

# Macrophytes in the Danube River

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**Abstract** Recording and assessment of aquatic macrophytes was a request for the Joint Danube Survey 2 (JDS2). New insight regarding occurrence, abundance and specific distribution of macrophytes was based on methodological adaptations better adjusted to the size of this large European river and permitted more appropriate statistical interpretation. Regarding the ecological status of sampling stretches, an intentional, preliminary way of interpretation is provided, respecting trendsetting new international literature. Due to longer river stretches recorded, a higher number of species was detected in JDS2. Each of the ten official river sections showed an individual character of the macrophyte vegetation. Results of JDS2 macrophyte survey are put in relation with international literature and side effects are discussed, which are of relevance when assessing macrophytes in large rivers for purposes of science, European Water Framework Directive or regarding conservation issues.

**Keywords** Danube River, Ecological status, European Water Framework Directive, Large rivers, Macrophytes

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## 1 Introduction

A somewhat casual but rather accurate explanation of the term ‘aquatic macrophytes’ was given by Westlake [1], who described them as the aquatic plants that can often be determined to species level with the unaided eye. Most scientists rank the following plant groups as macrophytes: macro algae, aquatic bryophytes and, among the vascular plants, water ferns and angiosperms. The European Water Framework Directive (WFD) introduced ‘macrophytes’ as one of the four biological quality elements to be applied in assessing the ecological status of surface waters. Therefore, macrophytes were part of the analytical programme for examining the ecological quality of the Danube River under the lead of ICPDR during the JDS2 survey, and Birk et al. [2] provided substantial reason for following this requirement. Based on experience gained during the first Joint Danube Survey in 2001, ICPDR adapted resources, sampling sites, methodology and organisation for the second macrophyte survey (JDS2, August 12–September 28, 2007), which provided deeper insight on the aquatic macrophyte vegetation of the Danube River. JDS2 defined the methodological adaptation of macrophyte survey for large rivers like the Danube. Regarding reference, conditions where near-natural examples are absent were first discussed during the preparation of JDS2 (Birk and Janauer, personal communication, 2008, Senec meeting) and – based on extensive statistical work – were recently published by Birk et al. [2].

Aquatic macrophytes are not only biological quality elements for assessing the ecological quality of water bodies, they also play an important role in the aquatic ecosystem: macrophytes add to total biodiversity as such, gain importance within the scope of the EU Habitats Directive, add spatial structure to the water body and provide niches and habitats for countless other aquatic organisms [3, 4]. Water chemistry is influenced especially with respect to the oxygen regime during photosynthetic periods and by the uptake of plant nutrients, keeping proliferous algae at bay.

The abiotic conditions of a large river like the main channel of the Danube restrict macrophyte growth to areas of decreased flow velocities and to water depth usually less than 1.5–2 m. But in side channels and floodplain water systems, macrophytes can become the dominant plant group [5].

This contribution puts the most important results of the macrophyte survey of Joint Danube Survey 2 in perspective and highlights associated relevant findings from the Danube catchment.

## 2 Methods

### 2.1 *Macrophyte Survey*

The aquatic macrophyte vegetation was assessed in the Danube main channel and in some mouth sections of important tributaries at all sampling sites of JDS2. Helophytes (reed and some bank species) were considered of importance when growing on the midwater line directly at the banks. Individual survey units (SU) were of 1 km length, and 3 river kilometres (rkm) were recorded on each side of the main river channel by boat, resulting in a total recorded length of 6 rkm at each sampling site. Abundance assessment followed the European Standard EN14184, recording all macrophyte species present in each survey unit and their abundance [6]. In the Danube countries, this approach is the most widely used for national macrophyte assessment in the context of the WFD. It features five estimator levels which are phrased – by literal translation of the German original [7] – ‘very rare, not more than five individuals’ (1), ‘rare’ (2), ‘frequent’ (3), ‘abundant’ (4) and ‘very abundant or mass development’ (5).

The estimator scale is of exponential character, which was posted first by Melzer et al. [8] and was numerically proved for running waters by Janauer and Heindl [9]. It integrates the vertical development of the plant stands, which is determined by environmental characteristics. Usually, several survey units are combined in a contiguous group to provide a more representative data set of species occurrence and abundance. This is in accordance with the related European Standard EN 14184 mentioned above, where ‘stretches of defined river lengths’ and ‘adapted to the scale and purpose of the study’ are recommended. Field workers with even little experience are able to assess the plant abundance estimates correctly and reproducibly after a very short learning period [6, 7], and this method was validated in 2008 with a group of 35 employees of Apele Romane (Romanian National Water Agency) during a quality assurance test (Janauer, personal communication).

The relative abundance of individual species relates to the total abundance of all species recorded in a river reach and is weighted by the length of the individual survey units (1 km in JDS2). Regarding this metric, see Pall and Janauer [10].

### 2.2 *Multivariate Data Analysis*

Multi Response Permutation Procedure (MRPP) was used to test the null hypothesis of no significant differences in the floristic and quantitative composition of survey

units among the ten section types of JDS2. MRPP is the non-parametric analogue of discriminant function analysis but without many of the associated assumptions. Bray-Curtis distance measures and a natural weighting ( $n/\text{sum}(n)$ ) was used in the MRPP [11].

MRPP provides the test statistic, a measure of ‘effect size’ (A-values) and a p-value. Differences among section types were described by indicator species analysis (ISA, [12]). A Monte Carlo simulation test with 1,000 randomised runs, assigning survey units randomly to types, was used to determine the significance ( $P \leq 0.05$ ) of the indicator values [11]. MRPP and ISA were conducted with PC-ORD version 5.1 [13].

### 2.3 Assessment of the Ecological Status

The procedure for providing a provisional ecological status assessment complied with the Austrian Directive for Running Waters – Macrophytes (ADR-M 2007 [14]). The following calculation method was used (Table 1):

**Table 1** Calculation for assessing ecological status ‘macrophytes’

Species	Abu	Class				# Classes
		1	2	3	4	
Species 1	$PM_1$	$PM_1$				1
Species 2	$PM_2$	$PM_2 / 3^2$	$PM_2 / 3^2$	$PM_2 / 3^2$		3
Species 3	$PM_3$	$PM_3$				1
Species 4	$PM_4$	$PM_4 / 2^2$	$PM_4 / 2^2$			2
Species 5	$PM_5$	$PM_5 \times 0$	$PM_5 \times 0$	$PM_5 \times 0$	$PM_5 \times 0$	4
...						
Sum $PM \cdot G$		Sum <sub>1</sub>	Sum <sub>2</sub>	Sum <sub>3</sub>	Sum <sub>4</sub>	Cross sum A
Sum $PM \cdot G \cdot CL$		Sum <sub>1</sub> *1	Sum <sub>2</sub> *2	Sum <sub>3</sub> *3	Sum <sub>4</sub> *4	Cross sum B
Index Value						Cross sum A / Cross sum B
Ecological Status Class						Index rounded to integer

Abu: abundance; # Classes: number of marks in different classes.  $PM_1$ : abundance estimate of species 1 (Abundance estimates according to Kohler et al. [7]). Each  $PM$  is divided by  $G$ , the square of the number of classes in which a species occurs. This puts more weight on species with a narrow ecological amplitude. Species occurring in all classes are excluded as ‘ubiquistic’ species, which are supposed to have no specific indicative value. Therefore, their  $PM$  is multiplied by zero. Then the sum is calculated for each class, and the values are summed to produce cross sum A. In the next step, the  $PM \cdot G$  sum is multiplied by the class identification, which then produces cross sum B. Cross sum A over cross sum B produces the final index value, which is rounded to integer.

Reference conditions were adapted to the conditions of the Danube River in the different section type reaches. For the Danube River, neither historical quantitative data nor modelling approaches are available to produce a priori macrophyte reference conditions. Therefore, with respect to differentiating ‘good’ from ‘moderate’ status in analogy to Birk et al. [2], various sources had to be used, including historical maps of the river course, results from side channels, saprobity maps of the Danube of various dates, JDS1 and JDS2 data on chemical components and macrophyte data from the whole-river macrophyte survey of the MIDCC project [15] to create reference conditions by expert judgement, including information on the ecological characterisation of macrophyte species.

### 3 Results

#### 3.1 General Characteristics of the Danube Macrophyte Survey

During the JDS2 macrophyte survey, 96 sites were sampled, 3 rkm on each side (Table 2). The accumulated length was 556.5 km (c. 21% of the navigable part of the Danube River) and covered aquatic macrophytes as well as bank-side ‘helophytes’ (e.g. common reed). Results show that this spatial expansion was a minimum requirement for collecting sufficient data for a survey of rivers the size of the Danube and large tributaries.

Sixty-nine aquatic species, three macro algae and 60 helophyte species were detected in 485 survey units (87% of all sampled rkm). When compared with JDS1, the number of aquatic species increased by 57%. This is due to – at least in part – the extension of sampled river length. Among the species found, some are rarely recorded on the main channels of large rivers, e.g. *Wolffia arrhiza* (L.) Horkel ex Wimm., *Lemna turionifera* Landolt, *Riccia fluitans* L. emend Lorb., *Azolla filiculoides* Lam., *Utricularia vulgaris* L., *Trapa natans* L. and *Stratiotes aloides* L.

Aside from river regulation and bank protection installations, a series of power stations in Germany and Austria, the Gabčíkovo hydroelectric plant in Slovakia and the two impoundments of the Iron Gates affect the habitats of macrophytes, deviating conditions of flow velocity, sediment type, water temperature and turbidity.

The greater number of aquatic species recorded in JDS2 (Table 3) may be caused in part by different bryophyte species agglomerated within individual patches and cushions, as well as on the strategy of surveying both sides of the river for 3 km each, regarding the non-bryophyte species, or on natural long-term variation.

**Table 2** Representative information of the JDS2 macrophyte survey

Survey	Geomorphologic sections	Sampling sites	rkm per site	Accumulated length (rkm)	Aquatic species
JDS1	9	98	2	313	44
JDS2	10	96	6	556	69

**Table 3** Comparison of macrophyte species richness: JDS1 and JDS2 result

Genus name	Species name	Author	present at	
			JDS1	JDS2
<i>Alisma</i>	<i>gramineum</i>	LEJEUNE		
<i>Alisma</i>	<i>lanceolatum</i>	With.		
<i>Alisma</i>	<i>plantago-aquatica</i>	L.		
<i>Amblystegium</i>	<i>varium</i>	(Hedw.) Lindb.		
<i>Azolla</i>	<i>filiculoides</i>	Lam.		
<i>Brachythecium</i>	<i>rivulare</i>	Schimp.		
<i>Bryum</i>	<i>capillare</i>	Hedw.		
<i>Bryum</i>	<i>klinggraeffii</i>	Schimp.		
<i>Bryum</i>	<i>pallescens</i>	Schleich. ex Schwägr.		
<i>Butomus</i>	<i>umbellatus</i>	L.		
<i>Callitriche</i>	<i>brutia</i>	Petagna		
<i>Callitriche</i>	<i>sp.</i>	-		
<i>Ceratophyllum</i>	<i>demersum</i>	L.		
<i>Cinclidotus</i>	<i>fontinaloides</i>	(Hedw.) P. Beauv.		
<i>Cinclidotus</i>	<i>riparius</i>	(Host ex Brid.) Arnott		
<i>Cratoneuron</i>	<i>filicinum</i>	(Hedw.) Spruce		
<i>Didymodon</i>	<i>tophaceus</i>	(Brid.) Lisa		
<i>Drepanocladus</i>	<i>aduncus</i>	(Hedw.) Warnst.		
<i>Drepanocladus</i>	<i>fluitans</i>	(Hedw.) Warnst.		
<i>Eichhornia</i>	<i>crassipes</i>	(Mart.) Solms		
<i>Elodea</i>	<i>canadensis</i>	Michx.		
<i>Elodea</i>	<i>nuttallii</i>	(Planch.) H.St.John		
<i>Enteromorpha</i>	<i>intestinalis</i>	(L.) Link		
<i>Eurhynchium</i>	<i>crassinervium</i>	(Taylor) Schimp.		
<i>Fissidens</i>	<i>rufulus</i>	B.S.G.		
<i>Fontinalis</i>	<i>antipyretica</i>	Hedw.		
<i>Funaria</i>	<i>hygrometrica</i>	Hedw.		
<i>Homalothecium</i>	<i>nitens</i>	(Hedw.) Robins		
<i>Hydrocharis</i>	<i>morsus-ranae</i>	L.		
<i>Hydrodictyon</i>	<i>reticulatum</i>	(L.)		
<i>Hygroamblystegium</i>	<i>fluviatile</i>	(Hedw.) Loeske		

(continued)

**Table 3** (continued)

<i>Hygroamblystegium</i>	<i>tenax</i>	(Hedw.) Jenn.	
<i>Hygrohypnum</i>	<i>eugyrium</i>	(Schimp.) Broth.	
<i>Hygrohypnum</i>	<i>luridum</i>	(Hedw.) Jenn.	
<i>Lemna</i>	<i>gibba</i>	L.	
<i>Lemna</i>	<i>minor</i>	L.	
<i>Lemna</i>	<i>trisulca</i>	L.	
<i>Lemna</i>	<i>turionifera</i>	Landolt	
<i>Leptodictyum</i>	<i>riparium</i>	(Hedw.) Warnst.	
<i>Leskea</i>	<i>polycarpa</i>	Hedw.	
<i>Limosella</i>	<i>aquatica</i>	L.	
<i>Myriophyllum</i>	<i>spicatum</i>	L.	
<i>Myriophyllum</i>	<i>verticillatum</i>	L.	
<i>Najas</i>	<i>marina</i>	L.	
<i>Najas</i>	<i>minor</i>	All.	
<i>Nitellopsis</i>	<i>obtusa</i>	(Desv. in Loisel.) J.Groves	
<i>Nuphar</i>	<i>lutea</i>	(L.) Sibth. & Sm.	
<i>Nymphaea</i>	<i>alba</i>	L.	
<i>Polygonum</i>	<i>amphibium</i>	L.	
<i>Potamogeton</i>	<i>acutifolius</i>	Link	
<i>Potamogeton</i>	<i>alpinus</i>	BALB.	
<i>Potamogeton</i>	<i>crispus</i>	L.	
<i>Potamogeton</i>	<i>friesii</i>	Rupr.	
<i>Potamogeton</i>	<i>gramineus</i>	L.	
<i>Potamogeton</i>	<i>lucens</i>	L.	
<i>Potamogeton</i>	<i>natans</i>	L.	
<i>Potamogeton</i>	<i>nodosus</i>	Poir.	
<i>Potamogeton</i>	<i>pectinatus</i>	L.	
<i>Potamogeton</i>	<i>perfoliatus</i>	L.	
<i>Potamogeton</i>	<i>praelongus</i>	WULF.	
<i>Potamogeton</i>	<i>pusillus</i>	L.	
<i>Potamogeton</i>	<i>trichoides</i>	Cham. & Schldtl.	

(continued)

**Table 3** (continued)

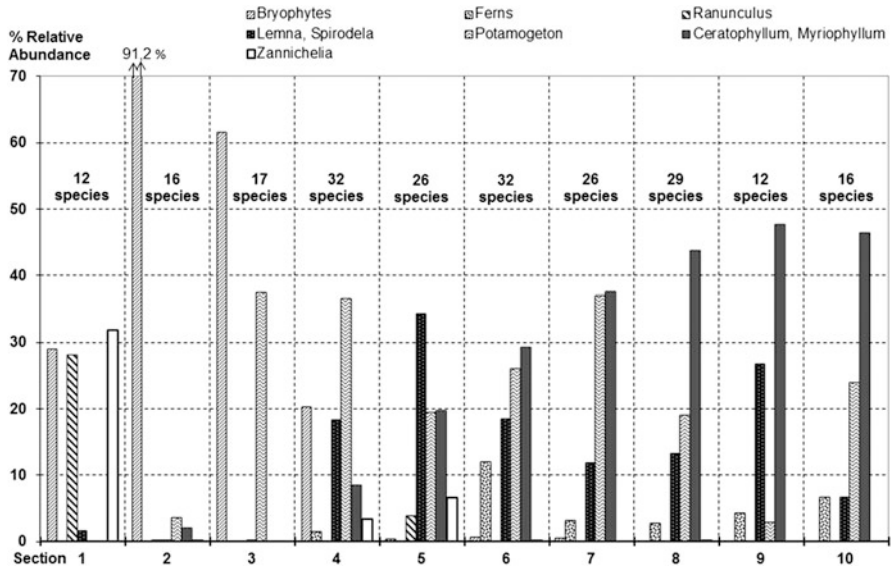
<i>Potamogeton</i>	<i>x zizii</i>	Koch ex Roth		
<i>Ranunculus</i>	<i>fluitans</i>	Lam.		
<i>Rhynchosstegium</i>	<i>confertum</i>	(Dicks.) B.S.G.		
<i>Rhynchosstegium</i>	<i>riparioides</i>	(Hedw.) Cardot		
<i>Riccia</i>	<i>fluitans</i>	L. emend Lorb.		
<i>Sagittaria</i>	<i>sagittifolia</i>	L.		
<i>Salvinia</i>	<i>natans</i>	(L.) All.		
<i>Schistidium</i>	<i>apocarpum</i>	(Hedw.) B.S.G.em. Poelt		
<i>Schistidium</i>	<i>rivulare</i>	(Brid.) Podp.		
<i>Sparganium</i>	<i>emersum</i>	Rehmann		
<i>Sparganium</i>	<i>erectum</i>	L.		
<i>Spirodela</i>	<i>polyrhiza</i>	(L.) Schleid.		
<i>Stratiotes</i>	<i>aloides</i>	L.		
<i>Trapa</i>	<i>natans</i>	L.		
<i>Utricularia</i>	<i>vulgaris</i>	L.		
<i>Vallisneria</i>	<i>spiralis</i>	L.		
<i>Veronica</i>	<i>beccabunga</i>	L.		
<i>Wolffia</i>	<i>arrhiza</i>	(L.) Horkel ex Wimm.		
<i>Zannichellia</i>	<i>palustris</i>	L.		

### 3.2 Species Richness and Floristic Composition

Species richness and relative abundance (RPM) of dominant species recorded during JDS2 in each river section are presented in Fig. 1.

The most conspicuous distribution of species groups along the Danube relates to bryophytes and rheophile *Ranunculus* species, which are important elements of the aquatic vegetation only in the Upper Danube, and the progress of *Ceratophyllum* and *Myriophyllum* species in the lower reach of the river. Especially in the middle reach, *Potamogeton* sp. and the duckweeds *Lemna* and *Spirodela* were recorded in higher abundance.





**Fig. 1** Species richness and relative abundance of dominant species determined for each Danube River section (according to JDS2 classification). Columns from left to right: bryophytes, ferns, *Ranunculus* sp., *Lemna* spp. and *Spirodela* sp., *Potamogeton* sp., *Ceratophyllum* and *Myriophyllum* spp., *Zannichellia* sp.

### 3.3 Statistical Comparison of JDS2 River Sections

MRPP and ISA were used to describe significant differences of the macrophyte species groups characteristic for the river sections of the Danube. Section limits were determined using macro-invertebrate and geomorphology features of the river course (see [16]).

MRPP results show that the different sections of the Danube River are habitats of significantly different macrophyte species compositions, underlining the ecological richness of this second largest river of Europe but also raising attention regarding the definition of reference conditions for ecological status assessment (Table 4).

Regarding ISA, the results revealed some special features. Except for Section 4, all other sections had at least one specific indicator species (Table 5) though Sections 9 and 10 – see below – have to be regarded as special, too. Section 4 is located between Greifenstein (AT) and the mouth of the Mosoni Duna (HU): the ISA seems to indicate that this reach is a kind of an ‘ecotone’, a boundary reach, between two possibly different sections. A stepwise analysis of the macrophyte species revealed that the point of separation of these new sections could be close to the inflow of the Morava River near Bratislava. In Sections 9 and 10, helophyte species were the indicator species. While reeds like *Typha* sp. and *Phragmites* sp. are regarded as natural near to the Delta, *Xanthium strumarium* L. indicates a disturbed riparian zone. In all other sections, indicator species were among the aquatic macrophytes.

**Table 4** Multi-response permutation procedure (MRPP) for Danube River sections (Sec.)

SEC.	ST-1	ST-2	ST-3	ST-4	ST-5	ST-6	ST-7	ST-8	ST-9	ST-10
ST-1	-									
ST-2	<b>0.0978</b>	-								
ST-3	<b>0.0888</b>	<b>0.1340</b>	-							
ST-4	<b>0.0300</b>	<b>0.0379</b>	<b>0.0633</b>	-						
ST-5	<b>0.0396</b>	<b>0.1500</b>	<b>0.1185</b>	<b>0.0781</b>	-					
ST-6	<b>0.0296</b>	<b>0.1234</b>	<b>0.1000</b>	<b>0.0743</b>	<b>0.0376</b>	-				
ST-7	<b>0.1688</b>	<b>0.2816</b>	<b>0.2377</b>	<b>0.1121</b>	<b>0.0849</b>	<b>0.0424</b>	-			
ST-8	<b>0.0269</b>	<b>0.1109</b>	<b>0.0919</b>	<b>0.0676</b>	<b>0.0429</b>	<b>0.0315</b>	<b>0.0399</b>	-		
ST-9	<b>0.0718</b>	<b>0.1482</b>	<b>0.1161</b>	<b>0.0467</b>	<b>0.0479</b>	<b>0.0413</b>	<b>0.1385</b>	<b>0.0282</b>	-	
ST-10	<b>0.1311</b>	<b>0.1944</b>	<b>0.1364</b>	<b>0.0598</b>	<b>0.0741</b>	<b>0.0434</b>	<b>0.1455</b>	<b>0.0351</b>	<b>0.0671</b>	-

Bold print indicates statistical significance, which was the case for each of the compared pairs of river stretches.

**Table 5** Indicator species per river section

Section 1 <i>Ranunculus fluitans</i> Lam. <i>Zannichellia palustris</i> L.	Section 6 <i>Spirodela polyrhiza</i> (L.) Schleid. <i>Salvinia natans</i> (L.) All.
Section 2 <i>Cinclidotus riparius</i> (Host ex Brid.) Arnott <i>Phalaris arundinacea</i> L.	Section 7 <i>Potamogeton perfoliatus</i> L. <i>Potamogeton nodosus</i> Poir. <i>Ceratophyllum demersum</i> L.
Section 3 <i>Fontinalis antipyretica</i> Hedw. <i>Lycopus europaeus</i> L.	Section 8 <i>Potamogeton pusillus</i> L.
Section 4 –	Section 9 <i>Xanthium strumarium</i> L.
Section 5 <i>Lemna gibba</i> L.	Section 10 <i>Phragmites australis</i> (Cav.) Trin. ex Steud <i>Typha latifolia</i> L.

## 4 Discussion

### 4.1 Species Distribution and Richness

Along the more than 2,600 km of river course covered by JDS2 (c. 91% of the total length of the Danube, from mouth to source), ten official river sections revealed significantly diverse macrophyte species assemblages.

An important feature of the aquatic vegetation is the concentration of bryophytes in the upper river reach, where hard substrates are lining the banks of the German and Austrian Danube (Sections 1 to 4, Fig. 1). Regulated river reaches and hydroelectric power plant impoundments, both mainly lined by rip-rap, provided

extremely favourable conditions for bryophyte colonisation. Gravel and sand deposits within groyne fields are only sparsely colonised or avoided by higher aquatic plant species. In the middle and lower reaches of the Danube, essentially no bryophytes were detected on the sediments of the main river channel.

*Zannichellia palustris* was found in the first five sections but was dominant only in the first. This species is often classified as indicating eutrophic conditions, but in contrast to this opinion, it is widespread in mesotrophic rivers, growing in closest distance to species like *Ranunculus trichophyllus* or *Groenlandia densa*, even intermingled with these species in the same plant stand [17, 18].

Regarding species richness, Fig. 1 indicates river Sections 4 and 6 as showing the most abundant composition of macrophytes. Section 4 was located between Krems (AT) and Gönyü (HU). It included the most eastern part of the alpine reach of the Danube, covering also three hydropower installations, as well as the macrophyte-rich Čunovo reservoir (SK). Based on macro-invertebrate data, these two very different water bodies were merged for JDS2 purposes [19]. But Birk et al. [2] clearly divided JDS-Section 4, merging its upper part with the traditional upper reach and its lower part with the Middle Danube reach, as already discussed in the final JDS2 report [20].

A prime hydromorphological feature of the Upper Danube is the great number of hydropower installations. The Bavarian impoundments were more species rich (average species number, 1.70 per km; mean length, 8.22 km; adapted from Pall and Janauer [10]) than the much longer reservoirs in Austria (average species number per km, 0.33; mean length, 27.61 km; adapted from Janauer and Jolankai [4]). This may be related to the greater hydrological monotony of the longer reservoirs. The situation in the Gabčíkovo impoundment (Middle Danube reach, SK) is quite different due to the wide, slow flowing and silted Čunovo part (maximum width: 3.04 km), providing favourable conditions for macrophyte development. The middle reach ends at the Iron Gate I reservoir, which is the longest in the Danube River (145 km). Its hydrophyte species number per km (Romanian riverside) was only 0.17 (Sarbu, survey 2000–2003, in [21]).

Groundwater upwelling possibly causing fast water flow in the outlet of the Rackeve-Soroksar side channel probably supported the occurrence of *Ranunculus fluitans* in Section 5.

Stronger aquatic plant development was also found in the reach between Novi Sad and Belgrade, where the head section of the Iron Gate reservoir is located: two aquatic ferns, *Salvinia natans* and *Azolla filiculoides* were detected in noticeable abundance. In this reach, the large tributaries Drava, Tisza and Sava merge with the Danube; their extensive floodplain waters could serve as the source of these free-floating ferns.

Section 7, the Iron Gate, holds a special position between the middle and lower Danube. In the three narrow gorge stretches, rock-lined banks exist, whereas in the wider parts of the Iron Gate reservoirs, calm waters and finer substrates prevail. Due to these heterogeneous conditions, natural moss stands were found on the rock face in the gorges and a moderate diversity of other macrophytes occurred in the wider valley parts.

Lemnaceae (*L. minor*, *L. gibba*, *Spirodela polyrhiza*) were found in the whole Danube in 2007. Surprisingly, high abundances of these free-floating species were recorded in survey units with flow faster than would be expected (e.g. Section 5), while their occurrence was sparse in rather slow flowing water (e.g. upper Iron Gate reservoir, Danube Delta).

Enhanced macrophyte growth possibly triggered by nutrient enrichment was recorded several kilometres down-river of the mouth sections of the rivers Timok and Olt and down-river of the cities Ruse (BG), Oltenita (RO) and Tutrakan (BG), resulting in higher species numbers and abundance (all in Section 8).

Pondweeds like *Potamogeton crispus*, *P. friesii*, *P. gramineus*, *P. lucens*, *P. natans*, *P. nodosus*, *P. pectinatus*, *P. perfoliatus*, *P. pusillus* and *P. trichoides* were rather evenly distributed across the middle and lower reaches (Sections 3 to 10). This is mainly due to the wide ecological amplitude of these species. Particularly *P. pectinatus* (synonym: *Stuckenia pectinata* (L.) Börner) is tolerant to a wide range of habitat properties, e.g. nutrient load, flow velocity or shading by 'aufwuchs'.

*Ceratophyllum demersum* and *Myriophyllum spicatum* occurred almost everywhere in the Danube. They influence the dominance relationship of aquatic plant species, but they have characteristically different values in occurrence in individual parts of the river. Such species even develop into indicator species when such species assemblages are analysed with statistical methods and therefore have their – variable – imprint on the whole macrophyte community. As, e.g. *C. demersum* increases in importance when proceeding from the upper reach to the lower reach of the Danube, the elimination of such 'ubiquistic' elements from ecological status assessment procedures seems like a fallacy, especially with respect to producing statistically reliable results. Neglecting such species leads, of course, to significantly higher separation of species groups, when species with a wider ecological amplitude are deleted. But statistical relevance is then much reduced. Between Chiciu (RO)/Siliistra (BG) and Reni, *Ceratophyllum demersum* dominated the aquatic vegetation to a great extent, but the species number decreased to 12 (Section 9).

In the Danube Delta, only the Vilкова-Chilia arm was rich in aquatic plants, especially along some of the small settlements situated on its banks, but the rare species *Stratiotes aloides* was also detected there (Section 10).

The statistically significant differentiation of macrophyte assemblages in the river sections of the Danube was also reported for different large water bodies of the lower Danube reach in Romania [22]. Two successive reaches of the main river channel, two large side channels in parallel location and three Delta channels display a highly significant set of different macrophyte compositions (Table 6).

The water bodies of the Danube River corridor between rkm 375 near Calarasi and the mouth of the three Delta channels are clearly individualised by their indicating macrophyte species, despite their close connectivity.

Results like that of the JDS2 river sections and that of the Romanian water bodies in the Danube River corridor (Table 6) show the need to survey river reaches in enough detail to enable distinguishing between seemingly similar and potentially different macrophyte assemblages, which would otherwise not be detected.

**Table 6** Individual character of macrophyte assemblages in running water bodies of the Danube River corridor [22]

	Cal	Bra	Bor	Mac	Chi	Sul	Sf.G
Species richness (S)	65	60	45	73	39	50	57
Total number of indicator species (IS) <sup>a</sup>	1	4	5	17	14	12	3
IS: hydrophytes and amphiphytes only	0	0	0	4	8	6	2
Top IS	None	None	None	Pot luc	Pot pec	Sal nat	Tra nat
Top non-IS species	Myr spi	Pol amp	Azo fil	Oen aqu	Pot cri	Hyd mor	Myr ver

River reach codes: *Cal* Danube main channel between Calarasi and Giurgeni, *Bra* Danube main channel between Giurgeni and Braila, *Bor* Borcea side channel (parallel to Cal), *Mac* Macin side channel (parallel to Bra), *Chi* Chilia Delta arm, *Sul* Sulina Delta channel, *Sf.G* Sfântu Gheorghe Delta arm. Species codes: Pot luc *Potamogeton lucens* L., Pot pec *Potamogeton pectinatus* L., Sal nat *Salvinia natans* (L.) All, Tra nat *Trapa natans* L., Myr spi *Myriophyllum spicatum* L., Pol amp *Polygonum amphibium* L., Azo fil *Azolla filiculoides* Lam., Oen aqu *Oenanthe aquatica* (L.) Poir., Pot cri *Potamogeton crispus* L., Hyd mor *Hydrocharis morsus-ranae* L., Myr ver *Myriophyllum verticillatum* L.

<sup>a</sup>According to indicator species analysis (ISA): Dufrière and Legendre [12]. Data basis: Sarbu et al. [22]

JDS2 Section 6, equally species rich as Section 4, was located in the HR/RS and RS/RO river reach, from the Hungarian border to the head water of the Iron Gate I reservoir. Influence from the large and floodplain-rich tributaries Tisza and Sava as well as the reduction in water flow velocity [23, 24] in this middle reach of the Danube may have caused the rich macrophyte development.

Despite the notable increase in especially *Ceratophyllum demersum* and *Myriophyllum spicatum*, overall species richness decreased in the lower Romanian Danube and towards the Danube Delta channels (Fig. 1), when considering typical hydrophytes. The widening of the river channel and the increase in bare sandy sediment in the shallow river littoral where macrophytes would sustain may influence this negative development.

## 4.2 Ecological Status Assessment and Determinant Side Effects to be Considered

The assessment of the ecological status of river reaches lies within the competence of each European Union Member State. Therefore only an ‘intentional ecological status’ was worked out for the JDS2 report. The following conditions were respected when applying the metrics described in the methods section of this contribution: (a) practically no fully near-natural conditions can be found along the whole Danube River corridor; (b) when considering ecological quality for ‘good

status', and its differentiation from 'moderate status', we followed a 'short-cut way' quite similar to the approach of Birk et al. [2]; (c) bryophytes occurring on rock-face-dominated banks and in constrained reaches indicated close-to-natural conditions; bryophyte occurrence on rip-rap or other hard anthropogenic surfaces was considered moderate ecological conditions, at best; (d) vascular aquatic species occurrence in regulated river reaches was weighted against undisturbed historical flow and morphology conditions; and (e) in the lower river reaches, the influence of the large catchment with regard to natural nutrient enhancement was considered close-to-natural conditions, but noticeable pollution influence was considered moderate status or worse. In addition, e.g. historical river maps or differential saprobic data were also integrated. Following this procedure, a considerable number of JDS2 sites were considered as 'good ecological conditions', but many, especially those in hydropower impoundments, were classified 'moderate' [16].

However, with that experience in mind, it became explicitly clear that a singular assessment of ecological status can be determined by several pressures not necessarily related to negative human influence.

Natural seasonal and interannual variation of aquatic macrophyte composition is common in running water systems. Such temporal changes have been studied in the German and Austrian catchment of the Danube. Short-term fluctuation of species composition but also the recovering process after reduction or increase of water pollution is reflected by the macrophyte population.

Table 7 shows that the sites of the two JDS in the main river channel, in the upper impoundment of the flood relief channel in Vienna and in the flood exposed oxbow system of Rosskopf, are characterised by a rather similar ratio of constant and variable hydrophyte species, respectively. The high ratio of variable species in the lower impoundment of the New Danube channel may be due to the intensive use as recreational area for water sports and leisure activities, which influence the near-bank areas throughout the summer season. The other extreme of c. 2/3 of constant species was reported for the groundwater-dominated Slovak river, which guarantees extremely constant flow and temperature conditions. Similar effects were

**Table 7** Ratio of constant and variable hydrophyte species in different water bodies of the Danube catchment

Water body	Tno <sup>a</sup>	% constant	% variable
JDS1 (2001)–JDS2 (2007)	48	47.9	52.1
New Danube UI (1995–2007)	17	41.2	58.8
New Danube LI (1988–2007)	22	27.3	72.7
Rosskopf (1987/1993/1994/2009)	31	41.9	58.1
Klatovske rameno (1996/2005)	27	70.4	29.6

JDS1–JDS2, main Danube River channel; New Danube UI, upper impoundment of the flood protection side channel located in Vienna; New Danube LI, lower impoundment (Wychera, personal communication); Rosskopf, oxbow series in the active Danube floodplain of the Eastern Austrian Danube reach (Jäger, courtesy); Klatovske rameno, groundwater-fed stream located in the alluvial cone of the Zytňý ostrov (SK) [25]

<sup>a</sup>Tno: total number of hydrophytes

recorded in student field courses on the Fischa River at Siegersdorf (Austria), where 60% of the species occurred annually in a 30-year period (Janauer, personal communication).

Other examples are recorded from the Bavarian (Germany) Danube catchment. An extensive time-series study was carried out at Moosach (Germany), a tributary to the Isar River of c. 31 km length, fed by groundwater and rich in carbonate and in macrophytes. Schweinitz et al. [26] aggregated the results of eight macrophyte surveys between 1970 and 2010. Aside from recording river reaches with or without changes in species composition, e.g. an increase in the eutrophic species group, evidence was provided of how to conserve ecologically sensitive, rather pristine macrophyte assemblages in parts of the water body system.

A similar study was conducted at Friedberger Au (Germany), which is 33 km long and also rich in carbonate and macrophytes. It merges with the Danube near Marxheim. Veit et al. [27] reported 53% constant and 47% variable hydrophyte species based on survey campaigns between 1972 and 1996. Seibold's recent results (1972–2012) are in press [28].

Results of long-term investigations should be considered when assessing the ecological status of the biological quality element 'macrophytes', as natural, non-anthropogenic interannual variation between constant and 'fluctuating' macrophyte species can affect the critical determination of 'good' or 'moderate' ecological status.

Many parts of the present Danube River and its floodplain corridor are no longer in near-natural condition due to human activities. Impounded stretches and reaches with embankments and other 'hard' types of regulation may fall under the category of 'heavily modified' river parts. Mitigation measures to reach 'good ecological potential' are then requested by the WFD. In many cases, fish passes are built to reconstruct longitudinal connectivity at least to some extent. But usually, no measures are considered practical for enhancing the potential of the reservoir part of hydropower plants (HPPs). In the reservoir of Freudenua HPP (Vienna, AT), considerable effort was put into ecological improvement of the reservoir stretch by constructing 'compensation structures' along its left bank. Different man-made side-channel environments improved habitat conditions for natural colonisation by aquatic plant species, predominantly submersed macrophytes. This increase in structural diversification of the narrow but up to several-kilometres-long side channels triggered the accumulation of many fish species covering rheophilic to eurytopic to stagnophilic species [29], which resulted in a considerable increase in ecological quality of the impoundment.

## 5 Conclusions

The JDS2 survey of the second largest river in Europe was of great importance for assessing the most determinant abiotic and biotic parameters along the navigable reach a second time. Regarding macrophytes, the survey method could be adapted

to the exceptional spatial dimension of the Danube River. The quality of our results is mirrored by extensive statistical analyses carried out by scientists working on intercalibration exercises. Added value is provided in using the macrophyte information when assessing the ecological status of Danube reaches in the future and in case of meeting ecological potential requirements in some river parts. As a side effect, information for conservational management was also provided.

In JDS2, macrophytes were detected in almost 90% of the survey units, but abundance was usually low, as expected for a large river. Assessing species occurrence and abundance over the full length of each survey unit provided information on the total basic population and not only on test squares possibly biased by subjective selection. The statistically individual character of the macrophyte composition in each river section was clearly shown. The linkage of species or species groups to different river reaches, e.g. bryophytes to the rip-rap-protected banks of the upper reach, and less flow-sensitive vascular species to the middle and lower reach are substantial to provide a background for correctly estimating the boundary between good and moderate ecological status of sampling sites.

Finally, deeper insight is requested regarding the natural temporal variation of macrophyte composition in running waters: particularly interannual species variation may erroneously create negative influence on the results of ecological status assessment according to the WFD, as well as on the appointment of conservation status in, e.g. Natura 2000, protected floodplain areas.

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