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An overview of aquatic vegetation in Serbia

Eine Übersicht über die aquatische Vegetation in Serbien

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Abstract

The majority of aquatic vegetation studies in the Middle Danube Basin (Serbia) were done independently during the last two decades, including data from small areas, which resulted in several classification solutions. The main purpose of this paper was to develop a numerical classification of the aquatic vegetation in Serbia, without fitting the vegetation groups into the existing phytocoenological classification scheme. Datasets of (i) surface and subsurface vegetation of free-floating duckweeds, ferns, liverworts and bladderworts, and (ii) vegetation of free-floating hydrocharids, submerged occasionally anchored ceratophyllids and rooted aquatic vegetation were compiled from phytocoenological relevés (974). In order to fill the geographical and methodological gaps of these datasets, additional data matrix (iii) was compiled from sample quadrats (1055), collected during the aquatic vegetation season (summer months) of 2009, 2010 and 2011 at 31 lakes in Serbia. The datasets were analyzed using SYN-TAX 5.1 program, by non-metric hierarchical clustering OrdClAn and the Goodman-Kruskal's gamma resemblance coefficient. The cluster analysis revealed 28 aquatic vegetation groups (VG), of which three have been recognized as new vegetation units for the area of study: VG dominated by *Vallisneria spiralis* and *Potamogeton perfoliatus*, VG characterized by *Polygonum amphibium* and VG with *Paspalum paspaloides* as a constant. Geographical ranges and constant, diagnostic and dominant species of vegetation groups were determined.

Keywords: *Charetea*, classification, Danube, freshwater, *Lemnetea*, macrophytes, *Potametea*

Erweiterte deutsche Zusammenfassung am Ende des Artikels

1. Introduction

Due to the essentially stable and buffered environmental conditions, the diversity of freshwater vegetation is much lower, when contrasted with the high diversity of zonal vegetation types (RODWELL et al. 2002). Three classes of freshwater vegetation which are present in Europe (*Charetea* Fukarek ex Krausch 1964, *Lemnetea* de Bolós et Masclans 1955 and *Potametea* Klika in Klika et Novák 1941) (RODWELL et al. 2002, LANDUCCI et al. 2015, MOLINA 2017) have also been recorded in Serbia (KOJIĆ et al. 1998). The aquatic habitats of

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Serbia mainly belong to the hydrological area of the Middle Danube Basin. According to the EC Water Framework Directive (EUROPEAN COMMISSION 2000), they primarily cover the Hungarian lowlands, spreading over the ecoregions of Dinaric Western Balkans, Eastern Balkans and the Carpathians. The species composition of these habitats is mostly affected by eutrophication and significant human pressures (NIKOLIĆ et al. 2007, 2009, RADULOVIĆ et al. 2010, 2011).

Although research of aquatic vegetation in Serbia began with SLAVNIĆ (1956), the majority of data was collected during the last two decades (PANJKOVIĆ 2005, RADULOVIĆ 2005, POLIĆ 2006, JENAČKOVIĆ et al. 2010, RANĐELOVIĆ & ZLATKOVIĆ 2010). Phytocoenological surveys mainly included the vegetation of lakes, ponds, ornamental pools and canals (JANKOVIĆ 1953, SLAVNIĆ 1956, RAUŠ et al. 1980, STOJANOVIĆ et al. 1990, 1994, RANĐELOVIĆ & BLAŽENČIĆ 1997, PANJKOVIĆ 2005, RADULOVIĆ 2005, POLIĆ 2006, RADULOVIĆ & VUČKOVIĆ 2014), while only a few studies were conducted on riverine ecosystems (JENAČKOVIĆ et al. 2010, RANĐELOVIĆ & ZLATKOVIĆ 2010, RADULOVIĆ et al. 2010, 2012). However, these studies were done independently and included data from small areas, which resulted in several classification solutions. Generally, early classification systems (STOJANOVIĆ et al. 1987, KOJIĆ et al. 1998) recognized 16 associations of freshwater vegetation in the area of research, grouped in four alliances (*Lemnion minoris* Koch et Tx. 1954 ex Oberd. 1957, *Potamion eurosibiricum* Koch 1928, *Nymphaeion albae* Oberd. 1957 and *Ruppion maritimae* Br.-Bl. 1931), three orders (*Lemnetalia* Koch et Tx. 1954, *Potametalia* Koch 1926 and *Rupietalia* J.Tx. 1960) and two classes (*Lemnetaea* and *Potametea*). The classification scheme and nomenclature was significantly, but not completely, improved by the project 'Habitats of Serbia', which included the harmonization of national habitat classification system with the EUNIS (European Nature Information System) Habitat Classification (DAVIES et al. 2004).

The aims of this study were to: (1) summarize the patterns of compositional variation of aquatic vegetation in the Middle Danube Basin (Serbia) (2) develop a numerical classification of the aquatic vegetation, without fitting the vegetation groups into the existing phytocoenological classification scheme and (3) identify the diagnostic, constant and dominant species of the main types of aquatic vegetation.

2. Material and methods

2.1 Dataset

Numerical classification was performed on three datasets. The first and the second dataset were extracted from the digital database of aquatic and semiaquatic vegetation in Serbia (CVIJANOVIĆ et al. 2016), also stored within the WetVegEurope database (LANDUCCI et al. 2015). The first dataset (i) included 331 phytocoenological relevés, *a priori* placed in alliances *Lemnion minoris* de Bolós et Masclans 1955 and *Utricularion vulgaris* Passarge 1964 of class *Lemnetea* de Bolós et Masclans 1955. Due to the inconsistency of the formal syntaxonomic classification of data within the database, the second dataset (ii) included 643 relevés of class *Potametea* Klika in Klika et Novák 1941, class *Charetea* Fukarek ex Krausch 1964 and alliance *Hydrocharition morsus-ranae* (Passarge 1964) Westhoff et den Held 1969 of class *Lemnetea* de Bolós et Masclans 1955. The main goal of such data-gathering was to distinguish vegetation groups *i*) among relevés *a priori* placed in ass. *Ceratophylletum demersi* (Soó 1927) Hild 1934 (1956), ass. *Potamogetono - Ceratophylletum demersi* (Hild et Rehnelt 1965) Pass. 1955 and ass. *Ceratophyllo-Trapetum natantis* Müller & Gors (1962) ex Pass.1992; *ii*) further, among relevés placed in ass. *Hydrochario-Nymphoidetum peltate* Slavnić 1956, ass. *Nymphoidetum peltatae* (Allorge 1922) Oberd. et Muller 1960 and ass. *Hydrocharidetum morsus-ranae* Van Langendonck

1935; *iii*) as well as among relevés of ass. *Utricularietum vulgaris* R. Lakušić 1968 ex V. Ranđelović 1995, ass. *Calitricho-Utricularietum vulgaris* V.Ranđelović 1998 and ass. *Utriculario-Nitelletum syncarpae* V. Ranđelović et J. Blaženčić 1995. The phytocoenological relevés span the period of five decades (1953–2010), including short and long-term phytocoenological surveys. All relevés were given according to the Braun-Blanquet Cover Abundance Scale (BRAUN-BLANQUET 1932) (Table 1). In order to fill the geographical and methodological gaps of these datasets, an additional data matrix (iii) was created from sample quadrats (1055), collected during the summer months of 2009, 2010 and 2011 at 31 lakes in Serbia (LAKETIĆ et al. 2013), using the UKTAG LEAFPACS method (Lake Assessment Methods, Macrophyte and Phytobenthos; GUNN et al. 2010, WILLBY et al. 2012). The sampling was carried out at 100 m sectors, repeated 2–8 times per lake, depending on the overall vegetation abundance. Each 100-m sector was divided into five sub-sectors at 20 m intervals. Samples were taken at 0.25, 0.5, 0.75 and > 0.75 m of water depth, at each sub-sector. The sectors were located within each of the main vegetation types characteristic for the lake (WILLBY et al. 2012). From the mid-point of the 100-m sector a boat transect was set up perpendicular to the lake shore, to the maximum depth of macrophyte colonisation. A series of sample points were surveyed at every 0.5 m depth interval, between the end of the transect and the shoreline marker. At each sample point, using the combination of a bathyscope and grapnel sampling all aquatic macrophyte species were recorded on a 3-point cover-abundance scale ('1' being less than 25% of quadrat area covered by species, '2' being up to 75% of the quadrat area covered, '3' being more than 75% cover).The original Braun-Blanquet scale from the first and the second dataset, as well as the three-point scale from the LEAFPACS dataset were converted into the van der Maarel scale (VAN DER MAAREL 1979) (Table 1).

2.2 Data analysis

Datasets were analyzed using SYN-TAX (version 5.1, http://www.exetersoftware.com/), by non-metric ordinal hierarchical clustering OrdClAn (PODANI 2005, 2006), using the Goodman-Kruskal γ resemblance coefficient (GOODMAN & KRUSKAL 1954).

Each cluster (min. five relevés) on dendrogram was identified and analyzed according to its floristic-sociological homogeneity, by statistical determination of constant, diagnostic and dominant species in Microsoft Excel 2003 program. Relevés from inhomogeneous clusters were excluded from further analysis (around 30%). The diagnostic species were defined by the *phi* (Φ) coefficient as a fidelity measure (CHYTRÝ et al. 2002). Species were considered to be constant if they occurred in more than 60% of relevés (WESTHOFF & VAN DER MAAREL 1978). Dominant species were determined as those with a cover of > 25% in > 10% of relevés (DÚBRAVKOVÁ et al. 2010, JANIŠOVÁ & DÚBRAVKOVÁ 2010, HEGEDÜŠOVÁ et al. 2012, LANDUCCI et al. 2013). Following CHYTRÝ & TICHÝ (2003), clusters with the same combination of constant, diagnostic and dominant species were merged into the same vegetation group.

Table 1. Cover abundance scales used in datasets.

Tabelle 1. Deckung-abundanz Skalen verwendet in Datensätze.

Scale/Corresponding cover	Scale values						
Braun-Blanquet scale	R	+	1	2	3	4	5
Corresponding cover [%]	0	0.1	5.0	17.5	37.5	62.5	87.5
Three-point scale				1	2		3
Corresponding cover [%]				12.5	50.0		87.5
van der Maarel scale	1	2	3	5	7	8	9

The term ‘Vegetation Group’ (VG) was considered in line with the International Code of Phytosociological nomenclature (WEBER et al. 2000), as an abstract unit without rank, which is based on the floristic-sociological criteria and corresponds to the phytocoenoses. The names of vegetation groups were derived based on species names, which were at the same time constant, diagnostic and dominant for that particular group.

Correspondence between the vegetation groups distinguished by cluster analysis and original classification of relevés in the first and the second datasets is presented in the Supplement E1. The nomenclature of syntaxa is listed according to the original publications, while the species nomenclature follows TUTIN et al. (1964–1980).

The maps documenting the geographical distribution of clusters were prepared using the OziExplorer (version 3.95.4b, www.oziexplorer.com) and DIVA-GIS software (version 5.2, www.diva-gis.org).

3. Results

3.1 Vegetation groups of the first dataset (surface and subsurface vegetation of free-floating duckweeds, ferns, liverworts and bladderworts)

The cluster analysis of the first dataset revealed eight aquatic vegetation groups: VG1 *Lemna gibba*, VG2 *Lemna trisulca*, VG3 *Riccia fluitans*, VG4 *Ricciocarpus natans*, VG5 *Utricularia vulgaris*, VG6 *Azolla filiculoides*, VG7 *Salvinia natans - Spirodela polyrhiza* and VG8 *Wolffia arrhiza*. Diagnostic, constant and dominant species are listed in Table 2. At the first level of clustering (Fig. 1), two types of vegetation groups were recognized relative to their tolerance to eutrophication (First type: VG2–VG5 and VG8, Second type: VG1, VG6 and VG7) (RADULOVIĆ et al. 2011, LAKETIĆ et al. 2013). The first type included species confined to oligotrophic and mesotrophic waters (*Lemna trisulca*, *Riccia fluitans*, *Ricciocarpus natans*, *Utricularia vulgaris* and *Wolffia arrhiza*), while the second type was characterized by the species typical of mesotrophic and eutrophic sluggish and standing waters (*Lemna gibba*, *Salvinia natans*, *Spirodela polyrhiza* and *Azolla filiculoides*). Apart from VG5, dominated by *Utricularia vulgaris*, all of the other vegetation groups are presented by a single cluster (Fig. 1). Cluster 5a comprises relevés with a poorly defined layer of submerged macrophytes (Supplement E2). In contrast to this, in Cluster 5b, *Utricularia vulgaris* is associated with other dominant submerged macrophytes (*Ceratophyllum demersum* subsp. *demersum*, *Ceratophyllum submersum* and *Myriophyllum verticillatum*, Supplement E2).

These vegetation groups mainly lie in the Northern lowland part of Serbia (Fig. 2), the wide alluvial lowlands along the Danube, Sava, Tisa, Tamiš and Begej rivers. Vegetation groups recorded in a single site (Apatinski and Monoštorski rit area – Gornje Podunavlje) were VG3 *Riccia fluitans* and VG4 *Ricciocarpus natans*.

3.2 Vegetation groups of the second dataset (vegetation of free-floating hydrocharids, submerged occasionally anchored ceratophyllids and rooted aquatic vegetation)

The OrdClAn clustering divided the second dataset into 17 vegetation groups (Supplement S1, Fig. 3): VG9 *Trapa natans*, VG10 *Ceratophyllum demersum* subsp. *demersum*, VG11 *Potamogeton crispus*, VG12 *Potamogeton pectinatus*, VG13 *Potamogeton obtusifolius*, VG14 *Potamogeton nodosus*, VG15 *Nymphaea alba*, VG16 *Nuphar lutea*, VG17 *Nymphoides peltata*, VG18 *Hydrocharis morsus-ranae*, VG19 *Najas marina*, VG20 *Vallisneria spiralis*, VG21 *Elodea canadensis*, VG22 *Elodea nuttallii*, VG23 *Ranunculus aquatilis*, VG24 *Utricularia vulgaris* and VG25 *Nitella opaca*. Vegetation groups confined to the local

Table 2. Frequency table of surface and subsurface duckweed vegetation groups VG1–VG8. *Statistical procedures applied. The numbers given in the table are percentage frequencies of species (over 20% only). Their upper indices are the fidelity value of a species for a particular vegetation group, expressed using the *phi* coefficient × 100 (*phi*-coefficient value higher than 0.25). Dominant species are in bold. Nominal species are on a grey background. Vegetation groups recorded at a single site are marked with an asterisk.

Tabelle 2. Häufigkeitstabelle der Wasserlinsen-Vegetationsgruppen auf und unter der Wasseroberfläche VG1–VG8. *Statistische Verfahren wurden angewendet. Die in der Tabelle gegebenen Zahlen sind prozentuale Stetigkeitswerte (nur Arten über 20% sind aufgeführt). Die hochgestellten Indices sind Treuewerte einer Art für die spezifische Vegetationsgruppe, ausgedrückt als *phi*-Koeffizient x 100 (nur *phi*-Koeffizienten höher als 0,25 sind angegeben). Dominante Arten sind fett gedruckt, namengebende Arten mit einem grauen Hintergrund. Die an einem einzelnen Wuchsort aufgenommenen Vegetationsgruppen sind mit einem Stern markiert.

Vegetation group	1	2	3*	4*	5	6	7	8
Number of relevés	36	26	7	14	22	38	119	17
Lemna gibba L.	**100^{60}**	.	.	.	.	24	.	.
Lemna trisulca L.	14	**100^{40}**	71	100^{29}	55	.	.	**41**
Riccia fluitans L.	.	.	100^{56}	43	.	.	.	.
Ricciocarpus natans (L.) Corda	.	.	.	**100^{100}**	.	.	.	.
Utricularia vulgaris L.	.	.	100^{31}	.	**100^{55}**	.	.	.
Azolla filiculoides Lam.	.	.	.	21	.	**100^{67}**	.	.
Spirodela polyrhiza (L.) Schleid.	**69**	**54**	86	71	23	**63**	**88^{27}**	53
Salvinia natans (L.) All.	53	31	.	.	32	63	**92^{45}**	.
Wolffia arrhiza (L.) Horkel ex Wimm.	.	.	.	.	.	.	.	**100^{82}**
Lemna minor L.	**92**	**92**	100	**100**	**86**	**97**	**72**	65
Ceratophyllum demersum L. subsp. *demersum*	**56**	**54**	.	.	41	**66**	**59**	**47**
Hydrocharis morsus-ranae L.	25	54	86	.	27	.	45	35
Myriophyllum spicatum L.	31	.	.	.	27	.	36	.
Ranunculus trichophyllus Chaix subsp. *trichophyllus*	.	.	100^{49}	.	.	.	.	.
Carex vesicaria L.	.	.	29	43^{56}	.	.	.	.
Hottonia palustris L.	.	.	43^{42}	21^{29}	.	.	.	.
Iris pseudacorus L.	.	.	.	21^{35}	.	.	.	.
Trapa natans L.	.	.	.	.	.	.	25	.
Vallisneria spiralis L.	.	.	.	.	.	.	23	.

area, Vlasinsko jezero lake (RANĐELOVIĆ & ZLATKOVIĆ 2010) (VG13, VG23-VG25), split off after the first clustering step. The rest of the relevés split further into the fraction of the rooted submerged vegetation (VG10 – Cluster 10a, VG11, VG12, VG14, VG19, VG20 and VG22) and the fraction mainly composed of rooted vegetation with floating leaves (VG9, VG10 – Cluster 10b, VG15–VG17), free-floating vegetation group dominated by *Hydrocharis morsus-ranae* (VG18), and vegetation group with submerged rooted species *Elodea canadensis* (VG21).

Vegetation groups defined by more than one cluster were VG10, VG11, VG15 and VG17 (Fig. 3, Supplement E2). Cluster 10a contained relevés dominated by *Ceratophyllum demersum* subsp. *demersum*, without or including a poorly defined layer of floating-leaved

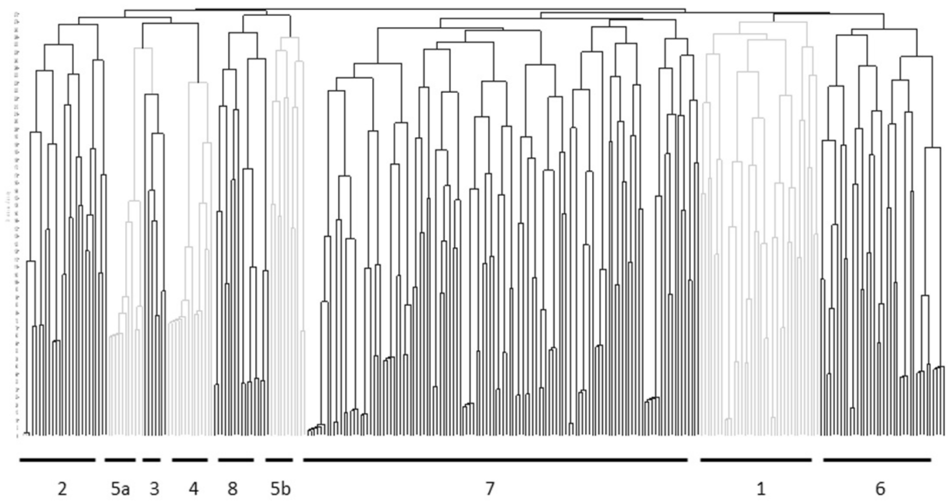

Fig. 1. Classification dendrogram of surface and subsurface duckweed vegetation. The numbers given in the dendrogram represent vegetation groups VG1–VG8.

Abb. 1. Klassifizierungs-Dendrogramm der Wasserlinsen-Vegetationsgruppen auf und unter der Wasseroberfläche. Die im Dendrogramm angegebenen Zahlen repräsentieren die Vegetationsgruppen VG1–VG8.

species. In contrast, the species *Ceratophyllum demersum* subsp. *demersum* was followed by a significant presence of greater duckweed *Spirodela polyrhiza* in Cluster 10b. VG11, with high constancy of *Potamogeton crispus*, followed the same concept of clustering. In comparison with the Cluster 11b, Cluster 11a comprised relevés with a constant layer of free-floating *Hydrocharis morsus-ranae*. In case of VG15, clusters were distinguished by a slightly higher constancy of *Nymphoides peltata* in Cluster 15b.

On the other hand, vegetation group dominated by *Nymphoides peltata* (VG17) was divided into two clusters, Cluster 17a with *Spirodela polyrhiza*, *Lemna minor* and *Salvinia natans* and Cluster 17b with *Nymphaea alba* and *Trappa natans,* occurring at a constancy of more than 20%.

This kind of vegetation is also widespread throughout the Northern lowland part of Serbia (Fig. 2), with more occasional stands in the Southern highlands. Vegetation group recorded in a single site (Vlasinsko jezero lake) was VG13, dominated by *Potamogeton obtusifolius* and VG25 with *Nitella opaca* as a constant species.

3.3 LEAFPACS vegetation data

The analysis of the LEAFPACS dataset yielded 14 vegetation groups (Supplement S2, Fig. 4): LVG1 *Salvinia natans - Spirodela polyrhiza*, LVG2 *Ceratophyllum demersum* subsp. *demersum*, LVG3 *Najas marina*, LVG4 *Vallisneria spiralis – Potamogeton perfoliatus*, LVG5 *Elodea nuttallii*, LVG6 *Trapa natans*, LVG7 *Potamogeton nodosus*, LVG8 *Nymphoides peltata*, LVG9 *Nymphaea alba*, LVG10 *Nuphar lutea*, LVG11 *Polygonum amphibium*, LVG12 *Paspalum paspaloides*, LVG13 *Typha angustifolia*, LVG14 *Phragmites australis*. These vegetation groups belong to four general types of aquatic and semiaquatic vegetation: surface and subsurface duckweed (LVG1), occasionally anchored and rooted

Fig. 2. Geographical distribution of aquatic vegetation in Serbia.

Abb. 2. Geographische Verbreitung von aquatischer Vegetation in Serbien.

submerged vegetation (LVG2–LVG5), rooted vegetation with floating leaves (LVG6–LVG12) and emergent reed vegetation (LVG13 and LVG14). The emergent reed vegetation groups were not evaluated further in this paper.

LVG groups defined by two clusters were LVG1, LVG2 and LVG6 (Supplement E3). While LVG1 and LVG6 were differentiated by the dominance of submerged species, clusters of LVG2 were distinguished by the presence, or absence, of pondweed species.

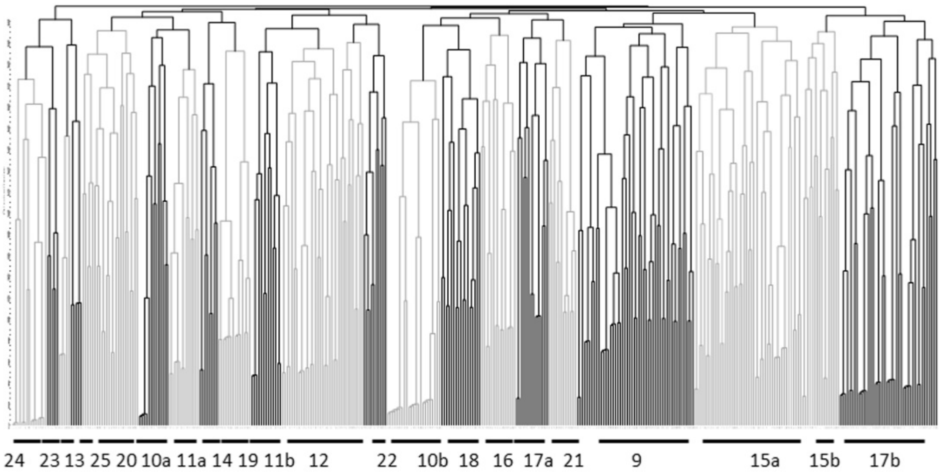

Fig. 3. Classification dendrogram of rooted submerged vegetation and rooted vegetation with floating leaves. The numbers given in the dendrogram represent vegetation groups VG9–VG24.

Abb. 3. Klassifizierungs-Dendrogramm der verwurzelt-untergetauchten Vegetation sowie der verwurzelten Vegetation mit schwimmenden Blättern. Die im Dendrogramm angegebenen Zahlen repräsentieren die Vegetationsgruppen VG9–VG24.

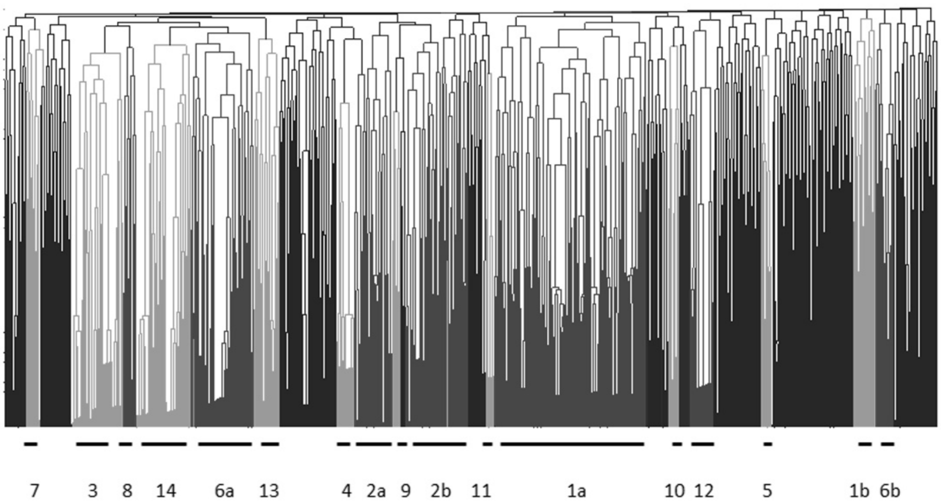

Fig. 4. Classification dendrogram of LEAFPACS dataset. The numbers given in the dendrogram represent LEAFPACS vegetation groups LVG1–-LVG12.

Abb. 4. Klassifizierungs-Dendrogramm des LEAFPACS-Datensatzes. Die im Dendrogramm angegebenen Zahlen repräsentieren die LEAFPACS-Vegetationsgruppen LVG1–LVG12.

When comparing the lists of constant, diagnostic and dominant species of vegetation groups derived from the phytocoenological datasets and LEAFPACS sample quadrants (third dataset), the following pairs of equivalent vegetation groups could be found: LVG1–VG7 *Salvinia natans - Spirodela polyrhiza*, LVG2–VG10 *Ceratophyllum demersum* subsp.

demersum, LVG3–VG19 *Najas marina*, LVG5–VG22 *Elodea nuttallii*, LVG6–VG9 *Trapa natans*, LVG7–VG14 *Potamogeton nodosus*, LVG8–VG17 *Nymphoides peltata*, LVG9–VG15 *Nymphaea alba* and LVG10–VG16 *Nuphar lutea*. On the other hand, LVG groups unique for the LEAFPACS dataset were LVG4 *Vallisneria spiralis – Potamogeton perfoliatus*, LVG11 *Polygonum amphibium* and LVG12 *Paspalum paspaloides*.

4. Discussion

4.1 Classification methods and dataset

A new classification of aquatic vegetation in Serbia was created, without fitting the vegetation groups into the existing phytocoenological classification scheme. This approach allowed relevés to be excluded during the analysis if they belonged to inhomogeneous clusters. According to some other relevant studies (ROLEČEK 2007, DÚBRAVKOVÁ et al. 2010), the selection of relevés could be done before the classification analysis, by geographical and ecological stratification of the datasets. Generally, the geographical stratification of data matrix includes random selection of particular number of relevés from predefined grid cells, in order to reduce the oversampling of some small areas. Since aquatic vegetation belongs to the azonal type, determined by local edaphic and hydrographic factors, this step was avoided. In fact, any preselection of relevés was avoided, in order to find the gaps and summarize the patterns of compositional variation of aquatic vegetation, within a study area and given vegetation datasets.

According to PODANI (2006), vegetation data should not be exclusively treated by numerical methods. The most critical step in selecting the appropriate classification method is the choice of a dissimilarity coefficient, which is ecologically meaningful and, at the same time, compatible with the ordinal data. Several types of agglomerative and divisive classification, metric and non-metric, methods were applied, including UPGMA (Unweighted Pair Group Method with Arithmetic mean), Ward's method and TWINSPAN in order to select the most suitable, ecologically interpretable, methodological approach. Since phytocenological relevés and LEAFPACS sample quadrants are expressed on ordinal scales, the GOODMAN & KRUSKAL (1954) γ measure of resemblance and hierarchical OrdClAn-H clustering (PODANI 2006) provided mathematically correct solution.

The phytocenological dataset compiled relevés from both lentic and lotic habitats, while the LEAFPACS dataset included only data on lake vegetation. According to KERUZORÉ et al. (2013), fens, ponds and lakes are crucial habitats for maintaining the diversity of macrophyte communities and production in large river ecosystems, such as river floodplains in the area of study (VUKOV et al. 2008, RADULOVIĆ et al. 2010, 2011). Therefore, the holistic assessment of aquatic vegetation of the Middle Danube Basin was obtained by additional LEAFPACS systematical survey of lake vegetation (LAKETIĆ et al. 2013).

Apart from the obvious reason for dividing the data into separate datasets (RODWELL 1995), the additional LEAFPACS data matrix clustering was performed in order to fill the existing geographical and methodological gaps of phytocoenological data. While Braun-Blanquet approach is based on replicate sampling in the central areas of the selected homogenous stands, the LEAFPACS sectors were chosen subjectively, where the position of individual samples is dependent only upon the water depth and distance between them (GUNN et al. 2010, WILLBY et al. 2012). Hence, the vegetation units potentially overlooked by the sampling method according to the Braun-Blanquet approach, were covered by the

LEAFPACS method. On the other hand, the use of the classification analysis on different datasets may represent a testing of the classification results and analysis itself (BRUELHEIDE & CHYTRÝ 2000).

4.2 Vegetation classification

Clusters located on different dendrogram branches are not necessarily less similar than the clusters of the same branch (DÚBRAVKOVÁ et al. 2010). Therefore, clusters with the same combination of constant, diagnostic and dominant species were classified into the same vegetation group. According to CHYTRÝ & TICHÝ (2003), vegetation units characterized by low uniqueness could possibly be merged with some other units.

Vegetation groups defined by two clusters were distinguished by heterogeneity of different vegetation layers. Previous research (RADULOVIĆ 2005) called into question the presence of the authentic submerged plant layer within the surface and subsurface free-floating communities. According to RADULOVIĆ (2005), typical stands of *Salvinia natans* and *Spirodela polyrhiza* (ass. *Salvinio natantis-Spirodeletum polyrhizae* Slavnić 1956) are confined to shallow littoral zones of eutrophic standing waters and consist of floating mats of various mixtures of duckweeds *Salvinia natans*, *Spirodela polyrhiza*, *Lemna minor* and some emergent associates. Under the influence of wind, or slow water flow, the floating stands could be moved towards the deeper water, where they are closely associated with a layer of submerged plants. On the other hand, stands of the ass. *Ceratophyllum demersum* subsp. *demersum* may vary from complete absence of the layer of floating-leaved plants, to the stands in shallow waters with a quite dense duckweed mat (PANJKOVIĆ 2005, RADULOVIĆ 2005).

The results of the numerical classification of vegetation and formal definition of derived vegetation units may correspond to the traditional delimitation of associations, but not necessarily, in which case the redefinition of traditional vegetation types could potentially be required (ROLEČEK 2007, SEKULOVÁ & HÁJEK 2009, DÚBRAVKOVÁ et al. 2010). Relevés in the second dataset, placed *a priori* in the association *Myriophyllo-Potametum* Soó 1934 (Supplement E1) (STOJANOVIĆ et al. 1994, PANJKOVIĆ 2005, RADULOVIĆ 2005, POLIĆ 2006) correspond to three vegetation groups (VG11, VG12 and VG14), dominated by different pondweed species (*Potamogeton crispus*, *P. pectinatus* and *P. nodosus*, respectively). In some other relevant studies (SLAVNIĆ 1956, STOJANOVIĆ et al. 1994, STEVANOVIĆ 2002, RADULOVIĆ 2005), the stands of this association were characterized by unstable physiognomy and floristic composition. Also, the vegetation classification in the Czech Republic (CHYTRÝ 2011) recognizes these vegetation units as distinct communities.

Stands with *Nymphaea alba* and *Nuphar lutea*, which were rather monodominant in the area of research (STEVANOVIĆ 2002), were traditionally placed together in the ass. *Nymphaeetum albo-luteae* Nowinski 1928 (Supplement E1) (BUTORAC 1995, PANJKOVIĆ 2005, RADULOVIĆ 2005, POLIĆ 2006). However, the classification analysis in this study distinguished these stands as different vegetation groups (VG15/LVG9 for *N. alba* and VG16/LVG10 for *N. lutea*). According to RODWELL et al. (1995), much of the vegetation with *N. lutea* is species-poor, consisting of little else aside from this species. Also, *N. lutea* seems to be a more nutrient-demanding and turbidity-tolerant plant than *N. alba* (RODWELL 1995, LAKETIĆ et al. 2013). While rare mixed *Nuphar-Nymphaea* stands are placed in the *Nuphar lutea* community by RODWELL et al. (1995), the same are defined as *Nymphaea alba* community type (ass. *Nymphaeetum albae* Vollmar 1947) by CHYTRÝ (2011), as well as in this study.

Following SLAVNIĆ (1956), the community dominated by *Hydrocharis morsus-ranae* and *Nymphoides peltata* (ass. *Hydrocharito morsus-ranae-Nymphoidetum peltatae* Slavnić 1956) was widely recorded in typical lowland, eutrophic lakes of the Middle Danube floodplain (STOJANOVIĆ et al. 1994, BUTORAC 1995, PANJKOVIĆ 2005, RADULOVIĆ 2005). However, as it was previously indicated by RADULOVIĆ (2005), the classification split the relevés of this community into two separate vegetation groups (VG17 and VG18, Supplement E1).

Although vegetation groups VG5 and VG24 were both defined by the same diagnostic species - *Utricularia vulgaris*; these vegetation units are distinguishable by other dominant and constant species. Stands of VG5 are characterized by high constancy of *Lemna minor*, followed by other duckweed species (Table 2). This vegetation group was recorded in lowland meso-eutrophic ponds and fluvial lakes in the Northern part of Serbia (BUTORAC 1995, RADULOVIĆ 2000, 2005, LAZIĆ 2003, 2006, PANJKOVIĆ, 2005, RADULOVIĆ et al. 2011), which correspond to ass. *Lemno-Utricularietum* Soó 1947 of class *Lemnetea* de Bolós et Masclans 1955 (CHYTRÝ 2011). On the other hand, stands of VG24 were recorded only in Vlasinsko jezero lake (RANĐELOVIĆ & BLAŽENČIĆ 1997, RANĐELOVIĆ 2002), which is a highland oligo-mesotrophic lake (RADULOVIĆ et al. 2011). This vegetation unit was also dominated by pondweed species *Potamogeton pusillus* and *P. obtusifolius*, as well as with *Ranunculus aquatilis* and *Polygonum amphibium*. Communities characterised by *Utricularia vulgaris* and pondweed species, belonging to class *Potametea* Klika in Klika et Novák 1941 were also recorded in oligotrophic and high altitude lentic habitats on the Iberian Peninsula (MOLINA 2017) and Sicily (RAIMONDO et al. 2011).

Some of the derived vegetation groups were recorded at just one particular site (VG3 *Riccia fluitans* and VG4 *Ricciocarpus natans*, VG13 *Potamogeton obtusifolius*, VG24 *Utricularia vulgaris* and VG25 *Nitella opaca*). Diagnostic species of VG13 and VG25 are of high conservation interest for the region of Serbia. These species are strictly protected at the national level (NATIONAL ASSEMBLY OF THE REPUBLIC OF SERBIA 2011), while the species *Nittela opaca* was recognized as critically endangered for Serbia (BLAŽENČIĆ 2014) and a low risk species at the Balkan Peninsula region (BLAŽENČIĆ et al. 2006). Despite the number of relevés included within these local vegetation types, their lists of dominant, diagnostic and constant species may be misinterpreted, if a sufficient geographical area was not covered by the sampling. According to ROLEČEK (2007), the essential condition for the formulation of ecologically meaningful species groups is that the original phytosociological dataset represents the vegetation of the study area well. If this is not the case, it may happen that a species group accurately reflects the structure existing in the analysed database, but not the reality in nature (WESTHOFF & VAN DER MAAREL 1978). The other problem which arises is mainly mathematical, not necessarily ecological, which considers the similarity between vegetation groups recorded on the same single site (VG3 *Riccia fluitans* and VG4 *Ricciocarpus natans*, Apatinsko-Monoštorski rit wetland area, [PANJKOVIĆ 2005]; VG13 *Potamogeton obtusifolius* and VG25 *Nitella opaca*, Vlasinsko jezero lake [RANĐELOVIĆ & ZLATKOVIĆ 2010]). Despite the various statistical procedures used for the equalization of the size of the relevé groups for the calculation of species' fidelities (TICHÝ & CHYTRÝ 2006, ROLEČEK 2007), none of these methods consider the effect of geographical coverage.

For some of the LVG groups, equivalent vegetation units were found among the groups derived from phytocoenological database (the first and the second dataset), but some of them were unique for LEAFPACS datasets (LVG4 *Vallisneria spiralis – Potamogeton perfoliatus*, LVG11 *Polygonum amphibium* and LVG12 *Paspalum paspaloides*). These LVG groups have been recognized as new vegetation units in the area of study. The community characterized by *Vallisneria spiralis* and various pondweed species (ass. *Potamo-Vallisnerietum spiralis* Braun-Blanquet 1931) has been recorded in Italy (COSENTINO et al. 2008), Greece (GRIGORIADIS et al. 2005) and Spain (NINOT et al. 2000), in habitats affected by hidromorphological degradation, with sluggish and oligo-eutrophic waters. On the other hand, the community of *Vallisneria spiralis* and *Potamogeton perfoliatus*, generally supplemented by *Myriophyllum spicatum*, *Ceratophyllum demersum* and *Najas marina* (*Potamo perfoliati-Vallisnerietum spiralis* Losev & Golub 1987 in GOLUB et al. (1991) has been recorded in meso-eutrophic lakes of Poland (HUTOROWICZ et al. 2006) and Italy (LANDUCCI et al. 2011). Apart from the terrestrial communities (*Polygonetum natantis* Soó 1927, sin. *Polygonetum natantis* Soó ex Brzeg et Wojterska 2001, *Potamo natantis-Polygonetum natantis* Knapp et Stoffers 1962), *Polygonum amphibium* is also constant within many aquatic community types (RODWELL 1995, DAWSON & SZOSZKIEWICZ 1999, LANDUCCI et al. 2011). Furthermore, an expansion along the Danube corridor was reported for the invasive species *Paspalum paspaloides* (BLAŽENČIĆ et al. 2000, STEVANOVIĆ et al. 2004, POLIĆ 2005, ANAČKOV et al. 2013). Predominantly pure stands of *Paspalum paspaloides* occur in shallow, sluggish aquatic habitats, which are located beyond the main river course and which are exposed to water currents only during high water levels (STEVANOVIĆ et al. 2004). This vegetation group belongs to emergent reed vegetation, but aquatic functional form of *Paspalum paspaloides* also appears in the stands of up to 1.5 m depth (BLAŽENČIĆ et al. 2000).

Comparing the vegetation groups from this study with results of a revised classification of the vegetation in the Czech Republic (CHYTRÝ & RAFAJOVÁ 2003, CHYTRÝ 2011), a high similarity is evident, regarding the species composition and habitat requirements among the equivalent vegetation units. Apart from VG20 *Elodea nuttallii* and VG22 *Vallisneria spiralis*, all vegetation units were also recorded in the Czech Republic. Due to modest marginal occurrence in the dataset (DÚBRAVKOVÁ et al. 2010), some vegetation units, such as those dominated by rare and protected species *Utricularia australis* and *Hottonia palustris* (STEVANOVIĆ 1999) weren't recognized by classification analysis as a separate cluster.

However, unsupervised classification approach, such as OrdClAn clustering method, could be very useful for demonstrating the patterns of compositional variation of vegetation within a study area (DÚBRAVKOVÁ et al. 2010), as well as in a given vegetation dataset.

Erweiterte deutsche Zusammenfassung

Einführung – Drei der europäischen Klassen der Süßwasservegetation (*Charetea* Fukarek ex Krausch 1964, *Lemnetea* de Bolós et Masclans 1955 und *Potametea* Klika in Klika et Novák 1941; RODWELL et al. 2002, LANDUCCI et al. 2015, MOLINA 2017) kommen auch in Serbien vor (KOJIĆ et al. 1998). Die aquatischen Lebensräume Serbiens gehören in erster Linie zum hydrologischen Einzugsgebiet des Mittleren Donaubeckens, das das ungarische Tiefland umfasst und sich vom Dinarischen Gebirge bis zum östlichen Balkan und den Karpaten erstreckt (EUROPÄISCHE KOMMISSION 2000). Die meisten Studien zu aquatischen Lebensräumen in Serbien wurden unabhängig voneinander in kleinen Gebieten durchgeführt und führten daher zu einer Reihe verschiedener Klassifikatiossysteme. Nomenklatur und Klassifikation wurden durch das Projekt "Lebensräume Serbiens" zwar wesentlich verbessert, aber nicht vollständig. Die Ziele der vorliegenden Studie waren daher: (1) Zusammenstellung der Variationsbreite der aquatischen Vegetation im Mittleren Donaubecken (Serbien), (2) Entwicklung einer numerischen Klassifikation der aquatischen Vegetation, ohne Anpassung an bestehende phytozönologische Systeme und (3) Identifizierung der diagnostischen, konstanten und dominanten Arten der wichtigsten aquatischen Vegetationseinheiten.

Material und Methoden – Die Analysen umfassten drei Datensätze: (i) Vegetationseinheiten mit frei auf oder unter der Wasseroberfläche schwimmenden Wasserlinsen, Wasserschlauch-Arten, Farnen und Lebermoosen, und (ii) Vegetationseinheiten von frei schwimmenden Hydrochariden, submers gelegentlich verankerten Ceratophylliden und bewurzelter aquatischer Vegetation, welche aus bisherigen 974 phytocoenologischen Aufnahmen zusammengestellt wurden, sowie (iii) eine zusätzliche Datenmatrix, die erstellt wurde, um die geographischen und methodischen Lücken der Datensätze (i) und (ii) zu füllen. Der dritte Datensatz besteht aus 1055 Aufnahmen, die während der Sommermonate 2009, 2010 und 2011 an 31 Seen in Serbien nach der UKTAG LEAFPACS Methode (Lake Assessment Methods, Macrophytes und Phytobentos, GUNN et al. 2010, WILLBY et al. 2012) angefertigt wurden. Diese Methode ist ein multimetrisches System, das entwickelt wurde, um den biologischen Status eines Ökosystems auf der Basis einer Reihe von Faktoren, z. B. Eutrophierung, Artenvielfalt und Vielfalt der Lebensformen von Makrophyten, beurteilen zu können. Die Analysen wurden unter Verwendung von SYN-TAX (Version 5.1) durch nicht-metrische ordinale hierarchische Clustering OrdClAn (PODANI 2005, 2006) unter Verwendung des Goodman-Kruskal-γ-Ähnlichkeitskoeffizienten (GOODMAN & KRUSKAL 1954) durchgeführt. Jedes Cluster auf dem Dendrogramm wurde identifiziert und analysiert, indem konstante, diagnostische und dominante Arten statistisch ermittelt wurden. Die diagnostischen Arten wurden definiert, indem der *Phi*-(ϕ)-Koeffizient als Maß verwendet wurde (CHYTRÝ et al. 2002). Als konstante Arten wurden jene mit einer Stetigkeit über 60 % bezeichnet (WESTHOFF & VAN DER MAAREL 1978), während sie als dominant angesehen wurden, wenn sie in mehr als 10 % der Aufnahmen eine Deckung von über 25 % hatten (DÚBRAVKOVÁ et al. 2010, JANIŠOVÁ & DÚBRAVKOVÁ 2010, HEGEDÜŠOVÁ et al. 2012, LANDUCCI et al. 2013). Nach CHYTRÝ & TICHÝ (2003) wurden die Cluster mit der gleichen Kombination von konstanten, diagnostischen und dominanten Arten in der gleichen Vegetationsgruppe zusammengefasst. Die Übereinstimmung zwischen den Vegetationsgruppen wurde durch die Clusteranalyse ermittelt. Die Karten, die die geographische Verteilung der Cluster zeigen, wurden mit der Software OziExplorer (Version 3.95.4b) und DIVA-GIS (Version 5.2) erstellt.

Ergebnisse – Die Clusteranalyse des ersten Datensatzes ergab acht aquatische Vegetationsgruppen mit ihren in Tabelle 2 aufgeführten diagnostischen, konstanten und dominanten Arten. Die erste Clusterstufe (Abb. 1) erkannte zwei Vegetationstypen basierend auf ihrer Eutrophierungstoleranz (RADULOVIĆ et al. 2011, LAKETIĆ et al. 2013). Die erste enthielt Arten, die für oligotrophe und mesotrophe Gewässer charakteristisch sind (*Lemna trisulca*, *Riccia fluitans*, *Ricciocarpus natans*, *Utricularia vulgaris* und *Wolffia arrhiza*), und die zweite enthielt die für mesotrophe und eutrophe langsam fließende und stehende Gewässer typischen Arten (*Lemna gibba*, *Salvinia natans*, *Spirodela polyrhiza* und *Azolla filiculoides*). Das OrdClAn-Clustering unterteilte den zweiten Datensatz in 17 Vegetationsgruppen (Beilage S1, Abb. 3). Der erste Schritt spaltete die Vegetationsgruppen aus dem Vlasinsko jezero-Seegebiet ab (RANDJELOVIC & ZLATKOVIC 2010), während sich die übrigen Aufnahmen in zwei Fraktionen aufteilten: die wurzelnde submerse Vegetation, und die hauptsächlich aus Schwimmblattpflanzen, freischwimmenden Einheiten dominiert von *Hydrocharis morsus-ranae* und Einheiten mit *Elodea canadensis* bestehende Vegetation. Die Analyse des LEAFPACS-Datensatzes ergab 14 Vegetationsgruppen (Beilage S2, Abb. 4), die zu vier allgemeinen Gruppen der aquatischen und semiaquatischen Vegetation gehören: (i) ober- und unterirdische Wasserlinsen-Gesellschaften, (ii) gelegentlich verankerte und wurzelnde submerse Vegetation, (iii) wurzelnde Vegetation mit Schwimmblättern und (iv) emergente Röhricht-Vegetation. Vegetationsgruppen, die für den LEAFPACS-Datensatz einzigartig sind, waren die folgenden drei: Vegetationsgruppen, die von *Vallisneria spiralis* und *Potamogeton perfoliatus* dominiert wurden, Vegetationsgruppen, gekennzeichnet durch *Polygonum amphibium* und Vegetationsgruppen mit *Paspalum paspaloides* als konstanter Art.

Diskussion – Für Serbien wurde eine neue aquatische Vegetationsklassifikation erstellt, ohne die Vegetationsgruppen in das bestehende phytozoenologische Klassifikationsschema einzuordnen. Der in dieser Studie verwendete Ansatz erlaubte es, dass Aufnahmen während der Analyse ausgeschlossen wurden, wenn sie zu inhomogenen Clustern gehörten. Da die Wahl des Distanzmaßes der kritischste Schritt bei der Auswahl der geeigneten Klassifikationsmethode ist, wurden verschiedene Arten von agglomerativen und divisiven Klassifikationsmethoden, sowohl metrische als auch nicht-metrische, getestet, um den am besten geeigneten, ökologisch interpretierbaren Ansatz zu finden. Die Zusammenstellung aller drei Datensätze hat eine ganzheitliche Bewertung der Wasservegetation im mittleren Donaubecken ermöglicht (LAKETIĆ et al. 2013). Darüber hinaus hat die LEAFPACS-Datenmatrix die bisherigen geographischen und methodischen Lücken gefüllt. Es hat sich gezeigt, dass sich eine Neudefinition einiger traditioneller Vegetationstypen als notwendig erweisen kann, wenn die Ergebnisse der numerischen Klassifikation nicht mit der formalen Definition der Vegetationseinheiten übereinstimmen (ROLEČEK 2007, SEKULOVÁ & HÁJEK 2009, DÚBRAVKOVÁ et al. 2010). So hat diese Studie gezeigt, dass Aufnahmen, die *a priori* zum *Myriophyllo-Potametum* Soó 1934 (Anhang E1, STOJANOVIĆ et al. 1994, PANJKOVIĆ 2005, RADULOVIĆ 2005, POLIĆ 2006) gestellt wurden, eigentlich zu drei Vegetationsgruppen (VG11, VG12 und VG14) gehören, die von verschiedenen Teichkrautarten (*Potamogeton crispus, P. pectinatus* und *P. nodosus*) dominiert werden. Bestände mit *Nymphaea alba* und *Nuphar lutea*, die traditionell zur Assoziation *Nymphaeetum albo-luteae* Nowinski 1928 (Anhang E1, BUTORAC 1995, PANJKOVIĆ 2005, RADULOVIĆ 2005, POLIĆ 2006) gestellt werden, teilt diese Studie in unterschiedliche Vegetationsgruppen (VG15 / LVG9 für *N. alba* und VG16 / LVG10 für *N. lutea*). Darüber hinaus wurde die von *Hydrocharis morsus-ranae* und *Nymphoides peltata* (ass. *Hydrocharito morsus-ranae-Nymphoidetum peltatae* Slavnić 1956) dominierte Gemeinschaft nun in zwei getrennte Vegetationsgruppen aufgeteilt (VG17 und VG18, Anhang E1). Obwohl zwei Vegetationsgruppen (VG5 und VG24) beide von der gleichen diagnostischen Art – *Utricularia vulgaris* – definiert werden, sind sie tatsächlich durch die Anwesenheit anderer dominanter und konstanter Arten unterscheidbar. VG 5, mit einer hohen Konstanz von *Lemna minor* und anderen Wasserlinsen-Arten, gehört folglich zur Klasse *Lemnetea* de Bolós et Masclans 1955, während die Bestände von VG24, die ausschließlich im See Vlasinsko jezero registriert wurden (RANĐELOVIĆ & BLAŽENČIĆ 1997, RANĐELOVIĆ 2002), von Leichkraut-Arten dominiert werden und daher zur Klasse *Potametea* Klika in Klika et Novák 1941 zu stellen sind. Der Vergleich zwischen den Vegetationsgruppen in dieser Studie und den Ergebnissen einer überarbeiteten Klassifizierung der Vegetation der Tschechischen Republik (CHYTRÝ & RAFAJOVÁ 2003, CHYTRÝ 2011) zeigt eine hohe Ähnlichkeit hinsichtlich der Artenzusammensetzung und des Lebensraumbedarfs von äquivalenten Vegetationseinheiten.

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Supplements

Supplement S1. Frequency table of rooted submerged vegetation and rooted vegetation with floating leaves VG9–VG25.

Beilage S1. Häufigkeitstabelle der verwurzelt-untergetauchten Vegetation sowie der verwurzelten Vegetation mit schwimmenden Blättern VG9–VG25.

Supplement S2. Frequency table of LEAFPACS vegetation groups LVG1–LVG14.

Beilage S2. Häufigkeitstabelle der LEAFPACS-Vegetationsgruppen LVG1–LVG14.

Additional supporting information may be found in the online version of this article.

Zusätzliche unterstützende Information ist in der Online-Version dieses Artikels zu finden.

Supplement E1. Correspodence between vegetation groups distinguished by cluster analysis and original classification of relevés in the first and the second dataset.

Anhang E1. Übereinstimmung zwischen den per Clusteranalyse ermittelten Vegetationsgruppen und der ursprünglichen Klassifizierung von Vegetationsaufnahmen im ersten und zweiten Datensatz.

Supplement E2. Frequency table of separate clusters of VG5, VG10, VG11, VG15 and VG17 (VG5 *Utricularia vulgaris*, VG10 *Ceratophyllum demersum* subsp. *demersum*, VG11 *Potamogeton crispus*, VG15 *Nymphaea alba*).

Anhang E2. Häufigkeitstabelle der einzelnen Cluster VG5, VG10, VG11, VG15 und VG17 (VG5 *Utricularia vulgaris*, VG10 *Ceratophyllum demersum* subsp. *demersum*, VG11 *Potamogeton crispus*, VG15 *Nymphaea alba*).

Supplement E3. Frequency table of separate clusters of LVG1, LVG2, LVG6 (LVG1 *Salvinia natans* - *Spirodela polyrhiza*, LVG2 *Ceratophyllum demersum* subsp. *demersum*, LVG6 *Trapa natans*).

Anhang E3. Häufigkeitstabelle der einzelnen Cluster LVG1, LVG2, LVG6 (LVG1 *Salvinia natans* - *Spirodela polyrhiza*, LVG2 *Ceratophyllum demersum* subsp. *demersu*m, LVG6 *Trapa natans*).

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Supplement E1. Correspodence between vegetation groups distinguished by cluster analysis and original classification of relevés in the first and the second datasets. Associations with the highest proportion of relevés in a particular vegetation group are in bold.

Anhang E1. Übereinstimmung zwischen den per Clusteranalyse ermittelten Vegetationsgruppen und der ursprünglichen Klassifizierung von Vegetationsaufnahmen im ersten und zweiten Datensatz. Zielassoziationen mit dem höchsten Anteil an Relevés in einer bestimmten Vegetationsgruppe in Fettschrift.

Vegetation group	Number of relevés	Number of species	Associations
VG1 Lemna gibba	36	32	**Lemnetum minori-gibbae (Miyawaki et J. Tx. 1960) Pass. 1996,** Wolffio-Lemnetum gibbae Bennema 1943, Salvinio-Spirodeletum polyrrhizae Slavnić 1956, Lemno-Spirodeletum pollyrhizae W. Koch 1954, Lemno minoris - Utricularietum vulgaris Soó (1928) ex. Pass. 1964
VG2 Lemna trisulca	26	24	**Lemnetum trisulcae Soó 1927,** **Lemnetum minori-trisulcae Den Hartog 1963 corr. Pass. 1996,** Lemno-Spirodeletum pollyrhizae W. Koch 1954, Salvinio-Spirodeletum polyrrhizae Slavnić 1956
VG3 Riccia fluitans	7*	12	**Lemno minoris - Riccietum fluitantis (Slavnić 1956) Pass.1996**
VG4 Ricciocarpus natans	14*	15	**Lemno minoris – Ricciocarpetum natantis Segal 1966**
VG5 Utricularia vulgaris	22	26	**Lemno minoris - Utricularietum vulgaris Soó (1928) ex. Pass. 1964**
VG6 Azolla filiculoides	38	26	**Lemno-minoris-Azolletum filiculoides Br.-Bl. 1952,** Lemno-Spirodeletum pollyrhizae W. Koch 1954
VG7 Salvinia natans - Spirodela polyrhiza	119	39	**Salvinio-Spirodeletum polyrrhizae Slavnić 1956,** Lemno-minoris-Azolletum filiculoides Br.-Bl. 1952, Lemno minoris - Utricularietum vulgaris Soó (1928) ex. Pass. 1964
VG8 Wolffia arrhiza	17	13	**Wolffietum arrhizae Myawaki et Tx. 1960**, Wolffio-Lemnetum gibbae Bennema 1943
VG9 Trapa natans	50	29	**Trapetum natantis Müller et Görs 1960,** **Ceratophyllo-Trapetum natantis Müller & Gors (1962) ex Pass.1992,** Hydrochari-Nymphoidetum peltatae Slavnić 1956, Nymphoidetum peltatae (Allorge 1922) Oberd. et Muller 1960, Ceratophylletum demersi (Soó 1927) Hild 1934 (1956)
VG10 Ceratophyllum demersum subsp. demersum	36	24	**Ceratophylletum demersi (Soó 1927) Hild 1934,** **Potamogetono - Ceratophylletum demersi (Hild et Rehnelt 1965) Pass. 1955,** Myriophyllo-Potametum Soó 1934
VG11 Potamogeton crispus	26	24	**Myriophyllo-Potametum Soó 1934,** Potamogetono - Ceratophylletum demersi (Hild et Rehnelt 1965) Pass. 1955, Ceratophyllo-Hydrocharitetum morsus-ranae Pop.1962
VG12 Potamogeton pectinatus	35	26	**Myriophyllo-Potametum Soó 1934,** Myriophyllo-Potamogetonetum pectinati Passarge 1996, Najadetum minoris Ubrizsy (1948) 1961, Ceratophyllo demersi - Vallisnerietum spiralis ass. Lazić 2006
VG13 Potamogeton obtusifolius	5*	4	**Potametum obtusifolii Carst. 1954**
VG14 Potamogeton nodosus	8	18	**Potametum nodosi Soó (1928) 1960, Segal 1964,** **Myriophyllo-Potametum Soó 1934**
VG15 Nymphaea alba	62	30	**Nymphaeetum albae Vollmar 1947,** **Nymphaeetum albo-luteae Nowinski 1928,** Hydrochari-Nymphoidetum peltatae Slavnić 1956, Myriophyllo-Nupharetum W. Koch 1926, Hydrochari-Nymphoidetum peltatae Slavnić 1956, Trapetum natantis Müller et Görs 1960, Nymphoidetum peltatae (Allorge 1922) Oberd. et Muller 1960, Ceratophylletum demersi (Soó 1927) Hild 1934 (1956)
VG16 Nuphar lutea	15	18	**Nymphaeetum albo-luteae Nowinski 1928**
VG17 Nymphoides peltata	56	32	**Nymphoidetum peltatae (Allorge 1922) Oberd. et Muller 1960,** Hydrochari-Nymphoidetum peltatae Slavnić 1956, **Nymphoideto-Hippuridetum Antić et al. 1969,** Myriophyllo-Potametum Soó 1934
VG18 Hydrocharis morsus-ranae	17	19	**Hydrocharidetum morsus-ranae Van Langendonck 1935,** **Ceratophyllo-Hydrocharitetum morsus-ranae Pop.1962,** Nymphaeetum albo-luteae Nowinski 1928
VG19 Najas marina	14	13	**Najadetum marinae Fukarek 1961,** **Potamogetono-Najadetum marinae Horvatić et Micev. 1960 in Horvatić 1963 corr.**
VG20 Vallisneria spiralis	24	22	**Ceratophyllo demersi - Vallisnerietum spiralis ass. Lazić 2006,** Ceratophylletum demersi (Soó 1927) Hild 1934, Myriophyllo-Potametum Soó 1934, Trapetum natantis Müller et Görs 1960, Nymphaeetum albo-luteae Nowinski 1928
VG21 Elodea canadensis	12	15	**Elodeetum canadensis (Pign. 1953) Soó 1964, Passarge 1964, Westhoff 1969**
VG22 Elodea nuttallii	10	21	**Elodeetum nuttallii Ciocârlan i sar. 1997**
VG23 Ranunculus aquatilis	5	12	**Polygono-Ranunculetum aquatilis V. Ranđelović i sar. 1995,** Potameto perfoliati-Ranunculuetum fluitantis W. Koch 1926
VG24 Utricularia vulgaris	15	13	**Calitricho-Utricularietum vulgaris V. Ranđelović 1998,** **Utricularietum vulgaris R. Lakušić 1968 ex V.Rand. 1995**
VG25 Nitella opaca	5*	7	**Nitelletum opacae Corillion 1957**

Supplement E2. Frequency table of separate clusters of VG5, VG10, VG11, VG15 and VG17 (VG5 *Utricularia vulgaris* , VG10 *Ceratophyllum demersum* subsp. *demersum,* VG11 *Potamogeton crispus* , VG15 *Nymphaea alba*). The numbers given in the table are constancy classes of species frequency (over 20% only). Their upper indices are the fidelity value of a species for a particular cluster, expressed using the phi coefficient × 100 (phi-coefficient value higher than 0.1). Dominant species are in bold.

Anhang E2. Häufigkeitstabelle der einzelnen Cluster Häufigkeitstabelle der einzelnen Cluster VG5, VG10, VG11, VG15 und VG17 (VG5 *Utricularia vulgaris* , VG10 *Ceratophyllum demersum* subsp. *demersum* , VG11 *Potamogeton crispus* , VG15 *Nymphaea alba*). Die in der Tabelle gegebenen Zahlen sind Stetigkeitsklassen (nur Arten über 20% sind aufgeführt). Die hochgestellten Indices sind Treuewerte einer Art für das spezifische Cluster, ausgedrückt als phi-Koeffizient x 100 (nur phi-Koeffizienten höher als 0,1 sind angegeben). Dominante Arten sind fett gedruckt.

Clusters	**5a**	**5b**	**10a**	**10b**	**11a**	**11b**	**15a**	**15b**	**17a**	**17b**
Utricularia vulgaris L.	**5^{39}**	**5^{39}**	.	.	.	.	.	.	.	.
Lemna minor L.	**5^{11}**	**3**	.	2	2	2	2	.	3	2
Lemna trisulca L.	5^{26}	.	.	.	.	.	.	.	2	.
Spirodela polyrhiza (L.) Schleid.	2	.	.	5^{15}	3	2	2	2	5	2
Ceratophyllum demersum L. subsp. demersum	.	**5**	**5^{9}**	**5^{13}**	**3**	**5**	**5^{18}**	2	**5**	3
Myriophyllum spicatum L.	.	3	5^{15}	4^{10}	**5^{15}**	**5^{15}**	3	**3^{14}**	2	4^{12}
Hydrocharis morsus-ranae L.	.	3	.	.	2	**4**	3	3	**2**	**4^{16}**
Trapa natans L.	.	2	.	.	.	.	3	2	.	3^{12}
Salvinia natans (L.) All.	.	2	.	2	.	.	2	2	3	2
Phragmites australis (Cav.) Trin. ex Steud.	.	2	.	.	.	.	.	.	.	.
Sparganium erectum L. subsp. erectum	.	2^{26}	.	.	.	.	.	.	.	.
Lycopus europaeus L.	.	2^{42}	.	.	.	.	.	.	.	.
Potamogeton perfoliatus L.	.	.	3^{23}	.	2	2^{23}	.	.	.	.
Potamogeton crispus L.	.	.	2	2	**5^{31}**	**5^{31}**	.	.	.	.
Nymphoides peltata (S.G.Gmel.) Kuntze	.	.	2	.	.	.	.	**4^{30}**	**5^{31}**	**5^{54}**
Polygonum amphibium L.	.	.	2	.	.	2	.	2	.	.
Lemna gibba L.	.	.	2	.	.	.	.	.	.	.
Potamogeton pectinatus L.	.	.	.	.	**3**	2^{24}	.	.	.	.
Ranunculus circinatus Sibth.	.	.	.	.	2	.	.	.	.	.
Potamogeton lucens L.	.	.	.	.	.	2	.	.	2^{11}	.
Nymphaea alba L.	.	.	.	.	.	.	**5^{61}**	**5^{37}**	.	.
Nuphar lutea Sm.	.	.	.	.	.	.	**4^{48}**	.	2	.
Najas marina L.	.	.	.	.	.	.	.	.	2	.
Potamogeton nodosus Poir.	.	.	.	.	.	.	.	.	2	.
Elodea canadensis Michx.	.	.	.	.	.	.	.	.	2	.

Supplement E3. Frequency table of separate clusters of LVG1, LVG2, LVG6 (LVG1 *Salvinia natans* - *Spirodela polyrhiza*, LVG2 *Ceratophyllum demersum* subsp. *demersum*, LVG6 *Trapa natans*). The numbers given in the table are constancy classes of species frequency (over 20% only). Their upper indices are the fidelity value of a species for a particular cluster, expressed using the phi coefficient × 100 (phi-coefficient value higher than 0.1). Dominant species are in bold.

Anhang E3. Häufigkeitstabelle der einzelnen Cluster LVG1, LVG2, LVG6 (LVG1 *Salvinia natans* - *Spirodela polyrhiza*, LVG2 *Ceratophyllum demersum* subsp. *demersum,* LVG6 *Trapa natans*). Die in der Tabelle gegebenen Zahlen sind Stetigkeitsklassen (nur Arten über 20% sind aufgeführt). Die hochgestellten Indices sind Treuewerte einer Art für das spezifische Cluster, ausgedrückt als phi-Koeffizient x 100 (nur phi-Koeffizienten höher als 0,1 sind angegeben). Dominante Arten sind fett gedruckt.

	1a	**1b**	**2a**	**2b**	**6a**	**6b**
Salvinia natans (L) All	$\mathbf{5^{31}}$	5	$\mathbf{4^{15}}$	**4**	$\mathbf{5^{25}}$	2
Spirodela polyrhiza (L) Schleiden	$\mathbf{5^{53}}$	$\mathbf{5^{13}}$	$\mathbf{3^{16}}$	**4**	2	4
Lemna minor L	$\mathbf{5^{78}}$	$\mathbf{5^{19}}$	.	.	.	.
Trapa natans L	.	.	.	.	$\mathbf{5^{61}}$	$\mathbf{5^{30}}$
Ceratophyllum demersum L subsp demersum	$\mathbf{5^{30}}$	**5**	$\mathbf{5^{14}}$	$\mathbf{5^{16}}$	**5**	**5**
Najas marina L	.	.	.	.	2	$\mathbf{3^{21}}$
Nymphoides peltata (S G Gmelin) O Kuntze	2	**4**	**4**	$\mathbf{2^{22}}$	**2**	**3**
Phragmites australis (Cav) Trin ex Steudel	.	.	.	.	2	$\mathbf{3^{22}}$
Utricularia australis R Br	.	.	.	.	.	$\mathbf{4^{85}}$
Utricularia vulgaris L	.	.	.	.	.	2^{23}
Elodea nuttallii (Planchon) St John	$\mathbf{5^{63}}$	$\mathbf{4^{19}}$	.	.	.	.
Lemna gibba L	$\mathbf{4^{77}}$	$\mathbf{4^{16}}$	.	.	.	.
Azolla filiculoides Lam	$\mathbf{2^{43}}$	**4**	.	.	.	.
Myriophyllum spicatum L	2	4^{21}	4	3^{30}	.	.
Paspalum paspaloides (Michx) Scribner	2	3	.	.	.	.
Hydrocharis morsus-ranae L	.	3^{14}	.	.	.	.
Lemna trisulca L	.	2	.	.	.	.
Nymphaea alba L	.	2	.	.	.	.
Wolffia arrhiza (L) Horkel ex Wimmer	.	2^{16}	.	.	.	.
Polygonum amphibium L	.	2	**3**	**2**	.	.
Callitriche palustris L	.	2	.	.	.	.
Potamogeton crispus L	.	.	**2**	.	.	.
Potamogeton lucens L	.	.	2^{14}	.	.	.
Typha angustifolia L	.	.	**2**	.	.	.
Potamogeton perfoliatus L	.	.	2	.	.	.

Supplement S1. Frequency table of rooted submerged vegetation and rooted vegetation with floating leaves VG9-VG25. * Statistical procedures applied. The numbers given in the table are percentage frequencies of species (over 20% only). Their upper indices are the fidelity value of a species for a particular vegetation group, expressed using the phi coefficient × 100 (phi-coefficient value higher than 0.16). Dominant species are in bold. Nominal species are on a grey background. Vegetation groups recorded on a single site are marked with an asterisk.

Beilage S1. Häufigkeitstabelle der verwurzelt-untergetauchten Vegetation sowie der verwurzelten Vegetation mit schwimmenden Blättern VG9-VG25. * Statistische Verfahren wurden angewendet. Die in der Tabelle gegebenen Zahlen sind prozentuale Stetigkeitswerte (nur Arten über 20% sind aufgeführt). Die hochgestellten Indices sind Treuewerte einer Art für die spezifische Vegetationsgruppe, ausgedrückt als phi-Koeffizient x 100 (nur phi-Koeffizienten höher als 0,16 sind angegeben). Dominante Arten sind fett gedruckt, namengebende Arten mit einem grauen Hintergrund. Die an einem einzelnen Wuchsort

Vegetation group	**9**	**10**	**11**	**12**	**13***	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22***	**23**	**24***	**25***
Number of relevés	**50**	**36**	**26**	**35**	**5**	**8**	**62**	**15**	**56**	**17**	**14**	**24**	**12**	**10**	**5**	**15**	**5**
Trapa natans L.	**100^{43}**			26	.	38	47	73	39	.	36	**71**	25	100	.	.	.
Ceratophyllum demersum L. subsp. demersum	**94**	**100^{17}**	**65**	83	.	100	**82**	**60**	**64**	76	86	**100**	75	100	.	.	.
Potamogeton crispus L.	.	31	**100^{44}**	31	40	.	.	.	.	.	43	54	.	80	.	.	.
Potamogeton pectinatus L.	.	.	35	**100^{62}**	.	.	.	.	.	.	.	21	33	60	.	.	.
Potamogeton obtusifolius Mert. & W.D.J.Koch	.	.	.	.	**100^{46}**	.	.	.	.	.	.	.	.	.	40	73^{58}	100^{46}
Potamogeton nodosus Poir.	.	.	.	.	.	**100^{36}**	.	.	.	.	.	.	25	30	.	.	.
Nymphaea alba L.	.	.	.	.	.	50	**97^{73}**	.	.	.	.	.	.	.	.	.	.
Nuphar lutea Sm.	.	.	.	.	.	.	**52^{40}**	**100^{42}**	.	.	.	.	.	.	.	.	.
Nymphoides peltata (S.G.Gmel.) Kuntze	26	.	.	.	.	.	**37**	.	**100^{63}**	.	.	.	.	.	.	.	.
Hydrocharis morsus-ranae L.	34	.	46	.	.	63	45	47	**59**	**100^{21}**	.	54	50	30	.	.	.
Najas marina L.	.	.	.	.	.	**75**	.	.	.	.	**100^{45}**	.	.	.	.	.	.
Vallisneria spiralis L.	.	.	.	.	.	25	.	27	.	.	.	**100^{49}**	.	.	.	.	.
Elodea canadensis Michx.	.	.	.	.	.	.	.	.	.	.	.	.	**100^{50}**	.	.	.	.
Elodea nuttallii (Planch.) H.St.John	.	.	.	.	.	.	.	.	.	.	.	.	.	**100^{81}**	.	.	.
Ranunculus aquatilis L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**100^{51}**	80^{70}	.
Utricularia vulgaris L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	100	**100^{45}**	.
Nitella opaca (C.Agardh ex Bruzelius)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	**100^{100}**
Myriophyllum spicatum L.	56	83^{18}	**100**	**91**	80	**100**	52	47	57	41	43	79	.	.	.	40	.
Sagittaria sagittifolia L.	.	.	.	.	.	25	.	.	.	.	.	.	.	.	.	.	.
Spirodela polyrhiza (L.) Schleid.	58	69	46	77	.	.	34	87	46	88	50	50	75	90	.	.	.
Salvinia natans (L.) All.	56	28	.	.	.	38	32	53	34	47	.	42	50	30	.	.	.
Lemna minor L.	34	31	23	66	.	.	31	73	36	100	21	33	92	80	.	.	.
Potamogeton perfoliatus L.	.	31	31	**43**	.	.	.	.	.	.	.	21	.	.	.	.	.
Ranunculus circinatus Sibth.	.	.	23	.	.	88^{43}	.	.	.	.	21	.	.	.	.	.	.
Polygonum amphibium L.	.	.	23	.	.	.	.	.	.	.	.	.	.	.	100	80	.
Potamogeton pusillus L.	.	.	.	.	60	.	.		.	.	.	.	.	.	100^{43}	100^{75}	40
Lemna trisulca L.	.	.	.	.	.	.	.	**33**	.	.	.	.	50	.	.	.	.
Lemna gibba L.	.	.	.	.	.	.	.	.	.	24	.	.	.	60	.	.	.
Eleocharis acicularis (L.) Roem. & Schult.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	80^{89}	.	.
Myriophyllum verticillatum L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	60^{42}	.	.
Callitriche palustris L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40	33^{48}	.
Potamogeton gramineus L.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40	27	.
Chara braunii Gm.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	40^{63}

Supplement S2. Frequency table of LEAFPACS vegetation groups LVG1-LVG14. * Statistical procedures applied. The numbers given in the table are percentage frequencies of species (over 20% only). Their upper indices are the fidelity value of a species for a particular vegetation group, expressed using the phi coefficient × 100 (phi-coefficient value higher than 0.25). Dominant species are in bold. Nominal species are on a grey background. Vegetation groups recorded on a single site are marked with an asterisk.

Beilage S2. Häufigkeitstabelle der LEAFPACS-Vegetationsgruppen LVG1-LVG14. * Statistische Verfahren wurden angewendet. Die in der Tabelle gegebenen Zahlen sind prozentuale Stetigkeitswerte (nur Arten über 20% sind aufgeführt). Die hochgestellten Indices sind Treuewerte einer Art für die spezifische Vegetationsgruppe, ausgedrückt als phi-Koeffizient x 100 (nur phi-Koeffizienten höher als 0,25 sind angegeben). Dominante Arten sind fett gedruckt, namengebende Arten mit einem grauen Hintergrund. Die an einem einzelnen Wuchsort aufgenommenen Vegetationsgruppen sind mit einem Stern markiert.

Vegetation group	**1**	**2**	**3**	**4***	**5**	**6**	**7**	**8**	**9**	**10***	**11***	**12**	**13**	**14**
Number of relevés	**77**	**98**	**57**	**21**	**12**	**88**	**13**	**15**	**11**	**8**	**9**	**26**	**29**	**60**
Salvinia natans (L) All	**83**^{28}	**71**	.	.	.	**85**	.	**67**	.	.	.	77	**100**	**60**
Spirodela polyrhiza (L) Schleiden	**100**^{56}	**65**	.	.	**100**	**30**	.	.	**73**	.	.	**65**	55	62
Ceratophyllum demersum L subsp demersum	**97**^{31}	**100**^{22}	.	**71**	.	**93**	.	**93**	**82**	.	.	**27**	**100**	**100**
Najas marina L	.	.	**100**^{71}	.	.	31	**54**	.	.	.	.	.	.	.
Potamogeton perfoliatus L	.	.	.	**100**^{70}	.	.	38	.	.	.	.	.	.	.
Vallisneria spiralis L	.	.	.	**95**^{98}	.	.	.	.	.	.	.	.	.	.
Elodea nuttallii (Planchon) St John	**70**^{67}	.	.	.	**100**^{23}	.	.	.	.	.	**100**	27	.	.
Trapa natans L	.	.	.	.	.	**100**^{70}	.	**53**	.	.	.	.	28	**62**^{28}
Potamogeton nodosus Poiret	.	.	.	.	.	.	**100**^{100}	.	.	.	.	.	.	.
Nymphoides peltata (S G Gmelin) O Kuntze	**26**	**40**	.	.	**42**	**24**	.	**100**^{27}	.	.	.	.	**41**	.
Nymphaea alba L	.	.	.	.	**75**^{35}	.	.	.	**100**^{46}	25	.	.	.	.
Nuphar lutea (L) Sm	.	.	.	.	25	.	.	**73**^{43}	.	**100**^{44}	.	.	.	.
Polygonum amphibium L	.	**31**^{26}	.	.	.	.	.	.	**91**^{33}	.	**100**^{33}	.	.	.
Paspalum paspaloides (Michx) Scribner	20	.	.	.	**100**^{37}	.	.	.	.	.	.	**100**^{55}	.	.
Typha angustifolia L	.	.	.	.	.	.	**69**^{28}	.	.	**25**	.	.	**100**^{64}	.
Phragmites australis (Cav) Trin ex Steudel	.	.	.	.	.	20	.	**33**	.	**100**^{25}	.	.	**38**	**100**^{71}
Myriophyllum spicatum L	35	47	**100**^{43}	**43**	**100**	.	**100**	.	**64**	.	**100**	.	.	.
Lemna minor L	**100**^{82}	.	.	.	**100**	.	.	.	.	.	.	**100**^{26}	48	.
Lemna gibba L	**88**^{80}	.	.	.	42	.	.	.	.	.	.	**100**^{30}	.	.
Wolffia arrhiza (L) Horkel ex Wimmer	27^{30}	.	.	.	.	.	.	.	.	.	.	96^{53}	.	.
Azolla filiculoides Lam	**36**^{45}	.	.	.	.	.	.	.	.	.	.	23	.	.
Lemna trisulca L	23^{28}	.	.	.	33	.	.	60^{25}	.	.	.	.	.	.
Najas minor All	.	.	.	.	.	.	69^{60}	.	.	.	.	.	.	.
Hydrocharis morsus-ranae L	.	.	.	.	.	.	.	.	.	25	.	.	**41**^{20}	.
Typha latifolia L	.	.	**32**^{53}	.	.	.	.	.	.	.	.	.	.	.
Utricularia vulgaris L	.	.	25	.	.	.	.	.	.	**88**^{33}	.	.	.	.
Potamogeton crispus L	.	.	.	.	.	.	.	.	.	.	**78**^{45}	.	.	.
Elatine triandra Schkuhr	.	.	.	.	.	.	.	.	.	.	**78**^{88}	.	.	.
Potamogeton acutifolius Link	.	.	.	.	.	.	.	.	.	.	56^{68}	.	.	.
Ranunculus aquatilis L	.	.	.	.	.	.	.	.	.	.	33^{57}	.	.	.
Equisetum fluviatile L	.	.	.	.	.	.	.	.	.	.	22^{47}	.	.	.
Callitriche palustris L	.	.	.	.	**58**^{45}	.	.	.	.	.	.	.	.	.