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Diversity of macrophytes in aquatic habitats of the Danube River (Bratislava region, Slovakia)

HELENA OŤAHEĽOVÁ & MILAN VALACHOVIČ

Institute of Botany, Slovak Academy of Sciences, Dúbravská cesta 14, SK-845 23 Bratislava, Slovakia, e-mail: helena.otahelova@savba.sk, milan.valachovic@savba.sk

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Abstract: Species diversity and the distribution of macrophytes in aquatic habitats of the Danube River corridor in the Bratislava region were investigated. Based on environmental variables, four major types of water bodies were distinguished: i/ main channel (eupotamal), ii/ open oxbows (parapotamal), iii/ separated water bodies (plesiopotamal), iv/ the Hrušov Reservoir (modified eupotamal).
From the total amount of 39 hydrophytes, only 5 occurred in the Danube main channel. The most species richness (35) was found in separated water bodies, which differ especially by their management and history. It was confirmed, that with decreasing lateral hydrologic connectivity, the alfa-diversity of macrophytes increase (TOCKNER et al. 1999).

Keywords: macrophytes, species diversity, distribution, aquatic habitats, Danube, Bratislava, large rivers, water bodies.

Introduction

Danube – the second longest European river connects several metropolises situated on its banks. Capitol of Slovakia, Bratislava is one of them. The settlement of the riverine area over the history and nowadays has always been bound to the river. People, living on its banks, utilised the river for many purposes. Human influences, which included the construction of dams, associated flow regulations, water diversion, and the riverbed alteration caused severe habitat modification having substantial environmental impact on the biota structure of the riverine ecosystem.

The relationships between physical environment and its management on one side, and the distribution and dynamics of aquatic vegetation on the other side, were discussed in many publications (HASLAM 1978, HENRY et al. 1996, PALL et al. 1996, DEMARS & HARPER 1998, KUM et al. 1999, AMOROS et al. 2000, JANAUER & WYCHERA 2000, JAROLÍMEK et al. 2001, BUNN & ARTHINGTON 2002, CRISTOFOR et al. 2003, VEIT & KOHLER 2003, KUM 2004, TRÉMOLIÈRES et al 2004).

Several of papers on aquatic vegetation of running waters in Slovakian reaches of the Danube and its tributaries, highlighted human impact on the biota (HRIVNÁK 2002a,b, HRIVNÁK et al. 2003, 2004 OŤAHEĽOVÁ & VALACHOVIČ 2002, 2003, OŤAHEĽOVÁ & BANÁSOVÁ 2005, JURSA & OŤAHEĽOVÁ 2005).

The aim of the paper is to investigate the relationships between the macrophytes species diversity patterns in the Danube aquatic habitats within the different types of the river hydrologic connectivity in the Bratislava region. Our hypothesis came up from the assumption that with decreasing lateral connectivity, the species alpha-diversity of macrophytes may grow towards separated oxbows (BORNETTE et al. 1998, TOCKNER et al. 1999, WARD & TOCKNER 2001).

Study area

The Danube inflows Slovakia from Austria at the Devín Gate-Devínska brána (1880 rkm) flowing down in the Danube Lowland (Fig. 1). At the beginning of its upper reaches in Slovakia, the Danube intakes the water from the Morava River (March River) – its largest tributary on the Slovak territory.

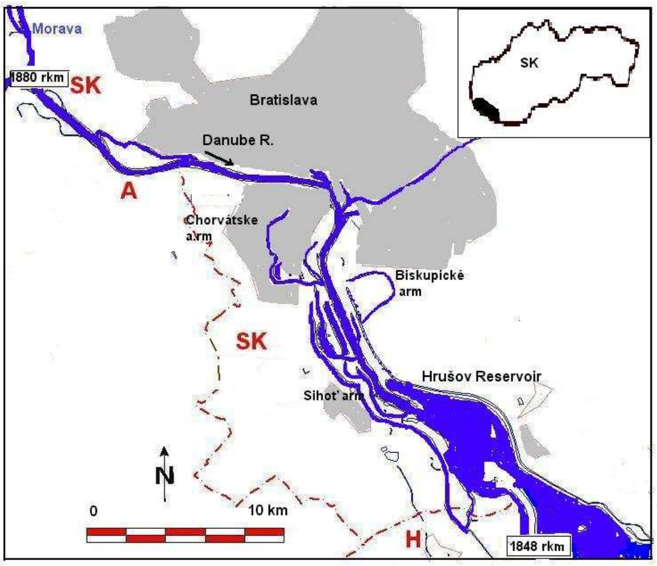

Fig. 1. Location of the study area: Danube river corridor in Bratislava region

Out of the full length of the Danube stretch in Slovakia (172 km), the study area encompassed the territory between the Danube reaches in Bratislava and its surroundings upstream and the Hrušov Reservoir downstream (1880-1848 rkm). The river average flow rate in Bratislava is 2020 $m^3.s^{-1}$, the minimum and maximum flow rates fluctuate from 570 $m^3.s^{-1}$ to 10000 $m^3.s^{-1}$, respectively.

The lowland relief characteristics, typical for the fluvial plain, varied in the study area from 140 to 125 m a.s.l. This flattening of the Danube's gradient caused the aggradation of gravel and sand in the past having created a massive fluvial plain during the Quaternary period. A dense network of branches, a so called Inland delta, has formed between Bratislava and the town of Komárno (PIŠÚT et al. 2004).

The area was used by man almost from times immemorial. Although the oldest dams in the riverine zone are known from 1450, only after the 1853 severe flood event, the dam's construction started to be taken comprehensively. In the second half of the19th century, the works in the Danube mainstream were aimed at the river training for the bank-full discharge, what actually meant the riverbed adjustment for navigation purposes. Since 1903, the works on the low water have been performed. In result, some oxbows were cut off and groynes were built (STANČÍKOVÁ 2000).

Next important stage relates to the construction of the Gabčíkovo Hydropower Plant (Gabčíkovo dam), including the Hrušov Reservoir, which was completed in 1993. The construction of the seepage canal and disconnection of some river branches (e.g. Sihoť arms, Biskupické arm) also belonged of this project. Hydroelectric plant setting in operation in 1992 increased the groundwater level near Bratislava improving hydrological environment in the area (KOCINGER et al. 1999). Numerous environmental interferences have created a network of water bodies with various types of lateral connectivity and hydrodynamics.

Based on environmental variables, we have distinguished four major types of studied channels with different gradients of lateral connectivity:

main channel (eupotamal) – the main Danube channel from the inflow of the Morava R. to the mouth of the Hrušov Reservoir (1880 –1856 rkm). In total, 40800 m along both Slovakian banks were surveyed.

open oxbows (parapotamal) – permanently or temporary connected with the main channel. Altogether, 16960 m of banks were surveyed.

separated oxbows (plesiopotamal) – side arms, usually isolated during the baseline river flow but connected during floods through overflowing, and water bodies outside the flood-protection dam. On aggregate, 29550 m of riverbanks were surveyed.

Hrušov Reservoir (modified eupotamal) – the Danube channel widens to create a reservoir at 1858-56 rkm. Except for serving as the main water source for the needs of hydropower plant, the reservoir inundates original river branches. Totally, 20045 m of riverbanks were surveyed.

Methods

Sampling procedure

The methodology, used in the study, followed a standard approach (KOHLER 1978, KOHLER & JANAUER 1995, JANAUER 2003).

A field survey of aquatic macrophytes was performed in summer of 1999–2003 from the boat. Study area was partly observed from the banks, as well. Along the main channel, the length of survey units (stretches) always made 1000 m, the length of other habitats varied in line with ecological uniformity. The main channel, including both banks of Hrušov Reservoir, was surveyed separately; other water bodies of the Danube corridor were investigated at the riverine length simultaneously. In each survey unit, the Plant Mass Estimate (PME) was evaluated using a five-level scale. The selected abiotic parameters: the bed substrate, bank structure, flow velocity class, connectivity type, and the CORINE land use type were assessed according to JANAUER (2003).

Data analysis

Based on the field data, a species list, including species abbreviations, was compiled (Tab. 1). No detailed taxonomical determination was made for filamentous algae, but their presence was recorded.

The PME data have created a basis for the Distribution Diagram and numerical derivates, the Relative Plant Mass (RPM) and the Mean Mass Index (MMT) (JANAUER 2003) were calculated from. The Distribution Diagram (Fig. 2) presents spatial macrophytes diversity patterns in the longitudinal gradient along the whole river corridor, the alluvial water bodies of the Bratislava region inclusive (1880-1848 rkm). Each unit in the diagram corresponds with the actual length of respective survey unit. The procedure to elaborate the distribution diagram, to calculate numerical derivates, and abiotic parameters was gained on-line on the web-site www.midcc.at.

The major gradients in species diversity were analysed through the ordination using the principal component analysis (PCA) from the CANOCO 4.5 package (TER BRAAK & ŠMILAUER 2002).

Results

Macrophytes diversity in aquatic habitats

The total number of 39 aquatic macrophyte species was recorded (Tab. 1). The distribution diagram (Fig. 2) displays the occurrence of macrophytes along the all Danube corridor in the Bratislava region (the main channel and alluvial water bodies), where general distribution and abundance of macrophytes have shown low rates. Relatively more frequent was *Elodea nuttallii*. Only 10 species displayed RPM ≥3% (Fig. 3). However, the patterns of macrophytes diversity were clearly different in studied channel types (Fig. 4).

Tab. 1. Alphabetic species list of the Danube R. corridor in Bratislava region

Hydrophytes & Amphiphytes	Abb.	MCh.	OOx.	SOx.	HrR.
Alisma gramineum Lej.	Ali gra	.	.	.	x
Batrachium circinatum (Sibth.) Spach	Ran cir	.	.	x	.
Batrachium trichophyllum (Chaix) Bosch	Ran tri	.	.	x	.
Berula erecta (Huds.) Coville	Ber ere	.	.	x	.
Butomus umbellatus L.	But umb	.	x	x	.
Callitriche cophocarpa Sendtn.	Cal cop	.	x	x	.
Ceratophyllum demersum L.	Cer dem	.	.	x	x
Eleocharis acicularis (L.) Roem. et Schult.	Ele aci	.	.	x	.
Elodea nuttallii (Planch.) H. St. John	Elo nut	.	x	x	x
Hippuris vulgaris L	Hip vul	.	.	x	.
Chara globularis Thuill	Cha glo	.	.	x	.
Chara vulgaris L. emend. Wallr.	Cha vul	.	.	x	.
Lemna minor L.	Lem min	.	x	x	x
Mentha aquatica L.	Men aqu	.	.	x	.
Myriophyllum spicatum L.	Myr spi	.	x	x	.
Myriophyllum verticillatum L.	Myr ver	.	.	x	.
Najas marina L.	Naj mar	.	x	x	x
Najas minor All.	Naj min	.	x	x	.
Nitella syncarpa (Thuill.) Kütz.	Nit syn	.	.	x	.
Nuphar lutea (L.) Sm.	Nup lut	.	x	x	.
Nymphaea alba L.	Nym alb	.	.	x	.
Persicaria amphibia f. *natans* (L.) Delarbre	Per amp	.	x	x	.
Potamogeton crispus L.	Pot cri	.	x	x	x
Potamogeton lucens L.	Pot luc	.	.	x	.
Potamogeton nodosus L.	Pot nod	x	x	x	x
Potamogeton pectinatus L.	Pot pec	x	x	x	x
Potamogeton perfoliatus L.	Pot per	.	x	x	x
Potamogeton pusillus L.	Pot pus	.	x	x	x
Potamogeton trichoides Cham. et Schltdl.	Pot tri	x	x	.	.
Rorippa amphibia (L.) Besser	Ror amp	.	x	.	.
Sagittaria sagittifolia L.	Sag sag	.	x	x	.
Schoenoplectus triqueter (L.) Palla	Sch tri	.	x	x	x
Sparganium emersum Rehmann	Spa eme	.	.	x	.
Sparganium erectum L.	Spa ere	.	.	x	.
Spirodela polyrhiza (L.) Schleid.	Spi pol	x	x	x	.
Utricularia vulgaris L.	Utr vul	.	.	x	.
Veronica anagallis-aquatica L.	Ver ana	.	x	x	.
Veronica beccabunga L.	Ver bec	.	x	.	.
Zannichellia palustris L.	Zan pal	x	x	x	x
algae filamentous	alg fil	.	x	x	.

Occurence x, MCh-main channel, OOx-open oxbows, SOx-separated oxboows, HrR-Hrušov Reservoir

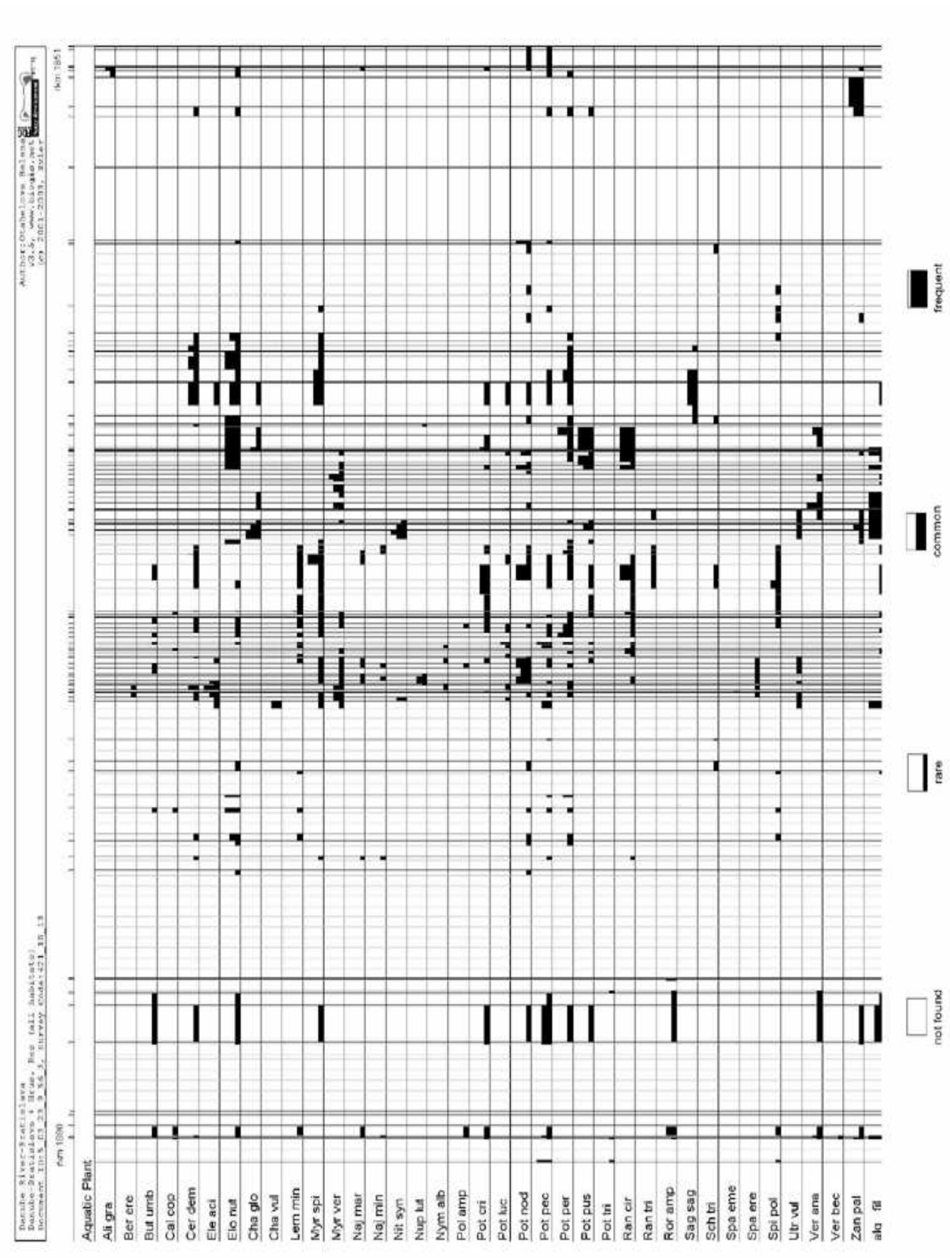

Fig. 2. Distribution diagram of aquatic macrophytes (hydrophytic species) along the Danube R. corridor in the Bratislava region.

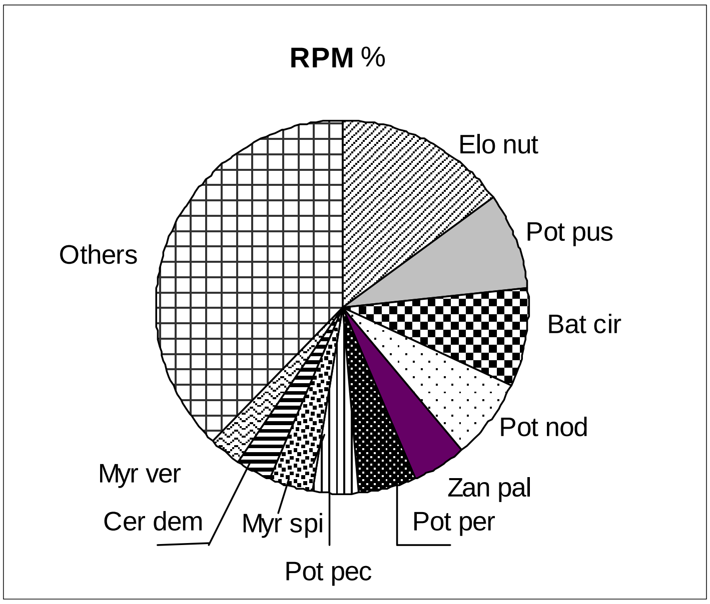

Fig. 3. Relative plant mass (RPM >3%) of aquatic macrophytes in the Danube R. corridor.

Along the Danube **main channel,** the occurrence of 5 hydrophytes was recorded. On the left bank, in the upper reach of the channel, moving downstream from the mouth of the Morava inflow, the mosaic patches of *Potamogeton pectinatus,* sparsely accompanied by *P. trichoides* and *Spirodela polyrhiza* were observed. The main channel in the Bratislava city centre contained no macrophytes. Only downstream, namely on its right side, in 1859-1858 rkm, under the oxbows mouths, the patches of *P. nodosus*, *Zannichellia palustris* and *Spirodela polyrhiza*, occurred sporadically.

In the **side channels** and **oxbows** permanently or temporarily connected with the main channel, 22 macrophyte species and filamentous algae were observed. Continual distribution was exhibited by the dominant alien species *Elodea nuttallii. Potamogeton pectinatus* was subdominant, followed by *P. perfoliatus*, and *Myriophyllum spicatum*.

In the **oxbows separated** except for floods, and in the water bodies outside the flood-protection dam, 35 macrophyte species and filamentous algae were registered. Besides *Elodea nuttallii* and *Batrachium circinatum*, such species as *Potamogeton pusillus* and *P. nodosus* were abundant.

In the **Hrušov Reservoir** 12 aquatic macrophytes were recorded. *Zannichellia palustris* was far dominant. Stands of *Potamogeton nodosus* were less frequent. *P. pectinatus* and *Alisma gramineum* occurred only locally. Low distribution ratio represents ”clumped” distribution of all recorded species.

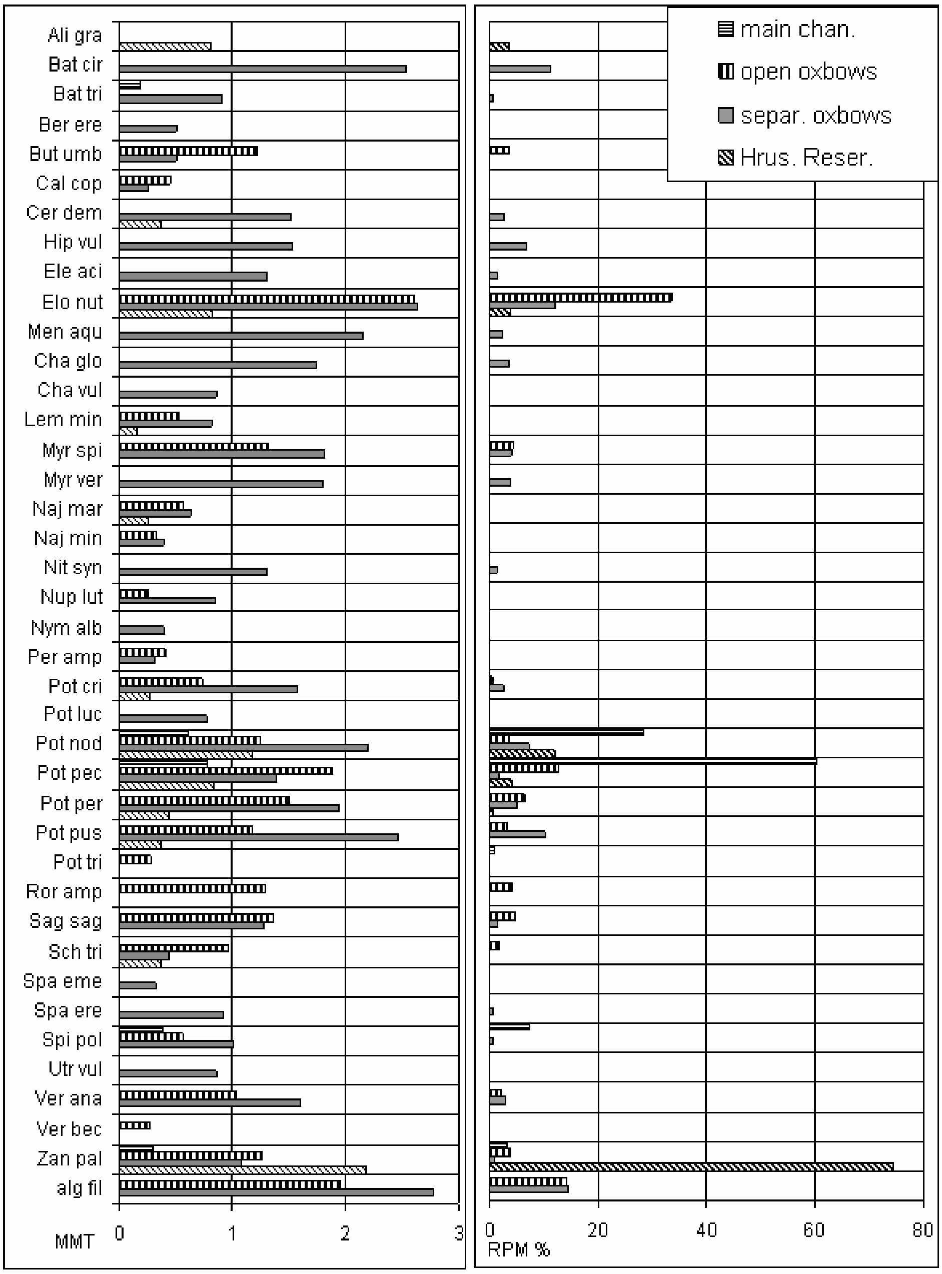

Fig. 4. A comparison of MMT and RPM values (>3%) of aquatic plants in selected types of water bodies.

Abiotic parameters

Studied channels differed primarily in hydrologic dynamics. Strong flow in the main channel slows down in open oxbows, where the water levels fluctuate substantially during the year. In the separated oxbows, the water is almost stagnant, low flow rates are temporal and occur only rarely.

The anthropic influence is most visible in the banks structure. While the rip-rap revetment provides a shoreline protection in the main channel, banks of the Hrušov Reservoir have mainly concrete surface. The oxbows are characterised by relatively large spatial heterogeneity of banks and bed substrates, with considerable share of fine sediments and gravel. The land use type is represented mostly by alluvial woodland and urban structures (Fig. 5).

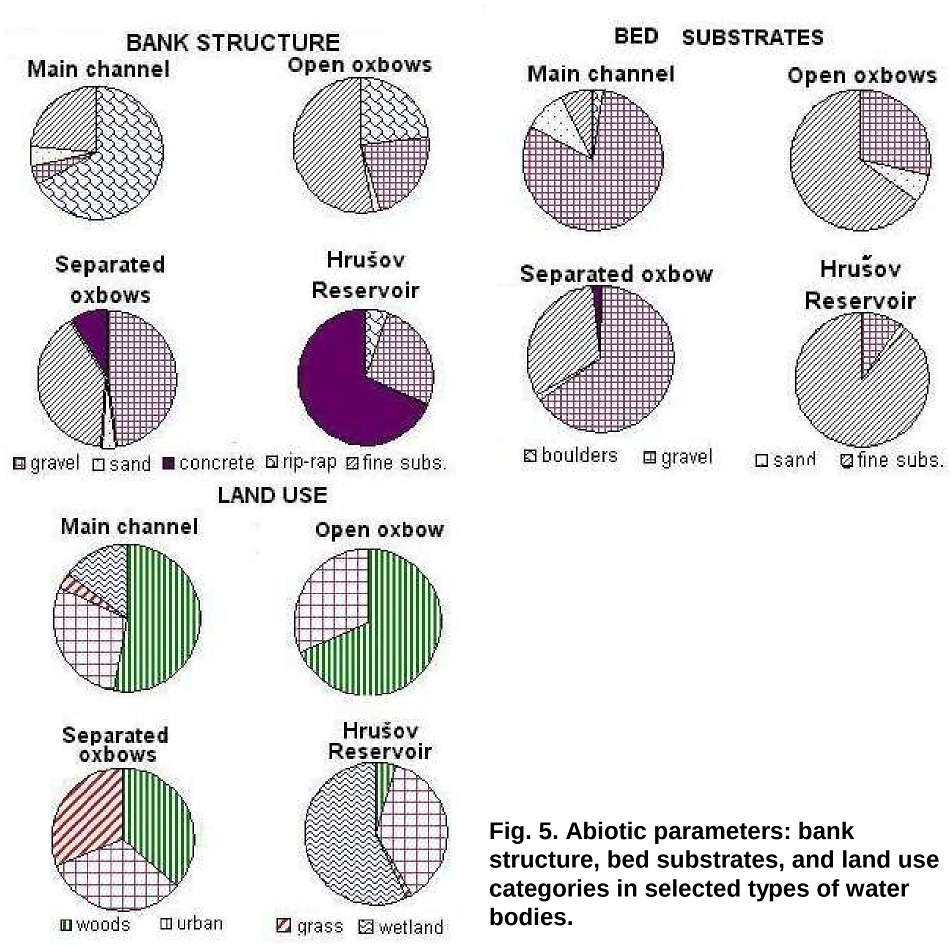

Fig. 5. Abiotic parameters: bank structure, bed substrates, and land use categories in selected types of water bodies.

Except for the high flow rate, the main channel is characterised by the banks strengthened with large stones, and by the gravel bed substrate. These patterns induce only low species diversity. Open oxbows are mostly surrounded by the alluvial forest; the banks and the bed are composed of fine substrate. The environment in separated oxbows varies considerably being greatly influenced by the management that predetermines the land use type. Fine bed's sediments layer in the Hrušov Reservoir provides a suitable habitat for aquatic plants.

Discussion

The abiotic and biotic patterns of the Danube corridor stretch in the Bratislava region, heavily altered by man, confirms the hypothesis that the loss of lateral connectivity, i.e. the plesiopotamal channel type, induces the highest species richness of macrophytes (TOCKNER et al.1999). And vice versa, the main channel, with high flow rate and rip-rap embankment, produces extremely unfavourable environment for macrophytes, equal to the adjacent upper stretches in Austria (PALL & JANAUER 1998).

Under the mouth of the Morava R., the macrophytes occurred only sporadically. The patches of *Potamogeton nodosus* were recorded near the outlets of the arm system. In the Hrušov Reservoir, which can be considered as a modified main channel, changed morphometry and subsequent flow slowdown caused the accumulation of fine sediments, what have created suitable conditions for macrophytes to spread in this aquatic habitat. *Zannichellia palustris* was the first macrophyte to colonise the area (OŤAHEĽOVÁ & VALACHOVIČ 2002). In the shallow reservoir's upper part, numerous stands of *Phragmites australis* survived.

Aquatic macrophytes in the Bratislava region occurred mainly in the Danube arm system, which is considerably altered by man. In the upper stretches (1880-1871 rkm), the extension of the Danube left-side inundation is limited by the only natural terrain configuration Mt. Devínska Kobyla. There, the frequency of hydrologic dynamics is higher than in the arms downstream, where the alluvial relief predominates. Submerse hydrophytes prevailed in the upstream arm system, e.g. *Potamogeton pectinatus.* Amphiphytes adapted to temporary waters, such as *Butomus umbellatus, Veronica anagallis-aquatica*, and *Rorippa amphibia,* occurred also.

In heavily modified arms along the Bratislava city centre left bank, partly used as a river harbour, *E. nuttallii* grew regularly, but not frequently, accompanied by patches of *Potamogeton* species, such as *P. nodosus, P. pectinatus*, and duckweeds.

With regard to the river corridor's longitudinal gradient, the highest species diversity was observed downstream Bratislava (1862-1856 rkm), in the net of open oxbows along the right-side inundation area (between dams), where the alluvial forest survived. Stands of *Myriophyllum spicatum, Potamogeton nodosus* and *Elodea nuttallii* occurred frequently there.

A semi-natural ecosystem has preserved in a relic of the remnant anabranch system Horná Sihoť and Dolná Sihoť (1859-1856 rkm). The Ramsar Convention designated this area as an internationally important wetland. At present, the lateral connectivity with the main channel in the downstream arm system is suppressed by the construction of the Gabčíkovo dam. Therefore, it is flooded very rarely and is donated with the seepage canal waters being largely stagnant, relatively deep, and of good water transparency (70-120 cm). Thus, it is relatively rich in aquatic macrophytes *(Batrachium circinatum, Potamogeton nodosus, P. crispus, Myriophyllum spicatum,* etc.*).* We expect their successful colonisation will proceed.

The highest species diversity and abundancy of macrophytes was typical for still water bodies, separated from the Danube inundation by dams, or connected with the Danube's arm system over the water pumps. This type of waters is characterised by rather wide ecological amplitude: from heavily modified to seminatural water bodies. The abiotic factors and structure of aquatic vegetation in localities, varying considerably, are strongly affected by the management and the time passing after their cut off from the main channel (Fig. 6).

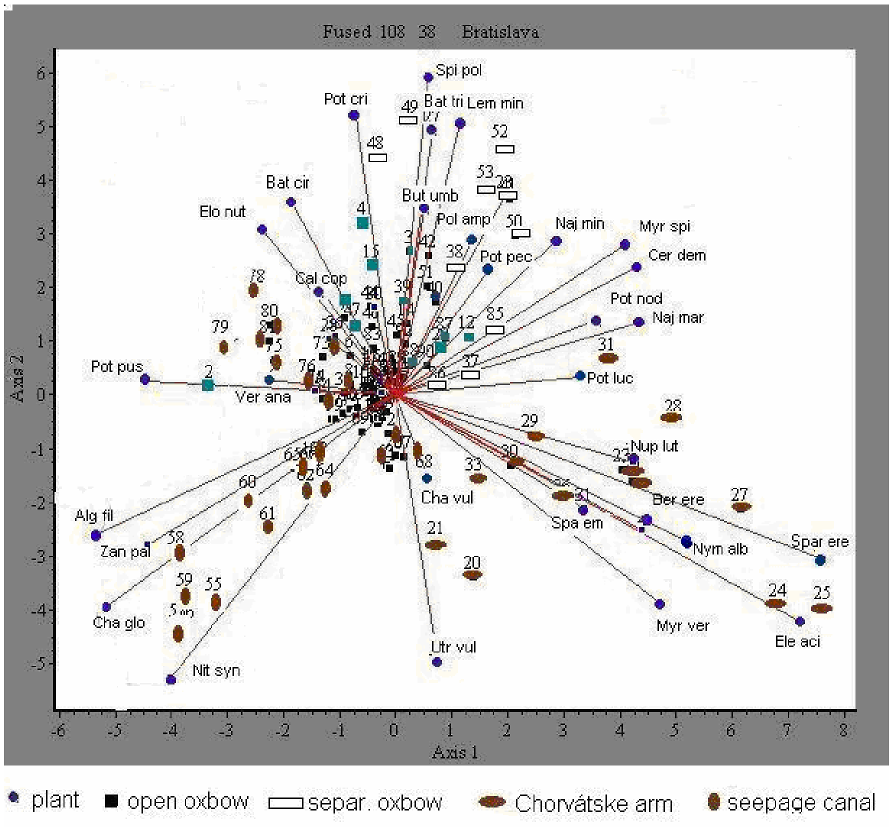

Fig. 6. Principal Component Analyses of aquatic macrophytes in the Danube R. corridor.

For instance, the Chorvatské arm in the Petržalka housing estate, which was canalised more than 25 years ago, displays high diversity of macrophytes and their growth forms, where floating leaf rhizophytes, such as *Nuphar lutea, Nymphaea alba* and other are frequent. On the contrary, the artificial seepage canal, which was constructed about 10 years ago, supports floating leaf rhizophytes very rarely, but submersed macrophytes, e.g. stoneworts (*Characeae*) are widespread there (JURSA, OŤAHEĽOVÁ 2005). This corresponds with the experience of BORNETTE & AMOROS (1996), who found out that in the former channels of the Rhône River, the richness and diversity of aquatic vegetation appeared to be lowest where disturbance frequency was lowest or disturbance intensity was highest.

Potamogeton nodosus, P. pectinatus, and *Zannichellia palustris* were detected in all types of channels, what prove their flow-resistance and tolerance to changing hydrological conditions and high nutrients content.

Despite considerable anthropogenic interferences to the river corridor in the Bratislava region, its preserved remnants still provide spatial niches for aquatic vegetation. Many endangered plants (*Alisma gramineum, Hippuris vulgaris, Nitella syncarpa*), or vulnerable species (*Berula erecta, Myriophyllum verticillatum, Najas minor, Nuphar lutea, Nymphaea alba, Utricularia vulgaris*) found suitable ecological conditions in heavily disturbed habitats of secondary or anthropogenic origin. On the other hand, the extensive propagation of the neophyte *Elodea nuttallii* was also recorded in these stands.

In conclusion, we fully agree with the opinion of TOCKNER et al. (1999), that the preservation of high diversity in the alluvial flood plain would be more fully realised by the reconstitution of fluvial dynamics and associated connectivity gradients, rather than by restoration strategies for individual groups or endangered species. We consider this way as more purposeful, more effective, and less cost demanding.

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