Arch. Biol. Sci., Belgrade, 61 (2), 297-306, 2009 DOI:10.2298/ABS0902297H

MACROPHYTE DISTRIBUTION AND ECOLOGICAL STATUS OF THE TURIEC RIVER (SLOVAKIA): CHANGES AFTER SEVEN YEARS

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Abstract — Characteristics of diversity, abundance, distribution, and ecological status of aquatic macrophytes were observed in 2000 and 2007 on a circa 4.5 km long section of the Turiec River using Kohler´s method. In comparison to 2000, the total number of macrophytes in 2007 increased markedly (from 25 to 35), although only the numbers of amphiphytes and helophytes were changed substantially. The number of hydrophytes increased from 11 to 12; an invasive, *Elodea canadenis*, was the only new species. The relative plant mass of hydrophytes represents the bulk of all recorded species (95 and 80% in 2000 and 2007, respectively), and it was changed for most hydrophytes. The most significant changes were detected for *Myriophyllum spicatum* (decrease), filamentous algae (decrease), and *Potamogeton crispus* (increase). In 2007, the mean mass total (MMT) sum of hydrophytes decreased from 16.46 to 14.5. On the other hand, the MMT sum of amphiphytes and helophytes doubled in value (7.4 and 14.1 in 2000 and 2007, respectively). Within hydrophytes, *Batrachium* species (including *B. aquatile* and *B. trichophyllum*), *Myriophyllum spicatum*, and *Potamogeton crispus* were ubiquitous (distribution ratio d > 0.5) in 2000, whereas in 2007 only *Batrachium* species and *Potamogeton* crispus were ubiquitous. At all times, *Batrachium* species were the most frequent species in the study area, and their abundance was relatively high (MMT > 2.5). A poor ecological status (MMP = 0.378 and MMP = 0.333 in 2000 and 2007, respectively) of the surveyed river section was found in both years, but a slight decline of quality as determined on the basis of aquatic plants was observed after 7 years.

Key words: Aquatic plants, Water Framework Directive, temporal changes, Turiec River, Slovakia

UDC 574.5:58(437.6:26)

INTRODUCTION

Aquatic macrophytes are essential ecological components wherever they occur in water bodies. Spatial, but above all temporal changes are typical of macrophyte vegetation in running waters. These processes are much more dynamic than in the case of terrestrial vegetation and influence the diversity, abundance, structure, and distribution of macrophytes. Changes are effected by various factors, but environmental influences (mainly artificial in cultivated landscapes) are extremely important. Running waters are very dynamic ecosystems, and river hydrology, morphology, nutrient status, disturbances, and pollution are often varying factors that strongly affect aquatic macrophytes (Janauer and Dokulil, 2006; Lacoul and Freedman, 2006). In addition to these changes, various biological interactions (e.g., competition) can be important as well. In Central Europe, temporal changes of macrophyte species and vegetation in running waters have been studied by many authors (Würzbach et al., 1997; Rydlo, 2001; Veit and Kohler, 2003; Baart et al., 2006; Janauer et al., 2006). In recent years, only a few papers were devoted to lowland watercourses of Slovakia: Oťaheľová and Banásová (2005) studied the response of aquatic macrophytes to restoration management in Morava River oxbows in 1995-2002; Oťaheľová et al. (2007a) compared aquatic macrophytes in the Klátovské Rameno watercourse in 1996 and 2005; and Hrivnák et al. (2008) analyzed changes in the Ipeľ River after the summer flood in 2006 compared to the situation in 2000. Still, no such surveys are known from rivers in the Carpathian region of Slovakia.

We chose a part of the Turiec River for study of temporal changes of aquatic macrophytes. Aquatic and marsh plants in the Turiec River and adjacent wetlands have not been studied in detail in the past. The first (often only sporadic) information about aquatic plants and vegetation were presented in several papers from the first third of the last century (Petrikovich, 1912; Textorisová, 1913, 1930; Margittai, 1915). Complementary data were published much later (Škovirová, 1987, 1993, 1994; Topercer, 2003; Bernátová et al., 2006). Vegetation of the Turiec River was thoroughly studied only by Hrivnák et al. (2004); data from this paper are used as the basic comparative material for our study. In the case of the Turiec River ecosystem, more attention has been paid to limnological and zoological objects, where the microzoobenthos, macrozoobenthos, and some groups of aquatic animals were studied over the last 20 years (Krno et al., 1996, 2002). Some notes on the occurrence of macrophytes and their seasonal dynamics are incidentally presented in these papers.

As the Turiec is one of the most important rivers from the nature-conservation point of view in Slovakia, we decided to focus attention on temporal changes in the river. The importance of such a study was underlined by the construction of a water reservoir in the upper part of the Turiec. Accordingly, the main objectives of our research were: i) to detect changes in distribution, diversity, and abundance of aquatic macrophytes in selected parts of the river after seven years; and ii) to assess its ecological status in 2000 and 2007.

STUDY AREA

The Turiec River is an intermediate-sized submountain to mainly basin river, which is situated in Northwest Slovakia. It has a total length of 66 km and altitudinal range of from 1060 m (at the river's source in the Kremnické Vrchy Mountains) to 377 m (in the town of Vrútky, where it empties into the Váh River). The river is an important left-hand tributary of the longest Slovak river, the Váh (Danube catchment). The studied part of the river is ca 4.5 km in length and is situated in the middle part of the Turiec River between the villages of Moškovec

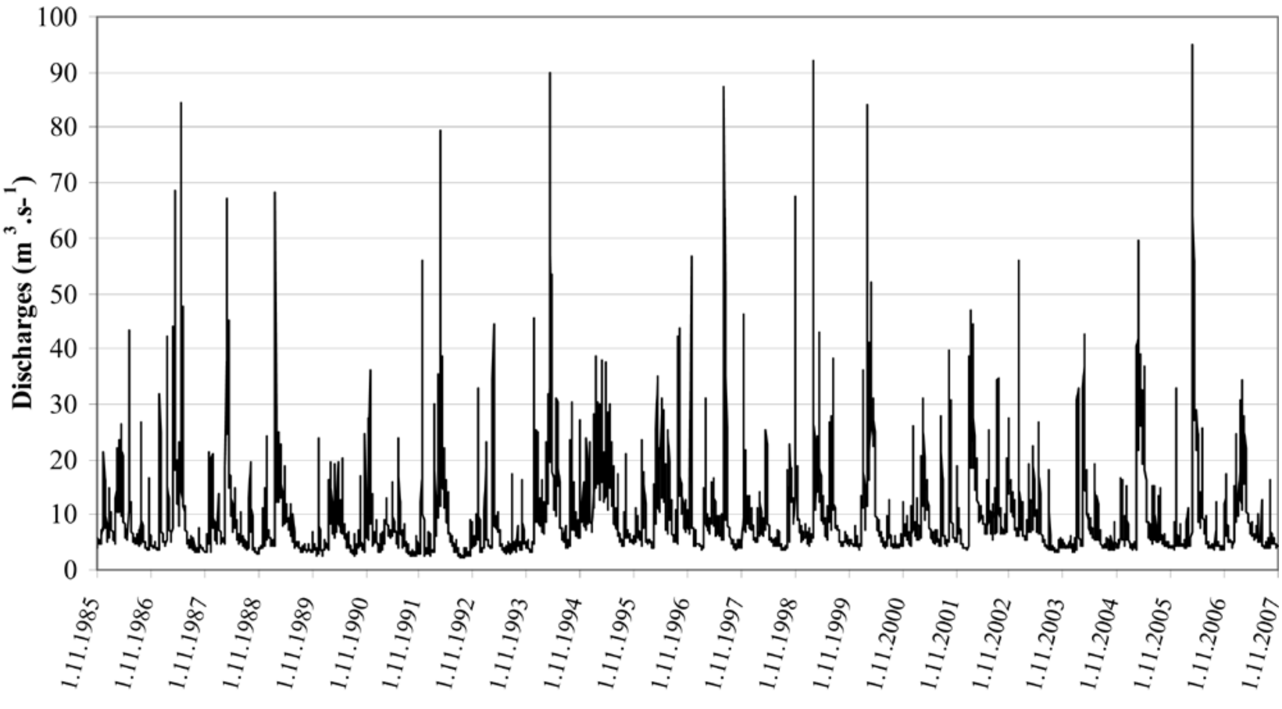

Fig. 1. Daily discharges at the hydrological station in Martin between 1985 and 2007 (provided by the Slovak Hydrometeorological Institute).

(48° 56′ 29.6″ N, 18° 49′ 48.6″ E) and Socovce (48° 57′ 11.7″ N, 18° 51′ 46.8″ E) downstream from the Turček water reservoir, which started to operate in 1996. From its source to its mouth, the land along the Turiec River changes from a moderately cool region to a moderately warm, very humid highland region (Lapin et al., 2002). Geological structure of the Turiec River catchment area is varied, but the studied part of the river is formed by Neogene rocks (Biely et al., 2002). Average width of the studied part of the river is almost 13 m, its average depth ca 0.6 m. Gravel and sand are the prevailing sediments of the river bottom, and flow velocity is moderate (30-60 cm $\cdot$ s^{-1}). Only one third of the banks are covered by trees or shrubs, and the prevailing surrounding land-use types are agricultural areas or semi-natural meadows and pastures (Hrivnák et al., 2004). Average annual discharge and water temperature are 6-8 $m^3 \cdot s$ and approx. 11°C, respectively. Daily discharges in the nearest hydrological station of Martin (about 15 km downstream) between 1985 and 2007 are presented in Fig. 1. For the Turiec, a fluctuating water regime is typical: spring/summer floods with maximum discharges and minimum discharges in the autumn. Discharges in both studied periods were similar (mean discharges in July-August of 2000 and 2007 were 5.6 and 4.7 $m^3 \cdot s^{-1}$, respectively, according to data from the Slovak Hydrometeorological Institute).

From the phytogeographical point of view, the studied part of the river is situated in the Turčianska Kotlina District within the Inner-Carpathian Basin (Inter-Carpaticum; Futák, 1966).

METHODS

Field research was carried out in July of 2000 and August of 2007. We selected 66 and 41 river sections in 2000 and 2007, respectively, with more or less uniform hydrological and ecological status, human impact, and macrophyte species distribution. Their location was recorded using the geographical position system (GPS). In each river section, all macrophytes (vascular plants, *Fontinalis antipyretica* and other bryophytes, and macroscopic algae such as filamentous algae, hereafter mentioned only by species) were sampled, and the plant mass estimate (PME) was assessed using a five-point scale (1 - rare, 2 - occasional, 3 - frequent, 4 - abundant, and 5 - very abundant; Kohler et al., 1971; Kohler, 1978; Kohler and Janauer, 1995; Janauer, 2003).

Based on the PME data, the following numerical derivatives were calculated (for details, see Kohler and Janauer, 1995; Janauer, 2003; and EN 14184): relative plant mass (RPM; %); mean mass indices (MMT - mean mass total and MMO - mean mass occurrence, whose maximum value is 5); and the distribution ratio (d; the ratio between MMT and MMO, ranging from 0 to 1). The procedure for calculation of numerical derivatives was downloaded from the web-site of the project "Multifunctional Integrated Study of the Danube Corridor and Catchment" (www.midcc.at).

The PME data for hydrophytes were used to compute the Shannon species diversity index H_s (Whittaker, 1972).

The ecological status of the studied part of the Turiec River (in the sense of the Water Framework Directive 2000/60/EC) was assessed for macrophytes based on hydrophytes. The reference index (RI) of aquatic plants was transformed into a scale from 0 to 1 and expressed as the module of macrophytes (M_{MP}). This value was calculated according to Schaumburg et al. (2004) for each river section. From these values, the weighted (by length of river sections) average was calculated for the whole studied part of the river. The RI is not defined if only a single species was recorded in a river section. A species categorization according to groups of ecological quality (A - species of reference conditions, B - species indifferent to the environment, and C - alien species and indicators of a disturbed environment) was performed addressing already obtained phytosociological experience in Slovakia with regard to the Inner-Carpathian area (see Table 1). The WFD specified a five-point scale of ecological quality status ranging from "high" to "bad". For the purpose of this paper, the classification of ecological status categories of the studied part of the river was based on M_{MP} values as follows: $M_{MP} \geq 0.4$ defines an appropriate status (from "high" to "moderate"); and $M_{MP} < 0.4$ defines a poor status (from "poor" to "bad").

Table 1. List of taxa, growth forms (GF), abbreviations (Abbr.), relative plant mass (RPM in %), and taxa categorization by groups of ecological quality (EQ) in the Turiec River in 2000 and 2007. Abbreviations: GF: Hy - hydrophytes, Am - amphiphytes, He - Helophytes; EQ: see Methods section; 1 - including *Batrachium aquatile* (strongly dominant) and *B. trichophyllum*, 2 - mainly *Rhynchostegium riparioides*, 3 - including *Glyceria fluitans* and *G. notata*.

Name of taxon/group	GF	Abbr.	Occurrence		RPM (%)		EQ
			2000	2007	2000	2007	
Filamentous algae	hy	Alg fil	■	■	9.9	2.5	.
[1]*Batrachium* sp.	hy	Bat spe	■	■	32.7	36.7	B
[2]Bryophytes	hy	Bryoph	■	■	3.0	4.5	.
Elodea canadensis	hy	Elo can		■	.	0.3	C
Fontinalis antipyretica	hy	Fon ant	■	■	11.0	6.9	B
Lemna minor	hy	Lem min	■	■	0.2	0.2	C
Myriophyllum spicatum	hy	Myr spi	■	■	14.4	1.8	B
Potamogeton crispus	hy	Pot cri	■	■	11.6	21.3	C
Potamogeton pectinatus	hy	Pot pec	■	■	2.2	1.2	C
Potamogeton perfoliatus	hy	Pot per	■	■	2.4	0.9	B
Potamogeton pusillus agg.	hy	Pot pus	■	■	0.3	0.2	C
Zannichellia palustris	hy	Zan pal	■	■	6.9	3.9	C
Berula erecta	am	Ber ere		■	.	0.1	.
Butomus umbelatus	am	But umb		■	.	0.1	.
Myosotis scorpioides agg.	am	Myo sco	■	■	0.1	0.2	.
Sparganium emersum	am	Spa eme		■	.	0.9	.
Veronica anagallis-aquatica	am	Ver ana	■	■	0.3	0.3	.
Agrostis stolonifera	he	Agr sto		■	.	0.8	.
Alisma lanceolatum	he	Ali lan	■		0.1	.	.
Alopecurus geniculatus	he	Alo gen		■	.	0.2	.
Carex acuta	he	Car acu	■		0.2	0.4	.
Carex buekii	he	Car bue		■	.	0.3	.
Epilobium hirsutum	he	Epi hir		■	.	0.8	.
Equisetum fluviatile	he	Equ flu	■	■	0.3	0.1	.
Equisetum palustre	he	Equ pal		■	.	0.1	.
[3]*Glyceria* sp.	he	Gly spe	■	■	0.1	0.8	.
Glyceria maxima	he	Gly max	■	■	0.1	0.1	.
Iris pseudacorus	he	Iri pse	■	■	0.9	0.4	.
Lythrum salicaria	he	Lyt sal		■	.	0.1	.
Petasites hybridus	he	Pet hyb		■	.	0.1	.
Persicaria amphibia	he	Per amp	■		0.1	.	.
Phalaroides arundinacea	he	Pha aru	■	■	0.4	7.4	.
Phragmites australis	he	Phr aus	■	■	0.9	0.3	.
Schoenoplectus lacustris	he	Sch lac	■		0.1	.	.
Scirpus sylvaticus	he	Sci syl		■		0.1	.
Scrophularia umbrosa	he	Scr umb		■		0.2	.
Solanum dulcamara	he	Sol dul		■		5.1	.
Sparganium erectum	he	Spa ere	■	■	1.9	0.7	.
Typha latifolia	he	Typ lat		■	.	0.2	.
Veronica beccabunga	he	Ver bec	■		0.1	.	.
Total number of taxa/Hy/Am/He	.	.	25/11/2/12	35/12/5/18	.	.	.
Total RPM/Hydrophytes RPM	.	.	.	.	100/94.6	100/80.4	.

The nomenclature of non-vascular and vascular plants follows Marhold and Hindák (1998), and abbreviations are explained in Table 1.

RESULTS

Structure of aquatic vegetation

In comparison to 2000, the total number of species in 2007 increased markedly, although only the numbers of amphiphytes and helophytes changed substantially. The number and diversity of hydrophytes increased only slightly (Table 1; $H_s = 1.44$ in 2000 and $H_s = 1.51$ in 2007); *Elodea canadensis* was the only new species. The length of river sections without any macrophytes decreased from 7.95% in 2000 to 5.25% in 2007. The RPM of hydrophytes represents the bulk of all recorded species (almost 95% and more than 80% in 2000 and 2007, respectively).

The RPM of hydrophytes changed substantially for most recorded species (Fig. 2). The most significant changes were detected for *Myriophyllum spicatum* (decrease), filamentous algae (decrease), and *Potamogeton crispus* (increase). Species of filamentous algae, *Batrachium aquatile* and *B. trichophyllum* (hereafter only *Batrachium* sp.), *Fontinalis antipyretica*, *Myriophyllum spicatum*, and *Potamogeton crispus* had RPM values higher than 10% in 2000, but there were only two such species (*Batrachium* sp. and *Potamogeton crispus*) in 2007.

Except for two species (*Potamogeton crispus* and *Bryophytes* sp.) recorded in both years among hydrophytes, MMT values more or less decreased

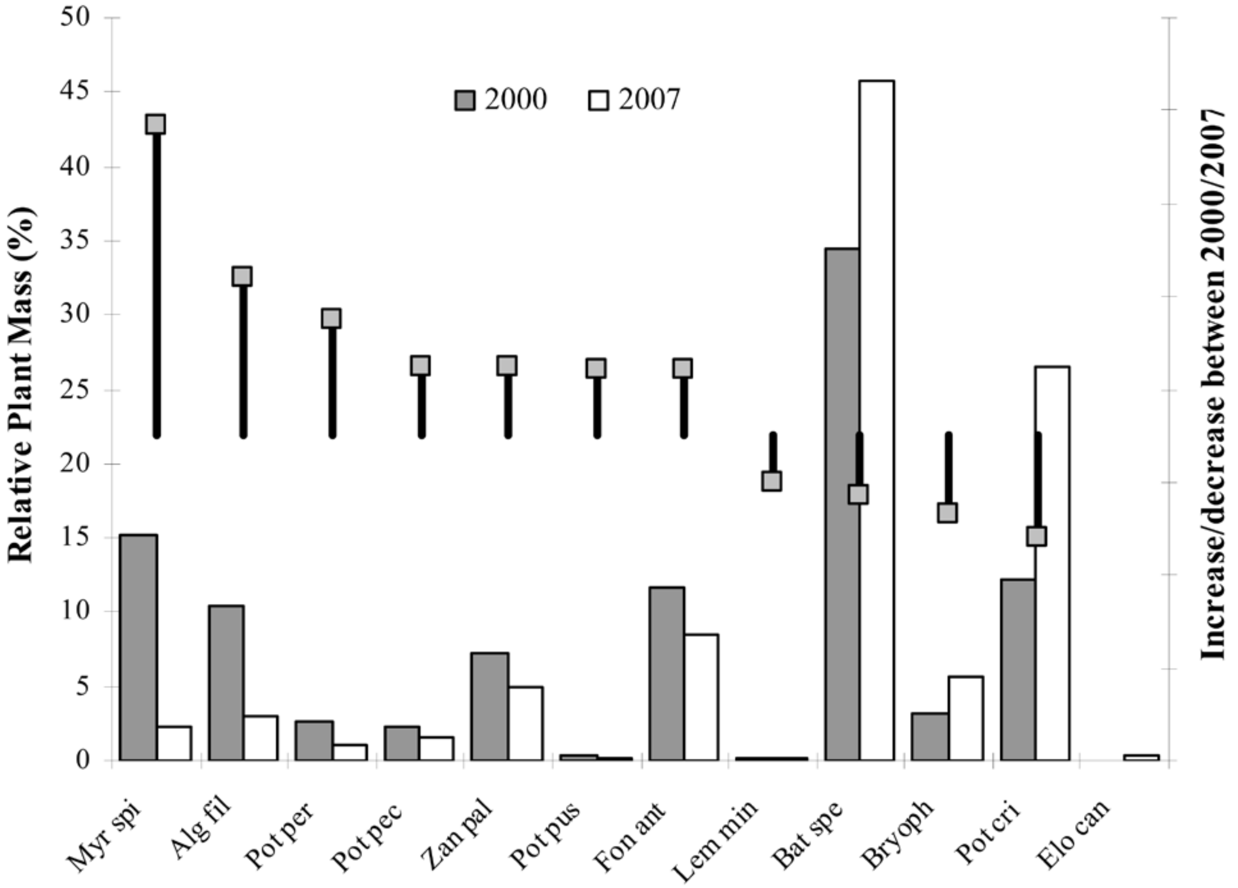

Fig. 2. Comparison of relative plant mass (%) of hydrophytes in the Turiec River in 2000 and 2007; increase and decrease of RPM between the two mentioned years are presented as a bar (multiple of relative changes).

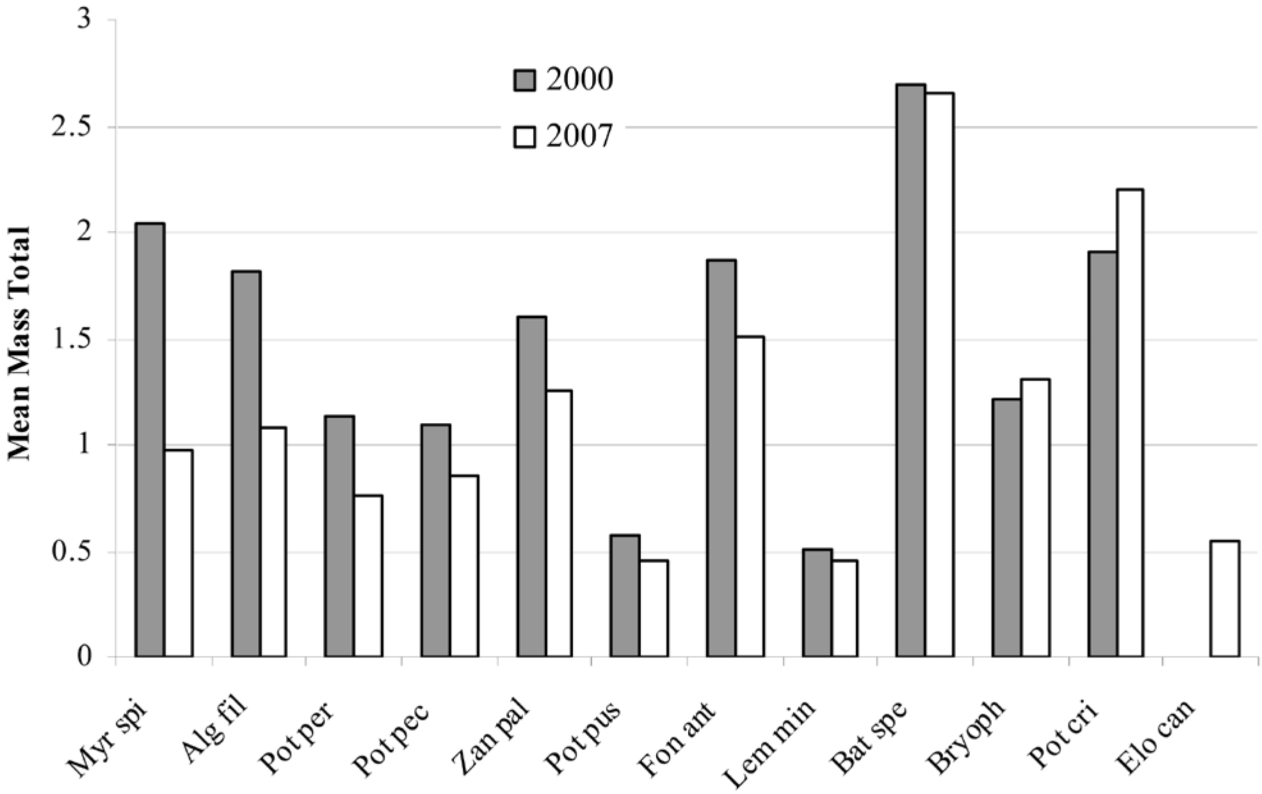

Fig. 3. Comparison of mean mass total (MMT) of hydrophytes in the Turiec River in 2000 and 2007.

for all species (Fig. 3). While several species (fil. algae, *Batrachium* sp., *Fontinalis antipyretica*, *Myriophyllum spicatum*, *Potamogeton crispus*, and *Zanichellia palustris*) had MMT higher than 1.5 in 2000, only half of them (*Batrachium* sp., *Fontinalis antipyretica*, and *Potamogeton crispus*) achieved similar values in 2007. In 2007, the MMT sum of hydrophytes decreased from 16.46 to 14.5. On the other hand, the MMT sum of amphiphytes and helophytes doubled in value (7.4 and 14.1 in 2000 and 2007, respectively).

Three species (*Batrachium* sp., *Myriophyllum spicatum*, and *Potamogeton crispus*) were ubiquitous (d > 0.5) in 2000, while only two (*Batrachium* sp. and *Potamogeton crispus*) were ubiquitous in 2007 (Fig. 4). Other species had a more or less clumped distribution (d < 0.5) in both years. In both years, *Batrachium* sp. were the most frequent species in the study area, and their abundance was relatively high (MMT > 2.5). Comparing studied years, wee see that the distribution ratio of *Batrachium* species increased and achieved almost the maximum (d = 0.96).

Ecological status

We calculated M_{MP} = 0.378 and M_{MP} = 0.333 in 2000 and 2007, respectively. A poor ecological status of the surveyed river section was found in both years, but a slight decline of quality as determined on the basis of aquatic plants was observed after 7 years.

DISCUSSION

The responses of distribution and abundance of macrophytes to environmental factors as possible indicators of ecological change are often discussed. The use of aquatic plants as indicators must rest on the foundation of known tolerances of species, within an ecoregional context (Lacoul and Freedman, 2006).

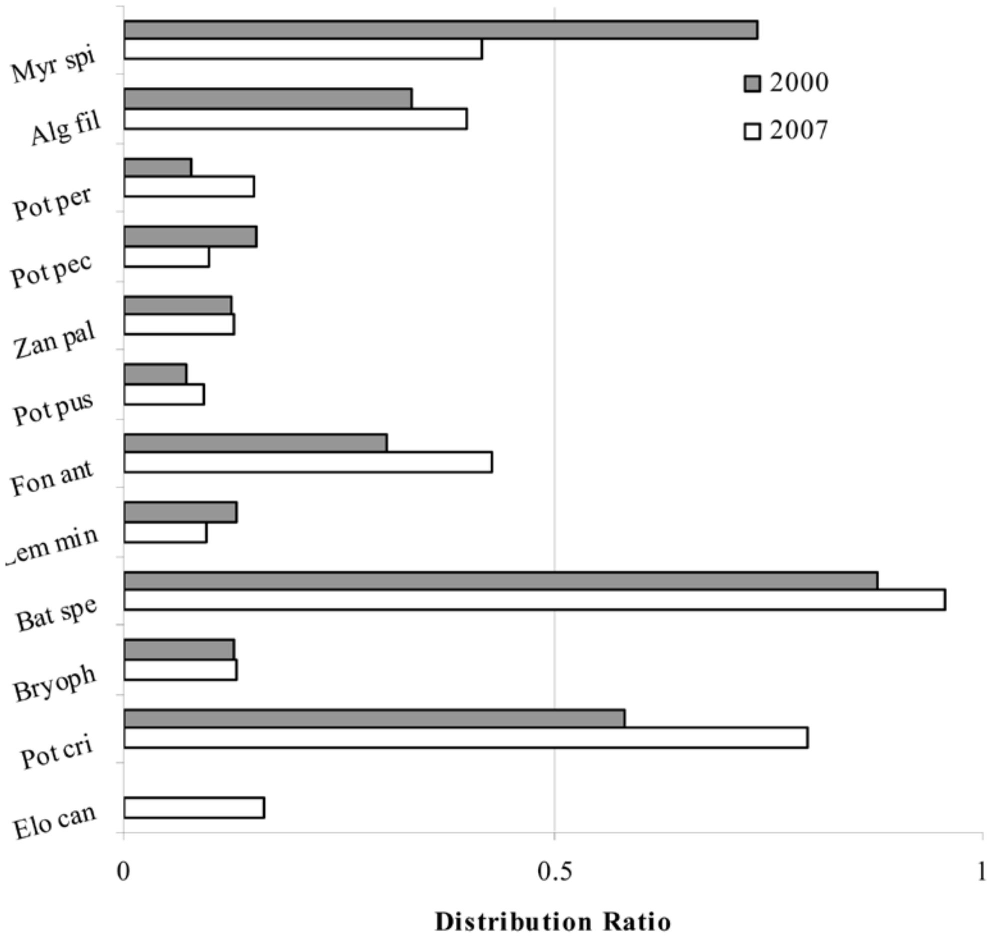

Fig. 4. Comparison of the distribution ratio (d) of hydrophytes in the Turiec River in 2000 and 2007.

In the course of 7 years, the species diversity of hydrophytes was relatively stable, while the abundance and spatial distribution of some species changed more considerably. No taxon disappeared during the research period, and *Elodea canadensis* was newly found. This taxon is an alien species. At present, the neophyte *E. nuttallii* has become more invasive in warmer water bodies in Slovakia (Oťaheľová, 1996; Ohrádková, 1998; Oťaheľová et al., 2007b). Both species are typical of standing to slow flowing, intermediate to deep, permanent waters, with an optimum in eutrophic waters with a fine or medium-size (sand) substrate on the bottom (Willby et al., 2000). In the region of the Turiec, *E. canadensis* is abundant, with optimum occurrence in standing waters of both natural or anthropogenic origin (Hrivnák and Kochjarová, 2008); *E. nuttallii* has never been recorded in this region.

The spatial distribution of hydrophytes along the Turiec River has become more uniform after 7 years. This change is clearly illustrated by the increase in RPM of *Batrachium* sp. and *Potamogeton crispus* at the expense of other hydrophytes (particularly *Myriophyllum spicatum*, fil. algae, and *Potamogeton perfoliatus*). The mentioned taxa (*Batrachium* sp. and *P. crispus*) and bryophytes showed an increase or at least stability of MMT. For the other taxa, these values decreased, most markedly in the case of *Myriophyllum spicatum*. A similar situation is observed in the case of the distribution ratio; the most striking increase in the distribution ratio was found for *Fontinalis antipyretica*, *Potamogeton crispus*, and *Batrachium* sp., while a decrease was recorded for *Myriophyllum spicatum*. Finally, practically all indices clearly increased for *Batrachium* sp. and *P. crispus*. These plants represent dominant taxa in the same river sections and tend to spread further at the expense of other hydrophytes.

Macrophytes have developed various basic strategies to overcome water force (Dawson, 1988). An example of biological interactions between both mentioned colonizers in a fluviatile habitat was reported by Haslam (1978). *Batrachium aquatile* is a light-requiring firmly shallow-rooted species, most closely associated with both medium-grained substrates (sand and gravel) and fast-flow conditions. The clumps of large plants with branching thread-like underwater leaves and floater leaves directly affect physical properties of the river, such as water movement (flow and turbulence) or bed sediments. They can provide protection for *Potamogeton crispus*, which also is a shallow-rooted species but usually prefers slower flow and is slightly susceptible to turbulence and highly shade-tolerant (Haslam, 1978).

A different situation was observed in the group of helophytes and amphiphytes, where the species number in both groups increased. In the case of helophytes, all changes have utmost importance, because their distributions vary according to dynamic hydrological conditions. During the growing season in 2007, the flow of water was evidently slower than in 2000. The most distinct increase of RPM was exhibited by *Phalaroides arundinacea* and *Solanum dulcamara* (Table 1). Both species prefer fine-grained sediment and are capable of colonizing the bed thanks to rapid development during favorable growth conditions.

In the case of amphiphytes, three new taxa, namely *Berula erecta*, *Butomus umbellatus*, and *Sparganium emersum*, occurred in 2007. The last-mentioned *S. emersum* and *B. umbellatus* were recorded in sterile forms submerged in their floating-leaved habitat in the river bed only in 2007. Elongated, pliable leaves resist shearing in moving water, maximize utilization of the reduced available light, and increase the surface area-to-volume ratio. This kind of morphology is most common for plants in areas of streams with appreciable current velocity (Wetzel, 1988).

Changes in the ecological status of the studied part of the Turiec River were relatively slight, and we detected only a negligible drop of M_{MP}. On the basis of higher occurrence of alien species and indicators of a disturbed environment (C category; Table 1), increasing frequencies of *Batrachium* sp. and *Potamogeton crispus*, and formation of species-poor stands in some parts of the river (with PME = 5 of any species), we consider the recent condition of both the macrophyte pattern and ecological status to be unsatisfactory with a negative trend. Considerable negative changes of water quality, sediment deposit, and some biotic features (zoobenthos) were observed between 1986, when relatively natural river conditions prevailed, and 2001, following construction of the Turček water reservoir. Krno et al. (2002) reported a considerable increase in abundance of meso- and eutrophic and decrease in abundance of oligotrophic zoobenthos species. They concluded that succession toward a river with a higher trophic level is in progress, which is in accordance with our results. It is noticeable that in spite of negative trends in the last years, some new and endangered plant taxa, e.g., *Butomus umbellatus*, were detected.

Further studies are needed to develop strategies for monitoring of biota, including macrophyte vegetation. In the event that negative ecological trends are confirmed, it will be necessary to propose optimal restoration management with one aim – to protect the unique river ecosystem and immediate floodplain area.

Acknowledgments — This study was supported by VEGA Grant Agency (1/5083/25 and 2/0013/08). We thank J. Ripka for technical assistance, G. Janauer for access to on-line data processing at www.midcc.at, and D. Gömöry for revising the English.

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