Effects of the Gabčíkovo hydroelectric-station on the aquatic vegetation of the Danube river (Slovakia)

Vplyv vodného diela Gabčíkovo na akvatickú vegetáciu Dunaja

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D e d i c a t e d t o t h e m e m o r y o f S l a v o m i l H e j n ý

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Vegetation in the river Danube was studied in 1972–2001 to document the changes associated with the construction of a water reservoir. Before 1993, only a single species of aquatic plant, *Potamogeton pectinatus*, was known to occur in the main channel of the river Danube, which forms the frontier between Slovakia and Hungary. In the 1980s the building of the Gabčíkovo hydroelectric power station started and was finished in 1993. At present, five different aquatic habitats occur in the study area. (i) In the upper part of the Čunovo reservoir, there are stands of reed; *Zannichellia palustris* and *Elodea nuttallii* were the first other macrophytes to colonize this area where there are now 11 species. (ii) The Old Danube consists of shallows and margins of the original riverbed, which since 1992 (1851–1811 river km) were occupied predominantly by *Zannichellia palustris.* The adjacent pools were colonized by *Elodea nuttallii, Potamogeton* species, *Batrachium trichophyllum, Ceratophyllum demersum* and *Lemnaceae* species, and *Phalaris arundinacea* dominates the littoral areas. (ii) The bypass canal harbours only the moss *Cinclidotus riparius* growing on the boulders. (iv) Two seepage canals were rapidly overgrown by macrophytes, many species of which were threatened species in Slovakia (*Apium repens, Groenlandia densa, Hippuris vulgaris, Chara* species). (v) Succession occurred in river arms on the left bank after the damming of the river which resulted in changes in spatial distribution and species composition of macrophytes; a North-American alien species *Elodea nuttallii* spread rapidly there.

K e y w o r d s : Macrophytes, aquatic habitats, vegetation succession, Gabčíkovo hydropower station, Danube river, Slovakia

Introduction

Standing and running waters are among the most dynamic ecosystems in Central Europe and recently were subject to a strong human impact. When succession in macrophyte communities is compared, unstable abiotic conditions must be taken into account. These extremely dynamic habitats attracted the attention of Hejný (1960) who focused on aquatic and marsh plants in wetlands and standing shallow surface water in the Podunajská and Potiská nížina lowlands in Slovakia. He proposed a new classification for aquatic plants based on functional types and suggested a new classification of growth forms.

The research he started on aquatic and marsh vegetation, especially in still and sluggish alluvial waters, was continued in the river Danube. Plant communities and phytosociological as well as autecological features of aquatic plants were studied (Oťaheľová 1978, 1980, Oťaheľová & Husák 1992, Adamec et al. 1993).

Besides several floristic records (Husák & Oťaheľová 1991, Dorotovičová-Juhászová 1992, Oťaheľová & Banásová 1997), numerous phytosociological relevés were obtained from this area and used to review the aquatic vegetation in the area. The description of natural plant communities was based mainly on data from the Danube and Tisa river lowlands (Oťaheľová 1995, Valachovič 2001).

Currently most studies on macrophytes of running water, especially those of large rivers, because of their potential use for assessing water quality following the Water Framework Directive of the European Community (European Commission 2000). Future research may provide data that can be used for pollution control and for studying the relationship between aquatic vegetation and the environment. The Slovak rivers, Danube, Ipeľ, and Turiec were surveyed, and optimum methods for inventory and monitoring tested (Oťaheľová & Valachovič 2001, Hrivnák et al. 2002).

Study area and methods

The river Danube is the biggest river in Central Europe. Although the 172.1 km long stretch of river in Slovakia is among the shortest in the countries the Danube posses through, this part of the river is interesting because it is where the rapid flow of water from the Alps first slackens and intensive sedimentation begins. A large inland delta and important freshwater ecosystem developed in this area. The natural flow of the river was later influenced by man. Although the construction of dikes started as early as around 1450, the first serious intervention by man was the construction of dikes after the extensive floods in 1853 to harness the flow of the river, mainly during the spring and summer floods. This reduced the development of new natural aquatic habitats to a minimum (Mucha 1999).

By the second half of the nineteenth century the main riverbed of the Danube had been dredged, principally for navigation purposes. The present course of the main channel was established, and the banks stabilized with boulders and groynes (Lisický & Holubová 1999, Stančíková 2000).

In the 1980s the building of the Gabčíkovo hydroelectric power-station started and was finished in 1993. A large water reservoir was constructed between the villages of Čunovo and Hrušov. Diversion of water into the new bypass canal began in October 1992. At present, there are five ecologically different aquatic habitats in this area (Fig. 1): (i) Čunovo reservoir – large water reservoir for Gabčíkovo hydroelectric power-station; (ii) Old Danube – original riverbed since 1992 (1851–1811 km); (iii) Bypass canal – new main riverbed of Danube for boats; (iv) Seepage canals – narrow canals along banks of water reservoir and bypass canal; (v) Semi-natural inland delta system on the left bank consisting of oxbows and arms.

The aim of this paper is to compare the occurrence of aquatic macrophytes in these habitats and relate this to environmental changes.

In particular habitats, aquatic vegetation was repeatedly recorded between 1972 and 2001 using the five-degree scale of plant mass proposed by Kohler (1978): 1 = rare, 2 = occasional, 3 = frequent, 4 = abundant, 5 = very abundant. This time scale made it possible to compare the vegetation before and after the construction of the water reservoir. The results are presented separately for the particular localities/habitats mentioned above.

The nomenclature of the vascular plants follows Marhold & Hindák (1998).

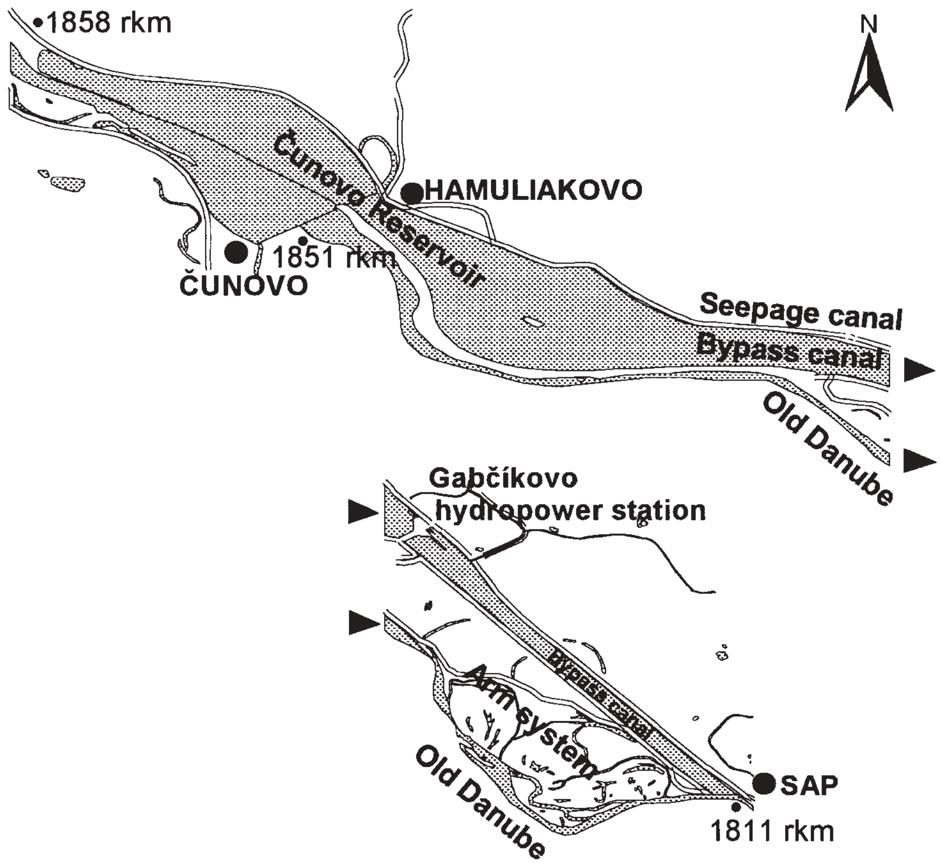

Fig. 1. – The study area with five ecologically different aquatic habitats.

Results and discussion

The Čunovo reservoir

The channel of the Danube widens downstream of Bratislava in a reservoir at the 1858 river km. Its area is approximately 4000 hectares, depending on water level (Mucha 1999). In its upper part, there is a navigation channel maintained at a depth of 3.5 m on the right side. The part next to the left bank (1858–1853 river km) is shallow, and due to the slow flow of the water there is a high deposition of sediment. The water from the reservoir inundated the original branches of the river, the "Kalinkovské ramená" and "Cormorant Island". Numerous stands of *Phragmites australis* survive in the reservoir and form the skeleton of a wetland ecosystem suitable for nature conservation. The left side of the reservoir, near Hamuliakovo (about 1853–1851 river km) is used mostly for recreation purposes. In August 1996, a sporadic plants of *Zannichellia palustris* and *Elodea nuttallii* were recorded and stands of reed. In the 2001 survey, 11 hydrophytes were found in the eulittoral zone (Table 1). The submerged species (euhydatophytes sensu Hejný 1960) were most frequent but their cover was low. Numerous patches of *Potamogeton nodosus* (a hydatoaerophyte) occurred especially off the beach along the left bank near Hamuliakovo. In the lentic environment where the water was clear and 160 cm deep, the gravel substrate covered by a 5–15 cm layer of mud was colonized by fertile plants of *Alisma gramineum*, which covered ca. 80% of the area.

The succession of submerged vegetation was similar in the Rozkoš reservoir in East Bohemia (Krahulec et al. 1980), Goczalkowice reservoir in Poland (Ćwiertnia 1962, 1966) and Spremberg reservoir in Germany (Richter 1974). However, the establishment of macrophytes in these reservoirs was faster than in the Danube River. *Elodea canadensis* dramatically increased in abundance in the first two years after damming and occupied deep water; in Bohemia it reached depths of 6 m (Krahulec et al. 1980). *Elodea nuttallii* spread in the Čunovo reservoir, but was limited to shallow water. This can be explained by water turbidity. The hydrological regime of the river Danube, namely the extensive floods, retard the growth of macrophytes**.**

Table 1. – Changes in composition and plant mass of aquatic vegetation in the upper part of the Čunovo reservoir (1852–1856.5 river km) after the damming of the Danube.

Species /sampling data	8. 8. 1996	9. 8. 2001
Alisma gramineum	.	2
Ceratophyllum demersum	.	1
Elodea nuttallii	1	2
Lemna minor	.	1
Najas marina	.	1
Potamogeton crispus	.	2
Potamogeton pectinatus	.	3
Potamogeton perfoliatus	.	2
Potamogeton pusillus	.	1
Potamogeton nodosus	.	2
Zannichellia palustris	1	4

The old channel of the river Danube (Old Danube)

Only a single species of vascular plant was recorder here prior to the construction of the power-station on the main channel of the Danube in Slovakia. Small clumps of *Potamogeton pectinatus* colonized on a shallow gravel terrace at 1830 river km in 1991. This species is also reported from similar sites in Hungary (Oťaheľová, unpubl.). Despite several suitable habitats for this species and its common occurrence in branches of the river in the area, we did not find it in the main channel. The moss *Cinclidotus riparius* grew abundantly on allochthonous, periodically flooded boulders then (Pišút 1981).

The diversion of water into a new riverbed (bypass canal) at 1851 river km in October 1992 resulted in a change in the hydrological regime. The mean discharge (ca 2000 $m^3 \cdot s^{-1}$) decreased considerably. Currently, the discharge of 200–400 $m^3 \cdot s^{-1}$ is released through a weir on the Old Danube (Turbek 1996). The length of the channel of the old Danube is about 40 km. The separation of the branches of the river from this channel seriously affected the ecosystem.

The environmental changes affected the vegetation. After seven years, in August 1999, *Zannichellia palustris* was the most widespread plant in the old Danube. There was almost a continuous sparse carpet in the shallows and margins of the riverbed where there is a thin layer of mud. *Elodea nuttallii* and *Polygonum amphibium* f. *natans* also grows there. There was a much higher species diversity in stretches of the channel where the banks were dissected. This is especially marked in the middle reaches (1830–1820 river km), where there were many connections with other branches of the river system before the technical adjustments. Apart from *Z. palustris* and *E. nuttallii*, other species typical of the side branches of the river grew there in small amounts.

The plant mass of the aquatic vegetation in the Old Danube river (1811–1848 river km) after damming in 21 August 2000 was: *Batrachium trichophyllum* 1, *Ceratophyllum demersum* 1, *Elodea nuttallii* 3, *Lemna minor* 1, *Myriophyllum spicatum* 1, *Najas marina* 1, *Polygonum amphibium* f. *natans* 1, *Potamogeton crispus* 1, *P. lucens* 1, *P. pectinatus* 1, *P. perfoliatus* 2, *P. pusillus* 2, *Spirodela polyrhiza* 1, *Zannichellia palustris* 4.

A helophytic species *Phalaris arundinacea* dominated the littoral zone. Other species recorded were: *Phragmites australis, Rorippa amphibia, R. silvestris, Rumex hydrolapathum, Typha angustifolia* and *T. latifolia*.

Rath (1997) found a similar composition of 16 species on the right bank (Hungarian part) of the Danube river between 1826 and 1843 river km in 1996.

The denuded banks of the Old Danube were rapidly overgrown by willow scrub. Šomšák (1999) reports that ideal conditions for the natural succession to willow-poplar communities (*Salici-Populetum* typicum, *phragmito-caricetosum* and *myosotidetosum*) exist in the backwaters, upstream of the confluence of the bypass canal and the old channel of the Danube.

Bypass canal

The bypass canal is a 17.8 km long structure. Because of the high discharge (5300 $m^3 \cdot s^{-1}$) passing through the canal and the considerable depth it is not suitable for the development of macrophytic vegetation. The moss *Cinclidotus riparius* is the only species that colonized the regularly washed boulders, which were used to stabilize the banks.

Seepage canals

The seepage canals are new artificial habitats, designed to drain the dikes around the water reservoir and bypass canal. Canals were built on both banks between July 1979 and May 1992. The bottom of each seepage canal is 2–7 m wide. The depth and discharge vary between 0.5 m and 6 m, and 0.3 and 4 $m^3 \cdot s^{-1}$ respectively.

Although these canals are young, about 25 macrophytic plant species were found in them. The cover of submerged stands of plants usually varied between 50 and 80%. Almost in all stretches of these canals *Characeae* algae (*Chara foetida, Ch. fragilis*, *Ch. hispida*) were found. Very rare and threatened plants of natural water bodies in Slovakia, such as *Apium repens, Groenlandia densa, Hippuris vulgaris,* as well as *Myriophyllum verticillatum* and *Utricularia vulgaris*, were found in these habitats (Bankó 2001).

The compostition and plant mass values of aquatic vegetation in the left seepage canal near Hamuliakovo village (from 48°02'50" to 48°03'22" N; and from 17°13'48" to 17°14'22" E), 8 August 2001: *Batrachium trichophyllum* 1, *Callitriche cophocarpa* 3, *Eleocharis acicularis* 2, *Elodea nuttallii* 2, *Groenlandia densa* 2, *Chara fragilis* 3, *Lemna* *minor* 1, *Myriophyllum verticillatum* 3, *Potamogeton crispus* 2, *P. lucens* 1, *P. pectinatus* 3, *P. perfoliatus* 1, *Zannichellia palustris* 2.

The system of river arms on the left bank

Since May 1993, the upper and middle part of the branches of the river on the left bank of the old Danube (Dobrohošť – Gabčíkovo section) is supplied with water from the bypass canal through a special inlet structure. The maximum discharge is 240 $m^3 \cdot s^{-1}$, which makes the simulation of flood conditions possible. Culverts and broad-crested weirs control the water level. The discharge of 30 $m^3 \cdot s^{-1}$ maintains the water levels and moisture conditions in the region during the period of vegetative growth. To prevent the water draining back to the old river Danube, all connection/contact points are blocked except the confluence of the main branch and the river (Lisický & Holubová 1999).

Water in this part of the system (Gabčíkovo – Sap section) is not artificially supplied to the various branches of the river. They are intensely influenced by the backward flow of water from the confluence of the old river and the bypass canal (Vranovský & Illyová 1999), which has resulted in increased sedimentation of silt in this area.

Although the research in macrophyte vegetation in this area was carried out in selected localities and requires further systematic study, it suggests that after the building of the dam changes in spatial distribution and species composition of macrophytes occurred. On the margins of the main connecting branch "Bodícka brána" (parapotamon-type, cf. Amoros et al. 1987) and side branch in the Dobrohošť – Gabčíkovo section, bushy clumps of *Elodea nuttallii* dominated. There was also an important development of *Batrachium trichophyllum, Potamogeton perfoliatus, P. pectinatus, Myriophyllum spicatum*. In the lentic conditions of contiguous side branches the macrophyte cover increased over the years (Table 2). A spur of the river at "Kráľovská lúka" showed rapid succession from the plesiopotamon-type to paleopotamon-type (Amoros et al. 1987, Krno et al. 1999), but is still a valuable habitat with threatened species such as *Nymphaea alba, Nuphar lutea, Trapa natans,* and *Salvinia natans* (Table 3). Some species that were common in the past, such as *Myriophyllum spicatum* and *M. verticillatum* (Oťaheľová 1980), are not longer present (Bankó 2001).

Table 2. – Changes in the composition and plant mass of aquatic vegetation in a side branch "Bodícka brána" (1830.0–1829.6 river km), before (1990) and after the damming of the Danube (1996, 1999). Plant-mass scale follows Kohler (1978).

Species/ samplig data	28. 6. 1990	8. 8. 1996	7. 8. 1999
Batrachium circinatum	1	1	2
Batrachium trichophyllum	.	.	1
Ceratophyllum demersum	1	3	3
Elodea nuttallii	.	.	1
Lemna minor	1	1	.
Myriophyllum spicatum	.	2	3
Najas marina	.	.	1
Potamogeton nodosus	.	2	3
Potamogeton pectinatus	1	.	.
Potamogeton perfoliatus	1	2	3
Potamogeton pusillus	1	.	.
Spirodela polyrhiza	.	1	.

Table 3. – Changes in the composition and plant mass of aquatic vegetation in an isolated branch "Kráľovská lúka" (1824.5-1825.8 river km), before (1972, 1990) and after the damming of the Danube (1995, 1999). Plant-mass scale follows Kohler (1978).

Species / samplig data	21. 7. 1972	23. 7. 1990	19. 6. 1995	27. 7. 1999
Batrachium trichophyllum	1	1	.	.
Batrachium circinatum	3	2	2	2
Ceratophyllum demersum	3	2	5	5
Hydrocharis morsus-ranae	.	.	1	3
Lemna minor	1	.	1	1
Lemna trisulca	.	.	.	1
Myriophyllum spicatum	2	2	1	.
Myriophyllum verticillatum	1	.	.	.
Najas marina	.	1	1	3
Najas minor	.	1	1	.
Nymphaea alba	3	4	1	2
Nuphar lutea	3	2	1	2
Potamogeton crispus	2	2	2	.
Potamogeton lucens	.	1	1	.
Potamogeton perfoliatus	1	2	1	.
Salvinia natans	.	.	1	1
Spirodela polyrhiza	1	1	1	2
Trapa natans	3	3	.	.

Conclusions

After the Gabčíkovo hydroelectric power project was completed, ecological conditions for macrophytes changed in the main channel of the river Danube and its contiguous connecting branches. In some parts of the channel the lotic environment changed to a lentic one, with the resulting establishment of macrophytes. *Zannichellia palustris* is the most widespread species in the reservoir and in the old river Danube. An alien North-American species *Elodea nuttallii* has spread into almost all types of water bodies. *Potamogeton nodosus* and *Alisma gramineum* have colonized habitats with an abundant supply of nutrients and slow flowing water, such as those in the Čunovo reservoir. It is possible that the action of wave will not prevent these species on the beaches becoming denser due to the deposition of silt by the Danube and the supply of nutrients from the recreation area. They will have to be mown in the recreation area, while in the upper part succession to wetland should be allowed to develop.

The seepage canals provided a niche, which was rapidly colonized by aquatic plants. Many were threatened species because their original habitats had disappeared due to the construction of water works (*Groenlandia densa*) or because of natural succession (*Hippuris vulgaris*). At present submerged stands of *Charetea, Potamion lucentis,* and *Potamion pusilli* still prevail in the canals. In succession macrophytes may be replaced by plants with floating-leaves, and for conserving species diversity it may be necessary to mow the macrophytes (Baumann 1985, Björk 1994).

The situation in the inland delta, including the Old Danube, is much more complicated. The rapid runoff of flood waters is the priority of water management authorities, while ecologists wish to conserve this semi-natural ecosystem in a sustainable way. This can perhaps be achieved by tapering the old riverbed and/or making it shallower, so that the river communicates with its side branches even when the discharge is low (Lisický & Holubová 1999).

Man affects river in many way, such as flow regulation, dredging, channelization and levee construction, which reduce the natural spatio-temporal heterogeneity that leads to high levels of biodiversity and productivity. Rehabilitation of damaged rivers aims to reconstitute the diversity of habitats and succesional stages (Ward 1998).

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Súhrn

Po zrealizovaní projektu Vodné dielo Gabčíkovo sa z hľadiska makrofytov zmenili ekologické podmienky v samotnom koryte a aj v priľahlom území. V úsekoch koryta, ktoré dostali inú vodohospodársku funkciu, pričom sa čiastočne zmenilo lotické prostredie na lentické, prebieha ecesia makrofytov. Najrozšírenejším rastlinným druhom v zdrži a starom koryte Dunaja je *Zannichellia palustris*. Neofyt *Elodea nuttalli* sa rýchle šíri takmer vo všetkých typoch vôd. *Potamogeton nodosus* a *Alisma gramineum* sa šíria najmä v zdrži na stanovištiach s relatívne pokojnou vodou a s bohatým prísunom živín. V budúcnosti sa dá predpokladať, že napriek vlneniu sa budú porasty na plážach zahusťovať, pretože sedimentácia dunajských naplavenín a prísun živín z rekreačnej oblasti budú pokračovať. Preto bude potrebné ich časom kosiť, zatiaľ čo v hornej časti zdrže by sa mala ponechať spontánna sukcesia smerujúca k vytvoreniu mokraďného ekosystému.

Priesakové kanále predstavujú ekologickú niku, ktorá bola rýchlo obsadená vodnými rastlinami. Výskyt mnohých z nich už bol ohrozený, pretože v regióne zanikli ich vhodné pôvodné biotopy, či už v súvislosti s výstavbou vodného diela (*Groenlandia densa*) alebo v dôsledku prirodzenej sukcesie (*Hippuris vulgaris*). V súčasnej dobe v kanáloch prevládajú submerzné spoločenstvá (*Charetea, Potamion lucentis, Potamion pusilli*). Keďže je predpoklad, že sukcesia bude smerovať k spoločenstvám na hladine plávajúcich zakorenených rastlín, bolo by žiadúce v záujme zachovania druhovej diverzity zvoliť vhodný manažment, napr. kosenie makrofytov.

Oveľa zložitejšia je situácia vo vnútrozemskej delte, vrátane starého koryta Dunaja. Prvoradým záujmom vodohospodárov je rýchly odtok vody počas povodní. Prírodovedci majú snahu zachovať tento seminaturálny ekosystém v udržateľnom stave, čomu by mohlo pomôcť buď zúženie starého koryta alebo jeho splytšenie tak, aby rieka bola prepojená s ramenami aj pri nízkych prietokoch (Lisický & Holubová 1999).

Mnohé ľudské zásahy do riek ako regulácie prietokov, bagrovanie koryta, kanalizácia a budovanie hrádzí, redukujú prirodzenú časovo-priestorovú heterogenitu, ktorá pozitívne ovplyvňuje biodiverzitu a produkciu. Obnova narušených riečnych ekosystémov sa stáva predmetom rekonštrukcie diverzity stanovíšť alebo sukcesných štádií (Ward 1998).

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