Ann. Bot. Fennici 44: 321–344 ISSN 0003-3847
Helsinki 26 October 2007

Vegetation of Estonian watercourses, III. Drainage basins of the Moonsund Sea, the Gulf of Riga and Saaremaa Island

Jaanus Paal[1], Tiiu Trei[2] & Malle Viik[2]

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

Received 7 Mar. 2006, revised version received 20 May 2007, accepted 30 May 2007

Paal, J., Trei, T. & Viik, M. 2007: Vegetation of Estonian watercourses, III. Drainage basins of the Moonsund Sea, the Gulf of Riga and Saaremaa Island. — *Ann. Bot. Fennici* 44: 321–344.

The general aims of the current study were to develop a classification of the plant communities of the watercourses connected with the three west-Estonian drainage basins: the Moonsund Sea, the Gulf of Riga and Saaremaa Island, to distinguish the main ecological variables which determine the occurrence of the dominating species and discriminate between the community types, and to establish a classification of the river reaches (habitats) and to identify the parameters distinguishing them. The data were clustered into 24 vegetation types of which 19 were dominated by vascular plant species, five clusters included communities of macroalgae and mosses. Distribution of communities of certain types is different in three drainage basins. Riverbed substrate, total N, NO_3-N and O_2 content in water proved to be the variables separating the clusters most reliably. The main environmental parameters affecting the occurrence of dominating species in the watercourses of western Estonia were bottom substrate, content of O_2 and NH_4-N, and N/P ratio in water. Of these parameters only NH_4-N content appears to be important for all rivers across the country. The river reaches clustered into four habitat types and they were significantly separated by the prevailing bed-forming material and by water turbidity. Cross tabulation of the vegetation types and habitat types demonstrates that different type plant communities can grow in almost every habitat type; at the same time, there was not any community type exclusively bound to one habitat type. Considering the wide ecological amplitude, large geographical distribution and high phenotypic plasticity of hydrophytes, it seems rather doubtful to develop, at least for European oligo-mesotrophic to meso-eutrophic lowland watercourses, some reliable sample or system of indicator species rendering evaluation of general water parameters or habitat characteristics.

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

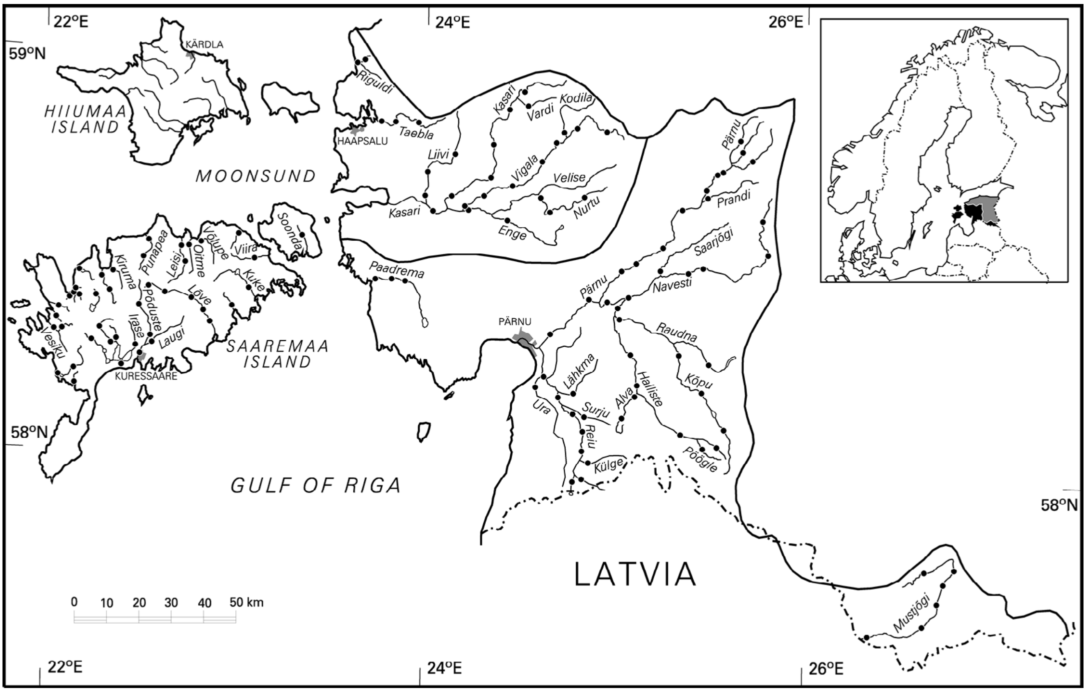

Fig. 1. Rivers of the drainage basins of the Moonsund Sea, the Gulf of Riga and Saaremaa Island, and location of the studied reaches.

Introduction

The current paper is a continuation of our two previous papers (Paal & Trei 2004, 2006) dealing with the vegetation of the Estonian watercourses flowing into the Gulf of Finland and into two largest lakes — Peipsi and Võrtsjärv. In the current paper plant communities of three remaining drainage basins, all located in western Estonia, are analysed. Like our earlier papers, the present study is also a 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 studied watercourses, (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 area under study comprises three west-Estonian drainage basins: the drainage basins of the Moonsund Sea (Väinameri), the Gulf of Riga (Liivi Bay) and Saaremaa Island (Fig. 1). Morphometrical parameters of the larger rivers given in Table 1 and data below concerning the study area are presented according to Loopmann (1979), Arukaevu (1986), Reap (1995) and Järvekülg (2001).

The drainage basin of the Moonsund Sea (MS) includes 155 rivers, brooks and ditches (Arukaevu 1986). The catchment area of the longest river, Kasari, is like wide fan and forms about 75% of the surface of the drainage basin. The sources of the longer rivers are situated 50–60 m above the sea level. Stream gradient decreases slowly and relatively evenly downstream and it is usually very small in the lower course. Nearly all rivers flow entirely in the West Estonian Lowland. Valleys of rivers are mostly absent or they are indistinct. In it's lower course, the Kasari River is surrounded by large plains where periodical floods take place.

The drainage basin of the Gulf of Riga (GR) comprises first of all the Pärnu River with it's numerous large and long tributaries which form the main river system in the drainage basin. The source of the Pärnu River is 76.2 m above sea level. Stream gradient is relatively high (1.14 $m\ km^{-1}$) on the medium course and very low on the lower course; mean stream gradient in the Pärnu River is 0.53 $m\ km^{-1}$, several rapids also occur. Extensive floods take place around the area where the Halliste River flows nearly upstream and falls in the Navesti River. Another bigger river is Mustjõgi located in the southern part of Estonia; it flows into the Gulf of Riga through the Koiva (Gauja) River and its lower course belongs to Latvia.

All watercourses of Saaremaa Island (SI) are short, narrow and low. The two longest of them are the Lõve and Põduste Rivers (Table 1). According to Horton-Strahler's stream order system they belong to the first and second orders, while only two downstream reaches of the Põduste River can be identified as third-order reaches (Trei & Pall 2004).

Most watercourses under discussion have been dredged and straightened, but they are characterised by permanent natural feeding. Weed cutting does not take place in Estonia.

The considerable share of reaches in the GR drainage basin have cool water owing to the fact that the rivers of this drainage basin rise from the karst springs on slopes of the Pandivere Upland and cold groundwater is the main contributor to discharge in their upper courses. For instance, in the upper course of the Pärnu River, the share of groundwater makes up 75%–79% of the total annual discharge (Eipre 1981). The share of groundwater is much smaller in the watercourses of the MS rainage basin, e.g. in the middle course of the Kasari River it accounts for about 28% (Järvekülg, 2001).

The water in midsummer is mostly slightly alkaline and seasonal changes in pH are small, due to the high concentration of mineral compounds, especially $Ca(HCO_3)_2$ (Järvekülg 2001).

The prevailing bottom substrata are gravel and shingle with sand and clay. Bottoms with dominating sand or clay also occur, sometimes extensive coverage with fine sediments (mud) is observed; limestone blocks occur in riverbeds locally. In limited areas, mainly near bridges, other hard substrata (boulders and cobbles) can

Table 1. Morphometrical parameters of the larger rivers of the study area. Notations: MS = the drainage basin of the Moonsund Sea, GR = the drainage basin of the Gulf of Riga, SI = the drainage basin of the Saaremaa Island. Data on Põduste River by Arukaevu (1986) and Järvekülg (2001).

Drainage basin	River	Length (km)	Catchment area (km^2)	Average width (m)		Average depth (m)		Mean discharge on the lower course ($m^3\ s^{-1}$)
				medium course	lower course	medium course	lower course	
MS	Kasari	112	3210	20	40	0.6–1.3	2–3	24.7
	Vigala	95	1580	10–15	20–25	0.3–1	1.5–3	14.3
	Velise	72	852	10	20	3	7	6–8
GR	Pärnu	144	6920	35	100	1.5	3	60–65
	Navesti	100	3000	30	50	2.5	4	24–26
	Halliste	86	1900	6	25	1.5	2	15–17
	Mustjõgi	84	total 1820, 994 in Estonia	8	20	0.6	0.7	10–12
	Reiu	73	917	8	20	0.6	1.5	6.5–7.5
SI	Lõve	31	159	4	7	0.3–0.4	0.5	0.8–1.2
	Põduste	30	206	1–6	10	0.1–0.7	0.8	0.7

be found as well, most of them related to human activity (building of bridges).

Data sampling

Data were collected from 120 reaches of 55 watercourses during July in 1994–1997, and altogether 280 descriptions of the vegetation were compiled.

Taking into consideration that at many sites the aquatic vegetation was very scarce owing to poor light conditions, only the data of 91 reaches, including 245 plant communities of 42 watercourses, were selected for statistical analysis. This sample comprised 74 communities of 19 reaches and eight rivers from the MS drainage basin, 103 communities of 39 reaches and 11 rivers from the GR drainage basin and 68 communities of 33 reaches and 23 watercourses from the SI drainage basin. As the choice of the sites for analysis depended on their accessibility to 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 characteristics were measured (Järvekülg 2001): (i) river width (m), (ii) river depth (m), (iii) current velocity in the main stream (m s^{-1}). In addition, (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) were estimated. The number of points at which the measurements and estimates 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 replications 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).

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 vascular plant communities was at least 4–5 m^2 on gravel and finer bed material, or 1 m^2 for cryptogam communities growing on boulders and limestone blocks. In 42.9% of the 90 reaches one or two plant communities (stands, assemblages) were distinguished, in 41.7% reaches three or four communities and in 14 reaches (15.4%) five or more communities were identified. 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 indentified afterwards 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 and 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

The methods used for data processing were the same as described in our previous papers (Paal & Trei 2004, 2006).

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. This method showed good concordance with the vegetation structure of the watercources where usually only one or two species are clearly dominating. Using this method, also the cophenetic correlation between the similarity matrix and the ultrametric distances matrix was higher than by 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 on water chemistry and the physical environment in the current study were only 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.

The effect of the main environmental variables on the occurrence of the most abundant plant species in the watercourse reaches was tested by the generalised linear model (GLZ) analyses. For this, the variables of water chemistry, except pH, were $\log_{10}$-transformed and abundance values of the dominating species were rescaled for presence/absence for every reach. Prior to the GLZ analysis, a correlation matrix of the environmental variables was calculated and only one of the variables, showing high correlation ($r \geq 0.6$), 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 six 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. The reaches were ordinated on a scatterplot of canonical scores.

Results

General environmental parameters

Current velocity was determined in the limits of 0.1–1.0 m s^{-1}, depending on stream gradient and water level. Most reaches of the studied watercourses had slow or moderate current velocity (< 0.5 m s^{-1}). The share of such reaches was 73.7% in the MS, 71.8% in the GR and 93.9% in the SI drainage basin where current velocity was as low as ≤ 0.3 m s^{-1} in 78.8% of reaches.

Water temperature varied in a wide range, from 8.9 °C to 23.9 °C. Cool-water (13.1–17.0 °C) and temperate-water (17.1–21.0 °C) reaches dominated, accounting for 39.6% and 33.0% of all studied reaches, respectively. Cold water (≤ 13 °C) was registered in 8.4% of the reaches, and warm water (> 21 °C) in 18.7% of the reaches. This proportion varied among different drainage basins. Warm water dominated in 52.6%, temperate water in 31.6% and cool water in 10.5% of the MS reaches. In the GR drainage basin cool water was prevailing in 53.8% of the reaches, temperate water was recorded in 25.6% and warm water in 15.4% of the reaches. In the SI drainage basin temperate-water and cool-water reaches prevailed in 42.4% and 39.4% of the reaches, respectively. The share of cold-water reaches was the highest (15.2%) in the watercourses of the SI drainage basin. In the rivers of the two other drainage basins cold water occurred in about 5% of the reaches. In the watercourses of the SI drainage basin warm water was only registered in one reach.

Water in all studied rivers was mostly weakly alkaline, with pH 7.4–8.0 (maximal limits 7.1–8.2). The highest values of pH (8.1–8.2) were measured in six reaches of the GR drainage basin.

The content of dissolved oxygen in water ranged mostly between 7.0 and 10.0 mg O_2 l^{-1}, some lower (4.6–6.4 mg O_2 l^{-1}) and higher (12.2 and 14.2 mg O_2 l^{-1}) values were recorded from the GR drainage basin. The rivers of this drainage basin showed the largest variance of this parameter in the entire study area.

The concentration of total N in the watercourses varied between 290 and 2940 mg m^{-3}. High values (> 1500 mg m^{-3}) according to an original scale elaborated by Järvekülg (2001) were established for 47.4% of the MS reaches, for 25.6% of the GR reaches and for 12.1% of the SI reaches. In most reaches (52.6% in the MS, 71.8% in the GR, and 75.8% in the SI drainage basins) the value of total N was moderate (505–1500 mg m^{-3}).

The content of NO_3-N in water was in the limits of 1–2425 mg m^{-3}. Very high values (> 1200 mg m^{-3}) according to the above scale were registered from 26.3% of the MS reaches and from 17.9% of the GR reaches. In the SI drainage basin reaches with such NO_3-N content were absent. High values (505–1200 mg m^{-3}) were recorded from 31.6% of the MS reaches, from 20.5% of the GR reaches and from 9.1% of the SI reaches. In the SI drainage basin the content of NO_3-N was very low (< 50 mg m^{-3}) in 39.4% of the reaches, and low (51–250 mg m^{-3}) or moderate (255–500 mg m^{-3}) in 24.2% and 27.3% of the reaches, respectively. In the MS drainage basin reaches with very low NO_3-N content were absent and only single reach with such content was recorded from the GR drainage basin.

The content of total P in the studied rivers varied from 10 to 522 mg m^{-3}. Two reaches near a wastewater discharge with values of 304 and 522 mg m^{-3}, respectively, were located in the watercourses of the GR drainage basin. Such values correspond to an extremely high concentration (> 300 mg m^{-3}; Järvekülg 2001) of total P. In the other drainage basins such high concentration of total P was not noted. The share of the reaches with very high (105–300 mg m^{-3}) and high (51–100 mg m^{-3}) content of total P was 57.9% in the MS, 46.1% in the GR and 21.2% in the SI drainage basins. In the last drainage basin the highest value of total P was 130 mg m^{-3}. Moderate content of total P (16–50 mg m^{-3}) was recorded from 42.1% of the MS reaches, from 48.7% of the GR reaches and from 63.6% of the SI reaches. Low content (< 15 mg m^{-3}) of total P was found only in five reaches (15.2%) of the SI drainage basin.

The content of PO_4-P exceeded 20 mg m^{-3} in 63.2% of the reaches in the MS drainage basin and in 48.7% of the reaches in the GR drainage basin. Among them, an extremely high content of PO_4-P (109–243 mg m^{-3}) was recorded from four reaches (21%) of the MS and (104–438 mg m^{-3}) from three reaches (7.7%) of the GR drainage basin. In the reaches of the SI drainage basin the highest value of the content of PO_4-P was 82 mg m^{-3}; in most (63.6%) of the SI reaches the corresponding variable was smaller than 20 mg m^{-3}.

Vegetation types

After merging several small indistinct clusters and following the established limit that a cluster must include as a minimum three samples, altogether 24 significantly distinct clusters (community types) were established. The value of the cophenetic correlation of the dendrogram was 0.789, indicating its good correspondence to the structure of the similarity matrix.

The established community types have usually one single dominant species. Nineteen types are dominated by vascular plant species, while five types include communities of macroalgae and mosses (Tables 2, 3 and 4). Two dominants are characteristic of the communities of cluster 2 (*Schoenoplectus lacustris*, *Sium latifolium*), cluster 20 (*Cladophora* spp., *Vaucheria* spp.), cluster 22 (*Fontinalis antipyretica*, *Vaucheria* spp.), and cluster 24 (*Amblystegium riparium*, *F. antipyretica*).

The most species-rich communities are dominated by *Equisetum fluviatile* (cluster 19, 48 taxa in all), *Schoenoplectus lacustris* (cluster 1, 45 taxa in all) and *Sparganium erectum* (cluster 14, 41 taxa in all). The mean number of species per community is the highest (16) in cluster 17, dominated by *Glyceria maxima*. Clusters 3 (dominated by *Butomus umbellatus*) and 13 (dominated by *Ranunculus aquatilis*) followed by a mean species number of 12. All communities on stones (clusters 20–24) are species-poor, comprising 6–15 taxa per type.

Among the 245 analysed communities, the most frequent are those dominated by *Schoenoplectus lacustris* (cluster 1; 16.7%), *Fontinalis antipyretica–Vaucheria* spp. (cluster 22; 7.8%), *Equisetum fluviatile* (cluster 19; 7.8 %), *Schoenoplectus lacustris–Sium latifolium* (cluster 2; 7.4 %), *Sparganium erectum* (cluster 14; 6.1%), *Hippuris vulgaris* (cluster 9; 4.9%), *Phragmites australis* (cluster 12; 4.9%), *Butomus umbellatus* (cluster 3; 4.5%) and *Nuphar lutea* (cluster 5; 4.1%).

The results of discriminant function analysis show (Table 5) that in terms of the environmental variables the obtained vegetation types are significantly separated by content of O_2, total N and NO_3-N in water, and riverbed substrate. Still, the average values of the environmental parameters, calculated for the vegetation clusters (Tables 6, 7 and 8), should be interpreted with some caution, 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 parameters of water chemistry are the content of O_2, NH_4-N and N/P ratio, which affect the occurrence of eight, seven and seven species, respectively; they are followed by such parameters as content of NO_3-N and PO_4-P in water, which influence significantly the occurrence of six species (Table 9). Of the parameters of the physical environment, bottom substrate is important for nine species, river depth for five, river width and current velocity for four species.

Among the analysed species the most sensitive to changes in the environmental variables are *Sium latifolium*, *Nuphar lutea* and *Sparganium* spp., which react significantly to eight, five and five parameters, respectively (Table 9). At the same time, *Amblystegium riparium* did not respond significantly to any considered variable, while the occurrence of *Berula erecta*, *Glyceria maxima*, *Mentha* × *verticillata*, *Potamogeton natans*, *Ranunculus aquatilis*, *Typha latifolia* and *Vaucheria* spp. is only affected by one variable.

According to cluster analysis, the studied watercourse reaches form four groups which can be interpreted as habitat types. The 1st habitat type includes 14.4% of the reaches; to this group belong the widest and deepest reaches with comparatively slow current; the water is to some extent turbid; bottom substrate is mostly gravel but sandy and even clayey bottoms are also rather frequent; mud sediments on bottom are lacking (Table 10). To the 2nd habitat type belong 22.2% of the reaches, representing the narrowest but rather deep slowly flowing watercourses; the water is usually slightly turbid, bottom substrate is varying with prevailing gravelly and stony bottoms; bottom is usually extensively covered with fine sediments. Of the reaches 20.0% can be classified under the 3rd type; these are quite shallow stretches with medium width and moderate velocity; the water is clear, the bottom substrate is mostly gravel covered partly with fine sediments. The last, 4th habitat type (including 43.3% of the reaches) covers rather wide but shallow reaches with moderate velocity; the water is clear, bottom is mostly gravelly or stony, but sandy bottoms occur as well; fine sediments are usually lacking.

The canonical ordination plot (Fig. 2) illustrates well the results of discriminant analysis: the mutual relationship of the river reaches on the scatterplot is first of all determined by extent of coverage of bottom with fine sediments and by water turbidity (Table 11). The river reaches of different habitat types are clearly separated from

Table 2. Centroids of clusters 1 to 10. The cluster number is followed by the number of communities in the cluster (in brackets). 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 (41)		2 (18)		3 (11)		4 (5)		5 (10)		6 (4)		7 (3)		8 (5)		9 (12)		10 (5)	
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
Acorus calamus	0	17	0	33	0	27	0	20	0	20	–	–	–	–	–	–	0	–	–	–
Agrostis stolonifera var. *prorepens*	0	2	0	6	–	–	–	–	–	–	–	–	–	–	–	–	0	8	–	–
Alisma plantago-aquatica	1	66	1	72	1	55	1	60	0	30	–	–	0	33	0	20	0	17	0	20
Berula erecta	0	7	0	6	–	–	0	20	–	–	–	–	–	–	–	–	0	17	0	20
Butomus umbellatus	0	32	1	61	10	100	–	–	0.5	50	–	–	–	–	1	80	0	42	–	–
Caltha palustris	0	22	0	28	0	9	0	20	–	–	–	–	0	33	–	–	0	–	–	–
Cardamine amara	0	2	–	–	–	–	–	–	0	10	–	–	–	–	–	–	0	–	–	–
Carex acuta	0	41	0	44	0	36	–	–	0	10	–	–	0	33	–	–	0	–	–	–
Carex spp.	–	–	–	–	–	–	0	40	–	–	–	–	–	–	–	–	0	–	–	–
Catabrosa aquatica	0	5	0	6	0	9	–	–	0	10	0	25	–	–	–	–	0	8	–	–
Elodea canadensis	–	–	–	–	0	9	–	–	0	10	0	25	–	–	–	–	0	–	–	–
Equisetum fluviatile	0	29	0	44	0	36	1	60	0	10	–	–	–	–	–	–	0	25	–	–
Filamentous macroalgae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	60
Glyceria maxima	0	10	0	6	0	27	–	–	–	–	0	25	–	–	0	20	0	–	–	–
Hippuris vulgaris	0	5	0	11	0	9	–	–	0	10	0.5	50	–	–	0	40	10	100	0	20
Hydrocharis morsus-ranae	0	7	0	6	–	–	–	–	0	10	–	–	–	–	–	–	0	–	–	–
Iris pseudacorus	0	10	0	6	–	–	1	60	–	–	–	–	0	33	–	–	0	–	–	–
Juncus nodulosus	–	–	–	–	–	–	0	20	–	–	–	–	–	–	–	–	0	–	–	–
Lemna minor	0	10	0	44	1	55	0	20	0	20	–	–	–	–	0	20	0	17	–	–
Lemna trisulca	0	15	0	11	0	27	–	–	0	20	–	–	–	–	–	–	0	25	0	20
Lythrum salicaria	0	12	0	17	0	18	0	20	–	–	–	–	–	–	–	–	–	–	–	–
Mentha aquatica	0	32	0	28	0	27	0	40	0	10	0	25	1	67	0	20	0	17	0	20
Menyanthes trifoliata	0	2	–	–	0	9	0	20	–	–	–	–	–	–	–	–	–	–	–	–
Myosotis scorpioides	0	34	0	22	0	36	0	40	0	20	0	25	–	–	0	40	0	8	0	20
Naumburgia thyrsiflora	0	39	0	33	1	55	0	20	0	20	–	–	0	25	–	–	0	8	–	–
Nuphar lutea	1	71	0.5	50	1	73	–	–	10	100	0	25	0	25	1	60	0	42	1	60
Nymphaea alba	0	5	0	11	–	–	–	–	0	10	–	–	–	–	–	–	–	–	–	–
Nymphaea candida	0	5	0	11	0	9	–	–	0	10	–	–	–	–	0	40	–	–	–	–
Phalaris arundinacea	0	34	1	56	0	36	1	60	–	–	–	–	–	–	–	–	0	17	–	–
Phragmites australis	0	27	0	28	0	18	–	–	–	–	–	–	–	–	–	–	0	17	–	–
Polygonum amphibium	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	20
Potamogeton alpinus	0	5	–	–	–	–	–	–	–	–	0	25	10	100	–	–	0	17	1	60
Potamogeton lucens	0	7	0	22	0	9	–	–	0	20	–	–	–	–	–	–	–	–	0	20
Potamogeton natans	0	5	–	–	0	9	–	–	0	20	–	–	–	–	–	–	0	25	10	100
Potamogeton pectinatus	0	5	–	–	0	9	–	–	–	–	–	–	–	–	–	–	0	8	–	–

Potamogeton perfoliatus	0	7	0	28	0	18	–	–	0	10	–	–	–	–	10	100	0	8	0	20
Potamogeton spp.	0	7	–	–	0	9	0	20	–	–	–	–	–	–	–	–	–	–	–	–
Ranunculus lingua	0	39	0	22	0	36	0	20	0	10	–	–	–	–	–	–	0	8	–	–
Ranunculus trichophyllus	0	2	–	–	0	9	–	–	–	–	–	–	–	–	–	–	0	8	–	–
Rorippa amphibia	0	15	0	22	0	45	–	–	0	10	–	–	–	–	0	20	–	–	–	–
Sagittaria sagittifolia	0	17	0	17	0	68	–	–	0	10	–	–	–	–	–	–	–	–	0	20
Schoenoplectus lacustris	10	100	10	94	1	100	1	80	0.5	50	0	25	1	67	0	20	0	33	0	20
Sium latifolium	1	76	10	89	1	91	–	–	0	40	–	–	–	–	1	60	0	33	0	20
Solanum dulcamara	0	7	0	17	0	18	0	20	–	–	0	25	–	–	–	–	0	8	–	–
Sparganium erectum	0	41	0.5	50	1	55	0	40	0	10	0	25	–	–	–	–	0	8	0	20
Sparganium spp.	0	10	0	6	–	–	0	20	0.5	50	10	100	1	67	0	20	0	17	1	60
Spirodela polyrrhiza	0	7	0	11	0	18	–	–	0	10	–	–	–	–	–	–	–	–	–	–
Teucrium scordium	–	–	–	–	–	–	–	–	–	–	0	25	–	–	–	–	–	–	–	–
Typha latifolia	0	7	0	11	0	9	10	100	–	–	–	–	–	–	–	–	0	8	–	–
Valeriana officinalis	0	5	–	–	–	–	0	20	–	–	–	–	–	–	–	–	–	–	–	–
Veronica anagallis–aquatica	0	10	0	6	0	9	–	–	0.5	50	–	–	–	–	0	20	0	8	–	–
Total number of species in cluster		45		37		37		23		30		13		10		15		28		18
Number of species in community		1–21		5–16		6–21		6–14		1–12		2–6		3–8		4–9		1–12		3–8
Mean number of species per community		10		11		12		9		7		4		5		6		6		5

each other; the statistical significance ($P < 0.001$) of both first roots (canonical axes) is highly reliable. High intrinsic variation in the river reaches representing the 2nd habitat type is also obvious, while the reaches of the 4th habitat type form a remarkably compact cluster.

Crosstabulation of the vegetation types and habitat types (Table 12) demonstrates that none of the community types is exclusively bound to one particular habitat type. Only the habitats of the 4th type were somewhat preferred by the communities of *Potamogeton perfoliatus* (8th cluster), *Ranunculus aquatilis* (13th cluster) and *Mentha* × *verticillata* (16th cluster). The total number of all these communities was not high, 5, 4 and 7, respectively. Of all 245 plant communities, 14.7% were classified under the 1st habitat type, 24.5% under the 2nd, 20.4% under the 3rd and 40.4% under the 4th habitat type.

Discussion

The watercourses of the SI drainage basin are characterized by extremely slow current (mostly < 0.3 m s^{-1}). This is caused by comparatively low precipitation rate on the Saaremaa Island as well as by weak development of the natural network of watercourses. In numerous places the discharge of springs and the amount of water in mires have also decreased due to large-scale melioration (Arold 2005).

The content of all determined nutrients was the highest in the watercourses of the MS drainage basin, especially in the lower reaches. This is mainly related to the fact that the main river of this drainage basin, Kasari, has a large catchment area where numerous big farms were engaged in intensive agriculture and cattle breeding in the period of sampling. Periodical floods have replenished the amount of nutrients in the rivers and streams. Also it should be mentioned that after the collapse of the Soviet-type collective farming and owing to the more effective purification of sewage from towns and settlements, water quality in several Estonian rivers has substantially improved during the last ten years (Järvekülg *et al*. 1997, Järvekülg 2000, Viik 2003).

The spring-fed rivers and streams of the GR drainage basin, flowing in the karst region, are

Table 3. Centroids of clusters 11 to 19. Denotations as in Table 2.

Species	Cluster																	
	11 (9)		12 (12)		13 (4)		14 (15)		15 (9)		16 (7)		17 (3)		18 (4)		19 (19)	
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
Acorus calamus	0	11	0	8	–	–	–	–	0	11	0	14	0	33	–	–	0	16
Agrostis stolonifera var. *prorepens*	–	–	0	17	0	25	0	20	0	33	–	–	–	–	–	–	0	5
Alisma plantago-aquatica	0	44	0	25	1	100	1	60	1	55	1	57	1	100	0.5	50	1	58
Berula erecta	10	100	–	–	–	–	0	13	–	–	0	14	–	–	–	–	0	5
Butomus umbellatus	0	33	0	25	–	–	0	40	0	11	0	14	1	100	0.5	50	0	21
Caltha palustris	0	33	0	8	0	25	0	13	1	77	0	14	1	67	0.	50	0	26
Calystegia sepium	–	–	–	–	–	–	–	–	0	11	0	14	–	–	–	–	0	5
Cardamine amara	–	–	–	–	0	25	0	7	–	–	–	–	–	–	0	25	–	–
Carex acuta	0	22	0	17	–	–	0	13	0	44	0	14	1	100	1	75	1	53
Carex spp.	–	–	0	8	–	–	–	–	0	11	–	–	–	–	–	–	–	–
Carex vesicaria	–	–	0	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Catabrosa aquatica	0	22	–	–	–	–	0	7	–	–	–	–	–	–	–	–	–	–
Ceratophyllum demersum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	25	–	–
Eleocharis palustris	–	–	–	–	0	25	–	–	–	–	–	–	–	–	–	–	0	5
Eleocharis spp.	–	–	–	–	0	25	–	–	–	–	–	–	–	–	–	–	–	–
Elodea canadensis	–	–	–	–	–	–	0	13	–	–	–	–	–	–	–	–	0	16
Epilobium hirsutum	–	–	0	8	0.5	50	0	7	0	22	–	–	–	–	–	–	–	–
Epilobium palustre	–	–	0	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Epilobium spp.	–	–	–	–	0	25	0	7	–	–	–	–	–	–	–	–	–	–
Equisetum fluviatile	0	33	0	33	–	–	0	20	0	11	0	43	0	33	0.5	50	10	100
Equisetum palustre	–	–	0	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Galium palustre	–	–	0	8	0.5	50	–	–	0	11	–	–	–	–	–	–	–	–
Glyceria fluitans	–	–	0	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Glyceria maxima	0	11	–	–	–	–	–	–	–	–	–	–	10	100	–	–	0	5
Glyceria plicata	0	22	–	–	–	–	0	20	0	11	–	–	–	–	–	–	0	5
Glyceria spp.	–	–	0	8	0	25	–	–	0	11	–	–	–	–	–	–	0	11
Hippuris vulgaris	0	22	0	8	–	–	0	13	–	–	–	–	–	–	–	–	–	–
Hydrocharis morsus-ranae	–	–	–	–	–	–	0	7	–	–	–	–	–	–	0	25	0	5
Iris pseudacorus	0	11	–	–	0	25	0	40	0	11	0	14	–	–	0	25	0	21
Juncus articulatus	–	–	–	–	0	25	–	–	–	–	–	–	–	–	–	–	–	–
Juncus articulatus var. *hylandri*	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	11
Juncus spp.	–	–	–	–	0	25	–	–	–	–	–	–	–	–	–	–	–	–
Lemna minor	0	11	0	8	0.5	50	0	20	0	22	1	57	–	–	0	25	0	16
Lemna trisulca	0	11	–	–	1	75	0	20	–	–	0	29	–	–	–	–	0	16
Lycopus europaeus	–	–	0	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lysimachia vulgaris	–	–	–	–	–	–	–	–	0	22	–	–	–	–	–	–	–	–
Lythrum salicaria	–	–	–	–	–	–	0	13	0	11	0	29	–	–	–	–	0	5
Mentha aquatica	0	11	0.5	0	0	25	0	27	0	11	–	–	1	67	–	–	0	37
Mentha × *verticillata*	–	–	0	17	0	25	–	–	0	33	10	100	1	67	–	–	0	5

Menyanthes trifoliata	–	–	0	8	–	–	–	–	–	–	–	–	–	–	–	–	0	16
Myosotis scorpioides	0	22	0	8	0.5	50	0	13	0	33	1	57	1	100	0	25	0	37
Myriophyllum spicatum	–	–	–	–	–	–	0	7	–	–	–	–	–	–	–	–	–	–
Naumburgia thyrsiflora	0	22	0	33	0	–	0	27	0	44	0	14	0	33	0.5	50	0	37
Nuphar lutea	0	33	0	17	0	–	0	27	0	33	0	43	0	33	1	75	0	37
Nymphaea candida	–	–	–	–	–	–	–	–	–	–	0	14	–	–	–	–	0	5
Oenanthe aquatica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	16
Phalaris arundinacea	0	33	0	42	–	–	1	60	10	100	5	86	5	100	0.5	50	0	32
Phragmites australis	–	–	10	100	0.5	50	0	27	0	11	–	–	1	100	–	–	0	37
Polygonum amphibium	–	–	–	–	–	25	–	–	–	–	–	–	–	–	–	–	–	–
Potamogeton alpinus	0	11	–	–	–	–	0	13	–	–	0	29	–	–	0	25	0	5
Potamogeton berchtoldii	–	–	–	–	–	25	–	–	–	–	–	–	–	–	–	–	–	–
Potamogeton filiformis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	25	–	–
Potamogeton friesii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	5
Potamogeton gramineus	–	–	–	–	0	25	–	–	–	–	0	29	–	–	–	–	–	–
Potamogeton lucens	0	11	–	–	–	–	–	–	–	–	–	–	–	–	0	25	0	16
Potamogeton natans	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	25	0	5
Potamogeton pectinatus	–	–	–	–	–	–	0	7	–	–	–	–	–	–	–	–	–	–
Potamogeton perfoliatus	0	11	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	5
Ranunculus aquatilis	–	–	–	–	10	100	–	–	–	–	–	–	–	–	–	–	–	–
Ranunculus flammula	–	–	0	17	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ranunculus lingua	0	33	0	33	–	–	0	40	0	22	0	43	–	–	–	–	0	32
Ranunculus spp.	–	–	–	–	–	–	0	7	0	11	–	–	–	–	–	–	–	–
Ranunculus trichophyllus	0	11	–	–	–	–	–	–	0	11	–	–	–	–	–	–	–	–
Rorippa amphibia	–	–	–	–	–	–	0	7	0	11	0	14	1	100	–	–	0	11
Rumex aquaticus	–	–	–	–	–	–	0	7	0	22	0	14	1	67	–	–	0	5
Rumex spp.	0	11	–	–	0	25	0	7	–	–	–	–	–	–	–	–	–	–
Sagittaria sagittifolia	0	11	–	–	0	25	0	13	–	–	0	14	–	–	10	100	0	26
Salix lapponum	–	–	0	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Schoenoplectus lacustris	0	44	0	33	0	25	0	47	0	44	1	43	1	100	1	75	0	37
Scirpus sylvaticus	–	–	0	25	0	25	–	–	0	22	–	–	–	–	–	–	0	5
Sium latifolium	0	44	0	33	0	25	0	33	1	55	1	86	1	100	1	75	0	47
Solanum dulcamara	0	33	–	–	–	–	0	13	0	22	0	14	–	33	–	–	0	5
Sparganium erectum	0	33	0	17	0	75	10	100	1	77	1	57	5	100	0.5	50	0	42
Sparganium spp.	0	22	0	8	0	25	0	33	–	–	–	–	–	–	–	25	0	36
Spirodela polyrrhiza	–	–	–	–	–	–	–	–	0	11	0	14	–	–	–	–	–	–
Stachys palustris	–	–	–	–	–	–	–	–	–	–	–	–	0	33	–	–	0	5
Typha latifolia	0	11	–	–	–	–	–	33	0	33	0	14	1	67	0	25	0	11
Valeriana officinalis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Veronica anagallis-aquatica	0	22	–	–	0.5	50	0	40	–	–	0	14	–	–	–	–	0	11
Filamentous macroalgae	0	33	0	25	1	75	0	27	0	11	0	14	–	–	–	–	0	37
Total number of species in cluster		33		33		31		41		36		31		22		23		48
Number of species in community		1–15		1–10		8–15		3–17		5–15		3–11		15–18		7–15		6–17
Mean number of species per community		8		7		12		10		10		10		16		11		10

characterized by high concentration of nitrogen compounds in water in their upper course. The upper aquifers of groundwater there had been contaminated as a consequence of the misuse of fertilizers on arable land in 1960–1990 (Järvekülg & Viik 1994). The amount of nitrogen compounds decreases downstream, except in the reaches located near a wastewater discharge.

The low content of nutrients in the streams and ditches of the SI drainage basin results from small catchment areas, as well as from the low natural level of nutrients in thin young soils on carbonate plains (Arold 2005).

The distribution of certain type plant communities is different in the three drainage basins dealt with in the current study. Of the 24 community types established, only 14 are common for all three drainage basins, among them 11 types of vascular plants and 3 community types of macroalgae and mosses (Table 13). Communities of *Glyceria maxima* were registered only in the MS drainage basin, while the communities of *Potamogeton alpinus* and *Ranunculus aquatilis* were not described elsewhere as in the watercourses of the Saaremaa Island.

In all five drainage basins of Estonia (cf. Paal & Trei 2004, 2006) the communities dominated by the following species (i.e. community types) were established: *Schoenoplectus lacustris* (in 69 reaches, or in 25.1% of the total number of reaches filtered out for data analysis), *Sparganium erectum* (in 49 reaches, 17.8%), *Nuphar lutea* (in 48 reaches, 17.5%), *Equisetum fluviatile* (in 37 reaches, 13.5%), *Hippuris vulgaris* (in 28 reaches, 10.2%), *Phragmites australis* (in 21 reaches, 7.6%), *Vaucheria* spp. (in 20 reaches, 7.3%) and *Phalaris arundinacea* (in 18 reaches, 6.5%). The communities dominated by *Clado-*

Table 4. Centroids of clusters 20 to 24. Denotations as in Table 2.

Species	Cluster									
	20 (8)		21 (7)		22 (19)		23 (5)		24 (7)	
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
Amblystegium riparium	0	13	0	29	0	21	–	–	10	100
Amblystegium tenax	–	–	0	14	–	–	–	–	–	–
Cratoneuron filicinum	–	–	–	–	0	5	0	20	–	–
Fontinalis antipyretica	0	25	0	29	10	100	10	100	10	100
Batrachospermum moniliforme	0	13	–	–	0	5	0	20	–	–
Batrachospermum spp.	–	–	–	–	–	–	0	20	0	14
Chaetophora spp.	–	–	–	–	–	–	0	20	–	–
Chantransia chalybea	–	–	–	–	0	21	–	–	–	–
Chara fragilis	–	–	–	–	0	5	–	–	–	–
Cladophora glomerata	2.5	50	0	43	5	84	0	40	–	–
Cladophora spp.	5	50	0	14	0	5	10	20	0	29
Lemanea spp.	0	25	0	14	0	16	–	–	–	–
Microspora spp.	–	–	–	–	0	11	–	–	0	14
Oedogonium spp.	–	–	–	–	0	5	–	–	–	–
Oscillatoria spp. as filaments	0	13	–	–	–	–	–	–	–	–
Oscillatoria spp. as film	0	25	–	–	0	11	–	–	–	–
Spirogyra spp.	0	13	–	–	0	11	0	20	–	–
Stigeoclonium spp.	0	25	0	14	–	–	–	–	–	–
Tetraspora spp.	0	13	–	–	–	–	–	–	–	–
Ulothrix aequalis	0	13	–	–	0	5	–	–	–	–
Ulothrix zonata	1	63	0	29	0	26	0	20	0	14
Vaucheria spp.	10	88	10	100	10	100	0	20	0	29
Total number of species in cluster		13		8		15		9		6
Number of species in community		2–7		1–4		3–6		1–4		2–5
Mean number of species per community		4		3		4		3		3

phora glomerata or *C*. spp. and *Vaucheria* spp. were also represented in rivers of all drainage basins, and if not to tangle with the question which species of these three prevail in a certain community, we can interpret them as belonging to the *Cladophora* spp.–*Vaucheria* spp. type, identified altogether 38 times.

Remarkably frequent, as recorded in the watercourses of four drainage basins, were also communities of *Sparganium* spp. (in 46 reaches, or in 16.7% of all 275 reaches), *Sagittaria sagittifolia* (in 26 reaches, 9.5%), and *Fontinalis antipyretica* (in 23 reaches, 8.4%), at the same time all these communities were lacking in the MS drainage basin. Communities dominated by *Butomus umbellatus* and *Potamogeton perfoliatus* did not occur in the rivers of the SI drainage basin but were represented elsewhere in 25 and 21 reaches (9.1 and 7.6%, respectively) (Table 13).

Only in the watercources of the Gulf of Finland were recorded community types of *Mentha aquatica*, *Nuphar lutea–Sagittaria sagittifolia*, *Sium latifolium* and *Amblystegium riparium–Cladophora glomerata–Fontinalis antipyretica* (Table 13). Rivers of the lakes Peipsi and Võrtsjärv drainage basin contain even more communities not represented in watercources of other drainage basins: *Acorus calamus*, *Elodea canadensis*, *Potamogeton crispus*, *P. pectinatus*, *Rorippa amphibia*, *Veronica anagallis-aquatica*, *Amblystegium riparium*, *Fontinalis antipyretica–Vaucheria* spp.–*Cladophora glomerata*.

Thus, the most frequent community types in the west-Estonian watercources are the same as elsewhere in Estonia. The one exception is *Fontinalis antipyretica–Vaucheria* spp. type, the communities of which were not established in the rivers of the other drainage basins, although either dominant species alone is frequent there as well. Another exception are the communities of *Ranunculus aquatilis* described only in the rivers of the Saaremaa Island.

Regarding differences between the community types of cryptogams, they 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 reliably estimated in the field. In addition, it deserves to mention that also communities of the macroscopic red algae *Batrachospermum moniliforme*, *Chantransia chalybea*, *Lemanea* spp. and *Hildenbrandia rivularis*, the brown alga *Heribaudiella fluviatilis*, the green alga *Chaetophora elegans* and macroscopic films of blue-green algae (cyanobacteria) can be found sporadically on hard bottoms in the Estonian rivers. As the above algae occurred in small assemblages or were found at less than three sites in the drainage basin, they were excluded from statistical analysis.

According to the prevailing life form of the dominating species, the established community types of the studied drainage basins can be arranged into four groups, as was done with the

Table 5. Separation of the vegetation types and habitat (river stretches) types by environmental parameters, summary of the discriminant function analyses. *F*-remove = value of the *F*-criterion associated with Partial Wilks' λ, *P* = significance level; pH = pH estimated *in situ*, O_2 = content of dissolved oxygen, O_2-sat = saturation with O_2 (%), BOD_5 = biological oxygen demand, N_{Tot} = content of total nitrogen, NO_3-N = content of NO_3-nitrogen, NO_2-N = content of NO_2-nitrogen, NH_4-N = content of NH_4-nitrogen, P_{Tot} = content of total phosphorus, PO_4-P = content of PO_4–phosphorus, N/P = ratio of P to N 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-remove	*P*	*F*-remove	*P*
pH	1.304	0.168	2.469	0.069
O_2 (mg l^{-1})	1.654	0.035	0.048	0.986
O_2-sat (%)	1.196	0.251	0.160	0.923
BOD_5 (mg O_2 l^{-1})	1.089	0.359	1.138	0.340
N_{Tot} (mg m^{-3})	2.475	0.001	1.949	0.130
NO_3-N (mg m^{-3})	2.239	0.002	0.802	0.497
NO_2-N (mg m^{-3})	1.054	0.399	0.994	0.401
NH_4-N (mg m^{-3})	1.186	0.260	0.059	0.981
P_{Tot} (mg m^{-3})	1.280	0.184	1.827	0.150
PO_4-P (mg m^{-3})	1.309	0.164	0.365	0.779
N/P	0.748	0.791	0.617	0.607
Wid (m)	1.037	0.420	1.019	0.389
Dep (m)	1.155	0.289	0.630	0.598
Vel (m s^{-1})	0.899	0.599	0.267	0.849
WTur	0.991	0.477	112.105	< 0.001
FSed	1.559	0.055	87.825	< 0.001
BSub	9.387	< 0.001	1.729	0.065

Table 6. Average values of the environmental variables for vegetation clusters 1 to 10. Mean = mean value, S.E. = standard error of the mean. Other denotations as in Tables 2 and 5.

Variable	Cluster																			
	1		2		3		4		5		6		7		8		9		10	
	Mean	S.E.	Mean	S.E.	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	0.0	7.7	0.0	7.7	0.1	7.6	0.1	7.7	0.1	7.7	0.0	7.7	0.1	7.8	0.1	7.7	0.1	7.8	0.1
O_2	8.6	0.2	7.5	0.3	8.0	0.5	8.5	0.6	7.9	0.3	9.6	0.9	8.4	1.1	9.1	0.4	8.6	0.4	9.2	0.4
O_2-sat	89.6	2.4	79.2	3.0	84.5	5.3	86.4	7.2	81.2	2.9	89.8	9.6	80.7	13.8	94.2	4.1	88.3	3.8	94.4	4.9
BOD_5	2.7	0.1	2.9	0.2	3.3	0.3	2.3	0.4	2.7	0.1	2.8	0.5	2.6	0.5	2.9	0.4	2.8	0.2	2.8	0.2
N_{Tot}	1159.5	75.9	1316.9	168.1	1515.8	188.6	599.0	107.1	1412.3	157.1	1390.8	533.3	818.0	242.9	1609.2	351.6	1254.0	140.2	994.2	200.2
NO_3-N	561.5	83.3	596.1	142.4	858.5	144.5	127.4	50.7	640.9	142.1	724.3	407.1	221.0	72.7	910.8	326.5	628.8	161.0	331.6	110.5
NO_2-N	91.5	31.9	68.6	25.5	124.7	60.2	9.4	5.4	80.8	61.2	9.8	5.2	4.0	1.5	115.4	72.4	42.3	21.1	5.2	1.4
NH_4-N	29.2	7.7	42.1	20.4	56.2	32.6	24.4	9.5	73.2	37.6	112.3	109.3	5.0	1.0	29.8	13.8	44.1	24.8	72.8	53.5
P_{Tot}	68.0	6.4	87.1	16.5	99.0	17.9	26.6	5.2	66.4	8.8	106.5	65.8	39.0	1.0	203.2	91.6	68.3	11.8	56.4	11.7
PO_4-P	37.3	5.5	51.9	14.5	66.8	14.9	8.2	3.2	36.4	7.6	73.8	54.4	16.0	1.7	161.4	81.0	40.8	10.0	28.8	8.9
N/P	140.5	36.5	71.8	14.3	61.4	19.3	53.8	20.2	362.2	248.7	79.7	40.2	14.2	3.7	55.3	40.2	167.4	119.9	62.7	47.6
Wid	19.6	2.9	13.7	2.1	19.0	4.2	9.4	2.9	11.6	3.3	13.0	2.4	7.3	1.8	9.4	1.7	11.7	1.6	5.8	0.9
Dep	0.8	0.1	0.8	0.1	0.7	0.1	0.5	0.1	0.9	0.1	0.7	0.0	0.5	0.2	0.5	0.1	0.6	0.0	0.6	0.1
Vel	0.4	0.0	0.3	0.1	0.5	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.2	0.1	0.4	0.1	0.2	0.1
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
WTur	1	51.2	1	55.5	1	63.6	2	60	1	60	1.5	75	1	66.7	1	80	1	66.7	2	40
FSed	1	56.1	1	55.5	1	63.6	2	40	2	40	2	50	2	66.7	1	100	1	66.8	3	60
BSub	3	82.9	3	88.9	3	100	3	80	3	70	2.5	75	3	100	3	60	3	66.9	3	40

Table 7. Average environmental variables of the vegetation clusters 11 to 19. Denotations as in Tables 2, 5 and 6.

Variable	Cluster																	
	11		12		13		14		15		16		17		18		19	
	Mean	S.E.	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	7.7	0.1	7.7	0.1	7.7	0.1	7.7	0.1	7.6	0.1	7.8	0.1	7.6	0.0	7.9	0.1	7.6	0.1
O_2	9.3	0.4	8.0	0.5	7.4	0.9	9.0	0.3	8.5	0.4	8.8	0.3	6.7	1.1	9.2	0.5	8.5	0.5
O_2-sat	90.3	5.3	84.3	5.9	78.5	11.2	89.9	3.5	87.3	4.0	88.6	3.5	71.7	13.3	92.0	6.2	87.3	5.1
BOD_5	2.7	0.2	3.0	0.3	2.6	0.4	2.8	0.2	2.7	0.1	2.5	0.2	3.9	0.6	2.3	0.8	2.7	0.2
N_{Tot}	1466.3	175.4	968.9	109.4	1533.0	155.7	1419.7	176.4	1501.6	204.9	1297.7	230.7	2672.3	14.7	1107.8	79.3	1144.8	129.8
NO_3-N	1081.1	231.5	230.4	85.3	95.5	94.2	751.1	175.0	762.4	218.1	778.9	218.5	1764.3	105.7	385.0	91.1	390.1	93.4
NO_2-N	83.2	75.9	62.8	57.1	2.9	2.0	60.9	42.0	65.0	25.7	38.4	22.4	326.7	73.3	5.5	0.6	114.5	54.8
NH_4-N	49.3	20.1	25.5	6.1	18.3	17.3	41.0	25.8	24.7	8.8	25.6	11.7	180.7	98.7	16.3	2.8	94.7	33.6
P_{Tot}	62.2	15.6	53.3	9.3	60.8	24.9	87.0	32.4	74.7	15.0	63.9	13.2	261.3	23.7	59.3	23.3	63.6	11.0
PO_4-P	38.3	13.1	23.9	8.6	31.8	17.9	56.5	28.5	45.2	13.3	33.3	10.8	215.0	28.0	31.5	20.8	35.4	9.2
N/P	418.9	194.7	61.6	23.2	1.7	1.3	336.5	195.9	61.6	42.1	202.4	75.2	9.6	1.4	279.8	101.8	60.1	12.2
Wid	11.3	2.4	6.9	1.7	2.9	0.9	15.2	6.7	10.1	3.0	18.3	3.9	8.0	2.0	31.9	22.8	11.2	2.2
Dep	0.6	0.1	0.5	0.1	0.3	0.1	0.6	0.1	0.6	0.1	0.5	0.1	0.7	0.0	1.2	0.3	0.7	0.1
Vel	0.3	0.1	0.3	0.1	0.3	0.1	0.5	0.1	0.4	0.1	0.5	0.1	0.1	0.0	0.3	0.2	0.2	0.0
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
WTur	1	66.7	1	75	1	100	1	53.3	1	55.5	1	71.4	1	66.7	1.5	100	2	21
FSed	2	33.3	1	75	1	75	1	53.3	1	55.5	1	57.1	1	66.7	1	75	2	21
BSub	3	77.8	3	83.3	3	75	3	73.3	3	66.7	3	71.4	3	100	3	50	3	47.4

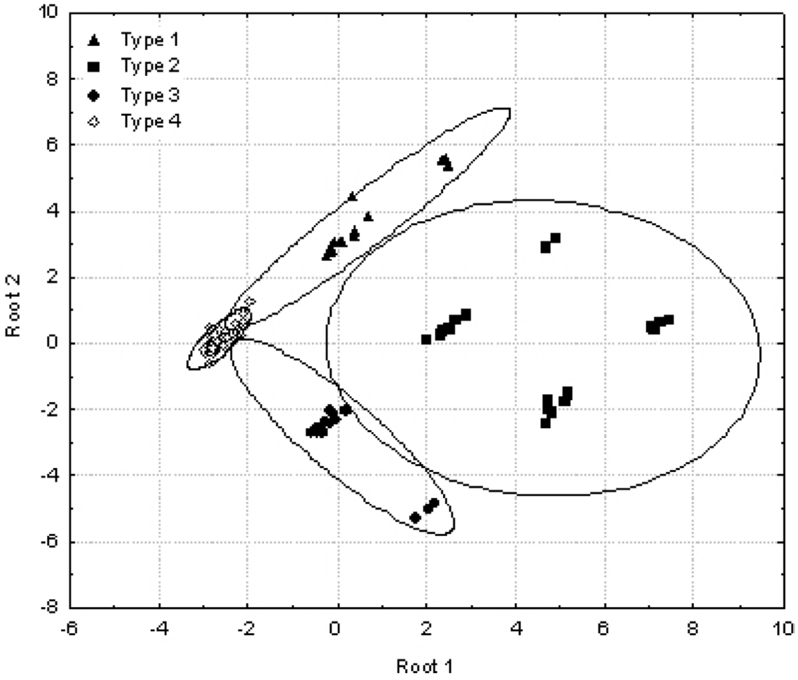

Fig. 2. Scatterplot of the habitats (river reaches) canonical scores, root 1 *vs.* root 2. The marks of every species-cluster are surrounded by the prediction interval ellipse (probability α = 0.95).

community types of the drainage basins dealt with in our previous publications (Paal & Trei 2004, 2006):

1. Communities of helophytes: *Equisetum fluviatile* (cluster 19), *Glyceria maxima* (cluster 17), *Mentha* × *verticillata* (cluster 16), *Pha-*

Table 8. Average environmental variables of the vegetation clusters 20 to 24. Denotations as in Tables 2, 5 and 6.

Variable	Cluster									
	20		21		22		23		24	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
pH	7.6	0.1	7.7	0.1	7.7	0	7.8	0.1	7.7	0.1
O_2	8.4	0.4	8.7	0.4	8.9	0.3	9.0	0.8	7.9	0.4
O_2-sat	86.1	4.1	90.9	3.8	90.1	2.8	88.2	8.3	81.3	3.9
BOD_5	2.4	0.2	2.7	0.2	3.0	0.2	2.2	0.2	2.5	0.3
N_{To}	1471.1	176.0	1356.4	247.0	1353.4	150.8	1263.0	160.9	1006.6	95.3
NO_3-N	677.8	197.3	838.9	207.4	728.8	124.6	752.6	427.8	231.4	73.2
NO_2-N	94.5	75.8	78.1	34.7	77.7	32.5	4.0	1.1	5.0	0.9
NH_4-N	77.3	49.4	26.1	11.3	45.9	15.7	11.0	6.2	12.3	4.1
P_{Tot}	68.6	17.0	87.4	21.1	89.5	23.0	41.8	5.5	62.9	13.7
PO_4-P	40.6	4.0	58.6	18.8	59.0	20.1	18.2	4.8	27.1	8.2
N/P	74.3	21.4	59.6	28.3	255.0	117.9	375.3	264.1	111.5	41.3
Wid	17.0	7.2	16.4	5.5	14.6	4.2	11.2	5.2	13.2	3.7
Dep	0.5	0.1	0.6	0.1	0.7	0.1	0.5	0.1	0.6	0.1
Vel	0.4	0.1	0.5	0.1	0.4	0.1	0.4	0.1	0.4	0.1
	Med	Freq	Med	Freq	Med	Freq	Med	Freq	Med	Freq
WTur	1	62.5	1	85.7	1	80.9	1	90.0	1	57.1
FSed	1	62.5	1	85.7	1.5	90.5	1	60.0	2	42.9
BSub	4	100	4	100	4	90.5	4	100	4	100

Table 9. 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: * = $P \leq 0.05$, ** = $P \leq 0.01$, *** = $P \leq 0.001$. Species preference to substrate was tested according to the parameter values of categorical variable BSub in model. Cl = clay, Sa = sand, Gr = gravel, St = stone. Denotation of environmental parameters as in Table 5.

Species	pH	O_2	BOD_5	NO_3-N	NH_4-N	PO_4-P	N/P	Wid	Dep	Vel	BSub
Acorus calamus	–	–2.20*	–	–	–	–	–	–	1.59***	–	–
Berula erecta	–	–	–	–	–	–	0.77***	–	–	–	–
Butomus umbellatus	–	–2.47**	–	0.75***	–	–	–	0.03**	–	–	–
Equisetum fluviatile	–	–	–	–0.64**	–	0.60**	0.53***	–	–	–	Cl***
Glyceria maxima	–	–	–	–	–	2.49*	–	–	–	–	–
Hippuris vulgaris	–	–	–	0.90**	–	–0.72*	–0.44*	–	–	–	–
Mentha × *verticillata*	–	–	–	0.48*	–	–	–	–	–	–	–
Nuphar lutea	–	–2.38**	1.28*	–	–	–	0.26*	–	1.27**	–	Sa***
Phalaris arundinacea	–	–	–	–	–	–	–	–	–	1.68**	Sa**
Phragmites australis	–	–	1.90**	–	–	–0.43*	–0.44***	–	–	–	–
Potamogeton alpinus	–	–	–	–	–0.74*	–	–	0.04*	–	–2.74*	–
Potamogeton natans	2.33*	–	–	–	–	–	–	–	–	–	–
Potamogeton perfoliatus	–	–	–	–	–	0.78**	–	–	1.88***	–	–
Ranunculus aquatiliss	–	–8.21***	–	–	–	–	–	–	–	–	–
Sagittaria sagittifolia	–	–	–	–	0.46*	–	–	–	3.10***	–	–
Schoenoplectus lacustris	–	–	1.16*	–	–	–	–	0.05***	–	–1.83**	Gr***
Sium latifolium	4.43***	–3.26*	–1.55*	0.89***	0.38*	–	–0.30*	–	1.96***	–	Gr***
Sparganium erectum	2.44**	–2.64*	–	–	–	–	–	–	–	–	Sa + Gr***
Sparganium spp. (*S. emersum*?)	–	–	–	–0.64*	–	0.71*	0.93***	–0.07**	–	–	Cl***
Typha latifolia	–	–	–	–	–0.49*	–	–	–	–	–	–
Amblystegium riparium	–	–	–	–	–	–	–	–	–	–	–
Cladophora glomerata	–	5.16*	–	–	1.12**	–	–	–	–	–	St***
Cladophora spp.	–4.27***	–	–	–	–1.14***	–	–	–	–	–	–
Fontinalis antipyretica	–	5.12*	–	–	1.12**	–	–	–	–	–	St***
Vaucheria spp.	–	–	–	–	–	–	–	–	–	1.61**	–

Table 10. Centroids of the habitat types (reach clusters) established by six physical environmental parameters. Mean = arithmetical mean, S.E. = standard error of mean, Med = median, Freq = frequency (%). The last four parameters presented in this table were not included in the analysis. Denotations as in Tables 2 and 5.

Parameter	Cluster							
	1 (20)		2 (29)		3 (17)		4 (25)	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Wid	18.7	7.2	8.7	1.4	9.8	2.2	14.2	2.3
Dep	0.9	0.2	0.8	0.1	0.5	< 0.1	0.6	0.1
Vel	0.3	0.1	0.2	< 0.1	0.4	0.1	0.4	< 0.1
	Med	Freq	Med	Freq	Med	Freq	Med	Freq
WTur	2	76.9	2	70	1	100	1	100
FSed	1	100	3	60	2	83.3	1	100
BSub	3	46.2	3	40	3	55.6	3	41
Stones		38.4		20		27.8		41
Gravel		23.1		60		38.9		46.1
Sand		15.4		20		27.8		2.6
Clay + silt		23.1		0		5.6		10.2

laris arundinacea (cluster 15), *Phragmites australis* (cluster 12), *Schoenoplectus lacustris–Sium latifolium* (cluster 2), *Sparganium erectum* (cluster 14), *Typha latifolia* (cluster 4);

2. Communities of the rooted vegetation with floating leaves: *Nuphar lutea* (cluster 5), *Potamogeton natans* (cluster 10);
3. Communities of the submerged vegetation: *Berula erecta* (cluster11), *Butomus umbellatus* (cluster 3), *Hippuris vulgaris* (cluster 9), *Potamogeton alpinus* (cluster 7), *P. perfoliatus* (cluster 8), *Ranunculus aquatilis* (cluster 13), *Sagittaria sagittifolia* (cluster 18), *Schoenoplectus lacustris* (cluster 1), *Sparganium* spp. (cluster 6);
4. Communities of mosses and macroalgae on stones: *Cladophora* spp.–*Vaucheria* spp. (cluster 20), *Vaucheria* spp. (cluster 21), *Fontinalis antipyretica–Vaucheria* spp. (cluster 22), *F. antipyretica* (cluster 23), *Amblystegium riparium–F. antipyretica* (cluster 24).

Table 11. Pooled within-group correlations between variables and canonical roots and χ^2-tests of successive roots. Denotations as in Table 5.

Variable	Root 1	Root 2	Root 3
Wid	–0.047	0.097	0.308
Dep	0.040	0.113	–0.506
Vel	–0.112	–0.064	0.076
WTur	0.674	0.621	–0.076
FSed	0.731	–0.668	0.055
BSub	–0.032	–0.016	–0.787
P (χ^2-test)	< 0.001	< 0.001	0.612

As in the case of the watercourses of the drainage basins of the Gulf of Finland and of lakes Peipsi and Võrtsjärv, the prevailing life forms were submerged species, dominating in 93 communities and in nine community types, and helophytes, dominating in 88 communities and in eight community types (38.0% and 35.9% of the total number of community types, respectively). The rooted vegetation with floating leaves was least represented, dominating in 15 communities (6.1%) and in two community types, while the mosses and macroalgae were prevailing in five community types and in 49 communities (20.0%). However, the above classification is somewhat problematic concerning *Schoenoplectus lacustris* (clusters 1 and 2). This species occurs as a helophyte in shallower areas, and as a submerged life form at deeper sites; since very often both forms occur in one and the same community, it is difficult to judge to which life form group the community belongs. In this study, the communities of cluster 1 are qualified as belonging to the group of the submerged vegetation and the communities of the cluster 2, to the group of the helophyte vegetation. Among the other dominating species, *Butomus umbellatus*, *Hippuris vulgaris* and *Sagittaria sagittifolia* were commonly represented by morphologically distinct submerged forms.

The share of different life forms in the three studied drainage basins was different. Percentage of the community types of helophytes was the highest (47.1%) and that of the macroalgae and mosses on stones was the lowest (17.7%) in the watercourses of the MS drainage basin; in both other drainage basins the respective values were 33.3% and 23.8%. As the frequency of cryptogam communities is obviously related to the abundance of suitable substrates (boulders, cobbles, limestone blocks), it is rather problematic to associate more explicitly the occurrence of vascular macrophyte life forms with certain environmental characteristics. According to Willby *et al.* (2000), macrophytes often show high phenotypic plasticity and species-level attributes, which may have an adaptive value in one part of an ecological range but are redundant in other parts; species-trait-environment relationships are attenuated accordingly.

Although issues of plant sytematics as well as some general problems of the ecology of aquatic plants were briefly addressed in our first paper (Paal & Trei 2004), in the present study we also deal with the problems related to the identification of the genus *Sparganium* specimens. At the time of our fieldwork (the first half of July) mainly vegetative plants of this genus occurred in the studied watercourses. Submerged vegetative specimens of *Sparganium emersum* and *S. erectum s. lato* were so similar in their morphological characteristics that it was impossible to

Table 12. Representation of vegetation types in habitat types.

No.	Dominant species	Number of communities	Habitat type			
			1	2	3	4
1	*Schoenoplectus lacustris*	41	9	11	8	13
2	*Schoenoplectus lacustris*–*Sium latifolium*	18	3	4	4	7
3	*Butomus umbellatus*	11	2	2	2	5
4	*Typha latifolia*	5	1	2	1	1
5	*Nuphar lutea*	10	–	4	3	3
6	*Sparganium* spp.	4	1	1	2	–
7	*Potamogeton alpinus*	3	–	1	1	1
8	*Potamogeton perfoliatus*	5	1	–	–	4
9	*Hippuris vulgaris*	12	3	1	3	5
10	*Potamogeton natans*	5	–	3	1	1
11	*Berula erecta*	9	1	2	4	2
12	*Phragmites australis*	12	2	1	2	7
13	*Ranunculus aquatilis*	4	–	–	1	3
14	*Sparganium erectum s. lat.*	15	2	5	2	6
15	*Phalaris arundinacea*	9	1	3	1	4
16	*Mentha* × *verticillata*	7	–	2	–	5
17	*Glyceria maxima*	3	–	1	–	2
18	*Sagittaria sagittifolia*	4	1	1	–	2
19	*Equisetum fluviatile*	19	3	7	4	5
20	*Cladophora glomerata*–*C.* spp.–*Vaucheria* spp.	8	1	2	1	4
21	*Vaucheria* spp.	7	–	1	–	6
22	*Fontinalis antipyretica*–*Vaucheria* spp.–*Cladophora glomerata*	19	2	3	6	8
23	*Fontinalis antipyretica*	5	–	1	1	3
24	*Amblystegium riparium*–*Fontinalis antipyretica*	7	1	2	2	2
Total		242	34	60	49	99

distinguish them. In order to avoid misidentification, submerged plants or vegetative plants with floating leaves, devoid of the reproductive organs, were recorded as *Sparganium* spp. Species were identified only in case the reproductive organs were present. Presumably, most plants, identified as *Sparganium* spp. belong to the species *Sparganium emersum*. Still, it is important to point out that in the flowing waters of Estonia grow numerous submerged plants of *Sparganium* never having reproductive organs.

Sparganium erectum s. lato was represented mainly by the subsp. *microcarpum*. Last autumn, *Sparganium erectum s. str.* was identified in one tributary of the Pärnu River (GR); it formed homogeneous patches which can be treated as a specific community type. Consequently, one could add one more community type of helo-

Table 13. Occurrence of communities of different types in the watercources of the Estonian drainage basins. GF = drainage basin of the Gulf of Finland (Paal & Trei 2004), P&V = drainage basin of lakes Peipsi and Võrtsjärv (Paal & Trei 2006), MS = drainage basin of the Moonsund Sea, GR = drainage basin of the the Gulf of Riga, SI = drainage basin of the Saaremaa Island.

	SL	P&V	VM	LL	SM
Acorus calamus	–	3	–	–	–
Berula erecta	–	–	1	5	3
Butomus umbellatus	10	4	8	3	–
Elodea canadensis	–	9	–	–	–
Equisetum fluviatile	11	7	5	8	6
Glyceria maxima	–	5	3	–	–
Hippuris vulgaris	11	5	3	4	5
Mentha aquatica	4	–	–	–	–
Mentha × *verticillata*	–	–	2	4	1
Nuphar lutea	11	27	2	6	2
Nuphar lutea–Sagittaria sagittifolia	3	–	–	–	–
Phalaris arundinacea	4	5	4	1	4
Phragmites australis	4	5	3	3	6
Potamogeton alpinus	4	11	–	–	3
Potamogeton crispus	–	4	–	–	–
Potamogeton natans	4	7	–	1	4
Potamogeton pectinatus	–	4	–	–	–
Potamogeton perfoliatus	4	12	3	2	–
Potamogeton vaginatus × *P. filiformis*	4	3	–	–	–
Ranunculus aquatilis	–	–	–	–	4
Ranunculus trichophyllus	5	10	–	–	–
Rorippa amphibia	–	6	–	–	–
Sagittaria sagittifolia	3	19	–	3	1
Schoenoplectus lacustris	19	9	14	24	3
Schoenoplectus lacustris–Sium latifolium	–	–	7	9	2
Sium latifolium	4	–	–	–	–
Sparganium erectum s. lat.	19	15	3	5	7
Sparganium spp.	12	30	–	2	2
Typha latifolia	–	3	2	1	2
Veronica anagallis-aquatica	–	7	–	–	–
Amblystegium riparium	–	3	–	–	–
Amblystegium riparium–Fontinalis antipyretica	–	5	–	5	2
Amblystegium riparium–Cladophora glomerata–Fontinalis antipyretica	7	–	–	–	–
Cladophora glomerata	16	–	–	–	–
Cladophora glomerata–Fontinalis antipyretica	9	–	–	–	–
Cladophora glomerata–Vaucheria spp.	–	14			
Fontinalis antipyretica	5	13	–	2	3
Fontinalis antipyretica–Vaucheria spp.	–	–	8	11	3
Fontinalis antipyretica–Vaucheria spp.*–Cladophora glomerata*	–	8	–	–	–
Vaucheria spp.	8	5	3	1	3

phytes to the list of the vegetation types presented in Tables 2, 3 and 4. These communities are very rare in Estonia, found earlier only in two localities: the Narva River (Kukk & Kull 2005) and Lake Ülemiste (Trei & Pedusaar 2006).

In some studied reaches, mats or string-like growths of filamentous macroalgae of different size covered water surface or part of it and were tangled round vascular plants or mosses. *Cladophora glomerata*, *Vaucheria* spp. and *Ulothrix zonata* were the main algae in these assemblages, sometimes, in the watercourses of the SI drainage basin, they were also accompanied with *Cladophora rivularis*.

Mass occurrence of loose-lying macroalgae is the evidence of water eutrophication. Probably, Butcher (1933) was the first to show that nutrient enrichment led to mass growth of *Cladophora glomerata* in the Tees River, England. The issue became actual in various waterbodies in the 1960s (Bellis & McLarty 1967, Whitton 1970, Trei 1982, 1991, Caffrey 1987, Demars & Harper 1998). Kelly and Whitton (1998) suggest that it is seldom well understood whether nitrogen or phosphorus plays a more important role in increasing the biomass of filamentous algae. According to Wallentinus (1984), *C. glomerata* has a very low natural requirement for phosphorus in the Baltic Sea, while nitrogen is the element determining mass occurrence of these algae. This was confirmed by Viitasalo *et al.* (1992), whose experiments with the wastewaters of the Helsinki area indicated that nitrogen induced considerable growth of *Cladophora* at very low phosphorus concentrations. In our study area, the water in all reaches with floating filamentous macroalgae was eutrophic or hypertrophic according to the Forsberg and Ryding (1980) scale, the content of total N being 600–1500 or > 1500 mg m^{-3}, respectively. The concentration of total P and PO_4-P in reaches with large loose-lying mats of filamentous algae varied considerably, the lowest values being 17–20 mg m^{-3} for total P and 2–3 mg m^{-3} for PO_4-P. These results confirm the standpoint that nitrogen indeed determines mass occurrence of filamentous algae. It should be mentioned that usually in reaches with copious filamentous algae, communities of vascular plants, including plants of different life forms, are also abundant, covering 70%–100% of the riverbed.

The content of total N and NO_3-N in water, besides the content of dissolved O_2, appeared to be the most important water chemistry parameter discriminating also all vegetation types of the watercouses of western Estonia (Table 5). The concentration of total N in water was essential in the separation of the vegetation types in the rivers of the drainage basin of the lakes Peipsi and Võrtsjärv as well (Paal & Trei 2006).

Among the physical environmental parameters, separating the vegetation types of the rivers flowing into the Gulf of Finland or into the two Estonian biggest lakes (Paal & Trei 2004, 2006), current velocity and bottom substrate appeared to be of importance. Current velocity is recognized by several authors as the main factor determining the nature of the riverbed, which in turn determines vegetation structure (Butcher 1933, Sirjola 1969, Wiegleb, 1984, Chambers *et al.* 1991, Janauer 2001, Riis & Biggs 2003). Still, in the watercourses of the drainage basins of western Estonia current velocity does not play a significant role, obviously due to the fact that differences in the velocity of these slow flowing rivers are small (Table 6, 7 and 8).

The environmental parameters affecting most the occurrence of single species in the watercourses of western Estonia were bottom substrate, content of O_2 and NH_4-N, and N/P ratio in water (Table 9). Of these parameters only NH_4-N content is of importance for all rivers across the country; N/P ratio in water appeared to be one of the main parameters influencing species occurrence in the Peipsi–Võrtsjärv drainage basin as well. Comparison of the parameters with the smallest effect on species presence/absence in the watercourses of different regions of Estonia reveals again almost no overlapping: these parameters were water pH, BOD_5, river width and current velocity in the drainage basins studied here (Table 9); content of O_2 and PO_4-P in water and river depth in the drainage basin of lakes Peipsi and Võrtsjärv; content of total N, NO_3-N, NO_2-N and total P in water and river depth in the Gulf of Finland drainage basin (cf. Paal & Trei 2004, 2006). The lists of species most sensitive to various environmental parameters are also quite different for the watercourses of different regions of Estonia.

Bottom substrate is the most important

common parameter discriminating the habitat (river reaches) types of the Gulf of Finland drainage basin and those of lakes Peipsi and Võrtsjärv drainage basins (Paal & Trei 2004, 2006); for the habitat types of the rivers of western Estonia the significance level of this parameter is 0.065 (Table 5), i.e. slightly above the conventional limit. Bottom substrate serves as a base for physical attachment of plants, while particle size composition may exert an essential effect on colonization of macrophytes (Butcher 1933, Baattrup-Pedersen & Riis 1999, Baattrup-Pedersen *et al.* 2003, Riis & Biggs 2003). Bottom sediments are also a potential source of nutrient supply for rooted vascular plants. Although numerous publications are devoted to this complicated problem (Barko & Smart 1981, Chambers *et al.* 1989, Pelton *et al.* 1998, Clarke & Wharton 2001, Kohler & Schneider 2003, Schneider & Melzer 2004), further research is needed to clarify the share of nutrients in water and sediments for rooted macrophytes in flowing waters. Until now, we have not determined the content of nutrients in sediments in our study area.

Another parameter, separating essentially habitat types is water turbidity: the significance level of this parameter for the watercourses of the Gulf of Finland and western Estonia is < 0.001, while for the rivers of lakes Peipsi and Võrtsjärv drainage basin, it is 0.055, i.e. negligibly above the conventional limit. In the former drainage basin water depth and in the latter drainage basin also river width appeared to be important. Although the results of discriminant analysis suggest more uniform habitat conditions in the watercourses of western or southwestern Estonia as compared with those of northern, eastern and southeastern Estonia, the large number of vegetation communities does not confirm this supposition.

All Estonian rivers and streams are situated at an altitude of 0–200 m above sea level and their plant communities represent the eutrophic lowland community group *sensu* Holmes *et al.* (1998). Although the frequency of certain type communities, number of species in communities and their abundance proportions vary, it is still obvious that the species occurrence depends here very much on several occasional factors such as diaspores availability and their germination success, ice cover in winter and its movement in spring, extraordinal supply of sediments during floods, etc. Clarke and Wharton (2001) have also established that in lowland eutrophic rivers sediment characteristics are highly variable even at the scale of a 100 m river reach and it is difficult to ascribe sediment preferences to particular species without further investigation. 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. Virtually all discussed plant species and communities have an extensive distribution areas (cf. Hultén & Fries 1986, Witt *et al.* 1986, Grigor'ev & Solomeshch 1987, Kuz'michev 1992) and high ecological tolerance (cf. Gessner 1955, Shilov 1975, Ellenberg 1988, etc.). Comparison of the ecological optima or amplitude limits, estimated by different researches for the same species, explicitly showed that these values are often rather inconsistent (cf. Paal & Trei 2004). Cross tabulations of the occurrence of the vegetation types and habitat types of the Estonian watercourses also confirm the conclusion drawn by Wiegleb (1984), that ecologically dissimilar habitats may have a similar vegetation, while ecologically similar habitats in different systems (even adjacent ones) may have a dissimilar vegetation. Analysis of limited drainage areas will always produce some results which may not be valid for other systems. The above author also pointed to the genetic variability of the species which, although morphologically similar, may be divided into a number of ecotypes able to colonize a different kind habitats. Willby *et al.* (2000) demonstrated the high phenotypic plasticity of hydrophytes and their wide ecological amplitude as well, and concluded that the attribute-based classification of European hydrophytes should be used cautiously for habitat assessment or prediction. On the basis of these facts, it seems rather doubtful to develop, at least for European oligo-mesotrophic to meso-eutrophic lowland watercourses, some reliable sample or system of indicator species rendering evaluation of general water parameters or habitat characteristics. Though Clarke and Wharton (2001) are not so pessimistic, they also recognized that until the macrophytes can be used as trophic indicators, thorough research is needed to reliably establish the spatial and temporal variability of sediment characteristics in rivers and its link with the chemistry of the water column. According to a recent study of Demars and Harper (2005), the annual turnover of aquatic plants is slow and reflects stochastic processes, species distribution in lowland rivers is controlled more by species colonization abilities and success than by local environmental conditions, and spatial structure appears to be the most important factor explaining plant distribution in lowland rivers.

Acknowledgements

The project was supported by the Estonian Ministry of the Environment, by the Estonian Science Foundation grant No 1649 and by the target financed research project No TF 0362107s02. We appreciate the help of our colleague H. Krall in the determination of some vascular plants and the assistance of the colleagues N. Ingerpuu and K. Vellak in the identification of bryophytes and E. Fremstad for supplying literature. We thank E. Jaigma for revising the English text of the manuscript.

References

Arold, I. 2005: *Eesti maastikud*. — Tartu Ülikooli Kirjastus, Tartu.

Arukaevu, K. 1986: *Eesti NSV jõgede, ojade ja kraavide ametlik nimestik*. — Valgus, Tallinn.

Baattrup-Pedersen, A. & Riis, T. 1999: Macrophyte diversity and composition in relation to substratum characteristics in regulated and unregulated Danish streams. — *Freshw. Biol.* 42: 375–385.

Baattrup-Pedersen, A., Larsen, S. E. & Riis, T. 2003: Composition and richness of macrophyte communities in small Danish streams — influence of environmental factors and weed cutting. — *Hydrobiologia* 495: 171–179.

Barendregt, A. & Bio, A. M. F. 2003: Relevant variables to predict macrophyte communities in running waters. — *Ecol. Modelling* 160: 205–217.

Barko, J. W. & Smart, R. M. 1981: Sediment-based nutrition of submersed macrophytes. — *Aquatic Bot.* 10: 339–352.

Bellis, V. J. & McLarty, D. A. 1967: Ecology of *Cladophora glomerata* (L.) Kütz. in southern Ontario. — *J. Phycol.* 3: 57–63.

Butcher, R. W. 1933: Studies on the ecology of rivers. I. On the distribution of macrophytic vegetation in the rivers of Britain. — *J. Ecol.* 21: 58–91.

Caffrey, J. M. 1987: Macrophytes as biological indicators of organic pollution in Irish rivers. — In: Richardson, D. H. S. (ed.), *Biological indicators of pollution*: 77–86. Royal Irish Academy, Dublin.

Chambers, P. A., Prepas, E. E. & Bothwell, M. L. & Hamilton, H. R. 1989: Roots versus shoots in nutrient uptake by aquatic macrophytes in flowing waters. — *Can. J. Fish. Aquat. Sci.* 46: 435–439.

Chambers, P. A., Prepas, E. E., Hamilton, H. R. & Bothwell, M. L. 1991: Current velocity and its effect on aquatic macrophytes in flowing waters. — *Ecol. Applications* 1: 249–257.

Clarke, S. J. & Wharton, G. 2001: Sediment nutrient characteristics and aquatic macrophytes in lowland English rivers. — *Sci. Total Environ.* 266: 103–112.

Demars, B. O. L. & Harper, D. M. 1998: The aquatic macrophytes of an English lowland river system: assessing response to nutrient enrichment. — *Hydrobiologia* 384: 75–88.

Demars, B. O. L. & Harper, D. M. 2005: Distribution of aquatic vascular plants in lowland rivers: separating the effects of local environmental conditions, longitudinal connectivity and river basin isolation. — *Freshw. Biol.* 50: 418–437.

Duda, R. & Hart, P. [Дуда, Р. & Харт, П.] 1976: [*Pattern classification and scene analysis*]. — Mir, Moscow. [In Russian].

Eipre, T. F. [Эйпре, Т. Ф.] 1981: [*Water resources of the karsted Pandivere Upland, Estonia*]. — Gidrometizdat, Leningrad. [In Russian].

Ellenberg, H. 1988: *Vegetation ecology of central Europe*, 4rd ed. — Cambridge University Press, Cambridge.

Feoli, E. & Gerdol, R. 1982: Evaluation of syntaxonomic schemes of aquatic plant communities by cluster analysis. — *Vegetatio* 49: 21–27.

Gessner, F. 1955: *Hydrobotanik. Die physiologischen Grundlagen der Pflanzenverbreitung im Wasser. I. Energiehaushalt*. — VEB Deutscher Verlag der Wissenschaften, Berlin.

Gollerbakh, M. M. & Krasavina, L. K. [Голлербах, М. М. & Красавина, Л. К.] 1983: [*Guide of freshwater algae of the USSR*, vol. 14]. Nauka, Leningrad. [In Russian].

Grasshoff, K., Ehrhardt, M. & Kremling, K. (eds.) 1983: *Methods of seawater analysis*: 125–149, 163–169. Verlag Chemie, Weinheim.

Grigor'ev, I. N. & Solomeshch, A. I. [Григорьев, И. Н. & Соломещ, А. И.] 1987: [Syntaxonomy of Bashkirian aquatic vegetation. I. Classes *Lemnetea* Tx. 1955 and *Potametea* Klika in Klika et Novak 1941]. — *Manuscript No. 6555–B87 deposited in the All-Russian Scientific and Technical Information Institute, Russian Academy of Sciences*. Moscow. [In Russian].

Holmes, N. T. H., Boon, P. J. & Rowell, T. A. 1998: A revised classification system for British rivers based on their aquatic plant communities. — *Aquatic Conservation: Marine and Freshwater Ecosystems* 8: 555–578.

Hultén, E. & Fries, M. 1986: *Atlas of North European vascular plants*, vol. 1–3. — I. Koeltz Scientific Books, Königstein.

Ingerpuu, N. & Vellak, K. (eds.) 1998: *Eesti sammalde määraja*. — EPMÜ ZBI & Eesti Loodusfoto, Tartu.

Janauer, G. 2001: Is what has been measured of any direct relevance to the success of the macrophyte in its particular environment? — *J. Limnol.* 60 (Suppl. 1): 33–38.

Järvekülg, A. 2000: Jõed ja inimesed läbi aegade. — In: *Kaasaegse ökoloogia probleemid*, vol. 8: 56–62. Teadusühing "IM Saare", Tartu.

Järvekülg, A. (ed.) 2001: *Estonian rivers*. — Tartu Ülikooli Kirjastus, Tartu.

Järvekülg, A. & Viik, M. 1994: Nitraatse lämmastiku ($NO_2{}'$-N) ja fosfaatse fosfori ($PO_4{}'''$-P) reostus Eesti jõgedes suvel. — In: Järvekülg, A. (ed.), *Eesti jõgede ja järvede seisund ning kaitse*: 83–104. Teaduste Akadeemia Kirjastus, Tallinn.

Järvekülg, A., Järvekülg, R., Pall, P. & Viik, M. 1997: Muutused Eesti jõgede seisundis ja kalastikus viimasel aastakümnel. — *Kaasaegse ökoloogia probleemid*, vol. 8: 51–55. Teadusühing "IM Saare", Tartu.

Kelly, M. G. & Whitton, B. A. 1998: Biological monitoring of eutrophication in rivers. — *Hydrobiologia* 384: 55–67.

Kohler, A. & Schneider, S. 2003: Macrophytes as bioindicators. — *Arch. Hydrobiol.* Suppl. 147(1–2): 17–31.

Kukk, T. & Kull, T. (eds.) 2005: *Eesti taimede levikuatlas*. — EMÜ Põllumajandus- ja keskkonnainstituut, Tartu.

Kuz'michev, A. I. [Кзузьмичев, А. И.] 1992: [*Hygrophile flora of south-western part of the Russian Plain and its genesis*]. Gidrometeoizdat, Sankt-Peterburg. [In Russian].

Leht, M. (ed.) 1999: *Eesti taimede määraja*. — EPMÜ ZBI & Eesti Loodusfoto, Tartu.

Loopmann, A. 1979: *Eesti NSV jõgede nimestik*. — Valgus, Tallinn.

Mäemets, A. 1984: Sugukond penikeelelised *Potamogetonaceae*. — In: Pärn, A. & Rohtmets, M. (eds.), *Eesti NSV floora*, vol. 9: 46–139. Valgus, Tallinn.

Moshkova, N. A. & Gollerbakh, M. M. [Мошкова, Н. А. & Голлербах, М. М.] 1986: [*Guide of freshwater algae of the USSR*, vol. 10(1)]. — Nauka, Leningrad. [In Russian].

Paal, J. 1987: Taxonomic continuum, some problems and methods for its quantitative analysis. — In: Laasimer, L. & Kull, T. (eds.), *The plant cover of the Estonian SSR. Flora, vegetation and ecology*: 108–122. Valgus, Tallinn.

Paal, J. & Trei, T. 2004: Vegetation of Estonian watercourses; the drainage basin of the southern coast of the Gulf of Finland. — *Ann. Bot. Fennici* 41: 157–177.

Paal, J. & Trei, T. 2006: Vegetation of Estonian watercourses, II. Drainage basin of lakes Peipsi and Võrtsjärv. — *Ann. Bot. Fennici* 43: 13–35.

Paal, Ya. L. & Kolodyazhnyi, S. F. [Пааль, Я. Л. & Колодяжный, С. Ф.] 1983: [Quantitative methods for analyzing transitions between vegetation syntaxa]. — *Bot. Zh.* 68: 1467–1474. [In Russian].

Pelton, D. K., Levine, S. N. & Braner, M. 1998: Measurements of phosphorus uptake by macrophytes and epiphytes from the LaPlatte River (VT) using ^{32}P in stream microcosms. — *Freshw. Biol.* 39: 285–299.

Podani, J. 2000: *Introduction to the exploration of multivariate biological data*. — Backhuys Publishers, Leiden.

Reap, A. 1995: *Eesti jõgede aastakeskmise äravoolu analüüs 1925–1990*. — Keskkonnaministeeriumi info- ja tehnokeskus, Tallinn.

Riis, T. & Biggs, B. J. F. 2003: Hydrologic and hydraulic control of macrophyte establishment and performance in streams. — *Limnol. Oceanograph.* 48: 1488–1497.

Shilov, M. P. [Шилов, М. П.] 1975: [On mosaicness and complexity of aquatic vegetation]. — *Nauchnye trudy* 163: 10–19. Kuibyshevskii gosudarstvennyi pedagogicheskii institut, Kuibyshev. [In Russian].

Schneider, S. & Melzer, A. 2004: Sediment and water nutrient characteristics in patches of submerged macrophytes in running waters. — *Hydrobiologia* 527: 195–207.

Sirjola, E. 1969: Aquatic vegetation of the river Teuronjoki, south Finland, and its relation to water velocity. — *Ann. Bot. Fennici* 6: 68–75.

Topachevskij, A. V. & Masyuk, N. P. [Топачевски, А. В. & Масюк, Н. П.] 1984: [*Guide of freshwater algae of the Ukrainian SSR*]. Vishcha shkola, Kiev. [In Russian].

Trei, T. 1982: *Cladophora glomerata* Matsalu lahes. — *Loodusevaatlusi 1980*, 1. Valgus, Tallinn: 144–152.

Trei, T. 1991: *Matsalu lahe põhjataimestik*. — Matsalu Riiklik Looduskaitseala, Tallinn.

Trei, T. & Pall, P. 2004: Macroflora in the watercourses of Saaremaa Island (Estonia). — *Boreal Env. Res.* 9: 25–35.

Trei, T. & Pedusaar, T. 2006: Macroflora in Lake Ülemiste (Estonia) – changes and the impact of environmental factors. — *Proc. Estonian Acad. Sci. Biol. Ecol.* 55: 199–215.

van den Hoek, C. 1963: *Revision of the European species of Cladophora*. — E. J. Brill, Leiden.

Viik, M. 2003: Kasari jõestiku vee kvaliteet kesksuvel aastatel 1990, 1997, 2002. — *Loodusevaatlusi 2000–2002*: 80–90. Matsalu Looduskaitseala, Lihula.

Viitasalo, I., Einiö-Selovuori, P., Arnold-Larsen, H. & Lehvo, A. 1992: The effect of different types of municipal sewage on the primary production, biomass and chlorophyll-a-content of *Cladophora glomerata*. — *Proceedings of the 12th Baltic Marine Biologists Symposium*: 163–167.

Vinogradova, K. L., Gollerbakh, M. M., Zauer, L. M. & Sdobnikova N.V. [Виноградова, К. Л., Голлербах, М. М., Зауер, Л. М. & Сдобникова, Н. В.] 1980: [*Guide of freshwater algae of the USSR*, vol. 13]. Nauka, Leningrad. [In Russian].

Wallentinus, I. 1984: Comparisons of nutrient uptake rates for Baltic macroalgae with different thallus morphologies. — *Mar. Biol.* 80: 215–225.

Whitton, B. A. 1970: Biology of *Cladophora* in freshwaters. — *Water Research Pergamon Press* 4: 457–476.

Wiegleb, G. 1984: A study of habitat conditions of the macrophytic vegetation in western Lower Saxony (Federal Republic of Germany). — *Aquatic Bot.* 18: 313–352.

Willby, N. J., Abernethy, V. J. & Demars B. O. L. 2000: Attribute-based classification of European hydrophytes and its relationship to habitat utilization. — *Freshw. Biol.* 43: 43–74.

Witt, D. H., Glime, J. M. & LaFarge-England, C. 1986: Bryophyte vegetation and habitat gradients of montane streams in western Canada. — *Hikobia* 9: 367–385.