

THE RESPONSE OF AQUATIC PLANTS TO CATCHMENT LAND USE FOR DIFFERENT TYPES OF LOWLAND RIVERS

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Abstract .The article deals with the problem of ecological quality of rivers in relation to catchment-scale threats. We aimed to detect the reaction of the river plants to the land use in a catchment in different spatial scales. The response of different ecological groups was considered as well as specific reactions of individual species. The study was based on surveys of 116 river sites in Poland representing three major European lowland river types: small sandy siliceous, stony siliceous and large siliceous. Field surveys were undertaken according to the standard monitoring approach including assessment of macrophyte abundance within 100 m river stretch. Land use was estimated for each survey site in five different spatial scales. The results showed that macrophytes strongly react to land use. The observations revealed that the width of a river corridor that is most strongly connected to macrophytes composition is related to an analysed river type. In small sandy and large siliceous this was a 500 m and 1000 m corridor, in stony – a 100 m and 500 m corridor. Several river type-specific reactions of macrophyte functional groups' development, as the reaction to catchment deterioration, were also revealed. Moreover, a relation between development of individual species and land use was found based on canonical correspondence analysis. **Keywords:** *macrophytes, monitoring, Water Framework Directive, ecology, aquatic plants ecology, river types, River Habitat Survey*

Introduction

The development of macrophytes is highly influenced by abiotic and biotic parameters. Among different parameters which influence growth of plants in a channel, the most important ones are biogenic concentration (Westlake 1975, Robach et al. 1996, Szoszkiewicz et al. 2006a), flow (Westlake 1975, Dawson 1988), hydrological regime (Westlake 1975, Haslam 1987), alkalinity and hardness (Trempe & Kohler 1995), shading (Westlake 1975, Dawson & Kern-Hansen 1979, Remy 1993) and hydromorphological modifications (O'Hare et al. 2006, Szoszkiewicz et al. 2006, Careya et al. 2011). All these parameters are strongly related to catchment land use structure (Hynes 1975, Worral & Burt 1999, Wilcock et al. 2004).

Understanding the relationships between catchment and the ecological status of rivers is very important for managing river quality and undertaking efficient protective actions (Allan & Flecker 1993, Bastian & Bernhardt 1993, Johnson & Gage 1997, Benini et al. 2010). Analyses of the relations between land use and ecological status can be efficiently supported by GIS systems such as CORINE Land Cover 2000 (European Environmental Agency 2000) which provide an opportunity to conduct extensive analyses of the land use structure. Based on such tools, it is possible to conduct spatial analyses and to find interactions between different environmental factors and biological elements (Richards & Host 1994, Xiang 1995, Allan & Johnson 1997, Johnson & Gage 1997, Cao et al. 1999). An extensive analysis of the relations between catchment land

use and ecological status of rivers was conducted by Streyer (2003). His results showed a strong relation between these two factors.

Rivers are strongly influenced by their surroundings, perhaps most strongly by conditions at the land-water interface (Naiman & Decamps 1990) but also by the entire catchment (Naiman et al. 1995). As Hynes (1975) so effectively argued in an early synthesis of landscape-stream interactions, "In every respect, the valley rules the stream." Increasingly today, we are experiencing the negative consequences of this relationship, as human degradation of landscapes is reflected in the deterioration of streams conditions (Naiman et al. 1995).

This article deals with the problem of ecological quality of rivers in relation to catchment-scale threats. On the basis of the macrophyte survey and GIS databases, we aimed to detect the reaction of river plants to the land use in a catchment in different spatial scales. The response of different ecological groups was considered as well as specific reactions of individual species.

The aim of the current water protection policy in the European Union is to reach a good ecological status in every catchment. To achieve this ambitious and difficult task, several problems associated with spatially related issues must be solved, first of which is the reduction of diffuse pollution (Karr & Schlosser 1987). Effective management of the entire catchments must be undertaken as well (Osborne & Wiley 1988, Delong & Brusven 1991, Johnson et al. 1997).

Material and methods

Site selection and river typology

The presented macrophyte records have been collected as a result of a 4-year survey campaign (2005-2008). Each survey was supplemented by hydromorphological, hydrochemical and land use data. It resulted in gathering a homogeneous database consisting of over 600 sites representing all river types observed in Poland. For the purpose of this paper, 116 survey sites were chosen (Table 1), representing a wide range of geographical and environmental gradients (Fig. 1). The chosen survey sites represented only three river types: small sandy, stony and large siliceous ones. They were also diverse in the terms of land use structure of the catchment.

All of the analysed rivers are of lowland type (location of the survey site is lower than 200 m above sea level). Surveyed sites represent small (catchment area 10-100 km²) and large rivers (catchment area larger than 1000 km²). The geology of all analysed rivers was siliceous. The substrate of the channel bed was divided into two types: sandy and stony. The number of river sites in each type is presented in Table 1.

Field surveys

Macrophyte surveys have been undertaken according to the Polish monitoring macrophyte method (Szozkiewicz et al. 2010). The survey is conducted along a 100 m river stretch. All aquatic species are recorded according to a 9-point scale.

Hydromorphological assessment of every analysed river site was conducted using the British River Habitat Survey (RHS) method (Environment Agency 2003). The RHS records contain land use information related to the land use structure in a 50 m distance from a river bank and along a 500 m river stretch. The data about the land use structure along RHS survey site was included in further analyses.

Table 1. Number of survey sites in analysed macrophyte types.

Macrophyte type	Number of sites	Catchment size	Channel substrate
Small sandy rivers	49	10-100 km ²	Sand, silt
Stony rivers	41	10-100 km ²	Gravel, pebble
Large siliceous rivers	26	>1000 km ²	Sand, silt, gravel, pebble



Figure 1. Location of survey sites

Land use assessment along river corridors

Catchment land use assessment was conducted using a digital hydrographical map of Poland (MPHP 2005), which included the layer of abiotic typology of rivers. Also the Polish database of land use, CORINE Land Cover, was used. It includes grids of minimal size of 25 ha. For the purpose of the analyses, land use types were merged into four main categories: built-up areas (which included housing, industry, railroads, roads, etc.), agricultural land (tilled lands, grasslands, pastures, etc.), forest and other semi-natural area, and the last category – surface waters and wetlands. The analyses were conducted using Arc Gis software ver. 9.2.

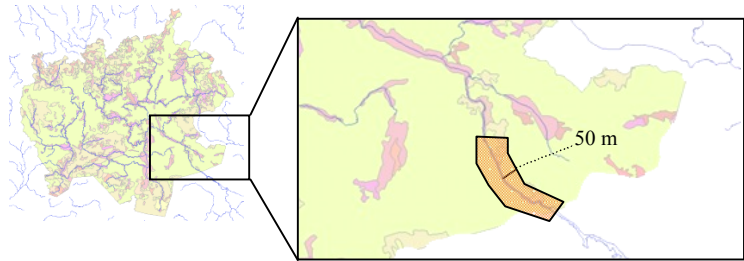
The applied analyses covered the land use structure in different spatial scales. They were conducted across the whole distance of the river (from the source to the survey

site), considering four different distances from the river bank: 100 m, 500 m, 1000 m and in the whole catchment. These data were supplemented by information on the structure of land use along the river on a distance of 500 m and a width of 100m (50m to the left and right side of the river) collected in accordance with the methodology of River Habitat Survey (*Fig. 2*).

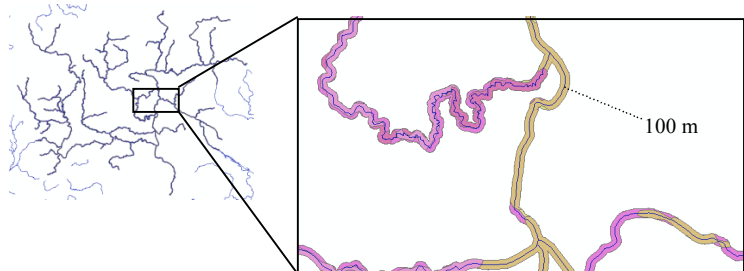
Analyses

To assess the strength of relations between macrophytes and different spatial scales of land use, the Monte-Carlo multivariate test on the species assemblage (full model, 500 permutations) was conducted. It was applied with the use of CANOCO software. The scale which was statistically most important for macrophyte development was utilized in further analysis.

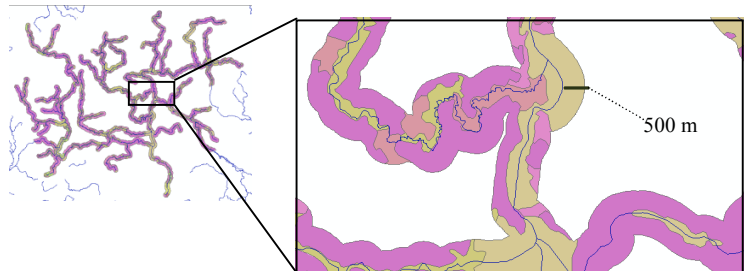
Land use assessment within 50 m distance from river bank in 500 m river stretch.



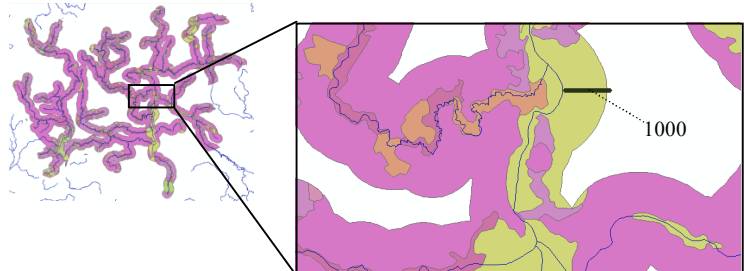
Land use assessment within 100 m distance from a river bank



Land use assessment within 500 m distance from a river bank



Land use assessment within 1000 m distance from a river bank



Land use assessment of the whole catchment from the sources to the survey site.

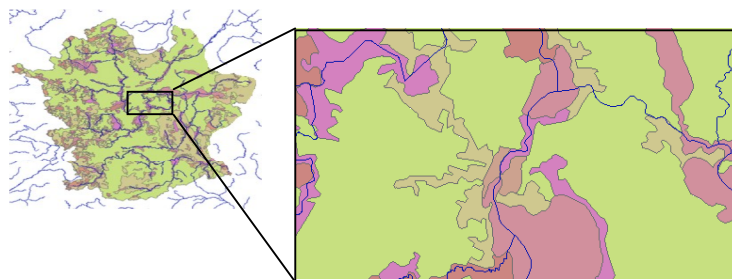


Figure 2. Land use assessment within 100 m, 500 m and 1000 m distance from the river for the whole catchment from the source to the survey site.

Functional groups of macrophytes were estimated in the gradient of agricultural land percentage. The purpose was to reveal the relation between the land use and the development of river macrophyte differences. Analyses considered six functional groups of macrophytes: filamentous algae, bryophytes, submerged, floating-leaved (rooted), emergent, and terrestrial and ecotonal weeds. Moreover, the relations between the land use and the macrophyte species were considered utilising CCA analysis. CANOCO software and STATISTICA ver. 8 were used for statistical analyses.

Results

Macrophyte reaction against different spatial scales of land use analysis

The undertaken Monte-Carlo permutation test revealed that the development of aquatic plants depends on the catchment land use (Table 2). The analysis based on the comparison of five distinct parameters (catchment area, percentage share of: (1) agricultural lands, (2) forest, (3) surface water and (4) built-up areas) with the data on percentage share of macrophytes observed in the surveyed river stretches. The results included such parameters as explained variance, statistical significance and F-statistics value. The highest values of explained variance were observed in case of stony rivers (explained cumulative variance = 1,16 for 100 m river corridor). In other analysed river types the value of explained cumulative variance was also relatively high. The highest values were observed in 500 m and 1000 m river corridors. In small sandy rivers and large siliceous ones a little bit higher values of explained variance are observed in case of 500 m (0,75 and 0,81 respectively) and 1000 m (0,76 and 0,8 respectively). In stony rivers a little bit more important appears to be 100 m corridor (explained cumulative variance = 1,16).

In the majority of the analysed cases, the land use types which explain the highest share of variance, are agricultural lands and forests. The difference is observed in case of surface waters and built-up areas. The former appears to be more important in case of small sandy and large siliceous rivers. The latter is more important in case of stony rivers. The catchment area was statistically not important as a parameter to explain macrophytes composition in almost all analysed cases.

The analyses conducted for all rivers without dividing them into separate types revealed complete lack of any statistical significance. Based on the results of Monte Carlo test, further Canonical Correspondence Analyses (CCA) were performed taking into account the comparison of 500 m river corridor land use with macrophytes

structure. The 500 m corridor was chosen due to the fact that this category appears to be statistically most important in all analysed river types.

Table 2. Monte-Carlo permutation test (full model) of macrophyte reaction to different spatial scales of land use structure.

Spatial category	Land use category	Small sandy rivers					Stony rivers					Large siliceous rivers				
		p value	Stat. signif.	F-stat.	Var. expl.	Cumulat. Var. Expl.	p value	Stat. signif.	F-stat.	Var. expl.	Cumulat. Var. Expl.	p value	Stat. signif.	F-stat.	Var. expl.	Cumulat. Var. Expl.
50 m (RHS survey site)	Heavily modified	0,02	*	1,59	0,15	0,54	0,35	-	1,06	0,16	0,65	0,92	-	0,64	0,09	0,48
	Agricultural land	0,052	-	1,37	0,13		0,318	-	1,06	0,16		0,84	-	0,7	0,1	
	Forests	0,32	-	1,38	0,13		0,164	-	1,17	0,17		0,66	-	0,86	0,12	
	Surface waters	0,114	-	1,32	0,13		0,386	-	1,09	0,16		0,13	-	1,32	0,17	
	Catchment area	-	-	-	-		-	-	-	-		-	-	-	-	
100 m	Heavily modified	0,09	-	1,53	0,15	0,7	0,008	**	1,49	0,22	1,16	-	-	-	-	0,72
	Agricultural land	0,042	*	1,32	0,13		0,002	***	1,9	0,28		0,54	-	1,54	0,2	
	Forests	0,002	***	1,72	0,16		0,002	***	1,77	0,26		0,38	-	1,07	0,14	
	Surface waters	0,036	*	1,43	0,14		0,114	-	1,27	0,19		0,008	**	1,87	0,24	
	Catchment area	0,154	-	1,22	0,12		0,032	*	1,4	0,21		0,39	-	1,01	0,14	
500 m	Heavily modified	0,078	-	1,63	0,16	0,75	0,044	*	1,42	0,21	1,09	-	-	-	-	0,81
	Agricultural land	0,012	*	1,44	0,14		0,002	***	1,85	0,25		0,014	*	1,73	0,22	
	Forests	0,002	***	1,88	0,18		0,002	***	1,74	0,27		0,002	***	1,76	0,23	
	Surface waters	0,034	*	1,56	0,15		0,276	-	1,15	0,17		0,022	*	1,7	0,22	
	Catchment area	0,152	-	1,22	0,12		0,064	-	1,31	0,19		0,4	-	1,7	0,14	
1000 m	Heavily modified	0,054	-	1,69	0,16	0,76	0,022	*	1,51	0,22	1,1	-	-	-	-	0,8
	Agricultural land	0,006	**	1,59	0,15		0,002	***	1,91	0,28		0,004	***	1,85	0,23	
	Forests	0,002	***	1,9	0,18		0,002	***	1,73	0,25		0,01	**	1,78	0,23	
	Surface waters	0,02	*	1,61	0,15		0,364	-	1,1	0,16		0,05	*	1,5	0,2	
	Catchment area	0,136	-	1,26	0,12		0,078	-	1,3	0,19		0,42	-	1	0,14	
Whole catchment	Heavily modified	0,756	-	0,77	0,08	0,58	0,304	-	1,2	0,18	0,84	0,78	-	0,72	0,1	0,71
	Agricultural land	0,034	*	1,44	0,14		0,15	-	1,17	0,17		0,1	-	1,34	0,18	
	Forests	0,022	*	1,44	0,14		0,1	-	1,23	0,18		0,12	-	1,31	0,17	
	Surface waters	0,624	-	0,9	0,09		0,774	-	0,79	0,12		0,51	-	0,93	0,13	
	Catchment area	0,46	-	1,4	0,13		0,102	-	1,27	0,19		0,45	-	0,97	0,13	

Explanation: ** - p value < 0.005, * - p value 0.005-0.05.

Macrophyte development in small sandy rivers

Basing on the results of Monte Carlo test, three vectors of land use categories were chosen in Canonical Correspondence Analysis. These were: agricultural lands, forests and surface waters. These three land use categories presented the highest statistical significance measured by the variance explained (respectively: 0,13, 0,16 and 0,14). They also presented relatively high values of F-statistic (respectively: 1,32, 1,72 and 1,43).

The conducted Canonical Correspondence Analysis revealed a relationship between different macrophyte species and forms of land use of the catchment (Fig. 3). Sites located in catchments dominated by forests were overgrown by the following bryophytes: *Brachythecium rivulare*, *Pellia endiviifolia* and *Conocephalum conicum*. They were accompanied by several vascular plants: *Carex paniculata*, *Caltha palustris*, *Berula erecta*, *Lysimachia thyrsoflora*, *Lysimachia nummularia*, *Epilobium palustre* and *Carex acutiformis*. The presence of agricultural lands was connected with the following species: *Potamogeton compressus*, *Callitriche sp.*, *Rorippa amphibia*, *Agrostis stolonifera*, *Scutellaria galericulata* and *Ranunculus sceleratus*.

The third vector revealed another direction of variability related to the abundance of surface waters and wetlands in the catchments. The following macrophyte species indicated the strongest relationship with this gradient: *Potamogeton natans*, *Phragmites australis*, *Lysimachia vulgaris* and *Juncus articulatus*.

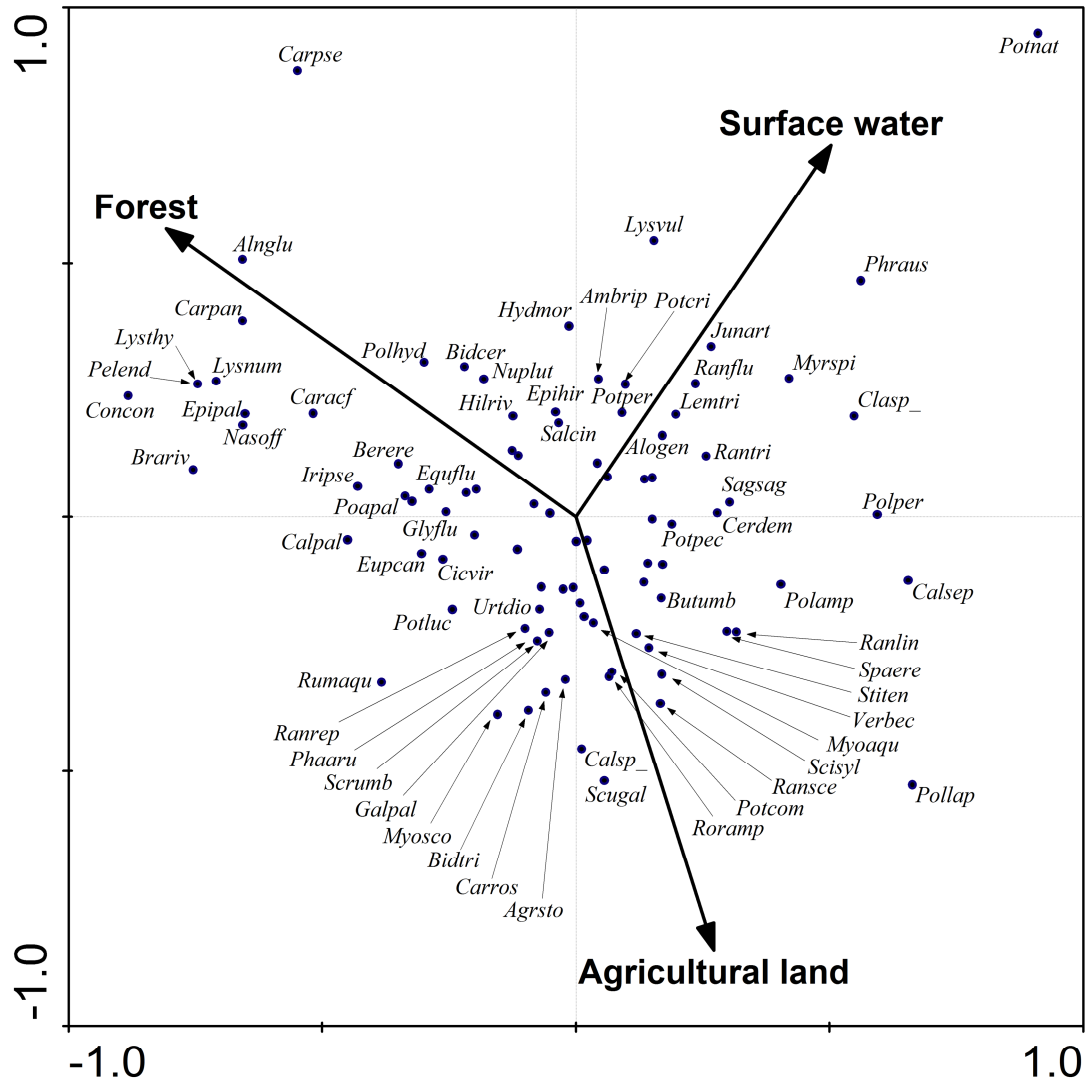


Figure 3. CCA ordination of macrophyte taxa and catchment land use types in small sandy rivers. Explanation: species names in Appendix 1; the diagram of canonical values for first and second axis. Implemented shortcuts of macrophyte names represent the first three letters of the Latin genus name and the second three are the letters of the Latin species name. Arrows represent analysed land use forms: surface waters and wetlands, forests and other semi-natural areas, built-up areas and agricultural lands.

Differences of the proportion of functional growth forms of macrophytes were observed in the gradient of variously utilised land in the catchment in small sandy rivers (Fig. 4). Analyses were limited to the amount of agricultural land since the former results had detected the strongest importance of this type of land utilisation on macrophytes. A low percentage of agricultural land was reflected strongly by high abundance of mosses. On the other hand, a high percentage of agricultural area was strongly related to high abundance of free-floating plants. Increased area of agricultural land was reflected by a decreased proportion of emergent plants.

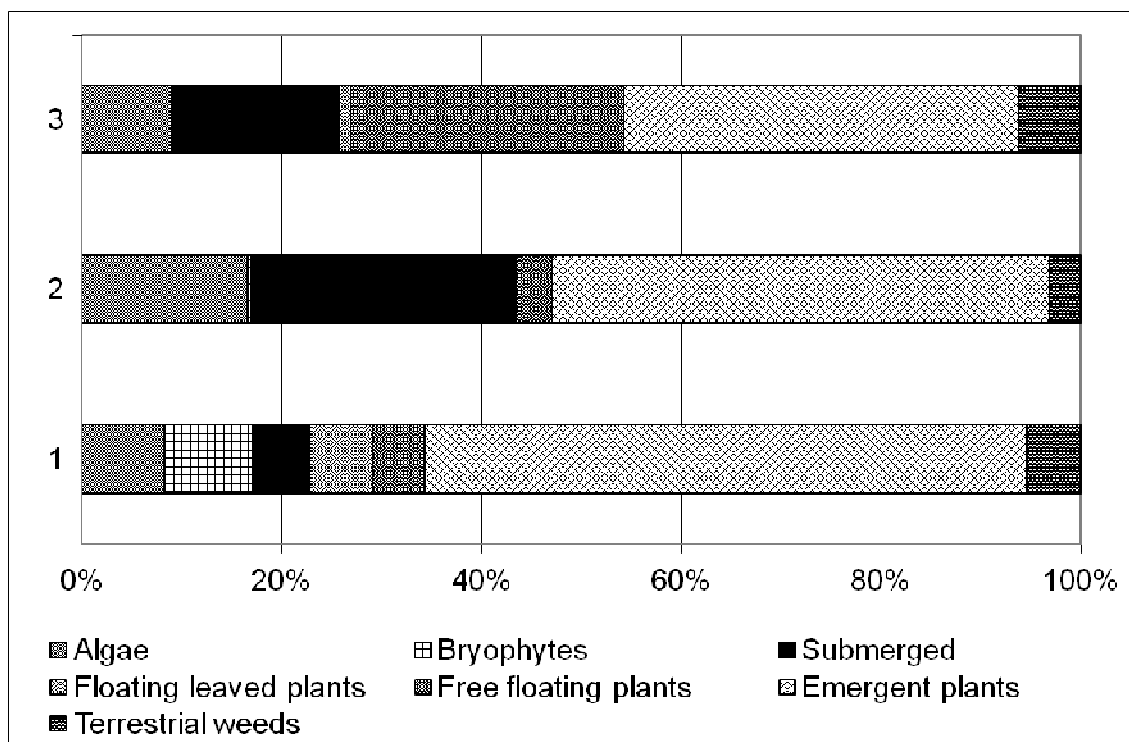


Figure 4. Proportions of functional growth forms of macrophytes developing in the gradient of agricultural land percentage in catchments of small sandy rivers. Explanation: percentage limits of agricultural land amount: 1: 0-33% (number of sites: 21), 2: 34-66% (number of sites: 38), 3: 67-100% (number of sites: 29).

Macrophyte development in stony rivers

Basing on the results of Monte Carlo test, three vectors of land use categories were chosen in Canonical Correspondence Analysis. These were: agricultural lands, forests and built-up areas. These three land use categories presented the highest statistical significance measured by variance explained (respectively: 0,22, 0,28 and 0,26). They also presented relatively high values of F-statistic (respectively: 1,49, 1,9 and 1,77).

Significant correlations between various macrophyte species and the analysed forms of land use in stony rivers were observed (Fig. 5). Conducted canonical analysis revealed that the sites located in catchments characterized by a major proportion of forests were inhabited by some bryophyte species, such as *Brachythecium rivulare* and *Scapania sp.*. Such vascular plants as *Lysimachia nummularia*, *Caltha palustris*, *Solanum dulcamara* *Sagittaria sagitifolia* and *Potamogeton alpinus* were also observed.

Agricultural lands were mainly connected with the presence of such vascular plants as: *Lemna gibba*, *Rorippa amphibia*, *Bidens frondosa* and *Callitriche sp.* Build-up areas were connected with the presence of such plants as: *Cladophora sp.*, *Bidens triparita*, *Polygonum hydropiper* and *Impatiens glandulifera* (Fig. 5).

The proportion of functional growth forms of macrophytes in the gradient of variously utilised land of the stony river catchment was different than in case of sandy rivers (Fig. 6). Bryophytes were generally much more abundant and most extensively developed when the percentage of agricultural land was medium (34-66%). The development of algae was relatively very intense except for rivers with limited agriculture in the catchment (lower than 33%). A low percentage of agricultural land

was reflected in a large proportion of emergent plants. In catchments mostly covered by such category of land use, also mosses are disappearing.

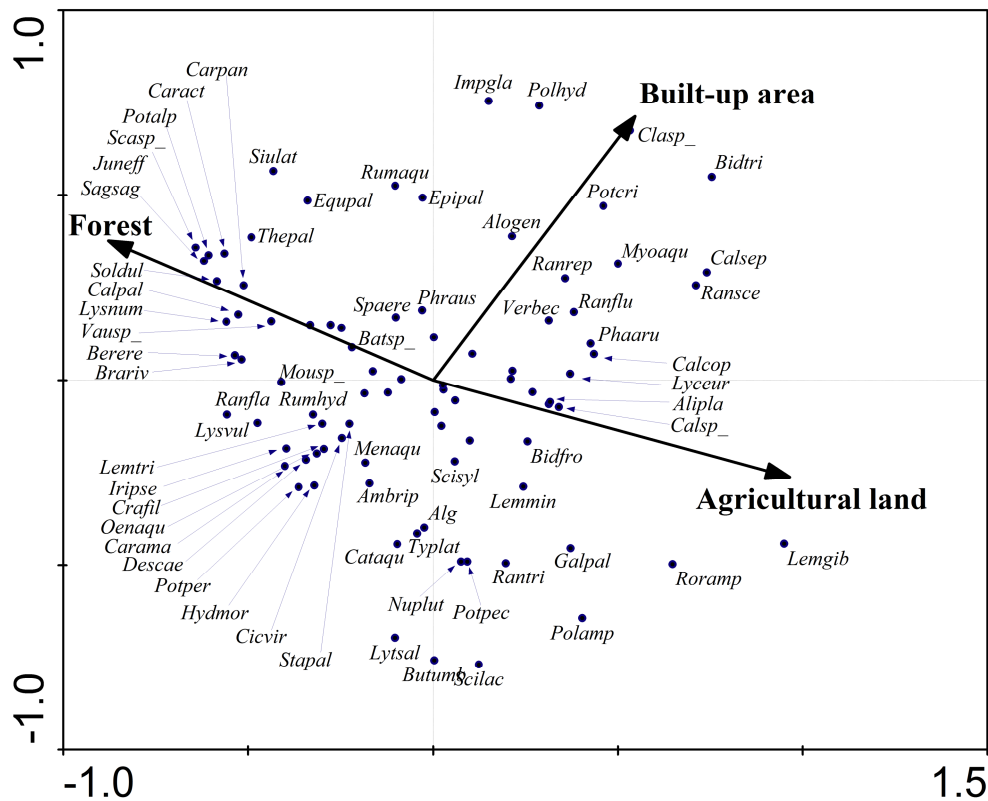


Figure 5. CCA ordination of macrophyte taxa and catchment land use types in stony rivers. Explanation: species names in Appendix 1; arrows represent analysed land use forms: surface waters and wetlands, forests and other semi-natural areas, built-up areas and agricultural lands.

Macrophyte development in large siliceous rivers

Basing on the results of Monte Carlo test, three vectors of land use categories were chosen in Canonical Correspondence analysis. These were: agricultural lands, forests and surface waters. These three land use categories presented highest statistical significance measured by variance explained (respectively: 0,22, 0,23 and 0,22). They also presented relatively high values of F-statistic (respectively: 1,73, 1,76 and 1,7).

A significant percentage of agricultural land in catchments of large siliceous rivers was reflected by the presence of such vascular plants as *Sparganium emersum*, *Polygonum amphibium*, *Calystegia sepium*, *Sparganium erectum*, *Bidens frondosa* and *Sparganium erectum* (Fig. 7). The gradient of forests in a catchment was correlated with several other species: *Ranunculus triophyllus*, *Stigeoclonium tenue*, *Nuphar lutea*, *Epilobium hirsutum* and *Fontinalis antypyretica*. There are also some species which closely correspond with surface waters and wetlands in catchments. These are *Bidens cernua*, *Polygonum hydropiper*, *Phragmites australis* and *Lysimachia vulgaris*.

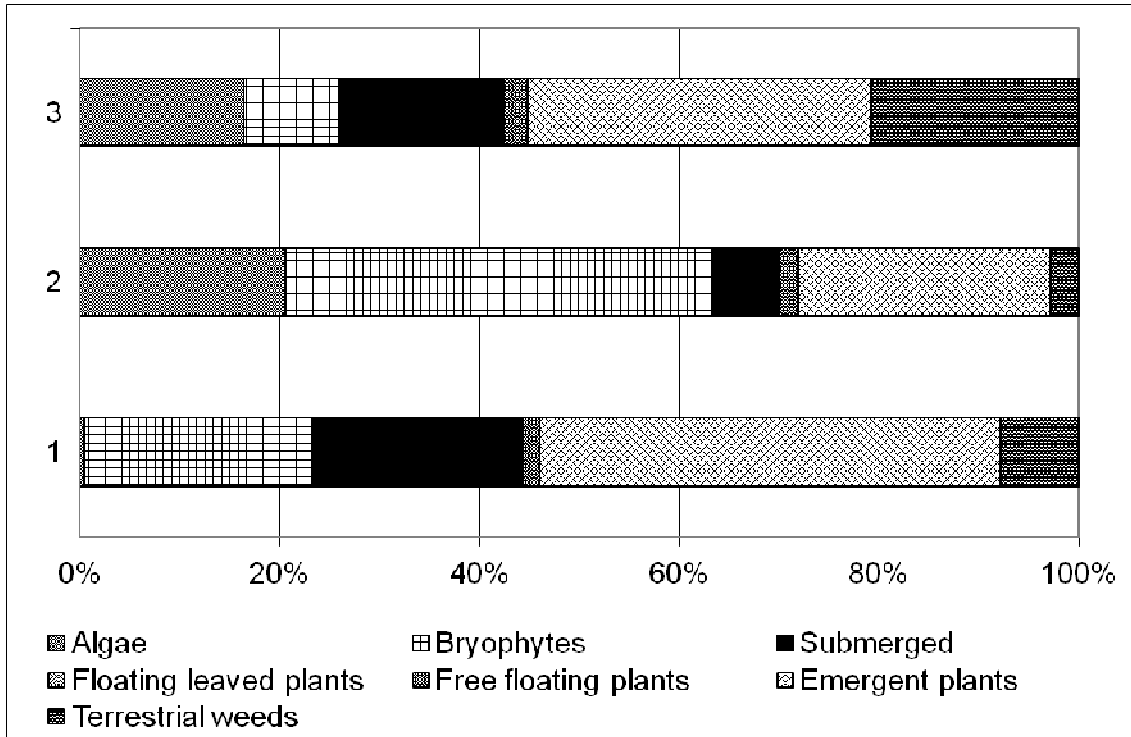


Figure 6. Proportions of functional growth forms of macrophytes developing in the gradient of agricultural land percentage in catchments of stony rivers. Explanation: the following percentage limits of agricultural land amount were implemented (y axis): 1: 0-33% (number of sites: 21), 2: 34-66% (number of sites: 38), 3: 67-100% (number of sites: 29).

Large siliceous rivers showed a unique pattern of the proportions of macrophyte functional groups (Fig. 8). Firstly, the proportion of submerged vascular plants was much higher in comparison to other river types, when the catchment had a small to medium percentage of agricultural land (lower than 66%). The presence of mosses was very limited. Increasing area of agricultural land was reflected in increasing cover of plants with floating leaves (rooted and free-floating).

Discussion

The presented results show the pattern of diverse development of aquatic plants under the variable use of catchment land. The principal pattern discovered was the change of vegetation across the gradient indicating the relation with the proportion of agricultural land and forests in catchments. A growing relative amount of farmlands causes bryophyte decline and increases abundance of filamentous algae and free floating species. Such a pattern indicates deterioration of ecological status, which was presented in the literature and explained as a result of replacement of forests by agricultural land in a catchment (Allan & Flecker 1993, Robach et al. 1996, Baattrup-Pedersen et al. 2006, Szoszkiewicz et al. 2006, Utz et al. 2009). Several long-term analyses that were conducted by Harding et al. (1998) found that land-cover patterns at the catchment scale from 1950, compared with land-cover patterns from 1970 and 1990, were the single strongest predictor of current biodiversity in North Carolina streams. According to existing scientific analyses, the degradation of catchment land use leads to

lower biodiversity of freshwater ecosystems (Bastian & Bernhardt 1993, Harrison, 1987; Kornas, 1983; Kronert et al. 1999).

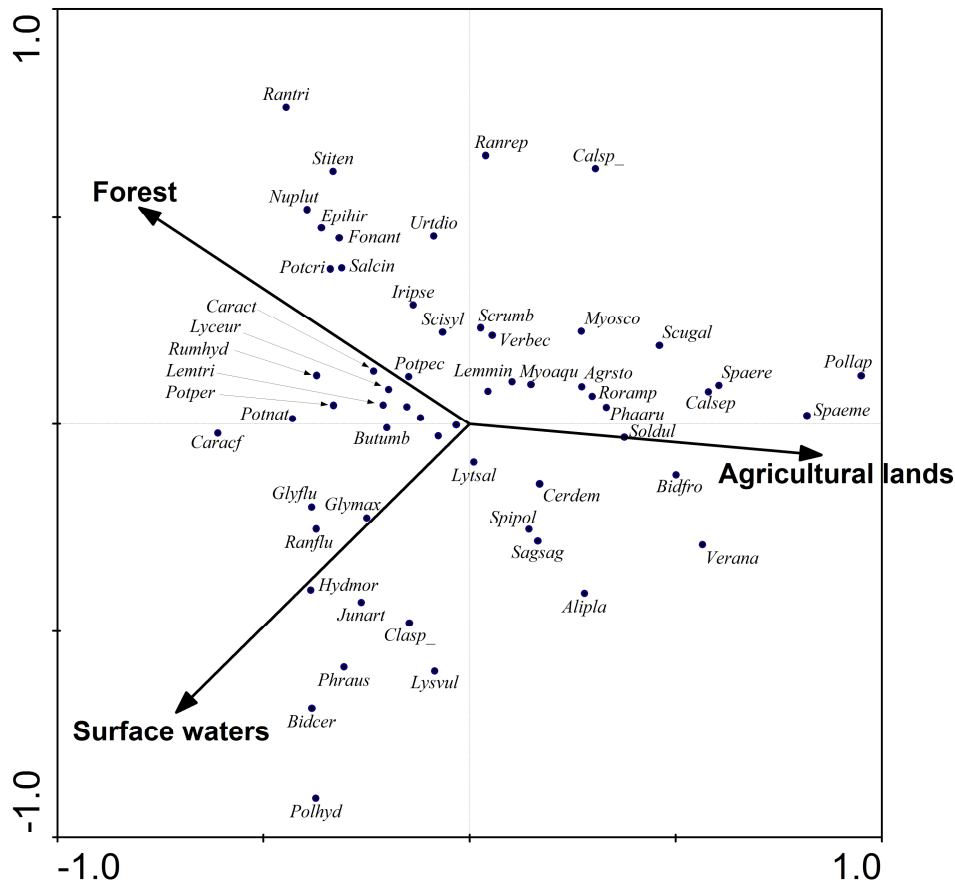


Figure 7. CCA ordination of macrophyte taxa and catchment land use types in large siliceous rivers. Explanation: species names in Appendix 1; arrows represent analysed land use forms: surface waters and wetlands, forests and other semi-natural areas, built-up areas and agricultural lands.

The surveys which also included analyses of relations between land use and ecological status of rivers were conducted by Streyer et al. (2003). He was analysing land use impact in different corridors on ecological status of rivers. He took into consideration several factors, which define ecological status, although the investigation of relations between the land use and macrophytes was less detailed. He did not analyse macrophyte composition, specifically, he did not analyse individual species preferences in different land use types. Although, similarly to the results in this article, he found the positive relation between the presence of cultivated lands and plant species abundance. He also observed that various land use types have different significance in different spatial scales.

Many surveys have confirmed that catchment deforestation resulting in an increased proportion of agricultural lands is the main factor influencing the quality of running waters (Allan & Flecker 1993, Hering et al. 2006 Robach et al. 1996, Baattrup-Pedersen et al. 2006, Szoszkiewicz et al. 2006a). This process causes such effects as increased

human population density in the river surroundings or increased erosion. Catchment modifications also often result in reinforcement or resection of the river channel (Baattrup-Pedersen & Riis 1999, Bunn et al. 1999, Sponseller et al. 2001, Szoszkiewicz et al. 2007). Also Smith et al. (1997) and Clark (1998) observed that catchment land use is an important factor influencing the ecological status of running waters independently of morphological modifications present in the river channel.

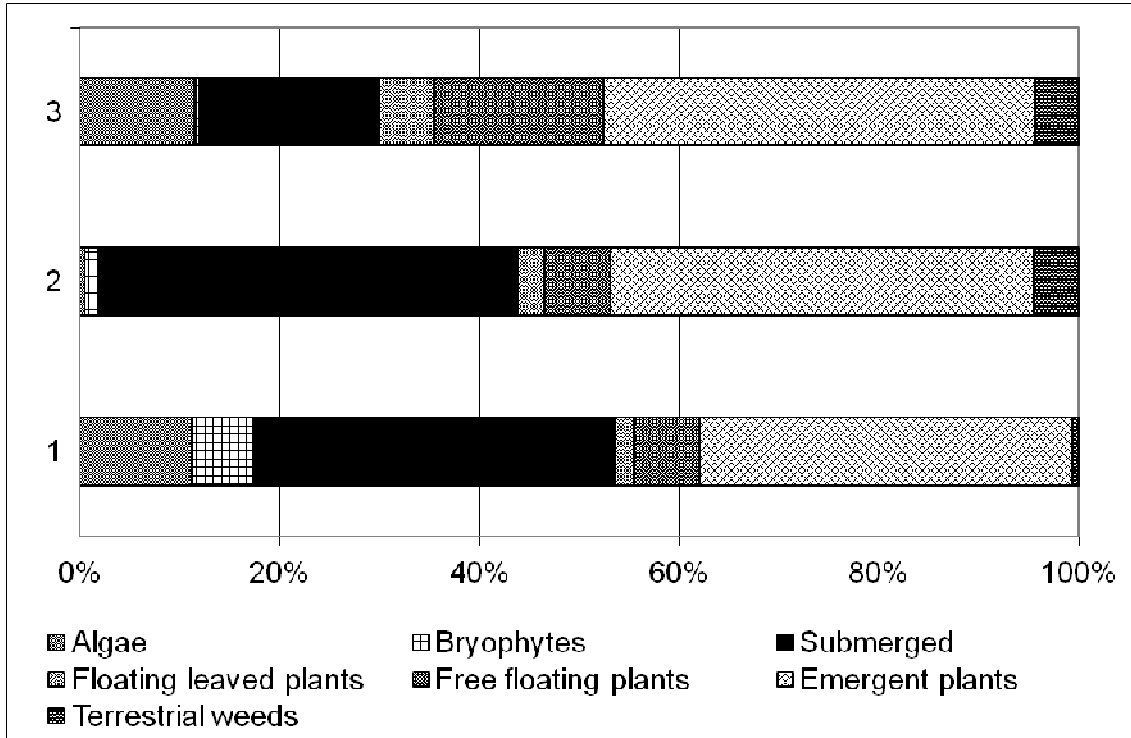


Figure 8. Proportions of functional growth forms of macrophytes developing in the gradient of agricultural land percentage in catchments of large siliceous rivers. Explanation: the following percentage limits of agricultural land amount were implemented (y axis): 1: 0-33% (number of sites: 21), 2: 34-66% (number of sites: 38), 3: 67-100% (number of sites: 29).

Within the revealed relation between vegetation development and land use, bryophyte decline seems to be the most significant indicator of catchment deterioration. Mosses and liverworts are regarded as sensitive indicators of any human modifications in rivers, because they are overgrown by other macrophytes in nutrient-rich ecosystems and prefer natural substrates such as stones or wood. Such preferences of this group of macrophytes are used in many biological methods of ecological status assessment to indicate natural conditions (Dawson et al. 1999, Haury et al. 2006, Meilinger et al. 2005, Szoszkiewicz et al. 2006a).

Analyses have shown that the proportion of built-up areas is less important than the presence of forests or agricultural lands. This observation is in contrast to conclusions presented by several other authors. Osborne and Wiley (1988) and Silva and Williams (2001) indicate urban land use as the most important predictor of water quality variability.

Applied statistical tools revealed the importance of spatial scale of the catchment structure analysis. The lowest variance explained is observed for investigations

conducted for the whole catchments and in the closest, local scale of 50 m corridors along 500 m long river stretch. The highest statistical significance is observed in case of 100 meters - 1000 meters from a river channel. Macrophytes in stony rivers are a little bit more related to closer surroundings (100 m – 500 m) and plants composition in small sandy and large siliceous rivers are more related to further land-use structure (500 m – 1000 m).

The analysis of the functional growth forms distribution along the gradient of percentage of agricultural land was supported by the results of CCA analysis. Conducted surveys revealed that the plants which most strongly indicate the presence of agricultural land and built-up areas in a catchment are algae (*Cladophora sp.*, *Spirogyra sp.*, *Oedogonium sp.*, *Enteromorpha sp.*) and the following vascular species: *Potamogeton nodosus*, *Potamogeton lucens*, *Lemna gibba* and *Spirodela polyrrhiza*. Most of these species are already used in biological monitoring as indicators of poor ecological quality (Haury et al. 2006, Holmes et al. 1999). Moreover, such typically ruderal species as *Agrostis stolonifera*, *Calystegia sepium*, *Epilobium hirsutum*, *Ranunculus sceleratus* and *Urtica dioica* are highly correlated with such areas. Although they are not included in any widely used European biological method due to their broad scale of tolerance to ecological conditions (Holmes et al. 1999, Haury et al. 2006, Szoszkievicz et al. 2006a), they may provide some clues indicating that the surveyed site is somehow impacted by human activity.

The CCA analysis of species distribution along the analysed gradients of land use types suggests that these are bryophytes which are most connected to the presence of forests and other semi-natural areas. Regarding liverworts, the most characteristic for such conditions were *Chiloscyphus polyanthos*, *Marchantia polymorpha*, *Marsupella emarginata*, *Pellia epiphylla* and *Scapania sp.*; and among bryophytes they were *Brachythecium rivulare* and *Brachythecium plumosum*. Also several vascular plants can be found as good indicators of natural conditions: *Carex pseudocyperus*, *Carex paniculata*, *Glyceria plicata* and *Juncus bulbosus*. Based on the results of CCA analysis, several species typical for catchments rich in surface waters and wetlands can also be identified. Among them there are bryophyte species (*Drepanocladus aduncus*), *Chara* species and several vascular plants (*Carex rostrata*, *Carex vesicaria*, *Hottonia palustris*, *Potamogeton obtusifolius*, *Ranunculus lingua*). Most of these species were identified as indicators of high quality conditions (Holmes et al. 1999, Haury et al. 2006).

Catchments dominated by built-up areas or agricultural lands were often under degradation according to hydromorphological and biological parameters, which results in a higher proportion of river stretches completely exposed to the sun. This may result in higher growth of macrophytes (Abernethy et al. 1996, Vermaat & Debruyne 2003). Moreover, sites characterized by lack of forests in the catchment are often nutrient-rich due to nutrient inflow through surface and ground waters. This results in intensive growth of macrophytes, mainly free floating and submerged. Sites characterized by a highly modified catchment are often exposed to intensive erosion of unnaturally high banks (Hellsten & Riihimäki 1996).

The conducted surveys showed that different river types are characterised by unique reaction of macrophyte development to catchment deterioration. Large siliceous rivers, which were generally the richest in submerged plants, indicated decline of this group of macrophytes with a growing percentage of agricultural land. Small sandy rivers which were especially rich in emergent plants indicated decline of this group of macrophytes

along with a growing percentage of agricultural land. Stony rivers located in a relatively natural catchments were rich in a variety of bryophytes. The result of the degradation of river catchments of this type was a significant increase in the share of common macrophytes.

Conclusions

1. The land use structure was a significant factor influencing ecological status of lowland rivers measured by a composition of macrophytes.
2. In all analysed river types statistically the most significant relation was the one between macrophytes and land use in 500 m corridors along the rivers. Macrophytes in stony rivers are also vulnerable to land use in 100 m corridors, whereas small sandy and large siliceous – to land use in 1000 m corridors.
3. Regardless of the river type, a significant area of agricultural land in the catchment resulted in a decline of bryophytes, whereas the proportion of filamentous algae and free floating species increased.
4. Several types of specific reactions of macrophyte development as a reaction to catchment deterioration were also revealed: a decline of submerged plants (large siliceous rivers); a decline of emergent plants (small sandy rivers); growing abundance and significant presence of terrestrial and ecotonal weeds (stony rivers).
5. The land use pattern influenced development of individual species. Agricultural land and built-up areas in a catchment stimulate development of some algae (*Cladophora sp.*, *Spirogyra sp.*) and several vascular plants (*Potamogeton lucens*, *Lemna gibba*, *Spirodela polyrhiza*). The dominance of forests and other semi-natural areas stimulates growth of liverworts (*Chiloscyphus polyanthos*, *Marchantia polymorpha*, *Marsupella emarginata*, *Pellia epiphylla* and *Scapania sp.*) and mosses (*Brachythecium rivulare*, *Brachythecium plumosum*) as well as several vascular plants (*Carex pseudocyperus*, *Carex paniculata*, *Glyceria plicata* and *Juncus bulbosus*).

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Appendices

Appendix 1. List of identified macrophytes and their abbreviations

Species name	Abbrev.	Species name	Abbrev.
<i>Acorus calamus</i> L.	Acocal	<i>Mentha aquatica</i> L.	Menaqu
<i>Agrostis stolonifera</i> L.	Agrsto	<i>Menyanthes trifoliata</i> L.	Mentri
<i>Alisma plantago-aquatica</i> L.	Alipla	<i>Microspora</i> sp.	Micsp_
<i>Alopecurus geniculatus</i> L.	Alogen	<i>Mnium hornum</i> Hedw.	Mnihor
<i>Amblystegium riparium</i> Hedw.	Ambrip	<i>Mnium undulatum</i>	Mniund
<i>Batrachospermum</i> sp. Roth	Batsp_	<i>Mougeotia</i> sp.	Mousp_
<i>Berula erecta</i> Huds.	Berere	<i>Myosotis scorpioides</i> L.	Myosco
<i>Bidens cernua</i> L.	Bidcer	<i>Myosotis</i> sp. L.	Myosp_
<i>Bidens frondosa</i> L.	Bidfro	<i>Myosoton aquaticum</i> Hedw.	Myoauq
<i>Bidens tripartita</i> L.	Bidtri	<i>Myriophyllum spicatum</i> L.	Myrspi
<i>Brachythecium plumosum</i> Hedw.	Brapl_	<i>Myriophyllum verticillatum</i> L.	Myrvet
<i>Brachythecium rivulare</i> Shimp.	Brariv	<i>Nasturtium officinale</i> W. T. Aiton	Nasoff
<i>Brachythecium rutabalum</i> Hedw.	Brarut	<i>Nuphar lutea</i> (L.) Sm.	Nuplut
<i>Butomus umbellatus</i> L.	Butumb	<i>Nymphaea alba</i> L.	Nymalb
<i>Calla palustris</i> L.	Calpas	<i>Oedogonium</i> sp.	Oedsp_
<i>Callitriche cophocarpa</i> Sendt.	Calcop	<i>Oenanthe aquatica</i> (L.) Poir.	Oenaqu
<i>Callitriche palustris</i> L.	Calpau	<i>Pellia endiviifolia</i> (Dicks.) Dumort.	Pelend
<i>Callitriche</i> sp. L.	Calsp_	<i>Petasites hybridus</i> L.	Pethyb
<i>Caltha palustris</i> L.	Calpal	<i>Peucedanum palustre</i> (L.) Moench	Peupal
<i>Calystegia sepium</i> L.	Calsep	<i>Phalaris arundinacea</i> L.	Phaar_

<i>Cardamine amara</i> L.	Carama	<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	Phraus
<i>Carex acuta</i> L.	Caract	<i>Plantago major</i> L.	Plamaj
<i>Carex acutiformis</i> L.	Caracf	<i>Poa palustris</i> L.	Poapal
<i>Carex elata</i> All.	Carela	<i>Polygonum amphibium</i> L.	Polamp
<i>Carex hirta</i> L.	Carhir	<i>Polygonum hydropiper</i> L.	Polhyd
<i>Carex paniculata</i> L.	Carpan	<i>Polygonum lapathifolium</i> L.	Pollap
<i>Carex pseudocyperus</i> L.	Carpse	<i>Polygonum persicaria</i> L.	Polper
<i>Carex riparia</i> Curtis	Carrip	<i>Potamogeton alpinus</i> Balb.	Potalp
<i>Carex rostrata</i> Stokes	Carros	<i>Potamogeton berchtoldii</i> Fieber	Potber
<i>Carex sp.</i> L.	Caresp	<i>Potamogeton compressus</i> L.	Potcom
<i>Carex vesicaria</i> L.	Carves	<i>Potamogeton crispus</i> L.	Poteri
<i>Catabrosa aquatica</i> (L.) P.Beauv.	Cataqu	<i>Potamogeton lucens</i> L.	Potluc
<i>Ceratophyllum demersum</i> L.	Cerdem	<i>Potamogeton natans</i> L.	Potnat
<i>Ceratophyllum submersum</i> L.	Cersub	<i>Potamogeton nodosus</i> Poir.	Potnod
<i>Chara sp.</i> L.	Chasp_	<i>Potamogeton obtusifolius</i> Mert.	Potobt
<i>Chara vulgaris</i> L.	Chavul	<i>Potamogeton pectinatus</i> L.	Potpec
<i>Chiloscyphus pallescens</i> (Ehrh. Ex Hoffm.) Dum.	Chipal	<i>Potamogeton perfoliatus</i> L.	Potper
<i>Chiloscyphus polyanthus</i> (L.) Corda	Chipol	<i>Potamogeton sp.</i> L.	Potsp_
<i>Cicuta virosa</i> L.	Cievir	<i>Potamogeton trichoides</i> Cham.	Pottri
<i>Cladophora sp.</i> Kutz.	Clasp_	<i>Potamogeton x</i> <i>sparganiiifolius</i>	Potxfl
<i>Conocephalum conicum</i> L. (Lindb.)	Concon	<i>Potentilla anserina</i> L.	Potans
<i>Cratoneuron filicinum</i> Spruce	Crafil	<i>Ranunculus acris</i>	Ranacr
<i>Deschampsia caespitosa</i> (L.) Beauv.	Descae	<i>Ranunculus aquatilis</i>	Racaqu
<i>Drepanocladus aduncus</i> Warnstorf	Dreadu	<i>Ranunculus circinatus</i>	Rancir
<i>Eleocharis palustris</i> L.	Elepal	<i>Ranunculus flammula</i>	Ranfla
<i>Elodea canadensis</i> Michx.	Elocan	<i>Ranunculus fluitans</i>	Ranflu
<i>Enteromorpha sp.</i>	Entsp_	<i>Ranunculus lingua</i>	Ranlin
<i>Epilobium hirsutum</i> L.	Epibir	<i>Ranunculus repens</i>	Ranrep
<i>Epilobium palustre</i> L.	Epipal	<i>Ranunculus sceleratus</i>	Ransce
<i>Epilobium sp.</i> L.	Episp_	<i>Ranunculus trichophyllus</i>	Rantri
<i>Equisetum fluviatile</i> L.	Equflu	<i>Rhynchosstegium riparioides</i> (Hedw.) C.Jens.	Rhyrip

<i>Equisetum palustre</i> L.	Equpal	<i>Rorippa amphibia</i> (L.) Besser	Roramp
<i>Eupatorium cannabinum</i> L.	Eupcan	<i>Rumex aquaticus</i> L.	Rumaqu
<i>Filipendula ulmaria</i> (L.) Maxim.	Filulm	<i>Rumex hydrolapathum</i> Huds.	Rumhyd
<i>Fontinalis antipyretica</i> Hedw.	Fonant	<i>Sagittaria sagittifolia</i> L.	Sagsag
<i>Galeopsis tetrahit</i> Lindtley	Galtet	<i>Salix alba</i> L.	Salalb
<i>Galium palustre</i> L.	Galpal	<i>Salix aurita</i> L.	Salaur
<i>Galium uliginosum</i> Pall. Ex M. Bieb.	Galuli	<i>Salix cinerea</i> L.	Salcin
<i>Geranium palustre</i> L.	Gerpal	<i>Salix fragilis</i> L.	Salfra
<i>Glechoma hederacea</i> L.	Glehed	<i>Scapania</i> sp.	Scasp_
<i>Glyceria fluitans</i> (L.) R. Br.	Glyflu	<i>Scapania undulata</i> (L.) Dum.	Scaund
<i>Glyceria maxima</i> (Hartman) Holmberg	Glymax	<i>Scirpus lacustris</i> L.	Scilac
<i>Glyceria plicata</i>	Glypli	<i>Scirpus sylvaticus</i> L.	Scisyl
<i>Hildenbrandia rivularis</i> (Fries) Fries	Hilriv	<i>Scrophularia umbrosa</i> Dumort.	Scrumb
<i>Hottonia palustris</i> L.	Hotpal	<i>Scutellaria galericulata</i> L.	Scugal
<i>Hydrocharis morsus-ranae</i> L.	Hydmor	<i>Sium latifolium</i> L.	Siulat
<i>Hygroamblystegium fluviatile</i> Loeske	Hygflu	<i>Solanum dulcamara</i> L.	Soldul
<i>Hygroamblystegium tenax</i> Jennings	Hygten	<i>Sparganium emersum</i> Rehmann	Spaeme
<i>Impatiens glandulifera</i> Royle	Impgla	<i>Sparganium erectum</i> L.	Spaere
<i>Iris pseudacorus</i> L.	Iripse	<i>Spirodela polyrhiza</i> (L.) Schleid.	Spipol
<i>Juncus articulatus</i> L.	Junart	<i>Spirogyra</i> sp.	Spisp_
<i>Juncus bulbosus</i> L.	Junbul	<i>Stachys palustris</i> L.	Stapal
<i>Juncus effusus</i> L.	Juneff	<i>Stellaria palustris</i> Retz.	Stepal
<i>Lemanea fluviatilis</i> L.	Lemflu	<i>Stigeoclonium tenue</i> Kutzing	Stiten
<i>Lemna gibba</i> L.	Lemgib	<i>Stratiotes aloides</i> L.	Stralo
<i>Lemna minor</i> L.	Lemmin	<i>Symphytum officinale</i> L.	Symoff
<i>Lemna trisulca</i> L.	Lemtri	<i>Taraxacum officinale</i> Wigg.	Taroff
<i>Lolium perenne</i> L.	Lolper	<i>Thelypteris palustris</i> Schott	Thepal
<i>Lycopus europaeus</i> L.	Lyceur	<i>Typha angustifolia</i> L.	Typang
<i>Lysimachia nummularia</i> L.	Lysnum	<i>Typha latifolia</i> L.	Typlat
<i>Lysimachia thyrsiflora</i> L.	Lysthy	<i>Urtica dioica</i> L.	Urtdio
<i>Lysimachia vulgaris</i> L.	Lysvul	<i>Vaucheria</i> sp.	Vausp_
<i>Lythrum salicaria</i> L.	Lytsal	<i>Veronica anagallis-aquatica</i> L.	Verana

<i>Marchantia polymorpha</i> L.	Marpol	<i>Veronica beccabunga</i> L.	Verbec
<i>Marsupella emarginata</i> Lindenb.	Marema		