in the two drainage basins reveals a clear discrepancy as well: bottom coverage with fine sediments and water turbidity are important for the species of the drainage basin of the Gulf of Finland, while the river width, character of the riverbed substrate, and current velocity are significant for the species of the Peipsi–Võrtsjärv drainage basin. The rivers of the Peipsi–Võrtsjärv drainage basin have much wider variation in width (5.2–22.1 m) than those of the Gulf of Finland drainage basin (8.1–16.1 m) and in the current study the width of the watercourses is the main parameter discriminating the habitat types. For both drainage basins, current velocity and bottom substrate are of equal significance. For the vegetation types of the Gulf of Finland drainage basin, water BOD_5 also appeared to be important, while for the vegetation types of the Peipsi–Võrtsjärv drainage basin, instead of this parameter total N content in water played a significant role.

Key words: aquatic vegetation, cluster analysis, discriminant analysis, ecology, environmental variables, generalised linear model analysis, habitat types, water chemistry

Fig. 1. Rivers of the drainage basin of lakes Peipsi and Võrtsjärv and location of the studied reaches.

Introduction

The current paper is a continuation of our first paper (Paal & Trei 2004) dealing with the vegetation of the Estonian watercourses flowing into the Gulf of Finland. Now plant communities of another large drainage basin — that of lakes Peipsi and Võrtsjärv — are analysed. Like our previous paper, the present study is also part of the larger project "Biota of the Estonian Rivers", which was carried out by the River Biology Group of the former Institute of Zoology and Botany of the Estonian Academy of Sciences. The purpose of the project was to obtain a complete overview of the structure and state of the ecosystems of the Estonian rivers (cf. Järvekülg 2001).

The aim of the present paper was (i) to elaborate a classification system of the macrophyte communities of the watercourses of the drainage basin of lakes Peipsi and Võrtsjärv, (ii) to identify the factors determining the structure of the vegetation types, (iii) to establish a classification of the river reaches (habitats) and to test the parameters distinguishing them and, (iv) to find out how well the vegetation types correspond to the habitat types.

Material and methods

Study area

The drainage basin of Estonia's two biggest inland water bodies, lakes Peipsi and Võrtsjärv, comprises 623 watercourses and has the largest (14 743 km^2) area in Estonia (Arukaevu 1986;

Fig. 1). Ten studied rivers are longer than 50 km, while the length of four of them exceeds 100 km (Table 1). The average density of the network of the watercourses is 0.69 km km^{-2}. Most of the bigger rivers have a wide fanlike catchment area. The rivers located in the northern part of the drainage basin rise mainly from the southern and the eastern slopes of the Pandivere Upland and flow along a Silurian limestone plateau. The watercourses located in the southern part of the study area rise mainly from the Upland of Haanja and Upland of Otepää and flow through a landscape characterised by alternating topography, with marked differences in altitude. Usually, big rivers have a relatively deep (to 30–50 m) valley, especially in their medium course; in the lower course they flow mostly along swampy plains (Loopmann 1979). The fall and the stream gradient of the rivers are very variable. The Piusa River has the highest (208 m) fall and the Emajõgi River the lowest (3.6 m) (Hang & Loopmann 1995).

The proportion of the rivers with a very large stream gradient (> 5 m km^{-1}) accounts for 8.3%, those with a large gradient (2.0–5.0 m km^{-1}) 35.0%, those with a moderate gradient (1.0–2.0 m km^{-1}) 31.7%, and those with a small gradient (0.5–1.0 m km^{-1}) 25.0% of all studied rivers. Very low current velocity (< 0.1 m s^{-1}) is characteristic of 17.3% of the reaches; moderate or slow flow velocity (0.1–0.5 m s^{-1}) characterises 59.9% of the studied reaches; 21.3% have a velocity of 0.5–1.0 m s^{-1}, while in some (1.5%) reaches it can exceed 1.0 m s^{-1} (Järvekülg 2001).

The proportions of groundwater, melt water and rain water as the source of river discharge vary to a large degree for different rivers. In the spring-fed reaches water is cold: in 12% of the reaches water temperature was lower than 13 °C in midsummer; in 43% of the reaches temperature was 13.1–17.0 °C in this period; in 6% of the reaches it was sometimes over 21 °C. Water is slightly alkaline: in 94% of the reaches pH was 7.1–8.0 with a maximum value of 8.4. The content of dissolved oxygen in 28% of the reaches was 7.1–9.0 mg l^{-1} and it exceeded 9.1 mg l^{-1} in 58% of the macrophyte–rich reaches open to sunshine. The content of COD_{Cr} values ranged mostly between 10–35 mg O_2 l^{-1}; in 20% of the reaches it was < 10 mg l^{-1} and in 11% of the reaches 36–50 mg O_2 l^{-1}. The content of total N varied widely, from 0.16–6.88 mg l^{-3}; in 44% of the reaches it ranged between 0.51–1.5 mg l^{-3}, while in almost half of the reaches (48%) it exceeded 1.5 mg l^{-3} (Järvekülg 2001).

The upper courses of the rivers rising from the Pandivere Upland and its surroundings are characterised by the high concentration of N compounds. This is a consequence of the misuse of fertilisers on arable land in the period of 1960–1990, which led to the contamination of the upper aquifers of groundwater, especially

Table 1. Morphometrical parameters of the larger studied rivers in the drainage basin of the lakes Peipsi and Võrtsjärv.

Name	Length (km)	Catchment area (km^2)	Width (m)		Depth (m)		Annual mean discharge in lower course (m^3 s^{-1})
			in the medium course	in the lower course	in the medium course	in the lower course	
Võhandu	162	1420	25	40	2	2	11–13
Põltsamaa	135	1310	20	25	1	2	15–25
Pedja	122	2710	20	25	1	2.5	10–12
Piusa	109	796	6	15	0.6	1.6	5.5–6
Ahja	95	1070	12	35	1	2.2	7–8
Õhne	94	573	10	18	0.5	2	4–5
Väike-Emajõgi	83	1380	10	35	1.2	4	8–10
Elva	72	456	6	18	0.5	2	2.5–3.5
Amme	59	501	10	15	1.5	1.5	3–4
Kullavere	53	627	10	18	1.2	1.5	1.5–1.8

in the areas of karst geology (Järvekülg & Viik 1994). In the upper reaches of the rivers of Pedja and Põltsamaa the content of NO_3-N varied in the range 3.32–5.71 mg l^{-3} and diminished downstream. In 45% of the reaches this parameter exceeded 0.51 mg l^{-3} followed by the lower values for the area of the Peipsi Lowland. High concentrations of phosphorus (max 2.1 mg l^{-3}) were caused by point source pollution with wastewaters from settlements. In 54% of the reaches the content of total P exceeded 0.05 mg l^{-3}, while at five sites (2.5%) it exceeded 0.30 mg l^{-3} (Järvekülg 2001).

Data collection

Data were collected from 102 reaches of 32 watercourses during June and July 1991, 1993 and 1995 and altogether 280 descriptions of plant communities were compiled. As the choice of field sites depended on accessibility for transport, they were usually situated near bridges.

Data were collected from river reaches with a length of 50–100 m, where the physical conditions of the river appeared visually homogeneous. The number of the reaches varied from three to ten for the bigger rivers and from one to three for the tributaries. For every reach, the following morphometric and hydrological characteristics were estimated (Järvekülg 2001): (i) river width (m); (ii) river depth (m); (iii) current velocity in the main stream (m s^{-1}); (iv) water turbidity (1 = clear, 2 = slightly turbid, 3 = turbid); (v) bottom substrate, i.e. prevailing bed-forming material (1 = silt or clay, 2 = sand, 3 = gravel, shingle, 4 = stones, limestone blocks), (vi) extent of coverage with fine sediment (1 = none, 2 = partial, 3 = extensive). The number of points at which the measurements were made differed among the reaches; when the conditions were more or less uniform, three points were considered sufficient for averaging, in the case of varying conditions additional points were included.

Water for chemical analyses was collected without replication in each reach from a depth of 0.1–0.5 m in the main stream (Järvekülg 2001). The following variables were evaluated: (i) pH, *in situ*, with the colorimetric scale GM-58; (ii) content of dissolved oxygen (mg l^{-1}), *in situ*, with the calibrated portable oxygen meter "Marvet Junior 95"; (iii) saturation with O_2 (%) for standard water temperature; (iv) biological oxygen demand (BOD_5, mg O_2 l^{-1}) obtained from the difference between the two measurements of dissolved oxygen before and after the incubation period (5 days at 20 °C in the dark); (v) content of total N, total P, nitrogen and phosphorus compounds (mg m^{-3}) determined in accordance with Grasshoff *et al.* (1983); (vi) N/P ratio calculated as the ratio of the amount of inorganic nitrogen (NO_3-N + NO_2-N + NH_4-N) to the amount of inorganic phosphorus (PO_4-P).

In 46.6% of the 102 reaches one or two plant communities (stands, assemblages) were distinguished, in 44.8% reaches three or four communities and in nine reaches (8.8%) five or more communities were identified. As the communities were considered as vegetation patches with a relatively homogeneous floristic composition and physiognomy, both features were mainly determined on the basis of the dominating species; the area for the communities was at least 4–5 m^2 on gravel and finer bed material, or 1 m^2 on boulders and limestone blocks. Every community was analysed separately neglecting the transitional areas between them. Species abundance in the community was estimated using the following scale: 1 = species occurring with relatively low abundance, 3 = species growing in small aggregations, 5 = species forming large aggregations or occurring in communities as co-dominants, 10 = dominating species. Occurrence of floating mats of filamentous macroalgae was evaluated using a three-step scale: 1 = scarce, 2 = moderate, 3 = abundant. Bryophytes and macroalgae were sampled and identified in the laboratory. The riverbank vegetation was excluded from analysis. For every community, the predominant bottom substrate material was specified using the same scale as for the whole reaches.

The taxonomic nomenclature of vascular plants is based on "Flora Europaea" vols. 1–5 (1964–1980). The guides by Mäemets (1984) and Leht (1999) were used for the identification of vascular plants, and the guide by Ingerpuu & Vellak (1998) for bryophytes. The algae were identified after van den Hoek (1963), Vinogradova *et al.* (1980), Gollerbakh and Krasavina

(1983), Topachevski and Masyuk (1984), and Moshkova and Gollerbakh (1986).

Data processing

For the cluster analysis of the plant communities, the unweighted average linkage method (Podani 2000) with the Euclidean distance as the similarity measure was employed. The method shows good concordance with the vegetation structure of watercourses, where usually only one or two species are clearly dominating. Also the cophenetic correlation between the similarity matrix and ultrametric distances matrix was higher when estimated with this method as compared with that estimated with the other tested methods.

On the basis of the obtained dendrogram, at first small clusters, including at least three communities, were separated. In order to measure the statistical reliability of the clusters, the α-criterion (Duda & Hart 1976) was used. To obtain a better interpretation of the estimates, it is more convenient to use the corresponding probabilities, instead of the direct values, as the coefficients of indistinctness (CI) (Paal & Kolodyazhnyi 1983, Paal 1987). If the value of CI for the clusters neighbouring in the dendrogram was higher than 5.0, the clusters were merged and analysis was repeated until a reliable classification structure was established.

To test which environmental variables discriminated between the vegetation clusters, discriminant analysis was carried out. As the data of water chemistry and the physical environment in the current study were measured only as the average values for the whole reach, the same environmental data set was used for all communities recorded from that reach. Prior to analysis, the chemical data of water, except for pH, were $\log_{10}$-transformed, which enabled a closer approximation of the distribution of their residuals to a normal distribution.

Effect of the main environmental variables on the occurrence of the most abundant plant species in the watercourse reaches was tested with the generalised linear model (GLZ) analyses. For this, the water chemistry variables, except pH, were $\log_{10}$-transformed and the dominating species abundance values were rescaled to presence–absence for every reach. Prior to the GLZ analysis a correlation matrix of environmental variables was calculated and from variables having high correlation ($r \geq 0.6$) only one was selected for further analysis. The GLZ was carried out assuming that a dependent variable follows the binomial distribution; logit link regression and the maximum likelihood criterion were used, for model building backward removal procedure, correction for overdispersion and the type III sum of squares (Wald test) were applied.

The river reaches were clustered using 6 physical environmental parameters (river width and depth, current velocity, water turbidity, extent of coverage by fine sediment and prevailing bed-forming material). Cluster analysis was performed employing the minimal incremental sum of squares method, the similarity matrix was calculated according to the distance for mixed data (Podani 2000). Discriminant analysis was carried out as in the case of vegetation clusters. Taking into account that by the detrended correspondence analysis the range of sample scores for the first and second ordination axes appeared to be only 0.945 and 0.840 standard deviation units of species turnover, which indicates that a linear model for ordination is preferable (Jongman *et al.* 1995), the reaches were finally ordinated by principal component analysis.

Results

After merging several small indistinct clusters and following the rule that a cluster must include a minimum of three samples, cluster analysis yielded 29 clusters comprising 258 communities in all (Tables 2A–D). Almost all clusters (vegetation types) are significantly distinct, only cluster 25 has a slight continuum with cluster 28: $CI_{25,28} = 5.2$. The value of the cophenetic correlation of the dendrogram is 0.801, indicating its good correspondence to the structure of the similarity matrix.

The results of discriminant function analysis show (Table 3) that in terms of the environmental variables the obtained vegetation clusters are significantly separated regarding the total N content in water, river width, current velocity

Table 2A. Centroids of clusters 1 to 8. The cluster number is followed by the number of communities in the cluster (in parentheses). Med = species median value, Freq = species frequency in communities (%); if the median is expressed as an average of two values, both were taken into account in the calculation of frequency.

Species	Cluster															
	1(7)		2(3)		3(5)		4(5)		5(11)		6(10)		7(7)		8(3)	
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
Agrostis stolonifera var. *prorepens*	0	14	1	67	–	–	–	–	0	9	0	30	0	14	–	–
Alisma plantago-aquatica	0	43	0	33	0	20	0	20	0	36	0	30	0	14	–	–
Butomus umbellatus	–	–	–	–	–	–	0	40	0	18	–	–	–	–	–	–
Calla palustris	0	14	–	–	–	–	0	20	–	–	–	–	–	–	–	–
Callitriche spp.	–	–	–	–	–	–	–	–	–	–	0	10	–	–	–	–
Caltha palustris	–	–	–	–	1	60	0	40	–	–	0	10	–	–	0	33
Cardamine amara	–	–	0	33	–	–	0	20	–	–	–	–	–	–	–	
Carex acuta	1	57	0	33	0	20	0	40	0	9	0	10	0	14	0	33
Catabrosa aquatica	–	–	–	–	–	–	–	–	0	9	–	–	–	–	0	33
Cicuta virosa	0	29	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elodea canadensis	0	29	–	–	–	–	0	20	0	27	0	40	0	14	0	33
Epilobium hirsutum	–	–	0	33	–	–	0	20	–	–	0	10	0	14	–	–
E. tetragonum	0	14	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Equisetum fluviatile	10	100	1	67	1	80	1	60	0	18	0	20	0	14	–	–
Eupatorium cannabinum	–	–	–	–	0	20	0	20	–	–	–	–	–	–	–	–
Glyceria maxima	0	14	0	33	1	80	1	60	–	–	–	–	0	29	–	–
G. plicata	–	–	0	33	–	–	–	–	–	–	–	–	0	14	–	–
Hippuris vulgaris	–	–	–	–	–	–	–	–	0	18	0	10	0	14	–	–
Iris pseudacorus	–	–	–	–	–	–	–	–	0	9	–	–	0	14	–	–
Lemna minor	0	29	–	–	–	–	0	40	0	9	0	10	0	29	–	–
L. trisulca	–	–	–	–	0	20	0	20	0	18	0	10	0	14	0	33
Lycopus europaeus	0	14	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lysimachia thyrsiflora	0	14	–	–	0	20	0	20	0	9	0	20	0	14	–	–
L. vulgaris	0	14	–	–	0	10	0	20	–	–	0	10	–	–	–	–
Lythrum salicaria	0	29	–	–	–	–	–	–	0	9	–	–	–	–	–	–
Mentha aquatica	–	–	0	33	–	–	–	–	0	9	–	–	–	–	–	–
Mentha × *verticillata*	–	–	–	–	–	–	–	–	0	9	–	–	–	–	–	–
Myosotis scorpioides	0	14	–	–	1	80	0	40	0	36	1	60	0	29	–	–
Nuphar lutea	0	43	0	33	0	20	1	60	1	55	0	10	–	–	–	–
Oenanthe aquatica	0	14	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Phalaris arundinacea	0	29	1	67	10	100	0	20	0	18	1	60	–	–	0	33
Phragmites australis	0	29	1	67	0	40	10	100	0	9	–	–	–	–	–	–
Polygonum amphibium	–	–	–	–	–	–	–	–	0	9	–	–	–	–	–	–
Potamogeton alpinus	–	–	–	–	–	–	–	–	10	100	0	40	0	14	–	–
P. berchtoldii	–	–	–	–	–	–	–	–	0	9	–	–	–	–	–	–
P. crispus	–	–	–	–	–	–	–	–	–	–	0	10	–	–	–	–
P. filiformis	–	–	–	–	–	–	–	–	–	–	0	10	0	14	–	–
P. gramineus	–	–	–	–	–	–	–	–	0	9	–	–	0	14	–	–
P. gramineus × *P. natans*	–	–	–	–	–	–	–	–	–	–	0	10	–	–	–	–
P. pectinatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	33
P. perfoliatus	–	–	–	–	–	–	–	–	0	18	0	10	–	–	–	–
P. spp.	–	–	–	–	–	–	–	–	–	–	0	10	–	–	–	–
P. vaginatus × *P. filiformis*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10	100
Ranunculus circinatus	–	–	–	–	–	–	–	–	0	9	–	–	0	14	–	–
R. lingua	0	14	–	–	0	40	–	–	0	9	0	10	–	–	–	–
R. trichophyllus	0	14	–	–	–	–	–	–	0	27	10	100	1	57	1	67
Rorippa amphibia	–	–	0	33	1	60	0	20	–	–	0	10	–	–	–	–
Rumex aquaticus	–	–	0	33	0	20	–	–	–	–	–	–	–	–	–	–
R. spp.	–	–	–	–	–	–	–	–	–	–	0	10	–	–	–	–
Sagittaria sagittifolia	0	29	–	–	0	20	0	20	0	27	–	–	–	–	–	–

continued

Table 2A. Continued.

Species	Cluster															
	1(7)		2(3)		3(5)		4(5)		5(11)		6(10)		7(7)		8(3)	
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
Schoenoplectus lacustris	–	–	–	–	0	40	0	20	0	18	–	–	0	14	–	–
Scirpus sylvaticus	0	29	1	67	0	20	0	20	0	27	0	30	0	14	0	33
Scolochloa festucacea	–	–	–	–	0	40	–	–	–	–	–	–	–	–	–	–
Sium latifolium	0	43	–	–	1	60	0	40	0	27	–	–	0	14	–	–
Solanum dulcamara	–	–	0	33	0	20	1	60	–	–	0	20	0	14	0	33
Sparganium erectum s. lat.	0	43	1	67	1	100	0	40	0	46	0.5	50	0	29	–	–
S. spp.	0	29	–	–	–	–	0	20	1	64	0	30	0	43	1	67
Spirodela polyrhiza	0	14	–	–	–	–	0	40	–	–	0	10	0	14	–	–
Stachys palustris	–	–	–	–	–	–	0	20	–	–	–	–	–	–	–	–
Typha latifolia	0	29	10	100	0	20	0	20	–	–	–	–	–	–	–	–
Valeriana officinalis	0	14	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Veronica anagallis-aquatica	0	43	–	–	–	–	0	20	1	55	1	70	10	100	1	100
V. beccabunga	–	–	–	–	–	–	–	–	–	–	0	10	–	–	–	–
Filamentous macroalgae	–	–	0	33	–	–	–	–	–	–	–	–	–	–	–	–
Total number of vascular plant species in cluster	30		18		24		31		34		33		27		13	
Number of species in community	3–14		6–12		5–14		6–16		4–17		2–17		3–10		5–8	
Mean number of species per community	8		9		10		10		8		7		6		6	

Table 2B. Centroids of clusters 9 to 16. Denotations as in Table 2A.

Species	Cluster															
	9(12)		10(4)		11(4)		12(9)		13(15)		14(30)		15(27)		16(19)	
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
Acorus calamus	–	–	–	–	–	–	–	–	0	7	–	–	0	11	0	5
Agrostis stolonifera var. *prorepens*	–	–	–	–	–	–	0	11	0	13	0	3	0	7	0	5
Alisma plantago-aquatica	0	8	–	–	0	25	0	33	0	27	0	3	0	33	0	32
Bidens tripartita	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	5
Butomus umbellatus	0	33	0	25	–	–	–	–	0	20	–	–	0	15	0	26
Calla palustris	–	–	–	–	–	–	–	–	–	–	–	–	0	7	–	–
Callitriche spp.	–	–	–	–	–	–	–	–	0	7	–	–	0	4	–	–
Caltha palustris	–	–	–	–	–	–	–	–	0	7	0	3	0	11	–	–
Cardamine amara	–	–	–	–	–	–	–	–	–	–	0	3	–	–	0	5
Carex acuta	–	–	–	–	–	–	–	–	0	20	0	7	0	11	0	16
C. spp.	–	–	–	–	–	–	–	–	–	–	–	–	0	4	–	–
Cicuta virosa	–	–	–	–	–	–	0	11	0	7	–	–	0	7	0	16
Eleocharis palustris	–	–	–	–	–	–	–	–	0	7	–	–	–	–	–	–
Elodea canadensis	0	33	0.5	50	0.5	50	10	100	0	40	0	30	0	33	0	16
Epilobium hirsutum	–	–	–	–	–	–	–	–	0	7	0	3	0	4	–	–
E. palustre	–	–	–	–	–	–	0	11	0	7	–	–	–	–	–	–
E. tetragonum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	5
Equisetum fluviatile	0	25	–	–	–	–	0	44	1	53	0	17	0	33	0	11
Eupatorium cannabinum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	11
Glyceria fluitans	–	–	–	–	–	–	–	–	0	7	–	–	–	–	–	–

continued

Table 2B. Continued.

Species	Cluster															
	9(12)		10(4)		11(4)		12(9)		13(15)		14(30)		15(27)		16(19)	
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
G. maxima	–	–	–	–	–	–	0	11	0	20	0	13	0	11	0	21
G. plicata	–	–	–	–	–	–	–	–	0	7	–	–	0	4	–	–
G. spp.	–	–	–	–	–	–	–	–	–	–	–	–	0	11	0	5
Hippuris vulgaris	0	8	–	–	–	–	0	11	–	–	–	–	0	11	–	–
Hydrocharis morsus-ranae	–	–	–	–	–	–	–	–	–	–	0	3	0	22	–	–
Iris pseudacorus	–	–	–	–	–	–	–	–	0	7	0	3	0	4	0	5
Juncus articulatus	–	–	–	–	–	–	–	–	–	–	–	–	0	4	–	–
Lemna minor	0	17	0	50	0	25	1	56	0	20	0	40	0	37	0	42
L. trisulca	0	33	0	50	0.5	50	0	33	0	13	0	33	0	22	0	16
Lycopus europaeus	–	–	–	–	–	–	0	11	–	–	0	13	0	7	0	5
Lysimachia thyrsiflora	0	8	–	–	0	25	–	–	0	13	0	13	0	22	–	–
L. vulgaris	0	8	–	–	–	–	–	–	0	7	–	–	0	7	–	–
Lythrum salicaria	–	–	–	–	–	–	–	–	0	7	–	–	–	–	0	11
Mentha aquatica	0	17	–	–	–	–	–	–	0	20	0	3	0	7	0	16
Mentha × *verticillata*	0	8	–	–	–	–	–	–	–	–	–	–	0	11	–	–
Myosotis scorpioides	0	8	–	–	0	25	0	33	0	47	0	17	0	22	0	47
Myriophyllum spicatum	–	–	–	–	–	–	–	–	–	–	–	–	0	7	–	–
Nuphar lutea	1	75	0	25	–	–	0	11	0	40	0.5	50	10	100	1	74
N. pumila	–	–	–	–	–	–	–	–	–	–	0	3	0	4	–	–
Nymphaea alba	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	5
Oenanthe aquatica	0	17	0	25	0	25	0	22	0	13	0	3	0	11	0	16
Phalaris arundinacea	–	–	–	–	–	–	0	11	0	47	0	10	0	15	0	16
Phragmites australis	–	–	–	–	–	–	0	22	0	20	0	7	0	22	0	26
Polygonum amphibium	0	8	–	–	–	–	–	–	–	–	0	3	–	–	–	–
Potamogeton alpinus	0	8	–	–	–	–	0	22	0	7	0	20	0	19	0	11
P. crispus	0	17	–	–	10	100	–	–	–	–	–	–	–	–	–	–
P. filiformis	0	17	–	–	0	25	–	–	–	–	–	–	0	4	–	–
P. gramineus	–	–	–	–	–	–	–	–	–	–	–	–	0	4	–	–
P. gramineus × *P. natans*	0	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
P. gramineus × *P. perfoliatus*	0	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
P. lucens	0	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
P. natans	0	17	–	–	–	–	–	–	0	7	0	3	0	4	0	16
P. natans × *hybridus* ?	0	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
P. pectinatus	0	17	10	100	–	–	–	–	–	–	0	3	–	–	0	11
P. perfoliatus	10	100	0	25	–	–	0	11	–	–	0	3	0	19	0	11
P. spp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	5
P. vaginatus × *P. filiformis*	–	–	0	25	–	–	–	–	–	–	–	–	–	–	–	–
Ranunculus circinatus	0	8	–	–	–	–	–	–	–	–	0	3	–	–	–	–
R. lingua	–	–	–	–	–	–	–	–	–	–	0	10	0	15	0	11
R. sceleratus	–	–	–	–	0	25	–	–	0	7	–	–	–	–	–	–
R. spp.	–	–	–	–	0	25	–	–	0	7	–	–	–	–	–	–
R. trichophyllus	–	–	0	25	0	25	–	–	–	–	0	10	0	4	–	–
Rorippa amphibia	–	–	–	–	–	–	–	–	0	20	–	–	0	15	0	11
R. sylvestris	–	–	–	–	–	–	–	–	0	7	–	–	–	–	–	–
Rumex aquaticus	–	–	–	–	–	–	–	–	0	7	–	–	–	–	–	–
R. obtusifolius	–	–	–	–	–	–	–	–	–	–	–	–	0	4	–	–
R. spp.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	5
Sagittaria sagittifolia	0	17	0.5	50	0	25	0	33	0	13	0	23	0	44	10	100
Schoenoplectus lacustris	0	42	–	–	0	25	0	11	0	33	0	7	0	26	0	16
Scirpus sylvaticus	–	–	–	–	–	–	–	–	0	27	0	13	0	11	0	11
Sium latifolium	0	17	–	–	–	–	0	11	0	27	0	10	0	33	0	32
Solanum dulcamara	0	8	–	–	–	–	–	–	0	27	0	10	0	7	0	5
Sparganium emersum	–	–	–	–	–	–	–	–	0	7	0	7	0	4	–	–
S. erectum s. lat.	0	8	–	–	–	–	0	44	10	100	0	47	0	30	0	47

continued

Table 2B. Continued.

Species	9(12) Med	9(12) Freq	10(4) Med	10(4) Freq	11(4) Med	11(4) Freq	12(9) Med	12(9) Freq	13(15) Med	13(15) Freq	14(30) Med	14(30) Freq	15(27) Med	15(27) Freq	16(19) Med	16(19) Freq
S. spp.	0	33	0.5	50	0.5	50	1	56	0	40	10	100	1	52	1	53
Spirodela polyrhiza	0	33	0.5	50	0.5	50	0	22	0	20	0	40	0	30	0	32
Typha angustifolia	–	–	–	–	–	–	0	11	0	7	–	–	–	–	–	–
T. latifolia	–	–	–	–	–	–	–	–	0	7	0	3	0	15	0	16
Valeriana officinalis	–	–	–	–	–	–	–	–	0	7	–	–	0	4	–	–
Veronica anagallis-aquatica	0	17	0	25	0	25	0	33	0	27	0	20	0	15	0	11
V. beccabunga	–	–	–	–	–	–	–	–	0	7	–	–	–	–	–	–
Filamentous macroalgae	0	42	0	25	0	25	–	–	0	7	–	–	–	–	0	11
Total number of vascular plant species in cluster	34		14		17		26		49		41		55		44	
Number of species in community	4–13		4–6		5–6		4–12		5–15		1–10		1–22		3–14	
Mean number of species per community	7		5		5		7		9		6		9		8	

Table 2C. Centroids of clusters 17 to 23. Denotations as in Table 2A.

Species	17(7) Med	17(7) Freq	18(4) Med	18(4) Freq	19(3) Med	19(3) Freq	20(5) Med	20(5) Freq	21(6) Med	21(6) Freq	22(5) Med	22(5) Freq	23(9) Med	23(9) Freq
Acorus calamus	–	–	2.5	50	10	100	–	–	0	17	1	60	0	22
Agrostis stolonifera var. *prorepens*	–	–	–	–	–	–	–	–	0	33	0	40	0	33
Alisma plantago-aquatica	0	14	0.5	50	0	33	–	–	0	33	1	60	1	67
Butomus umbellatus	0	14	10	100	0	33	0	20	0.5	50	0	20	0	33
Calla palustris	–	–	0	25	–	–	–	–	–	–	–	–	0	11
Caltha palustris	–	–	–	–	–	–	–	–	0	17	–	–	–	–
Carex acuta	–	–	0.5	50	0	33	–	–	–	–	0	40	0	11
Catabrosa aquatica	–	–	–	–	–	–	–	–	0	17	–	–	–	–
Cicuta virosa	–	–	0.5	50	–	–	–	–	–	–	–	–	0	22
Elodea canadensis	–	–	0	25	0	33	–	–	0	17	–	–	0	11
Epilobium hirsutum	–	–	–	–	–	–	0	20	–	–	–	–	–	–
Equisetum fluviatile	–	–	0	25	1	67	0	20	0.5	50	0	20	1	67
Eupatorium cannabinum	–	–	–	–	–	–	–	–	–	–	–	–	0	22
Glyceria maxima	–	–	0.5	50	–	–	–	–	0.5	50	10	100	0	44
G. spp.	–	–	–	–	–	–	–	–	–	–	–	–	0	11
Hippuris vulgaris	0	29	–	–	–	–	10	100	–	–	–	–	–	–
Hydrocharis morsus-ranae	–	–	–	–	–	–	–	–	–	–	0	20	–	–
Iris pseudacorus	–	–	0	25	–	–	–	–	–	–	0	40	0	33
Lemna minor	0	43	0	25	–	–	–	–	0	17	0	20	0	33
L. trisulca	0	29	0	25	–	–	–	–	0	33	–	–	0	11
Lycopus europaeus	–	–	0	25	–	–	0	20	–	–	–	–	0	11
Lysimachia thyrsiflora	–	–	–	–	–	–	0	20	0	17	–	–	0	22
L. vulgaris	–	–	–	–	–	–	0	20	–	–	0	20	0	33
Lythrum salicaria	–	–	0.5	50	–	–	0	20	–	–	–	–	0	11
Mentha aquatica	–	–	0	25	0	33	–	–	0	17	0	40	0	11
Mentha × *verticillata*	–	–	–	–	–	–	–	–	–	–	–	–	0	22
Menyanthes trifoliata	–	–	–	–	–	–	0	40	–	–	–	–	–	–
Myosotis scorpioides	–	–	0	25	1	67	0	20	1	83	1	60	0	44

continued

Table 2C. Continued.

Species	Cluster													
	17(7)		18(4)		19(3)		20(5)		21(6)		22(5)		23(9)	
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
Nuphar lutea	0	43	1	1	67	0	40	1	73	–	–	0	22	–
N. pumila	–	–	0	75	–	–	–	–	–	–	–	–	–	–
Oenanthe aquatica	0	14	–	–	–	–	0	40	0	17	0	20	0	11
Phalaris arundinacea	–	–	–	–	1	100	–	–	0.5	50	1	60	1	56
Phragmites australis	–	–	0	25	–	–	–	–	0	33	0	40	0	33
Potamogeton alpinus	–	–	0	25	–	–	0	20	–	–	–	–	–	–
P. crispus	–	–	–	–	–	–	0	20	–	–	–	–	–	–
P. friesii	0	14	–	–	–	–	–	–	–	–	–	–	–	–
P. gramineus × *P. natans*	–	–	–	–	0	33	–	–	–	–	–	–	–	–
P. lucens	0	14	–	–	–	–	–	–	–	–	–	–	–	–
P. natans	10	100	–	–	–	–	0	20	–	–	–	–	–	–
P. pectinatus	–	–	0	25	–	–	–	–	–	–	–	–	–	–
P. perfoliatus	1	57	–	–	–	–	0	50	–	–	0	20	0	22
Ranunculus lingua	–	–	–	–	–	–	0	20	–	–	–	–	0	22
R. trichophyllus	–	–	–	–	0	33	1	60	–	–	–	–	0	11
Rorippa amphibia	–	–	0	25	0	33	0	20	10	100	1	60	1	56
Rumex aquaticus	–	–	–	–	0	20	–	–	0	17	0	20	0	22
R. spp.	–	–	–	–	–	–	–	–	0	50	–	–	0	11
Sagittaria sagittifolia	1	100	0	25	1	67	0	20	0.5	33	0	20	0	44
Schoenoplectus lacustris	0	29	–	–	0	33	0	40	–	–	0	20	10	100
Scirpus sylvaticus	–	–	0	25	–	–	–	–	–	–	0	20	–	–
Scolochloa festucacea	–	–	–	–	–	–	–	–	0	17	0	20	–	–
Senecio paludosus	–	–	–	–	–	–	–	–	–	–	–	–	0	11
Sium latifolium	–	–	0.5	50	0	33	1	60	0	33	–	–	1	67
Solanum dulcamara	–	–	0	25	–	–	–	–	0	17	0	40	0	44
Sparganium erectum s. lat.	–	–	0	25	1	67	1	80	1	67	1	80	1	67
S. spp.	0	43	–	–	1	67	0	20	0.5	50	0	20	–	–
Spirodela polyrhiza	1	57	0.5	50	–	–	–	–	0	33	0	20	0	22
Stachys palustris	–	–	–	–	0	33	–	–	–	–	–	–	0	22
Typha latifolia	–	–	0	25	0	33	–	–	0	17	0	20	0	44
Veronica anagallis-aquatica	–	–	0	25	1	67	0	20	0.5	50	0	20	0	22
V. beccabunga	–	–	–	–	–	–	–	–	0	33	–	–	–	–
Filamentous macroalgae	0	29	–	–	2	67	–	–	0.5	50	0	40	0	44
Total number of vascular plant species in cluster	15		29		22		25		31		29		42	
Number of species in community	3–10		5–13		10–12		6–10		7–19		7–12		8–19	
Mean number of species per community	6		10		11		8		11		10		13	

Table 2D. Centroids of clusters 24 to 29. Denotations as in Table 2A.

Species	Cluster											
	24(5)		25(13)		26(3)		27(5)		28(8)		29(14)	
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
Amblystegium fluviatile	–	–	0	8	–	–	0	20	–	–	–	–
A. riparium	10	100	0	39	10	100	0	20	0	37	0	43
A. tenax	–	–	–	–	0	33	–	–	–	–	–	–
Batrachospermum moniliforme	–	–	–	–	–	–	0	20	–	–	–	–
B. spp.	–	–	0	8	–	–	0	20	0	13	0	14
Chantransia chalybea	–	–	0	15	–	–	–	–	0	13	0	14
Chiloscyphus polyanthos	–	–	0	8	–	–	–	–	–	–	–	–
Cladophora glomerata	1	100	5	100	1	100	0	40	10	100	10	100
C. spp.	–	–	0	8	–	–	–	–	0	13	–	–
Cratoneuron filicinum	0	20	–	–	–	–	–	–	–	–	–	–
Enteromorpha spp.	–	–	–	–	–	–	–	–	0	13	–	–
Filamentous macroalgae	–	–	0	8	–	–	–	–	0	13	0	7
Fontinalis antipyretica	10	100	10	100	–	–	5	60	10	100	0	21
Hildenbrandia rivularis	–	–	0	15	–	–	–	–	–	–	0	7
Marchantia polymorpha	–	–	0	15	–	–	0	20	0	13	–	–
Microspora spp.	–	–	–	–	–	–	–	–	–	–	0	14
Oedogonium spp.	–	–	–	–	0	33	–	–	–	–	0	7
Oscillatoria spp. — as film	0	20	0	15	0	33	0	20	0	25	–	–
O. spp. — as filaments	–	–	–	–	–	–	–	–	–	–	0	7
Plagiomnium ellipticum	–	–	–	–	–	–	0	20	–	–	–	–
Rhizoclonium hieroglyphicum	–	–	0	8	–	–	–	–	–	–	–	–
Rhynchostegium riparioides	–	–	–	–	–	–	0	20	–	–	–	–
Spirogyra spp.	0	40	0	8	–	–	0	20	0	38	0	29
Stigeoclonium spp.	–	–	–	–	–	–	–	–	–	–	0	29
Tetraspora spp.	–	–	–	–	–	–	–	–	0	13	–	–
Ulothrix aequalis	–	–	–	–	–	–	–	–	0	25	–	–
U. zonata	–	–	0	23	0	33	0	20	1	88	0	14
Vaucheria spp.	1	80	1	62	–	–	10	100	10	100	3	64
Total number of species in cluster	7		16		6		13		14		14	
Number of species in community	3–7		1–6		3–4		2–6		4–7		1–6	
Mean number of species per community	5		4		3		4		6		4	

and riverbed substrate. Still, the average values of the environmental parameters, calculated for the vegetation clusters (Tables 4A–D), should be interpreted with some precaution, as these parameters were not estimated for every single community but only as an average for the whole river reach.

For the occurrence of the dominating species, the most important parameter of water chemistry is water NH_4-N content, which affects the occurrence of nine species, followed by water pH and N/P ratio, which influence significantly the occurrence of at least eight species, presence–absence of seven species depends significantly on water NO_3-N content (Table 5). Of the parameters of the physical environment, river width is important for 16 species, current velocity and bottom substrate for ten and seven species, respectively. From water chemistry parameters only water N/P ratio and PO_4-P content have usually an enhancing effect on plant species occurrence. Striking is the negative influence of river width on the presence of cryptogam species. Among the analysed species the most sensitive to changes of the environmental variables are *Acorus calamus*, *Butomus umbellatus*, *Potamogeton crispus*, *P. perfoliatus*, *Schoenoplectus lacustris* and *Veronica anagallis-aquatica*, which respond significantly to at least five parameters.

Table 3. Separation of the vegetation types and habitat (river reaches) types by environmental parameters, summary of the discriminant function analyses. F = the F-criterion value associated with Partial Wilks' λ-criterion, P = significance level; pH = pH estimated *in situ*, O_2 = content of dissolved oxygen, O_2-sat = oxygen saturation, BOD_5 = biological oxygen demand, N_{Tot} = total nitrogen content, NO_3-N = NO_3-nitrogen content, NO_2-N = NO_2-nitrogen content, NH_4-N = NH_4-nitrogen content, P_{Tot} = content of total phosphorus, PO_4-P = PO_4-phosphorus content, N/P = ratio N to P calculated from the ratio of the amount of inorganic nitrogen (NO_3-N + NO_2-N + NH_4-N) to the amount of inorganic phosphate (PO_4-P), Wid = river width, Dep = river depth, Vel = current velocity, WTur = water turbidity, FSed = extent of bottom coverage with fine sediments, BSub = bottom substrate.

Variable	Vegetation types		Habitat types	
	F	P	F	P
pH	1.343	0.121	1.099	0.338
O_2 (mg l^{-1})	1.294	0.153	1.602	0.208
O_2-sat (%)	1.265	0.174	1.368	0.260
BOD_5 (mg O_2 l^{-1})	1.404	0.090	1.381	0.257
N_{Tot} (mg m^{-3})	1.546	0.043	1.913	0.154
NO_3-N (mg m^{-3})	1.055	0.396	0.260	0.771
NO_2-N (mg m^{-3})	0.700	0.875	0.624	0.538
NH_4-N (mg m^{-3})	0.943	0.555	0.293	0.746
P_{Tot} (mg m^{-3})	1.416	0.085	0.951	0.390
PO_4-P (mg m^{-3})	1.374	0.105	0.984	0.378
N/P	0.976	0.506	0.063	0.939
Wid (m)	2.106	0.001	80.816	< 0.001
Dep (m)	1.210	0.220	1.218	0.301
Vel (m s^{-1})	1.525	0.048	0.244	0.784
WTur	1.370	0.107	3.013	0.055
FSed	0.695	0.879	1.167	0.316
BSub	10.643	< 0.001	9.980	< 0.001

The studied watercourse reaches form three groups which can be interpreted as habitat types. The 1st habitat type includes 52.0% of the reaches; to this group belong the rivulets and the narrow stretches with comparatively slow current and small depth; the riverbed substrate is mostly gravel but sandy bottoms occur frequently as well, bottom is at least partly covered by fine sediments (Table 6). To the 2nd habitat type belong 24.5% of the reaches representing watercourses that are on average twice as wide as in group 1 while also deeper and with slightly faster current; bottom is sandy in more than half of the cases but it can often be covered with gravel or even with stones, fine sediments are almost lacking. Of the reaches 23.5% can be classified as the 3rd type; they are the widest stretches with the largest average depth and the highest velocity among the streams; the bottom substrate of the reaches of this group is variable: sandy bottoms prevail but bottoms formed mainly of gravel, silt, clay or stones are rather frequent as well. The water of all watercourses is clear. According to discriminant analysis, the established habitat types are significantly separated by river width and riverbed substrate (Table 3).

The ordination biplot (Fig. 2) is in good concordance with the results of discriminant analysis: the relatively continuous pattern of scattering of the river reaches along the first principal component (eigenvalue 0.968) is largely determined by river width; eigenvalue of the second principal component is only 0.015 and variation along that axis is mainly related to bottom substrate and extent of bottom coverage with fine sediments. It is also obvious that there is much

Table 4A. Average values of the environmental variables for vegetation clusters 1 to 8. Mean = mean value, S.E. = standard error of the mean. Other denotations as in Tables 2 and 3.

Variable	Cluster															
	1		2		3		4		5		6		7		8	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
pH	7.8	0.1	7.7	0.1	7.8	0.1	7.9	0.1	7.8	0.1	7.8	0.1	7.7	0.1	8.0	0.1
O_2	8.7	0.5	9.4	0.2	9.8	0.3	9.5	1.1	10.1	0.6	10.5	0.3	9.7	1.0	11.0	0.9
O_2-sat	84.4	5.2	92.7	1.9	97.2	6.8	97.0	11.4	100.9	6.9	100.2	2.3	92.7	9.5	108.0	4.7
BOD_5	2.8	0.3	3.1	0.4	2.4	0.2	4.2	1.3	2.9	0.4	2.1	0.2	2.1	0.3	3.2	0.4
N_{Tot}	1076.0	271.0	1884.7	481.8	1546.8	286.6	1895.4	374.3	1780.0	347.3	1580.3	574.0	3265.6	759.0	918.7	183.4
NO_3-N	310.1	152.3	713.0	532.9	1138.6	365.4	470.4	267.4	894.5	287.0	1140.0	489.0	2330.0	691.3	480.7	37.6
NO_2-N	5.1	1.9	5.0	2.0	5.2	0.8	9.4	3.7	12.6	5.6	5.3	1.0	11.9	3.0	4.7	1.2
NH_4-N	18.4	6.1	17.3	1.8	16.6	3.5	27.4	11.1	21.4	5.5	15.0	3.1	60.7	37.5	11.0	5.0
P_{Tot}	49.0	4.2	77.3	31.2	51.0	13.6	89.0	17.8	58.5	14.7	34.0	5.7	48.9	9.2	31.7	6.9
PO_4-P	20.7	7.2	32.0	17.2	27.0	11.6	51.4	11.8	34.0	12.1	18.8	5.4	25.9	6.2	19.7	11.2
N/P	26.9	18.5	65.6	57.0	109.7	58.9	13.0	9.1	223.0	134.0	245.8	188.8	219.2	126.0	44.7	17.6
Wid	9.3	2.2	12.0	6.6	23.4	3.4	8.4	3.0	8.0	1.3	10.3	1.1	9.0	1.9	12.3	0.3
Dep	0.8	0.3	0.7	0.2	0.8	0.1	0.6	0.1	0.5	0.1	0.6	0.1	0.5	0.1	0.7	0.1
Vel	0.3	0.1	0.7	0.4	0.6	0.1	0.2	0.0	0.3	0.0	0.5	0.0	0.4	0.1	0.5	0.1
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
WTur	2	57.1	1	66.7	2	60.0	2	60.0	1	90.9	1	100	1	85.7	1	100
FSed	2	42.9	1	66.7	1	80.0	2	40.0	1	54.5	1	70.0	1	57.1	1	66.7
BSub	3	42.9	3	66.7	4	60.0	4	60.0	4	54.5	3	80.0	3	71.4	3	100

Table 4B. Average environmental variables of the vegetation clusters 9 to16. Mean = mean value, S.E. = standard error of the mean. Other denotations as in Tables 2 and 3.

Variable	Cluster															
	9		10		11		12		13		14		15		16	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
pH	7.8	0.1	8.0	0.1	7.9	0.1	7.8	0.1	7.7	0.0	7.7	0.0	7.7	0.0	7.7	0.0
O_2	10.4	0.3	9.0	1.3	10.0	1.6	9.3	0.9	9.5	0.3	9.0	0.4	9.1	0.5	9.0	0.4
O_2-sat	107.0	4.5	92.8	12.4	101.3	15.9	93.9	9.1	91.9	3.2	87.6	4.1	90.6	4.6	90.7	4.1
BOD_5	3.1	0.3	3.3	0.7	3.0	0.8	3.1	0.3	2.8	0.3	2.9	0.2	3.1	0.2	2.7	0.2
N_{Tot}	1356.3	198.2	1394.5	523.5	1979.5	732.5	2201.1	513.4	1360.6	219.4	1974.0	231.9	1766.8	173.2	1247.3	148.6
NO_3-N	626.3	200.5	513.5	186.7	1131.3	590.4	1008.2	360.6	751.4	195.4	946.3	199.2	642.5	162.8	457.9	98.1
NO_2-N	12.5	4.4	36.0	23.8	36.0	23.8	32.2	11.4	6.3	1.2	12.4	2.4	9.5	1.6	15.7	5.9
NH_4-N	56.5	31.0	138.5	107.5	138.3	107.7	34.7	8.3	28.5	12.2	34.7	6.6	28.6	4.1	76.3	30.1
P_{Tot}	70.3	10.3	163.8	96.0	149.8	101.5	309.6	224.1	71.8	19.9	68.6	1.8	55.1	5.2	105.8	27.2
PO_4-P	41.0	8.5	128.3	82.3	112.0	88.3	233.7	184.9	42.9	19.0	40.4	10.7	25.5	4.4	58.4	19.1
N/P	44.9	21.7	7.2	1.4	244.3	233.6	53.0	39.2	40.0	13.2	50.1	14.8	73.6	45.5	17.6	4.9
Wid	20.8	2.6	15.5	2.6	17.0	2.0	8.9	2.0	12.1	2.6	8.2	0.9	10.0	1.3	16.1	2.1
Dep	0.9	0.1	1.0	0.1	0.8	0.2	0.7	0.1	0.6	0.1	0.6	0.1	0.8	0.1	1.1	0.1
Vel	0.4	0.1	0.5	0.2	0.4	0.1	0.2	0.0	0.5	0.1	0.3	0.0	0.2	0.0	0.3	0.1
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
WTur	1	66.7	1.5	75.0	1.5	75.0	2	55.6	1	73.3	1	70.0	2	40.7	2	36.8
FSed	2	41.7	2	0	2	0	2	55.6	1	60.0	2	33.3	2	33.3	2	21.1
BSub	4	58.3	3	75.0	3	75.0	3	66.7	3	46.7	3	66.7	3	40.7	3	52.7

Table 4C. Average environmental variables of the vegetation clusters 17 to 23. Mean = mean value, S.E. = standard error of the mean. Other denotations as in Tables 2 and 3.

Variable	Cluster													
	17		18		19		20		21		22		23	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
pH	7.7	0.1	7.8	0.1	8.0	0.2	7.6	0.1	7.8	0.1	7.7	0.1	7.8	0.1
O_2	8.9	0.6	10.5	0.5	11.2	0.8	9.7	0.6	9.2	0.8	9.4	0.2	10.2	0.4
O_2-sat	88.7	5.8	105.3	4.8	120.3	5.5	95.0	8.8	94.2	9.9	89.4	2.2	106.9	6.4
BOD_5	3.1	0.4	2.2	0.5	2.6	0.3	2.5	0.2	2.9	0.3	2.6	0.3	2.8	0.3
N_{Tot}	1481.1	377.1	746.5	148.6	1924.0	1159.5	2011.2	474.7	1530.3	245.8	2350.2	350.0	1547.4	325.0
NO_3-N	922.3	332.6	176.5	58.9	1329.3	1254.8	1531.0	482.1	691.3	216.2	1986.6	413.8	897.7	352.1
NO_2-N	21.1	14.1	2.5	0.9	7.0	1.5	4.4	0.4	17.2	7.9	8.4	2.9	10.4	5.4
NH_4-N	79.7	63.4	13.5	1.7	14.7	1.9	18.0	4.1	98.0	59.9	23.0	2.2	15.6	3.4
P_{Tot}	111.0	57.5	51.3	6.7	50.7	19.0	29.6	5.5	77.8	17.1	45.4	17.2	58.1	11.3
PO_4-P	77.4	50.3	27.3	8.1	32.0	15.6	7.0	2.3	49.0	13.9	23.8	13.0	31.9	9.4
N/P	79.7	47.4	6.4	1.3	258.8	256.4	302.8	168.2	29.0	13.8	133.2	35.7	161.7	104.1
Wid	23.3	3.9	21.5	6.4	15.7	7.4	18.0	4.1	21.2	3.7	17.2	3.9	22.6	3.5
Dep	1.2	0.1	1.1	0.2	0.7	0.1	0.7	0.1	0.9	0.1	1.0	0.1	0.8	0.1
Vel	0.3	0.1	0.7	0.2	0.2	0.1	0.5	0.1	0.3	0.1	0.7	0.2	0.4	0.1
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
WTur	2	57.1	1	75.0	1	100	2	80.0	1	83.3	1	100	1	55.6
FSed	2	14.3	2	0	2	66.7	2	60.0	2	50.0	1	100	2	44.4
BSub	3	71.4	3	50.0	4	66.7	3	60.0	3.5	66.7	3	40.0	4	55.6

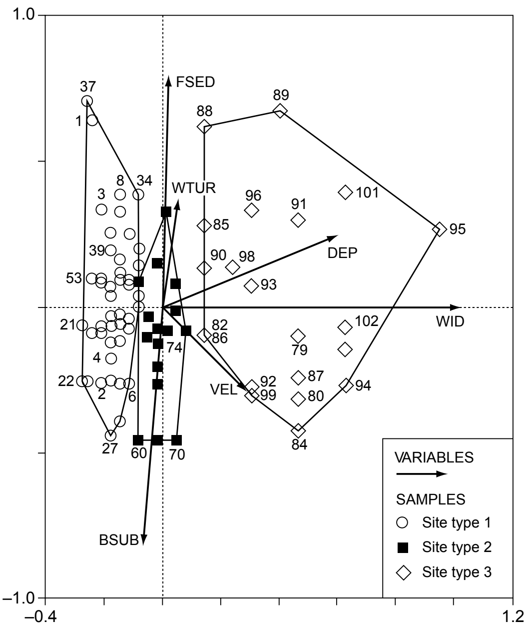

Fig. 2. Ordination of the habitats (river reaches) by the first and second principal component represented as abscicca and ordinate, respectively.

higher within-cluster variation in the third habitat type compared with the first two types.

Cross tabulation of the vegetation types and the habitat types (Table 7) demonstrates that only the communities of two vegetation types are exclusively bound to one habitat type. The communities of 8th cluster dominated by *Potamogeton vaginatus* × *P. filiformis* (= *Potamogeton* × *meinshausenii*; cf. Paal & Trei 2004) were only recorded in the stretches of the 2nd type, while the communities of *P. crispus* (11th cluster) were only represented in the habitats of the 3rd type. Habitats of the last type are preferred also by communities of *Phalaris arundinacea* (3rd cluster), *Potamogeton natans* (17th cluster), *Rorippa amphibia* (21st cluster) and *Schoenoplectus lacustris* (23rd cluster); *Phragmites australis* (communites of 4th cluster) occurred abundantly mainly in the narrow shallow rivers (1st habitat type). Of the total 258 plant communities, 39.9% were recorded in the 1st habitat type, 25.6% in the 2nd and 34.5% in the 3rd habitat type.

Table 4D. Average environmental variables of the vegetation clusters 24 to 29. Mean = mean value, S.E. = standard error of the mean. Other denotations as in Tables 2 and 3.

Variable	Cluster											
	24		25		26		27		28		29	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
pH	7.7	0.1	7.8	0.1	7.9	0.2	7.6	0.1	7.7	0.1	7.8	0.0
O_2	10.5	0.9	10.2	0.4	10.3	1.4	10.4	0.7	10.1	0.4	9.9	0.6
O_2-sat	103.2	10.1	101.2	4.5	104.3	15.8	103.0	8.3	94.3	4.9	95.3	5.9
BOD_5	2.9	0.7	2.7	0.3	2.2	0.6	4.3	1.1	2.9	0.3	3.4	0.3
N_{Tot}	1649.6	560.1	1473.1	312.3	1905.7	889.0	1413.6	310.8	2118.4	482.9	1721.9	234.0
NO_3-N	924.6	498.7	781.3	324.5	1068.7	731.6	457.4	164.8	1342.4	378.0	621.5	201.1
NO_2-N	8.2	2.5	6.3	1.4	6.3	2.6	15.4	9.5	6.6	0.9	11.7	4.2
NH_4-N	18.2	5.5	23.8	4.9	39.0	25.6	33.2	11.3	26.1	5.7	48.8	23.5
P_{Tot}	49.2	13.6	45.2	7.3	42.01	5.7	53.2	17.1	49.1	4.6	64.9	10.4
PO_4-P	15.0	5.2	23.9	5.8	15.3	13.8	26.2	12.6	24.3	3.9	31.9	8.9
N/P	204.4	185.3	180.8	146.3	606.8	366.7	23.9	4.4	80.9	28.5	64.1	41.3
Wid	9.4	2.3	11.2	1.9	7.7	1.8	10.8	3.8	12.0	3.1	8.1	1.2
Dep	0.6	0.1	0.5	0.0	0.7	0.2	0.7	0.1	0.7	0.1	0.6	0.1
Vel	0.4	0.0	0.4	0.0	0.6	0.2	0.3	0.1	0.7	0.1	0.3	0.0
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
WTur	1	80.0	1	100	1	100	1	60.0	1	55.6	1	62.5
FSed	1	60.0	2	53.8	1	100	2	20.0	1	55.6	2	50.0
BSub	5	100	5	100	5	100	5	100	5	100	5	100

Table 5. Effect of the environmental variables on the occurrence probability of the dominating species by generalised linear model logit link analyses. For all continuous variables model parameter estimates and their significance level is presented: * = $P \le 0.05$, ** = $P \le 0.01$, *** = $P \le 0.001$. Species preference to substrate was tested according to the parameter values of categorical variable BSub in model. Gr = gravel, Sa = sand; denotation of other environmental parameters as in Table 3.

Species	Environmental parameter										
	pH	O_2	BOD_5	NO_3-N	NH_4-N	PO_4-P	N/P	Wid	Dep	Vel	BSub
Acorus calamus	–	–	–	–10.21***	–2.77**	12.25**	11.47***	0.09***	–	–	–
Butomus umbellatus	–	–	–7.42***	–	–1.90***	–	–1.64***	0.12***	–	1.70**	–
Elodea canadensis	3.32***	–	–	–	–	1.05***	–	–0.05**	–	–	–
Equisetum fluviatile	–	–	–	–	–	–	–	0.07**	–	–1.82*	Gr + Sa*
Glyceria maxima	–	–	–12.53***	2.31***	–	1.76***	–	0.10***	–	–	Gr***
Hippuris vulgaris	–	–	–	–	–	–	2.84***	–	2.27**	–	–
Nuphar lutea	–	–	–	–	–	–	–	–	0.83*	–1.29**	Gr**
Phalaris arundinacea	–	–	–	–	–	–	0.54**	0.05**	–	1.17*	–
Phragmites australis	–	–	3.35*	–	–	–	–	–	–	–	–
Potamogeton alpinus	–	–	–	–	–1.60***	–	–	–	–2.12***	–	–
P. crispus	–	–	–10.34**	–10.84**	–	13.71**	13.39***	0.10*	–	–	–
P. vaginatus × *P. filiformis*	4.36**	–	–	–	–	–	–	–	–	–	–
P. natans	–3.42**	–	–	–	–	–	–	0.13***	–	–	–
P. pectinatus	8.47***	–	–	–2.18***	5.57***	–	–	–	–	5.00***	–
P. perfoliatus	–3.30***	13.29***	–	–1.45***	1.32**	–	–	0.11***	–	–	–
Ranunculus trichophyllus	2.33*	–	–4.06*	–	–	–	0.94***	–	–	–	Sa***
Rorippa amphibia	–	–	–	–	–	–	0.82***	0.09***	–	–	Gr + Sa***
Sagittaria sagittifolia	–	–	–	–1.10**	–	–	–	–	3.73***	–	–
Schoenoplectus lacustris	–	–	4.96**	1.11**	–2.54***	–	–	0.13***	–	–1.44*	Gr***
Sium latifolium	–2.64**	–	–	–	–1.27**	–	–	0.07***	–	–1.65*	–
Sparganium emersum.	–	–	–	–	0.75*	–	–	–	–	–1.79**	Gr + Sa***
S. erectum s. lat.	–	–	–	–	–	–	–	–	–	–	–
Typha latifolia	–	–	–	–	–	–	–	0.07**	–	–	–
Veronica anagallis-aquatica	–	–5.48**	–	–	–1.94***	1.12*	0.88**	–	–2.12***	–	–
Amblystegium riparium	–	–	–	–	–	–	–	–0.09**	–	–	–
Cladophora glomerata	–	–	–	–	–	–	–	–0.08**	–	1.42*	–
Fontinalis antipyretica	–	6.24*	–	–	–	–	–	–0.06*	–	1.35*	–
Vaucheria spp.	–3.56***	8.15**	–	–	–	–	–	–	–	–	–

Discussion

General aspects of the structure, ecology, distribution of river plant communities and some floristic remarks were addressed in our previous paper (cf. Paal & Trei 2004). Therefore we will deal here mainly with the established differences between the plant communities of the drainage basin of lakes Peipsi and Võrtsjärv and those of the drainage basin of the Gulf of Finland.

In the drainage basin of the lakes of Peipsi and Võrtsjärv, among the 258 analysed communities, the most frequent were those dominated by *Sparganium* spp. (11.6%), *Nuphar lutea* (10.5%), *Sagittaria sagittifolia* (7.4%), *Sparganium erectum s. lat.* (5.8%), *Cladophora glomerata–Vaucheria* spp. (5.4%), *Fontinalis antipyretica* (5.0%) and *Potamogeton perfoliatus* (4.7%). Among the 181 communities occurring in the drainage basin of the Gulf of Finland the most frequent community types were dominated by *Sparganium erectum s. lat.* and *Schoenoplectus lacustris* (both 10.5%), *Cladophora glomerata* (8.8%), *Sparganium* spp. (6.6%), while three community types were dominated by *Hippuris vulgaris*, *Equisetum fluviatile*, and *Nuphar lutea* (all 6.1%). One can see that the community types dominated by *Sparganium* spp., *Sparganium erectum s. lat.* and *Nuphar lutea* occurred with high frequency in both basins. The communities of *Sagittaria sagittifolia* type, frequent in the current study area, occurred rarely in the other drainage basin (7.4% *versus* 1.7%), while *Cladophora glomerata–Vaucheria* spp. type (5.4% in the current study) was not established in the other drainage basin. Conversely, *Schoenoplectus lacustris*, *Equisetum fluviatile* and *Hippuris*

Table 6. Centroids of the habitat types (reach clusters) established by 6 physical environmental parameters. Mean = arithmetical mean, S.E. = standard error of mean, Med = median, Freq = frequency (%). The last 4 parameters presented in this table were not included in the analysis. Denotations as in Table 3.

Parameter	Cluster					
	1(53)		2(25)		3(24)	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
Wid	5.2	0.2	10.6	0.3	22.1	1.3
Dep	0.5	< 0.0	0.7	0.1	1.0	0.1
Vel	0.3	< 0.0	0.4	< 0.0	0.5	0.1
	Med	Freq	Med	Freq	Med	Freq
WTur	1.0	60.4	1.0	72.0	1.0	54.2
FSed	2.0	35.8	1.0	52.0	1.0	25.0
BSub	3.0	47.2	2.0	52.0	2.0	50.0
Stones		5.7		16.0		8.3
Gravel		47.2		32.0		25.0
Sand		39.6		52.0		50.0
Clay + silt		7.5		0.0		16.7

Table 7. Representation of vegetation types in habitat types.

Vegetation type No.	Dominant species	Number of communities	Habitat type 1	2	3
1	*Equisetum fluviatile*	7	5	–	2
2	*Typha latifolia*	3	2	–	1
3	*Phalaris arundinacea*	5	–	1	4
4	*Phragmites australis*	5	4	–	1
5	*Potamogeton alpinus*	11	6	4	1
6	*Ranunculus trichophyllus*	10	3	6	1
7	*Veronica anagallis-aquatica*	7	4	1	2
8	*Potamogeton vaginatus* × *P. filiformis*	3	–	3	–
9	*P. perfoliatus*	12	–	3	9
10	*P. pectinatus*	4	–	2	2
11	*P. crispus*	4	–	–	4
12	*Elodea canadensis*	9	5	2	2
13	*Sparganium erectum s. lat.*	15	8	2	5
14	*S.* spp.	30	18	8	4
15	*Nuphar lutea*	27	15	7	5
16	*Sagittaria sagittifolia*	19	4	5	10
17	*Potamogeton natans*	7	1	–	6
18	*Butomus umbellatus*	4	–	1	3
19	*Acorus calamus*	3	1	1	1
20	*Hippuris vulgaris*	5	–	2	3
21	*Rorippa amphibia*	6	1	–	5
22	*Glyceria maxima*	5	1	1	3
23	*Schoenoplectus lacustris*	9	1	1	7
24	*Amblystegium riparium–Fontinalis antipyretica*	5	2	2	1
25	*F. antipyretica*	13	5	6	2
26	*Amblystegium riparium*	3	2	1	–
27	*Vaucheria* spp.	5	3	1	1
28	*Fontinalis antipyretica–V.* spp.*–Cladophora glomerata*	8	3	3	2
29	*C. glomerata–V.* spp.	14	9	3	2
Total		258	103	66	89
Excluded from classification		22	13	5	4
Grand total		280	116	71	93

vulgaris dominated more frequently in the communities of the drainage basin of the Gulf of Finland (10.5%, 6.1% and 6.1% *versus* 3.5%, 2.7% and 1.9%, respectively). Also the frequency of the cryptogam communities was somewhat higher in the latter drainage basin where they accounted for 21.4% of the total number of communities; in the other drainage basin the share of the cryptogam communities was 18.6%.

At first sight, the typological variation of the vegetation of the rivers dealt with in the current study seems to be somewhat higher than that of the vegetation of the rivers of the drainage basin of the Gulf of Finland. In this study, 29 community types were established on the basis of 258 communities in 102 reaches, while 181 communities in 85 reaches described in the drainage basin of the Gulf of Finland formed altogether 23 types.

In the studied rivers, the communities of *Mentha aquatica*, *Nuphar lutea–Sagittaria sagittifolia*, *Sium latifolium*, *Fontinalis antipyretica* and *Amblystegium riparium–Fontinalis antipyretica–Chara* spp. were lacking or represented less than three times. In fact, as the communities of *Mentha aquatica* were recorded only two times, they were excluded from data processing. The communities of *Nuphar lutea–Sagittaria sagittifolia* presented in the drainage basin of the Gulf of Finland correspond quite well to the 16th community type in the current study, dominated by *Sagittaria sagittifolia*, where *Nuphar lutea* has an average frequency of 74% (Table 2B). *Sium latifolium* is also a rather common species in the rivers of the Peipsi–Võrtsjärv drainage basin, occurring frequently but in smaller numbers in several communities. At the same time, eight additional community types of vascular plants and three community types of cryptogams were established from the drainage basin of lakes Peipsi and Võrtsjärv: *Typha latifolia* type (cluster 2, $n = 3$), *Veronica anagallis-aquatica* type (cluster 7, $n = 7$), *Potamogeton pectinatus* type (cluster 10, $n = 4$), *Potamogeton crispus* type (cluster 11, $n = 4$), *Elodea canadensis* type (cluster 12, $n = 9$), *Acorus calamus* type (cluster 19, $n = 3$), *Rorippa amphibia* type (cluster 21, $n = 6$), *Glyceria maxima* type (cluster 22, $n = 5$), *Amblystegium riparium–Fontinalis antipyretica* type (cluster 24, $n = 5$), *Amblystegium riparium* type (cluster 26, $n = 3$) and *Fontinalis antipyretica–Cladophora glomerata–Vaucheria* spp. type (cluster 28, $n = 8$). Actually, the communities dominated by *Typha latifolia*, *Potamogeton crispus* and *Glyceria maxima* occurred also in the drainage basin of the Gulf of Finland but only at 1–2 sites. Moreover, the differences between the community types of cryptogams should be interpreted cautiously as the abundance proportions for the species recorded in these communities may vary considerably depending on the species and the supporting substrate. Nor can the coverage of these species be visually firmly estimated in the field. Thus, in both drainage basins communities of almost the same types are represented despite the fact that habitats where the substrate is usually formed of boulders or limestone, characteristic of the rivers of the Gulf of Finland formed in the limestone bedrock, are mostly lacking in the drainage basin of lakes Peipsi and Võrtsjärv. Consequently, there is no clear difference between the composition of the vegetation types in the two studied drainage basins. The vegetation communities of both drainage basins resemble the eutrophic lowland community group established in Great Britain (Holmes *et al.* 1998). Still, one can observe variation in the frequency of the community types and in the number of species in the communities.

In the rivers flowing into the Gulf of Finland, the mean number of species per community was the highest (14 species) for the communities dominated by *Sium latifolium*. It was followed by nine species in the communities of *Butomus umbellatus*, *Equisetum fluviatile*, *Sagittaria sagittifolia*, *Sparganium* spp. and *Schoenoplectus lacustris*. In the Peipsi–Võrtsjärv drainage basin, this parameter was the highest (13 species) for the communities dominated by *Schoenoplectus lacustris*. The communities of *Acorus calamus* as well as those of *Rorippa amphibia* had on average 11 species, and 10 species were characteristic of the community types dominated by *Butomus umbellatus*, *Glyceria maxima*, *Phalaris arundinacea* and *Phragmites australis*.

Thus, the communities of the Peipsi–Võrtsjärv drainage basin appear to be slightly richer in species; at the same time, all communities of vascular plants have a simple monodominant structure, a feature of the plant communities of running waters, which is recognised by numerous authors (e.g. den Hartog & Segal 1964, Wiegleb 1981a, 1981b, Feoli & Gerdol 1982, Chernaya 1987, Sinkevičienė 1992, Muotka & Virtanen 1995).

According to the prevailing life form of the dominating species, the distinguished community types (clusters) of the Peipsi–Võrtsjärv drainage basin can be arranged into the following four groups similarly to the community types of the drainage basin of the Gulf of Finland (the species are listed in alphabetical order):

1. Communities of helophytes: *Acorus calamus* (cluster 19), *Equisetum fluviatile* (cluster 1), *Glyceria maxima* (cluster 22), *Phalaris arundinacea* (cluster 3), *Phragmites australis* (cluster 4), *Rorippa amphibia* (cluster 21), *Schoenoplectus lacustris* (cluster 23), *Sparganium erectum s. lat.* (cluster 13), *Typha latifolia* (cluster 2).
2. Communities of the rooted vegetation with floating leaves: *Nuphar lutea* (cluster 15), *Potamogeton natans* (cluster 17).
3. Communities of the submerged or partially emergent vegetation: *Butomus umbellatus* (cluster 18), *Elodea canadensis* (cluster 12), *Hippuris vulgaris* (cluster 20), *Potamogeton alpinus* (cluster 5), *P. crispus* (cluster 11), *P. vaginatus* × *P. filiformis* (cluster 8), *P. pectinatus* (cluster 10), *P. perfoliatus* (cluster 9), *Ranunculus trichophyllus* (cluster 6), *Sagittaria sagittifolia* (cluster 16), *Sparganium* spp. (cluster 14), *Veronica anagallis–aquatica* (cluster 7).
4. Communities of mosses and macroalgae on stones: *Amblystegium riparium* (cluster 26), *A. riparium–Fontinalis antipyretica* (cluster 24), *Cladophora glomerata–Vaucheria* spp. (cluster 29), *F. antipyretica* (cluster 25), *F. antipyretica–Vaucheria* spp.–*C. glomerata* (cluster 28), *Vaucheria* spp. (cluster 27).

As in the drainage basin of the Gulf of Finland, submerged plant species were the most common (45.7%) life form in the studied watercourses, dominating in 118 communities and 12 community types. Helophytes and cryptogams prevailed in 58 communities and 9 community types (22.5%), and in 48 communities and 6 community types (18.6%), respectively. The group of communities dominated by rooted vegetation with floating leaves, including 34 communities and two community types (13.2%), was also the smallest in this drainage basin. The relationships between the life form groups in the two drainage basins are similar. In the basin draining the Gulf of Finland the respective figures were 39.8%, 25.4%, 24.9% and 9.9%.

Among the species, *Butomus umbellatus*, *Hippuris vulgaris* and *Sagittaria sagittifolia* were commonly represented by morphologically distinct submerged forms; *Schoenoplectus lacustris* occurred as a submerged life form at deeper sites and as a helophyte in shallower areas, with both forms often growing in the same reach. *Alisma plantago-aquatica*, *Cardamine amara*, *Myosotis scorpioides*, *Nuphar lutea*, *Sparganium* spp., *Rorippa amphibia* and *Veronica anagallis-aquatica* were found as submerged or as emerged forms.

The mass occurrence of loose-lying filamentous macroalgae was recorded from five nutrient-rich reaches in the drainage basin of lakes Peipsi and Võrtsjärv. Among them, one reach was situated not far from the discharge of the wastewaters of the town of Valga into the Pedeli River, another was situated downstream of a fish-breeding reservoir and the rest were located in the upper reaches of the spring-fed River Pedja, rich in nitrogen compounds, rising from the Pandivere Upland. The species commonly belonging to assemblages of filamentous algae were *Cladophora glomerata* (most frequent), *C. rivularis*, *Vaucheria* spp., *Ulothrix zonata*, *Spirogyra* spp. In the drainage basin of the Gulf of Finland, the same situation was noted near an obviously ineffective wastewater treatment plant.

Among the environmental parameters significantly discriminating between the vegetation types for both drainage basins, current velocity and bottom substrate are of equal significance. This result is in good accordance with the viewpoint of several authors. Already Butcher (1933) pointed to current as the main factor determining the nature of the riverbed, which in turn determines the type of the vegetation. Janauer (2001) considered water flow the most prominent environmental factor for running waters, which defines grain size and sediment composition, as well as channel type and development of the flood plain. Sirjola (1969) noted that several macrophyte species have different tolerance of the current. According to Chambers *et al.* (1991), while current velocity exerts a strong direct effect on the growth of aquatic macrophytes, its indirect effect is expressed via the impact on riverbed fertility; velocities > 1 m s^{-1} will inhibit or prevent macrophyte growth. For the vegetation types of the drainage basin of the Gulf of Finland, also water BOD_5 appeared to be important, while for the vegetation types of the Peipsi–Võrtsjärv drainage basin, instead of this parameter, total N content in water played a significant role.

The river reaches in the Gulf of Finland drainage basin are grouped into four habitat types significantly separated by water depth and turbidity as well as by riverbed substrate, while the reaches of the watercourses of the Peipsi–Võrtsjärv drainage basin represented only three habitat types separated first of all by river width followed by riverbed substrate. The rivers in the drainage basin of lakes Peipsi and Võrtsjärv have a much wider variation in width compared with those in the Gulf of Finland drainage basin: the mean values for the former habitat types vary from 5.2 to 22.1 m, whereas for the latter habitat types the respective values vary from 8.1 to 16.1 m. Therefore, river width is the main parameter discriminating the habitat types in the current study. Demars and Harper (1998) have also remarked that at a catchment scale the overriding factor is stream-size and this allows other environmental factors such as field-by-field land use change, riparian disturbance by cattle or bankside shade to obscure water quality relationships.

Despite significant differences in several parameters among the habitat types, they do not appear crucial, at least for the dominating plant species or, on the other hand, the ecological amplitude of the studied species is considerably wider than that of the analysed sample. This is obvious from the cross tabulation (Table 7) of the vegetation types and the habitat types demonstrating, as in our previous paper, that plant communities of many different types can grow in a single habitat type and, *vice versa*, plant communities of a certain type can occur in different type of habitats. Thus we can claim only with some probability that the community types established for the Peipsi–Võrtsjärv drainage basin are confined to particular habitats or ecological conditions. From Tables 4A–D it appears, for example, that the communities dominated by *Potamogeton crispus* and *Elodea canadensis* (clusters 11 and 12) were more frequently recorded from waters with high N and P content, while the *Potamogeton vaginatus* × *P. filiformis* communities (cluster 8) were characterized by high water O_2 content, and the communities of *Veronica anagallis-aquatica*, *Hippuris vulgaris, Glyceria maxima* (clusters 7, 20 and 22, respectively) and the communities of the cryptogams *Fontinalis antipyretica–Vaucheria* spp.–*Cladophora glomerata* (cluster 28) were more characteristic of habitats with high water N content but with moderate P content; the communities of *Sagittaria sagittifolia*, *Potamogeton natans* and *Butomus umbellatus* were typically growing in deeper reaches, etc. In comparison with the ecological conditions for the communities of the drainage basin of the Gulf of Finland, only a few similarities were found. For the *Potamogeton vaginatus* × *P. filiformis* communities (cluster 8), high water O_2 content is characteristic of both drainage basins. In the drainage basin of the Gulf of Finland, the communities of *Hippuris vulgaris* occurred in habitats with high water N content, while the communities of the cryptogams *Fontinalis antipyretica–Cladophora glomerata* were most often recorded in habitats with high N content and very high P content in water. The communities of *Potamogeton natans* and *Butomus umbellatus* were not found in the deepest reaches but in waters with average depth, while the *Sagittaria sagittifolia* communities were found at the same depth.

On the level of single species the disagreement is even more conspicuous, though partly this is based on the more advanced GLZ model used for data analysis in the present paper. In the drainage basin of the Gulf of Finland, *Hippuris vulgaris*, *Equisetum fluviatile*, *Phalaris arundinacea* and *Potamogeton alpinus* are the species most sensitive to changes of the environmental variables; species such as *Nuphar lutea*, *Potamogeton natans* and *P. perfoliatus* are the most inert, showing no significant response to any environmental variable, while *B. umbellatus* display only response to water turbidity. According to the current data, *P. perfoliatus* and *Butomus umbellatus* are, besides *Acorus calamus*, *Potamogeton crispus*, *Schoenoplectus lacustris* and *Veronica anagallis-aquatica*, the species affected by the largest number of environmental variables.

Similarity of species reaction to some environmental variables in both drainage basins appears with species such as *Equisetum fluviatile*, *Hippuris vulgaris*, *Phalaris arundinacea*, *Ranunculus trichophyllus*, *Sium latifolium*, *Veronica anagallis-aquatica*, *Fontinalis antipyretica* and *Vaucheria* spp. According to the current data GLZ analyses, presence of the first species is negatively affected by increasing current velocity (Table 5). Negative effect has on occurrence of *Ranunculus trichophyllus* high BOD_5 of water, on *Sium latifolium* water high pH and on *Veronica anagallis-aquatica* high NH_4-N content. At the same time, water high N/P ratio is promoting occurrence of *Hippuris vulgaris* and *Phalaris arundinacea*, and high O_2 content the presence of *Fontinalis antipyretica* and *Vaucheria* spp. Negative influence of river width on the presence of *Amblystegium riparium*, *Fontinalis antipyretica* and *Cladophora glomerata* is also striking. This can be explained by rather strong correlation between river width and its depth (r = 0.57), which means that wider watercourse stretches are usually too deep for cryptogams to grow.

For the occurrence of the dominating species, water NH_4-N, PO_4-P and O_2 content, as well as N/P ratio prove to be the most important chemistry parameters in the watercourses of both compared drainage basins. For several species of the Peipsi–Võrtsjärv drainage basin water pH plays also an important role. Comparison of the physical environmental parameters significantly influencing species occurrence in both drainage basins reveals clear dissimilarity: when in the Gulf of Finland drainage basin coverage of the bed with fine sediment and water turbidity are important variables, then for the species of the drainage basin of the two large lakes river width is the most crucial factor. These facts illustrate well the conclusion made by Barendregt and Bio (2003) that there is no one explicitly prevailing environmental variable explaining the structure or distribution of macrophyte communities; each individual species displays its specific preference through setting of variables. It is evident from our study that not only do species differ in their environmental response but the same species can exhibit different responses to environmental variables between different drainage basins of a relatively small country. Virtually all the discussed plant species and communities have an extensive distribution (cf. Hultén & Fries 1986, Vitt *et al.* 1986, Grigor'ev & Solomeshch 1987, Kuz'michev 1992) and a high ecological tolerance (cf. Gessner 1955, Shilov 1975, Ellenberg 1988).

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