BOREAL ENVIRONMENT RESEARCH 17: 460–472
ISSN 1239-6095 (print) ISSN 1797-2469 (online)

Helsinki 30 November 2012

Temporal changes in the composition of macrophyte communities and environmental factors governing the distribution of aquatic plants in an unregulated lowland river (Emajõgi, Estonia)

Aive Kõrs[1)], Sirje Vilbaste[1)], Kairi Käiro[1)], Peeter Pall[1)], Kai Piirsoo[1)], Jaak Truu[2)] & Malle Viik[1)]

[1)] *Centre for Limnology, Institute of Agricultural and Environmental Sciences, Estonian University of Life Sciences, Riia Street 181, EE-51014 Tartu, Estonia*
[2)] *Institute of Ecology and Earth Sciences, University of Tartu, Vanemuise Street 46, EE-51014 Tartu, Estonia*

Received 3 June 2011, final version received 19 Mar. 2012, accepted 5 Mar. 2012

Kõrs, A., Vilbaste, S., Käiro, K., Pall, P., Piirsoo, K., Truu, J. & Viik, M. 2012: Temporal changes in the composition of macrophyte communities and environmental factors governing the distribution of aquatic plants in an unregulated lowland river (Emajõgi, Estonia). *Boreal Env. Res.* 17: 460–472.

The species composition and dominating species were determined in five 25-m river reaches every week or every second week during the vegetation period of three consecutive years (2006–2008). The number of species and the composition of macrophytes at each site differed from year to year. A total of 33 taxa of vascular plants were identified. *Butomus umbellatus*, *Glyceria maxima*, and *Sagittaria sagittifolia* were registered at all sites each year. The number of constant species was low and we identified a large number of occasional taxa. The dominant species varied during the vegetation period. According to CCA, year was a statistically important parameter for determining the composition of the macrophyte community. The hydrological parameters (discharge, water level, water temperature) had an effect on the distribution of the aquatic plants. Among hydrochemical parameters conductivity, O_2, O_2 saturation, and sulphate content were statistically significant parameters governing the distribution of the macrophyte taxa.

Introduction

Several environmental factors affect the temporal and spatial distribution of macrophytes in streams. Already Butcher (1933) found that the main factors governing the composition and abundance of macrophytes in England were stream hydrology (current), light availability, and bottom substrate. Later, the importance of nutrients (Barko and Smart 1981, Demars and Harper 1998, Schorer *et al*. 2000, Clarke and Wharton 2001, Madsen and Cedergreen 2002, Kohler and Schneider 2003, Schneider and Melzer 2004, Baldy *et al*. 2007) and other chemicals (Mosisch and Arthington 1998, Samecka-Cymerman and Kempers 2007) was recognised. Because of different human activities, nowadays it is difficult to find pristine macrophyte communities in European lowland streams (Baattrup-Pedersen *et al*. 2006, and references therein). In the tem-

Editor in charge of this article: Johanna Mattila

perate zone, the anthropogenic disturbance of macrophyte communities in running waters is expressed as eutrophication (Robach *et al*. 1996, Kelly and Whitton 1998, Thiébaut and Muller 1999, Hilton *et al*. 2006), pollution of water (Dickman *et al*. 1983, Daniel *et al*. 2005), change in the hydrological regime as a consequence of building dams and channels (Baatrup-Pedersen and Riis 1999, Riis *et al*. 2008, Catford *et al*. 2011), and decline in weeds as a consequence of cutting (Baattrup-Pedersen and Riis 1999, Riis *et al*. 2000, Baattrup-Pedersen *et al*. 2002, 2003).

The distribution of macrophytes in running waters is never determined by only one environmental factor. In fact, a complex of different factors is responsible for their dissemination and abundance. Therefore, multimetric analyses are widely used in such kind of studies (Mackay *et al*. 2003, Daniel *et al*. 2006, Riis *et al*. 2008, Chessman and Royal 2010).

There are only a few allusions to the aquatic vegetation of the Emajõgi (Sirgo 1936, Mäemets 1990, Paal and Trei 2006b). At the same time, the communities of macrophytes in other Estonian rivers have been described and analysed quite thoroughly (Järvekülg 2001, Trei and Pall 2004, Paal and Trei 2004, 2006a, 2006b, Paal *et al*. 2007). Temporal changes in macrophyte communities, however, have been observed in only one stream (Vilbaste *et al*. 2008).

Studies about temporal changes of aquatic plants are scarce. Some papers deal with long-term changes focusing on interannual alternations. The species composition and richness of Danish lowland streams was studied in 13 stream sites over 100 years (Riis and Sand-Jensen 2001). Ceschin *et al*. (2010) examined changes in floristic composition in the Tiber during more than 30 years. Hrivnák *et al*. (2009a) compared the diversity, abundance, distribution, and ecological status of macrophytes in the River Turiec before and after a seven-year period. Long-term changes of river macrophytes were also observed by Whitton *et al*. (1998) and Veit and Kohler (2003). We found only one study of the seasonal dynamics of macrophyte abundance. Hrivnák *et al*. (2009b) sampled macrophytes in two regulated streams seven times during the vegetation period. They detected significant differences in the total abundance of macrophytes as well as in the abundance of macrophyte groups (hydrophytes, amphiphytes, helophytes) in different months within the vegetation period.

This study was designed to examine how the composition and structure of macrophyte communities in a river changed over time. Specifically, we wanted to know (1) how persistently macrophyte taxa occupy the same place in consecutive years, (2) how the dominant species act during the vegetation period, and (3) which environmental factors govern the distribution of macrophyte species. We hypothesised that even though macrophytes are perennial vascular plants in rivers and the Emajõgi is a lowland stream, significant changes in the floristic composition and arrangement of the dominating species take place during the vegetation period in consecutive years as the river is characterised by extensive spring floods.

Material and methods

The Emajõgi draws its water from Võrtsjärv, the second largest lake in the Baltic countries, and falls into lake Peipsi, the fourth largest lake in Europe (Fig. 1). Its length is 100 km, the catchment area is 9628 km^2, the mean annual discharge is 60–70 m^3 s^{-1}, and the mean annual runoff is 2.26 km^3. The Emajõgi is a typical lowland river with a small fall (3.6 m) and low water velocity (0. 2 m s^{-1}); the stream gradient in the middle and lower courses is extremely small, only 1 cm km^{-1}. The width of the studied river reaches is 50–60 m, and it is too deep (4–5 m) and its waters are too turbid to support macrophyte growth in the central part of the channel.

The macroflora of the Emajõgi was studied during three consecutive years (2006–2008). The species composition and the dominating taxa were determined in five 25-m river reaches (sites) every week during the vegetation period (May–October) in 2006 and 2007 and every second week in 2008, all in all 64 times. The dominating taxon was appointed subjectively as a taxon giving appearance to the macrophyte community, its relative cover (not measured) and frequency were the largest as compared with those of the other taxa. In some cases, there was no clear dominant. A four-step scale was used for

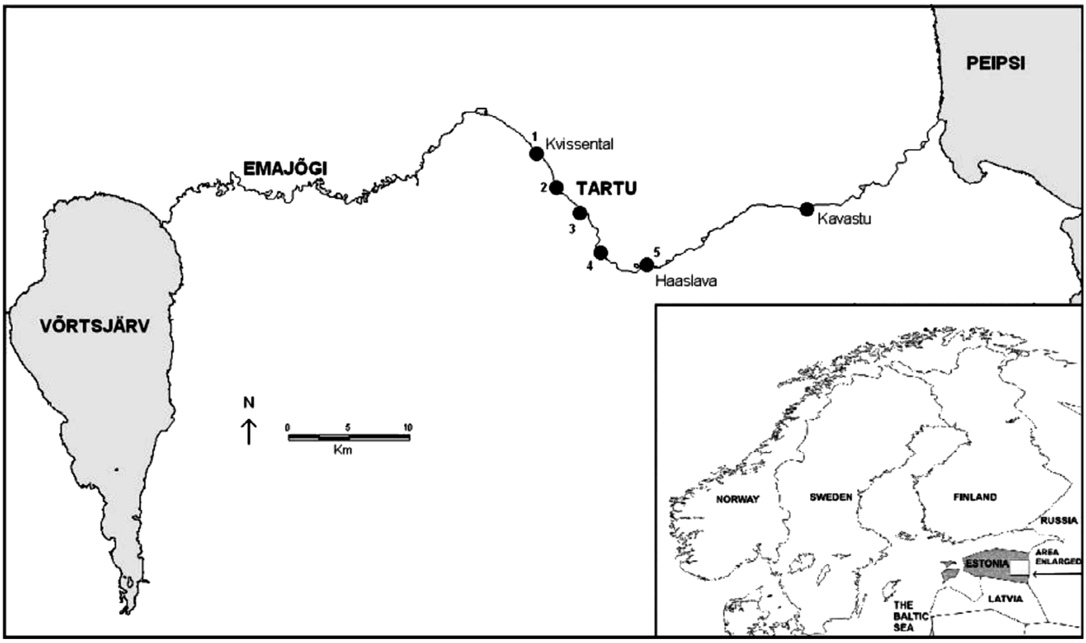

Fig. 1. Map of the study area.

each taxon in the community: 0 = not present, 1 = present, 5 = numerous (in case when there was no clear dominant and two species were equally frequent), 10 = dominant. Sites 1, 2, and 4 were situated on the right river bank while sites 3 and 5 were on the left bank. The study area depended on the water level at the beginning of vegetation period and the flooded bank vegetation was included. The macrophytes reached to the depth of approximately 1 m and the width of the studied vegetation stripe was 3–12 m.

The data of weekly mean discharge, water level and temperature were obtained from the Estonian Meteorological and Hydrological Institute (Fig. 2). Hydrochemical data (oxygen concentration in water (O_2), O_2 saturation (%), water colour, biological oxygen demand (BOD_7), chemical oxygen demand (COD), NO_2-N, NO_3-N, NH_4-N, total N (N_{tot}), soluble reactive phosphorus (SRP), total P (P_{tot}), pH, chlorides (Cl), sulphates (SO_4^{2-}), and conductivity of the water) for two sites, Kvissental and Kavastu, were drawn from the state monitoring programme (Table 1). These data were collected monthly at the Haaslava and Kvissental sites in 2006 or bimonthly at the Kvissental site in 2007 and 2008. Kvissental is situated close to site 1 where macrophytes were sampled while the Kavastu site is located further downstream of site 5 (Fig. 1). In the analysis, the macrophyte data from the same week were used only when hydrochemical data were available (Kvissental n = 12, Haaslava n = 18).

As the distributions of some environmental parameters (NO_3-N, NH_4-N, total N) was not normal, we used nonparametric statistics. Spearman's correlation was calculated to relate water level, discharges, water temperature, and the environmental parameters (Table 2). Differences between the number of species and the duration of vegetation period between the Kvissental and Haaslava sites were tested using a nonparametric Wilcoxon matched pairs test. Calculations were performed with STATISTICA for Windows 8.0 (StatSoft Inc.).

Multivariate analysis was used to identify the main gradients in the composition of the macrophyte community using the program CANOCO 4.5 (Ter Braak and Šmilauer 2002). In order to study the relationship of macrophyte species with the environmental parameters, Canonical Correspondence Analysis (CCA) with a forward selection procedure was carried out. Plant abundance data for multivariate analysis were

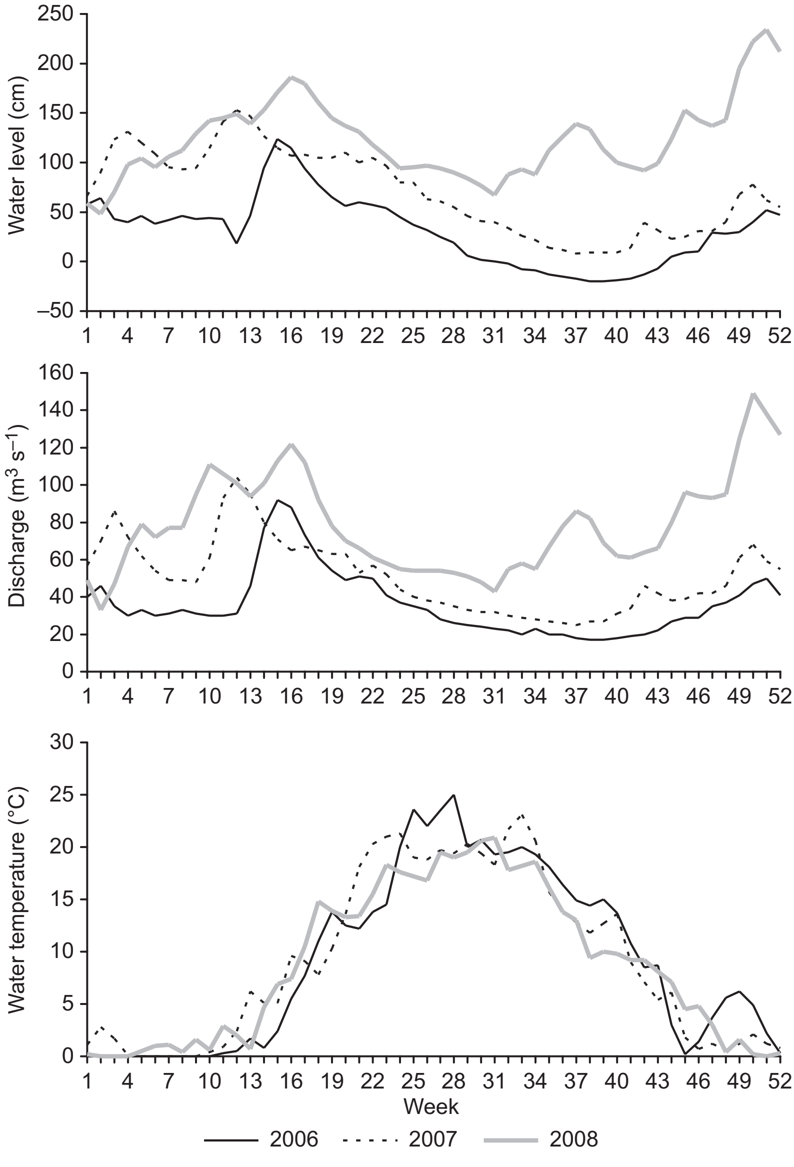

Fig. 2. (**A**) Water level, (**B**) discharge, and (**C**) water temperature according to the Tartu gauge (58°22´51´´N, 26°43´37´´E; zero is 29.61 m a.s.l.) of the Emajõgi in 2006, 2007, and 2008.

transformed to rank scale (0 = not present, 1 = present, 2 = numerous, 3 = dominant). Prior to CCA, we applied Detrended Correspondence Analysis (DCA) to check gradient lengths. In all cases (Kvissental and Haaslava sites separately, and pooled data from these locations) DCA gradient lengths were larger than two and based on this CCA method was selected for further data analysis.

The statistical significance of the environmental parameters was tested using the Monte Carlo permutation test with 999 permutations.

Results

A total of 33 taxa of vascular plants were identified, three species were registered at all sites every year (*Butomus umbellatus*, *Glyceria maxima*, *Sagittaria sagittifolia*) while five of them were only determined once at one site (Table 3). The number of constant taxa (occurring at the same site during three years) formed less than one third of the total number of taxa. More than 60% of taxa at all five sites were occasional (registered once or twice at a site).

Table 1. Environmental parameters of the Emajõgi at Kvissental (n = 12) and Kavastu (n = 18) sites in 2006–2008: O_2 = oxygen concentration, O_2 sat. = oxygen saturation, Colour = water colour, BOD_7 = biological oxygen demand, COD = chemical oxygen demand, N_{tot} = total N, SRP = soluble reactive phosphorous, P_{tot} = total P, Cond. = conductivity of water.

	O_2 (mg l^{-1})	O_2 sat. (%)	Colour (mg Pt l^{-1})	BOD_7 (mg O_2 l^{-1})	COD (mg O_2 l^{-1})	NH_4-N (mg l^{-1})	NO_2-N (mg l^{-1})	NO_3-N (mg l^{-1})	N_{tot} (mg l^{-1})	SRP (mg l^{-1})	P_{tot} (mg l^{-1})	pH	Cl (mg l^{-1})	SO_4^{2-} (mg l^{-1})	Cond. (μS cm^{-1})
Kvissental															
2006															
Mean	10.1	91	53	3.7	12	0.148	0.009	1.00	1.9	0.013	0.073	8.1	8.2	19	397
Median	9.9	93	50	3.6	13	0.083	0.007	0.84	1.7	0.008	0.067	8.1	8.3	17	388
Min	6.8	76	35	1.3	10	0.020	0.003	0.02	0.8	0.002	0.029	7.7	5.1	13	350
Max	12.8	101	85	6.0	15	0.430	0.021	3.10	3.7	0.076	0.150	8.3	10.0	33	495
2007															
Mean	11.0	93	73	2.9	14	0.102	0.010	2.14	3.0	0.007	0.049	8.0	7.9	26	407
Median	11.5	91	80	2.4	13	0.075	0.012	2.90	3.9	0.007	0.048	7.9	8.2	24	387
Min	8.0	81	40	1.5	11	0.020	0.003	0.05	1.0	0.002	0.034	7.7	5.9	18	353
Max	14.0	102	100	4.6	20	0.180	0.018	4.50	4.8	0.012	0.065	8.2	9.3	37	468
2008															
Mean	10.3	85	91	2.3	16	0.064	0.009	2.07	2.7	0.010	0.036	7.9	8.0	23	412
Median	10.7	83	100	2.4	15	0.063	0.008	2.15	2.8	0.008	0.036	7.9	8.0	22	422
Min	7.0	80	45	1.0	12	0.020	0.005	0.16	1.2	0.004	0.025	7.8	7.8	18	363
Max	13.0	101	120	3.6	23	0.110	0.014	3.80	4.2	0.018	0.046	8.1	8.2	30	440
Kavastu															
2006															
Mean	10.0	87	52	3.1	12	0.235	0.012	1.17	2.0	0.014	0.082	7.9	10.3	21	432
Median	10.8	90	50	2.8	11	0.155	0.009	0.91	1.9	0.008	0.062	8.0	9.8	20	407
Min	8.0	74	35	1.8	10	0.036	0.003	0.12	0.9	0.002	0.050	7.6	8.0	15	367
Max	12.7	97	80	5.0	15	0.640	0.025	3.40	4.0	0.094	0.170	8.2	14.0	37	515
2007															
Mean	10.5	88	73	2.6	13	0.120	0.014	1.69	2.5	0.009	0.057	7.9	10.1	27	422
Median	11.7	89	73	2.5	13	0.090	0.014	1.60	2.3	0.006	0.059	7.9	9.9	28	415
Min	6.1	71	40	1.2	1	0.020	0.005	0.17	0.9	0.002	0.034	7.7	6.5	17	354
Max	14.4	100	110	4.1	20	0.410	0.027	4.50	5.0	0.035	0.070	8.2	16.0	36	490
2008															
Mean	9.6	78	103	2.4	18	0.100	0.014	2.19	3.0	0.014	0.052	7.8	8.7	22	379
Median	9.3	77	95	2.1	18	0.090	0.013	2.35	3.1	0.013	0.052	7.8	8.6	22	371
Min	5.0	69	45	1.0	12	0.060	0.009	0.20	1.2	0.002	0.032	7.5	6.8	17	316
Max	13.1	97	190	4.5	26	0.200	0.024	4.10	5.0	0.031	0.064	8.3	11.0	32	472

Table 2. Spearman's correlation coefficients between water level (Wl), discharge (Dis), water temperature (T) measured in Tartu and the following environmental parameters: oxygen concentration in water (O_2), O_2 saturation % (O %), water colour (Col.), biological oxygen demand (BOD_7), chemical oxygen demand (COD), NH_4-N, NO_2-N, NO_3-N, total-N (N_{tot}), soluble reactive phosphorous (SRP), total P (P_{tot}), pH, chloride (Cl), sulphate (SO_4^{2-}), conductivity of water (Cond) measured at Kvissental site during vegetation period in 2006, 2007, and 2008. Correlations whose $p < 0.05$ were considered significant, n.s. = not significant, $r_S \geq 0.6$ set in boldface.

	Wl	Dis	T	O_2	O %	Col.	BOD_7	COD	NH_4-N	NO_2-N	NO_3-N	N_{tot}	SRP	P_{tot}	pH	Cl	SO_4^{2-}
Dis	**0.93**	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
T	–0.32	–0.35	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–
O	0.30	0.39	**–0.82**	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–
O %	n.s.	n.s.	n.s.	**0.60**	1.00	–	–	–	–	–	–	–	–	–	–	–	–
Col.	**0.68**	**0.71**	–0.30	0.38	n.s.	1.00	–	–	–	–	–	–	–	–	–	–	–
BOD_7	**–0.60**	**–0.62**	**0.66**	–0.57	n.s.	–0.54	1.00	–	–	–	–	–	–	–	–	–	–
COD	**0.67**	**0.68**	n.s.	n.s.	n.s.	**0.84**	–0.48	1.00	–	–	–	–	–	–	–	–	–
NH_4-N	n.s.	n.s.	**–0.61**	0.42	n.s.	n.s.	–0.40	n.s.	1.00	–	–	–	–	–	–	–	–
NO_2-N	0.47	0.52	–0.38	0.35	n.s.	0.52	–0.54	0.38	0.49	1.00	–	–	–	–	–	–	–
NO_3-N	**0.69**	**0.75**	**–0.75**	**0.75**	n.s.	**0.72**	**–0.76**	0.53	0.38	**0.68**	1.00	–	–	–	–	–	–
N_{tot}	**0.67**	**0.73**	**–0.77**	**0.75**	n.s.	**0.72**	**–0.76**	0.58	0.37	**0.64**	**0.96**	1.00	–	–	–	–	–
SRP	0.29	0.37	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	1.00	–	–	–	–
P_{tot}	–0.45	–0.40	n.s.	n.s.	n.s.	n.s.	0.39	–0.33	n.s.	n.s.	n.s.	–0.27	0.27	1.00	–	–	–
pH	–0.57	–0.52	**0.63**	–0.36	0.28	–0.36	**0.66**	–0.27	–0.53	–0.54	**–0.64**	**–0.63**	n.s.	n.s.	1.00	–	–
Cl	–0.39	–0.46	–0.30	n.s.	n.s.	–0.31	n.s.	–0.40	0.48	n.s.	n.s.	n.s.	–0.28	n.s.	n.s.	1.00	–
SO_4^{2-}	0.31	0.33	**–0.61**	**0.66**	n.s.	0.40	**–0.69**	0.35	0.40	0.55	**0.66**	**0.67**	n.s.	–0.28	–0.36	0.33	1.00
Cond.	n.s.	n.s.	**–0.73**	**0.66**	n.s.	n.s.	–0.50	n.s.	0.50	0.28	0.47	0.47	n.s.	–0.29	–0.28	0.50	**0.70**

Table 3. Distribution of macrophyte taxa at different sites (1–5) in the Emajõgi in the years 2006, 2007, and 2008. C = constant, O = occasional, and D = dominant taxon.

		1			2			3			4			5		
Taxon	Code	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
Acorus calamus	AC CAL	–	–	–	–	–	–	–	–	–	–	–	–	C	C	C
Agrostis stolonifera	AG STO	–	–	–	–	O	–	–	–	–	–	O	O	–	–	–
Alisma plantago-aquatica	AL P-A	–	O	O	–	–	–	O	–	O	–	–	O	–	O	O
Alopecurus geniculatus	AL GEN	–	–	O	–	–	–	–	–	O	–	–	–	–	–	O
Butomus umbellatus	BU UMB	C	C	C	C	C	C	C	C	C	C	CD	CD	C	C	C
Cicuta virosa	CI VIR	–	–	–	–	–	–	–	–	O	–	–	–	–	–	O
Eleocharis palustris	EL PAL	–	–	O	–	–	O	–	–	O	–	–	O	–	–	O
Glyceria fluitans	GL FLU	–	–	–	–	–	–	–	–	–	–	–	–	–	–	O
Glyceria maxima	GL MAX	CD	CD	CD	CD	CD	CD	CD	CD	CD	CD	CD	CD	CD	CD	CD
Hippuris vulgaris	HI VUL	–	–	O	–	–	–	–	–	O	–	–	–	–	–	O
Juncus spp.	JUN SP	–	–	–	–	O	O	–	–	–	–	–	–	–	–	–
Lysimachia thyrsiflora	LY THY	–	–	–	–	–	–	O	–	–	–	–	–	–	–	–
Mentha aquatica	ME AQU	–	–	O	–	–	–	–	–	O	–	–	–	–	–	–
Myosotis scorpioides	MY SCO	–	–	–	–	–	–	–	O	O	–	–	–	–	–	–
Myriophyllum spicatum	MY SPI	–	–	–	–	–	–	–	–	–	–	–	–	–	–	O
Nuphar lutea	NU LUT	CD	CD	CD	O	–	O	C	C	C	–	–	–	C	C	C
Oenanthe aquatica	OE AQU	–	O	O	–	–	–	–	O	O	–	–	–	–	O	–
Phragmites australis	PH AUS	O	–	–	–	–	–	O	–	–	–	–	–	–	–	–
Phalaris arundinaceae	PH ARU	O	–	O	–	–	–	O	–	O	–	–	–	–	–	O
Poaceae sp.	POA SP	–	–	–	–	–	–	C	C	C	–	–	–	–	–	–
Polygonum amphibium	PO AMP	–	–	–	–	–	O	–	–	–	–	–	–	–	–	–
Potamogeton pectinatus	PO PEC	–	O	O	C	C	C	C	C	C	C	C	C	C	C	C
Potamogeton perfoliatus	PO PER	–	–	–	O	–	C	C	C	–	O	–	–	C	C	C
Rorippa amphibia	RO AMP	–	O	OD	–	O	–	C	C	C	–	–	–	–	O	O
Sagittaria sagittifolia	SA SAG	C	C	C	CD	CD	CD	CD	C	C	CD	C	C	CD	CD	CD
Schoenoplectus lacustris	SC LAC	–	–	–	–	–	–	C	C	C	–	–	–	–	–	–
Scolochloa festucacea	SC FES	C	C	C	–	–	–	–	O	–	–	–	O	–	–	–
Sium latifolium	SI LAT	C	C	C	–	–	–	O	O	–	–	O	O	–	O	O
Sparganium emersum	SP EME	O	–	–	–	O	–	O	–	O	–	–	–	–	–	–
Sparganium erectum s.l.	SP ERE	–	–	O	C	C	C	C	CD	CD	–	–	–	–	–	O
Sparganium spp.	SP SPP	–	–	–	–	O	–	–	–	–	–	–	–	O	–	–
Stachys palustris	ST PAL	–	–	O	–	–	–	–	–	O	–	–	–	–	–	O
Typha latifolia	TY LAT	–	–	–	–	–	–	O	–	–	–	–	–	–	–	–
Number of species		9	10	17	7	10	10	17	14	20	5	6	9	8	11	19
C + O			6 + 13 = 19			5 + 8 = 13			9 + 16 = 25			4 + 6 = 10			7 + 14 = 21	

There were only five species which were considered the dominants: *Butomus umbellatus*, *Glyceria maxima*, *Sagittaria sagittifolia*, *Nuphar lutea* and *Rorippa amphibia*. The last species was a constant taxon at only one site (3), however, it dominated at site 1 where it was an occasional taxa.

The dominant species in the community of macrophytes changed during the vegetation period. In the spring of 2006 and 2007, the Kvissental site was dominated by *G. maxima*. In June, there were no clear dominant taxa but both *G. maxima* and *Nuphar lutea* occurred numerously. In summer, *N. lutea* was the dominant and *G. maxima* dominated again in autumn. In 2008, there were even three species which dominated consecutively during the vegetation period: *R. amphibia*, *G. maxima*, *N. lutea*, and again *G. maxima*. At all remaining four sites, *G. maxima* dominated in the spring of each year. At sites 2 and 5 (Haaslava), *S. sagittifolia* was the dominating species in summer and *G. maxima* replaced it again in autumn. At site 3, *S. sagittifolia* dominated each summer, *G. maxima* replaced it in autumn 2006 and 2008; however, in 2007 there was no dominant in autumn. At site 4, *S. sagittifolia* was the dominant in summer 2006, while *B. umbellatus* dominated in 2007 and 2008. Also *G. maxima* dominated here each year in autumn.

The hydrology of the Emajõgi was not similar in different years (Fig. 2). In 2006, the water level and discharge were the lowest. In April, there was only a short high-water period and in late summer and autumn (from the end of July to the end of October) there was a long period when the water level remained constantly below the gauge zero. In contrast, 2008 was the high-water year. The average water level was more than four times and the average discharge more than two times higher in 2008 as compared with those in 2006. There was no typical late-summer low-water period in 2008. The hydrological situation in 2007 was intermediate between those in 2006 and 2008.

The numbers of taxa determined at each site differed from year to year. However, they were significantly (Wilcoxon matched pairs test: $z = 2.022$, $n = 5$, $p = 0.043$) lower in the low-water year (2006) as compared with those in the high-water year (2008). At the Haaslava site, the difference was especially pronounced, 8 and 19 registered taxa, respectively (Table 3).

The duration of vegetation period for the dominant species, except *G. maxima* was different at the Kvissental and Haaslava sites. The plants started their vegetation significantly earlier (Wilcoxon matched pairs test: $z = 2.521$, $n = 11$, $p = 0.008$) and ended later (Wilcoxon matched pairs test: $z = 2.934$, $n = 11$, $p = 0.003$) at the Kvissental site than at the Haaslava site (Table 4).

In 2006, the summer maximum water temperature was 26.6 °C (July 10) and the average for one week was 25.0 °C. In 2007 and 2008, the water temperature never exceeded 23.0 °C.

The concentrations of SRP and P_{tot} in the water were the highest in 2006 and the lowest in 2007. The concentration of nitrogen compounds, however, was the highest in 2006 and the lowest in 2007 (Table 1). The nitrogen-compound content (except for NH_4-N), O_2, water colour, and sulphates were positively correlated with the water level and discharge, while BOD_7, P_{tot}, pH, and Cl were negatively correlated with those hydrological parameters (Table 2). BOD_7,

Table 4. Duration of the vegetation period in weeks for the dominant species at Kvissental and Haaslava site in 2006, 2007 and 2008.

	Kvissental			Haaslava		
	2006	2007	2008	2006	2007	2008
Butomus umbellatus	23–41	21–40	23–39	25–36	24–36	23–38
Glyceria maxima	18–41	18–43	19–45	19–41	18–43	19–45
Nuphar lutea	21–40	21–41	21–37	24–38	23–36	25–36
Rorippa amphibia	21–40	19–43	19–41	not found	19–36	21–39
Sagittaria sagittifolia	24–40	21–40	25–39	25–36	23–37	25–35

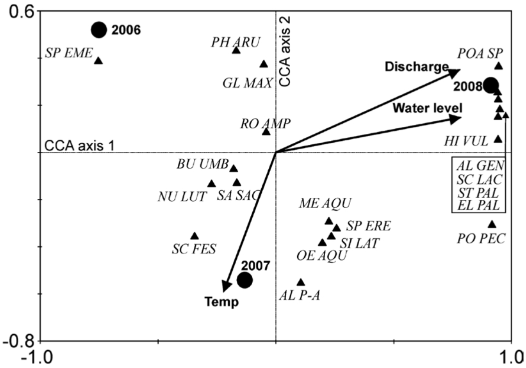

Fig. 3. Canonical correspondence analysis (CCA) ordination plot of the macrophyte data accounting for 49.5% of inertia in the abundances and 72.2% of variance in the weighted averages of species with respect to the hydrological parameters at the Kvissental site of the Emajõgi in 2006, 2007, and 2008 (number of observations is 64). The eigenvalues of CCA axis 1 and CCA axis 2 are 0.295 and 0.198, respectively. Species are indicated by triangles and hydrological parameters by arrows. For abbreviations of taxa, *see* Table 3. The class variable "year" is indicated by a circle.

and pH were positively correlated with water temperature and O_2 content. All nitrogen compounds, sulphates, and water conductivity were negatively correlated with water temperature. O_2 content was positively correlated with NO_3-N, N_{tot}, sulphates, and water conductivity. Water colour was strongly and positively correlation with COD, NO_3-N, and N_{tot}. BOD_7 was negatively correlated with NO_3-N, N_{tot}, and sulphates but positively correlated with pH. All nitrogen compounds correlated positively with each other. NO_3-N, and N_{tot} were positively correlated with sulphates and negatively with pH. There was a positive correlation between sulphates and water conductivity.

According to CCA (Canonical Correspondence Analysis), year is a statistically important ($p > 0.01$) parameter for determining the composition of the macrophyte community. Also temporal fluctuation of the hydrological parameters (discharge, water level and temperature) had an effect on the distribution of aquatic plants (Figs. 3 and 4). In the low-water year (2006), the composition of macrophyte communities in the same river reach differed significantly from that in the high-water year (2008), especially in case of the Kvissental site. Among the taxa which gained

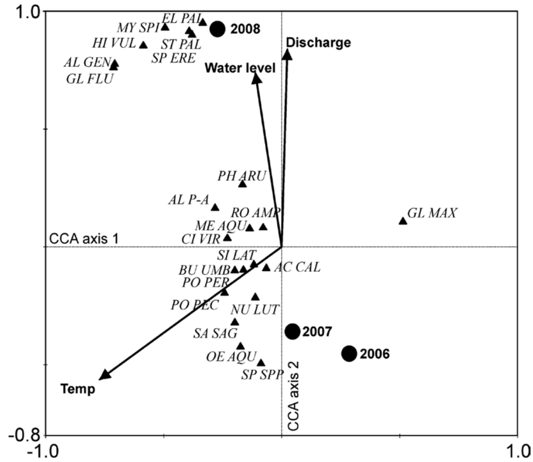

Fig. 4. Canonical correspondence analysis (CCA) ordination plot of the macrophyte data accounting for 43.1% of inertia in the abundances and 77.5% of variance in the weighted averages of species with respect to the hydrological parameters at the Haaslava site of the Emajõgi in 2006, 2007, and 2008 (number of observations is 64). The eigenvalues of CCA axis 1 and CCA axis 2 are 0.259 and 0.214, respectively. Species are indicated by triangles and hydrological parameters by arrows. For abbreviations of taxa, *see* Table 3. The class variable "year" is indicated by a circle.

from high water were the true aquatic plant *Hippuris vulgaris* as well as the helophytes *Eleocharis palustris*, *Stachys palustris* and *Alopecurus geniculatus*. *Butomus umbellatus*, *S. sagittifolia*, and *N. lutea* preferred lower water. CCA based on the hydrochemical parameters revealed water conductivity, O_2, O_2 saturation (%), and sulphates as the statistically significant parameters governing the distribution of the macrophyte taxa (Fig. 5).

Discussion

Wiegleb (1983) investigated the flora of rivers in West Germany in 1978, 1979, and 1981. He noted that considerable changes had occurred in the vegetation during this short period. We obtained similar results. Our investigation showed that the number of species growing in the same place year after year (constant species) was low. At the same time, we found a large number of occasional taxa despite the fact that the majority of the studied macrophytes were perennials. The main reasons for the abundant occurrence of occasional species can be disturbance of (spring) floods (Champion and Tanner 2000, Lenssen *et al*. 2004), changes in hydrological conditions (Biggs 1996, Riis and Biggs 2003), and impact of boat traffic (Vermaat and De Bruyne 1993, Asplund and Cook 1997, Mosisch and Arthington 1998, Asplund 2000).

According to Vilbaste *et al*. (2008) and Hrivnák *et al*. (2009b) the total plant coverage in the rivers of the temperate zone reaches its maximum during the period from the end of July to September. The major factors controlling seasonal variation in macrophyte growth and abundance are water and air temperatures (Hrivnák *et al*. 2009b), phenological cycles, interspecific competition for resources, disturbance by flood (Champion and Tanner 2000) as well as the dispersal strategies of aquatic plants (Hrivnák *et al*. 2009b).

We noted that the dominant plant species may change during the vegetation period. *Glyceria maxima* was the main dominant in the Emajõgi throughout the study period at all river sites each year. The species occurred throughout the vegetation period but dominated mainly in spring and autumn. In summer (July–August), other macrophyte species such as *N. lutea*, *S. sagittifolia* and *B. umbellatus* reached their maximum outnumbering *G. maxima*, which grows fast early in the vegetation period and soon reaches maximum. However, as the lifetime of the shoots of this species is short it produces a series of new shoots (Buttery and Lambert 1965). In southern, England in the River Frome, older shoots of *G. maxima* reach maximum in July, while new shoots peak in September (Westlake 1966).

In the Emajõgi, macrophytes grew mostly in shallow water near the shore and water level affected the distribution of hydrophytes. Several studies have stressed the importance of hydrological conditions. Hrivnák *et al*. (2009b) demonstrated that the dominating hydrophyte group is influenced by water depth. Weiher and Keddy (1995) found that species richness is related to water depth, water level and their fluctuations. Riis *et al*. (2001) observed that helophytes and amphiphytes dominated in shallow waters near the banks but declined rapidly with increasing depth and distance to the bank. Hydrophytes

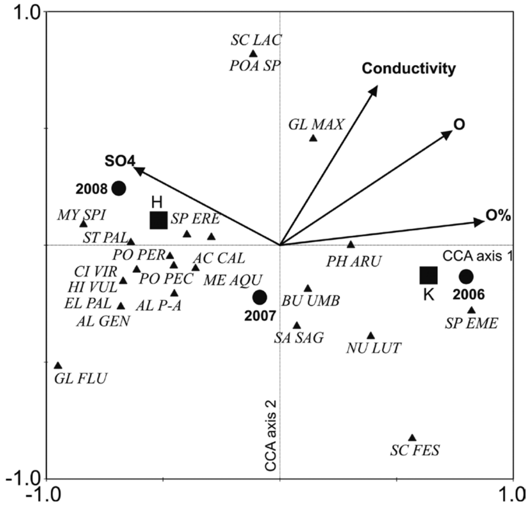

Fig. 5. Canonical correspondence analysis (CCA) ordination plot of the macrophyte data accounting for 43.1% of inertia in the abundances and 77.5% of variance in the weighted averages of species with respect to the hydrochemical parameters at the Haaslava (H) and Kvissental (K) sites of the Emajõgi in 2006, 2007, and 2008. Hydrochemical data were measured monthly at the Haaslava and Kvissental sites in 2006 or bimonthly at the Kvissental site in 2007 and 2008 (total number of observations is 28). Only statistically significant ($p < 0.05$) environmental parameters are shown: O_2 concentration, O_2 saturation (%), sulphate (SO_4^{2-}), and water conductivity. The eigenvalues of CCA axis 1 and CCA axis 2 are 0.235 and 0.223, respectively. Species are indicated by triangles and hydrochemical parameters by arrows. For abbreviations of taxa, *see* Table 3. Year and sampling location were included into the analysis as passive variables. The class variable "year" is indicated by a circle and sampling sites are indicated by squares.

dominated at moderate and great depths irrespective of the distance from the banks. The main dominating helophyte in our study, *G. maxima*, prefers deep and wide rivers (Riis *et al*. 2000) like the Emajõgi. Among hydrophytes the main dominants were *S. sagittifolia* and *N. lutea*. Development of *S. sagittifolia* is apparently retarded at depths greater than 0.9 m. Optimum conditions for its development are at water depths of 0 to 0.8 m (Hroudová 1980). Formation of different leaf forms indicates the high adaptability of *S. sagittifolia* to habitats with a fluctuating water level (Hroudová *et al*. 1988). As *N. lutea* tolerates water movement better than other species of this genus, it occurs in slowly flowing streams (Heslop-Harrison 1955). In our study, *N. lutea* clearly benefitted from the low water level in 2006.

The association between sulphates and composition of the macrophyte community at the Haaslava site was intriguing (Fig. 5). Very likely, sulphates had accumulated in the sediments over time. As an example, according to the monitoring data of 2002, the wastewater of the city of Tartu contained 584 tonnes of sulphates. Some of the sulphates may have originated from fuel for boats operating on the Emajõgi, as sulphur and sulphur oxide are among the constituents of the fuel (Mosish and Arthington 1998). In our study, sulphates originated from the sediments, indicating the turbulence caused by the waves in the river reach (Haaslava) where the speed of boats was not restricted. In this river reach, the macrophyte community decomposed earlier in autumn as compared with the river reach (Kvissental) where the speed of boats was restricted (Table 4). Vermaat and De Bruyne (1993) investigated the factors limiting the distribution of water plants in a lowland river in the Netherlands. They also found that the waves caused by boat traffic affected negatively the growth of plants. The vegetation was more abundant in the river section with the least load of boat traffic. Increased turbidity due to boat traffic may limit the light available to plants and, as a consequence, the area where plants can grow will decrease (Asplund 2000). Plants grew better in sheltered conditions and waves from boat traffic limited the shoreward extent of plant growth (Vermaat and De Bruyne 1993).

Eaton *et al*. (1981) results as cited in Murphy and Eaton (1983) showed that *G. maxima* is a strongly-rooted emergent which forms compact fringing stands even on canals with a heavy boat traffic and is notably quick to re-establish after physical damage. Also in our study, *G. maxima* resisted the boat traffic well. There were no differences in the time of starting or ending the vegetation period between the two sites (Table 4). As compared with the Kvissental site, at the Haaslava site *N. lutea* started its vegetation 2–4 weeks later in spring and decomposed 1–5 weeks earlier in autumn. The helophytes *B. umbellatus*, *R. amphibia* and *S. sagittifolia* deteriorated from the boat traffic in the same way (Table 4).

The role of biogens governing the distribution of aquatic plants has still remained disputable. The nutrient effect on river macrophytes is difficult to assess because aquatic plants are capable to take up biogens from both the sediment and the water (Barko and Smart 1981, Kelly and Whitton 1998, Clarke and Wharton 2001, Kohler and Schneider 2003, Schaumburg *et al*. 2004, Schneider and Melzer 2004). In this study, the effects of nutrients remained unclear; however, in our previous study on the Väike-Emajõgi, multiple regression analysis revealed the importance of NO_2-N, NO_3-N, NH_4-N, P_{tot} and N_{tot} to the total coverage of macrophytes. The number of species depended on N_{tot}, NH_4-N, NO_2-N, NO_3-N and SRP (Vilbaste *et al*. 2008). It is known that plants excrete oxygen into the water, which accounts for statistically significant positive relationship between the oxygen content of water and macrophyte community (Fig 5). In slightly alkaline waters of Estonia, pH and electrical conductivity are negatively related to each other (Table 2). The importance of hydrochemical parameters on the distribution of macrophytes needs to be clarified in further research.

Conclusions

This study demonstrates that instability is a characteristic feature of the river vegetation. Temporal changes in the composition and distribution of macrophytes were considerable. In this study, some of the more resistant plant species were able to grow at the same river site from year to year. However, most of the observed species were occasional. The cover of the dominant taxa changed during the vegetation period. Each plant species had its own growth cycle and the coverage reached a maximum at a specific time.

The annual and seasonal patterns of macrophyte composition were affected by different environmental variables and it is difficult to determine crucial factors. In the Emajõgi, annual and temporal changes in macrophyte distribution were associated most of all with hydrological conditions, especially with water level fluctuations. Changes during the vegetation period were particularly strongly related to water temperature, water level fluctuations and competition within the macrophyte community. Changes in the distribution of the vegetation were also caused by spring floods and heavy boat traffic. The role of some environmental parameters that proved to be statistically significant for the distribution of macrophyte species remained unclear. It should be noted, however, that the distribution of the vegetation is affected by many other environmental factors that were not considered in this study and deserve to be addressed in further research.

Acknowledgements: The research was supported by the target-financed project SF 0170011s08 of the Estonian Ministry of Education and Research and by the grants no. 6580 and 7600 of the Estonian Science Foundation. Mrs. Ester Jaigma kindly revised the English text of the manuscript.

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