

# The effects of physical-chemical water parameters on the *Nymphaeion* alliance development in northwestern Serbia

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## Abstract

*Nymphaeion* alliance vegetation is dominant floating-leaved vegetation in the Danube–Tisza–Danube hydrosystem in northwestern Serbia and comprises *Nymphaeetum albae*, *Nymphaeetum albo-luteae*, *Nymphoidetum peltatae* and *Trapetum natantis* associations. Comparative analysis of physical-chemical water parameters on localities where these – in most parts of Europe endangered and vulnerable stands – develop showed that most phytocenoses are associated with specific habitat conditions. Of the analyzed water properties, the factors that cause *Nymphaeion* alliance phytocenoses differentiation are primarily pH, alkalinity and COD-MnO<sub>4</sub>. Formation of the *Nymphaeetum albae* stands is significantly associated with the highest values of pH, COD-MnO<sub>4</sub> and alkalinity, and the lowest nitrate, nitrite, dissolved and the total phosphorus content values, in comparison to the other studied associations. *Nymphoidetum peltatae* stands develop in waters characterized by the lowest pH and COD-MnO<sub>4</sub>, low alkalinity, and the highest nitrate and nitrite values in relation to the other analyzed phytocenoses. *Trapetum natantis* stands, on the other hand, prefer the warmer sections of the canal network, neutral pH, and the highest values of BOD<sub>5</sub>, dissolved and total phosphorus. Habitat conditions in which *Nymphaeetum albo-luteae* stands develop are of the widest range in comparison to other investigated phytocenoses.

**Keywords:** *Nymphaeion*; water properties; *Nymphaeetum albae*; *Nymphaeetum albo-luteae*; *Nymphoidetum peltatae*; *Trapetum natantis*; Serbia

## Introduction

Floating-leaved plants are a common component of channels, rivers, lakes, ponds and other water basins. Floating-leaved phytocenoses of *Nymphaeion* Oberd. 1956 alliance play an important role in the shallow aquatic ecosystems [1]. *Nymphaeion* alliance (order *Potametalia* W. Koch 1926, class *Potametea* Tx. et Prsg. 1942, according to Soó [2]) vegetation is the dominant aquatic vegetation in the Hydrosystem Danube–Tisza–Danube (Hs DTD) in the northwestern Serbia. In the aforementioned sections, this alliance is represented by stands of the following associations: *Nymphaeetum albae* Vollmar 1947, *Nymphaeetum albo-luteae* Nowinski 1928, *Nymphoidetum peltatae* (Allorge 1922) Oberd. et Müller 1960 and *Trapetum natantis* Müller et Görs 1960.

*Nymphaea alba*, *Nuphar lutea* and *Nymphoides peltata* have least concern status on the “Red list of threatened species for Europe” [3], while *N. alba* and *N. lutea* have strictly protected national conservation status in Serbia [4]. *Nymphoidetum peltatae* stands in aquatic vegetation of Vojvodina are in the withdrawal phase [5]. *Trapa natans*,

the edicator of *Trapetum natantis* association, is threatened in much of Europe and is subject of conservation efforts aimed at preserving and restoring its population (IUCN-LC). *T. natans* is located on the red lists of many European countries [3], and is included under “Appendix I” of the “Convention on the conservation of European wildlife and natural habitats” (Bern Convention) and IPA list (IPA criterion A, threatened species).

Factors affecting the development and distribution of *Nymphaeion* alliance phytocenoses were a subject of numerous studies, whereby physical-chemical water parameters [6–10], substrate composition [6,8,10], hydromorphological characteristics [7,11–19], water level fluctuations [18], presence of dams and weirs that disrupt the natural aquatic ecosystem regimen [13], waterflow velocity [20], etc. were investigated. According to Džigurski et al. [21,22], hydromorphological conditions in the studied hydromelioration facility (2–8 m canal depth, variable flow rate and navigation intensity, presence of more than 20 weirs, regulated water level changes, canal age 50–200 years) affect the development of macrophytes differently. Dawson and Szoszkiewicz [23] indicate that *Nymphaeion* alliance vegetation is typically found in habitats characterized by slow water flow. Findings of several extant studies suggest that, in the key phases of the *Nymphaea alba* lifecycle, dynamic changes and significant

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increases in the water level adversely affect the development of this species [24,25]. Optimum development of ass. *Nymphoidetum peltatae* stands is noted in slow-flowing waters [11,26], whereas, although *Nuphar luteum* favors more stagnant waters, it can tolerate smaller fluctuations in water flow and level [11]. On the other hand, *Trapa natantis* is particularly tolerant of rapid water flow and fluctuations in water level [11,27].

The aim of this paper is to present floristic composition, distribution and physical-chemical water parameters of *Trapa natantis*, *Nymphaeetum albo-luteae*, *Nymphaeetum albae* and *Nymphoidetum peltatae* stands in northwestern Serbia, which are valuable in the aquatic ecosystem biodiversity conservation efforts. The findings of this study, i.e., the defined optimal levels of the physical-chemical water parameters of these phytocenoses contribute to the implementation of the “European water framework directive” (WFD), which requires monitoring of the ecological status of surface waters [28–31].

## Material and methods

Vojvodina, as the lowest part of the Pannonian Plain, due to the inflow of water masses formed in the Alps, Carpathians and Dinarides, is the largest hydro-confluence in Europe. Owing to this dense network of watercourses, regulation of their unfavorable water regimens was necessary, which was

achieved via the construction of the Hs DTD canal network [32]. Hs DTD is a central part of the Rhine–Main–Danube navigational route and one of the largest hydrosystems in Europe (Fig. 1).

Hs DTD is located in the Province of Vojvodina, in northern Serbia (44°39'15.04" and 46°10'11.32" north latitude to the 18°50'15.00" and 21°33'27.82" east longitude). Bačka part of the Hs DTD comprises a network of nine canals, between the Danube River (in the west and south) and Tisza (in the east), 421 km in length. In terms of elevation, the network is partitioned into eight pools. In this context, a pool consists of one or more canals delimited by weirs, boat transits and pumping stations, with controlled water regimen. In the region, Hs DTD serves multiple purposes, providing drainage, irrigation, and navigation, and is used for fishing and recreation, as well as industrial and municipal wastewater acceptance.

Long-term studies of aquatic vegetation of Hs DTD in Bačka (Vojvodina Province, Serbia) were conducted in the vegetative period between 2004 and 2007, by applying the Braun-Blanquet method [33]. Plant species were determined according to Josifović [34], Tutin et al. [35,36] and Jávorka and Csapody [37]. All the relevés recorded in the investigated phytocenoses were aggregated in one synoptic phytosociological table that shows the presence, abundance and coverage degree (from “+” to “5”). Only the stands that covered at least the minimum area recommended for these types of vegetation were recorded (>10 m<sup>2</sup>).

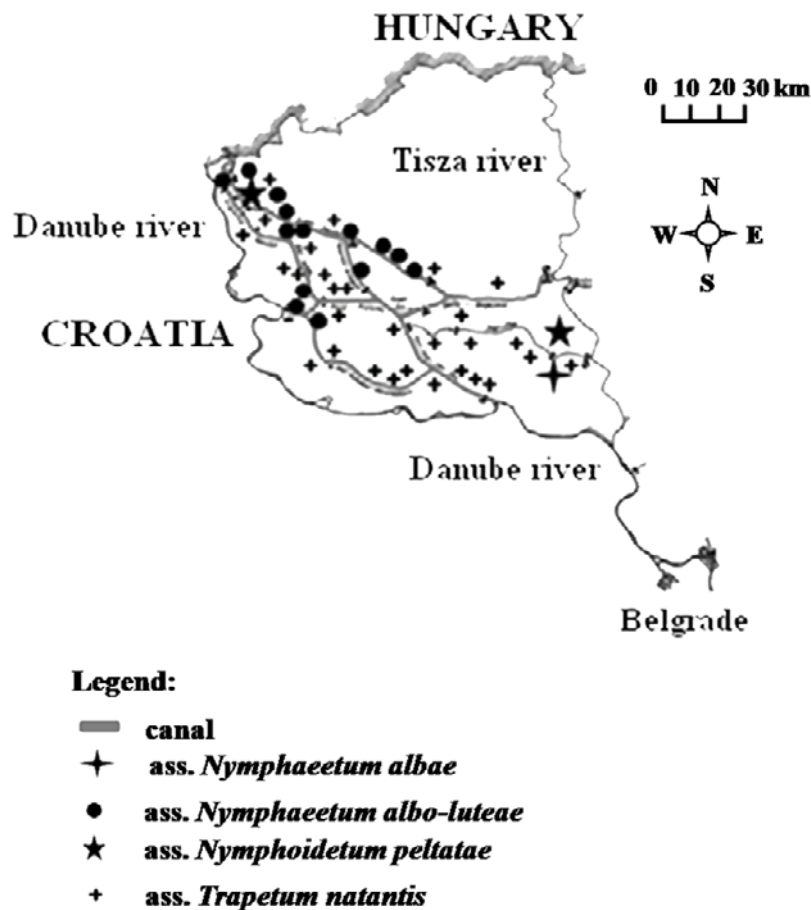


Fig. 1 Distribution of studied phytocenoses of *Nymphaeion* alliance on Hs DTD in Bačka.

In the study period, the water samples were collected three times a year, during the vegetative period (May–August), 30 cm from water surface, on the canal sections where existence of *Nymphaeion* alliance phytocenoses were previously ascertained (Fig. 1). Water samples were taken at locations minimum 400 m apart. Basic physical and chemical water properties were determined according to standard methods [38]. The following parameters were monitored: temperature, pH value (with pH-meter), alkalinity, chemical (COD-MnO<sub>4</sub>) and biological (BOD<sub>5</sub>) oxygen demand, and nutrient content (NH<sub>4</sub><sup>+</sup>, NO<sub>3</sub><sup>-</sup>, NO<sub>2</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup> and total phosphorus).

The water chemical analysis data pertaining to the aforementioned parameters was processed using STATISTICA 7.0 software [39]. The statistical significance of the differences among the studied phytocenoses, in terms of the analyzed water parameters, was established by applying ANOVA and Fisher LSD-test.

## Results

### Species composition of the studied plant associations

Floating-leaved vegetation *Nymphaeion* of Hs DTD is represented by stands of associations *Nymphaeetum albae*, *Nymphaeetum albo-luteae*, *Nymphoidetum peltatae* and *Trapetum natantis*.

Ass. *Nymphaeetum albae* stands develop at water depths of 0.5–2 m, on the section that is a natural depression and is used as a fishpond (Fig. 1). This section is characterized by a wide waterbed, slow water flow and water level fluctuations of significantly lower intensity compared to the other canal network sections. The studied stands consist of 12 plant species (Tab. 1) – a floristic poverty characteristic of this phytocenosis, on average comprising 2–15 taxa [40]. In addition to floating-leaved species *Nymphaea alba*, this distinctive collection also includes submerged species *Ceratophyllum demersum* and *Myriophyllum spicatum*; thus, this association is significantly bilayer. In the ecological series in the study site, these stands build on the stands of *Ceratophylletum demersi* (Soó 27) Hild. 1956 and ass. *Nymphoidetum peltatae*, and towards the shore, emerged stands of *Scirpo-Phragmitetum* W. Koch 1926 and ass. *Typhetum angustifoliae* Pign. 1953.

At a significant number of sites within the canal network, ass. *Nymphaeetum albo-luteae* forms a narrow fringe towards emerged vegetation, only occasionally forming broad bands that extend to the middle of the canal. These stands achieve optimum development in water depths of 1–2.5 m. The floristic composition consists of 18 hydrophytes, whereby the distinctive collection, in addition to the characteristic association species, comprises *C. demersum*, *M. spicatum*, *Vallisneria spiralis* and *Salvinia natans* (Tab. 1). Ass. *Nymphaeetum albo-luteae* stands exhibit a typical bilayer structure. In the ecological series, towards deeper water, abundant populations of *Myriophyllum spicatum* and stands of *Ceratophylletum demersi*, *Ceratophyllo demersi-Vallisnerietum spiralis* Lazić 2006, *Potametum nodosi* Soó (1928) 1960, Segal 1964 and *Trapetum natantis* are found, and towards the shore, associations *Hydrocharidetum morsus-ranae* van Langendonck 1935, *Salvinia-Spirodeletum polyrrhizae*

Slavnić 1956, *Scirpo-Phragmitetum*, *Typhetum angustifoliae* and *Typhetum latifoliae* G. Lang 1973.

Ass. *Nymphoidetum peltatae* was established on only two, mutually distant sites, at water depths of 0.5–2.5 m. The analyzed stands comprise 15 macrophyte species (Tab. 1). In addition to the edificator, whose abundance and wide coverage provides a unique character to these stands, species of the characteristic group comprising *T. natans*, *Hydrocharis morsus-ranae*, *C. demersum*, *V. spiralis*, *Lemna minor*, *Spirodela polyrrhiza* and *S. natans* contribute to the heterogeneous structure of these stands. Low values of abundance and coverage of the submerged plants in these stands attest to the significant influence of ass. *Nymphoidetum peltatae* stands on the reduced growth of submersed macrophytes [41]. At study sites, towards the middle of the canal, ass. *Nymphoidetum peltatae* stands build on the stands of ass. *Ceratophylletum demersi* and ass. *Nymphaeetum albae*, or *Sagittaria sagittifolia* L. and *Potamogeton perfoliatus* L. populations. Towards the shore, they are in contact with the stands of ass. *Scirpo-Phragmitetum* and ass. *Typhetum angustifoliae*.

**Tab. 1** Synoptic table of the *Nymphaeion* alliance in Hs DTD in Bačka.

Phytocenoses	NA	NL	NP	TN
<b>Number of relevés</b>	15	32	20	44
<b>Number of species</b>	12	18	15	20
<b><i>Nymphaeion</i></b>				
<i>Nymphaea alba</i> L.	V <sup>3-5</sup>	III <sup>1-3</sup>	II <sup>+</sup>	I <sup>+</sup>
<i>Nuphar lutea</i> (L.) Sm.		V <sup>2-5</sup>	III <sup>+1</sup>	I <sup>+</sup>
<i>Nymphoides peltata</i> Hill.	I <sup>1</sup>	I <sup>+</sup>	V <sup>2-5</sup>	
<i>Trapa natans</i> L.	I <sup>+</sup>	III <sup>+1</sup>	IV <sup>+</sup>	V <sup>3-5</sup>
<i>Hydrocharis morsus-ranae</i> L.	I <sup>+</sup>	III <sup>+1</sup>	IV <sup>+2</sup>	IV <sup>+2</sup>
<i>Polygonum amphibium</i> L.	I <sup>+</sup>			I <sup>+</sup>
<b><i>Potametalia and Potametea</i></b>				
<i>Myriophyllum spicatum</i> L.	IV <sup>+2</sup>	IV <sup>+1</sup>	III <sup>+2</sup>	IV <sup>+1</sup>
<i>Ceratophyllum demersum</i> L.	IV <sup>+3</sup>	V <sup>+3</sup>	V <sup>+2</sup>	IV <sup>+2</sup>
<i>Potamogeton perfoliatus</i> L.	I <sup>+</sup>	I <sup>+</sup>	II <sup>+</sup>	I <sup>+1</sup>
<i>Najas marina</i> L.	I <sup>+</sup>	I <sup>+</sup>		I <sup>+</sup>
<i>Vallisneria spiralis</i> L.		IV <sup>+1</sup>	IV <sup>+1</sup>	II <sup>+1</sup>
<i>Elodea canadensis</i> Rich		I <sup>+</sup>		I <sup>+</sup>
<i>Potamogeton crispus</i> L.		I <sup>1</sup>		I <sup>+</sup>
<i>Potamogeton pectinatus</i> L.			I <sup>+</sup>	II <sup>+1</sup>
<b>Others</b>				
<i>Lemna minor</i> L.	I <sup>+</sup>	III <sup>+</sup>	IV <sup>+</sup>	III <sup>+</sup>
<i>Spirodela polyrrhiza</i> (L.) Schleid.	I <sup>+</sup>	II <sup>+3</sup>	IV <sup>+</sup>	IV <sup>+1</sup>
<i>Utricularia vulgaris</i> L.	I <sup>1-3</sup>	I <sup>+</sup>		I <sup>+</sup>
<i>Salvinia natans</i> (L.) Allioni		IV <sup>+2</sup>	V <sup>+1</sup>	II <sup>+1</sup>
<i>Lemna trisulca</i> L.		III <sup>+</sup>	III <sup>+</sup>	I <sup>+</sup>
<i>Sagittaria sagittifolia</i> L.		I <sup>1</sup>	II <sup>+</sup>	I <sup>+</sup>
<i>Lemna gibba</i> L.				I <sup>+</sup>

NA – *Nymphaeetum albae*; NL – *Nymphaeetum albo-luteae*; NP – *Nymphoidetum peltatae*; TN – *Trapetum natantis*.

Ass. *Trapetum natantis* is the dominant floating-leaved vegetation in the Hs DTD canal network (Fig. 1) [21]. These stands achieve optimal development in the central, deeper parts of the canal (about 3 m), characterized by frequent water fluctuations, as well as in the calm and shallower sections (about 0.5 m). They have developed in the form of narrow or wider bands, while covering the entire canal width in some places. The floristic composition consists of 20 species (Tab. 1). In addition to the edicator, the characteristic group includes free-floating *H. morsus ranae* and *S. polyrrhiza*, and submerged *C. demersum* and *M. spicatum*. In deeper waters, in the absence of competition from other floating plants, these stands independently form a wide belt. At lower depths, they form a belt of floating vegetation, together with the stands of communities *Nymphaeum albo-luteae*, *Hydrocharidetum morsus-ranae*, *Salvinio-Spirodeletum polyrrhizae* and *Lemno-Spirodeletum*. Apart from the floating community stands, in the ecological series, stands of ass. *Trapetum natantis* build on the submerged stands of associations *Ceratophylletum demersi*, *Ceratophyllo demersi-Vallisnerietum spiralis* and *Myriophyllo-Potametum* Soó 1934 and the emerged stands of associations *Scirpo-Phragmitetum*, *Typhetum angustifoliae* and *Typhetum latifoliae*.

#### Physical-chemical water parameters of the analyzed phytocenoses habitat

The physical-chemical parameter water analysis revealed that pH, alkalinity and COD-MnO<sub>4</sub> are the key factors that cause the phytocenoses differentiation in *Nymphaeum albae*, *Nymphaeum albo-luteae*, *Nymphoidetum peltatae* and *Trapetum natantis* (Fig. 2, Tab. 2, Tab. 3, Fig. 3).

The water temperature analysis revealed that the existing differences are not statistically significant. Mean values ranged from 23.86°C on the localities where the stands of ass. *Nymphaeum albo-luteae* are formed, through 24.35°C in the stands of ass. *Nymphoidetum peltatae* and 24.5°C in the stands of ass. *Nymphaeum albae*, to 24.65°C in the stands ass. *Trapetum natantis* (Fig. 2). However, in the ass. *Trapetum natantis* stand habitats, the extreme temperature of 29°C was noted.

The pH value proved to be a very important factor that caused the phytocenoses differentiation within the *Nymphaeion* alliance (Tab. 2, Fig. 3). The highest average value (8.172) was noted at sites where stands of ass. *Nymphaeum albae* develop, while in all other phytocenoses, it was around 7.6 (Fig. 2). Very broad ecological valence with respect to pH was observed at the habitats of the stands *Nymphaeum albo-luteae* (min = 7.1, max = 8). Statistically highly significant differences between the water pH values in the habitat of ass. *Nymphaeum albae* and ass. *Nymphoidetum peltatae* ( $P = 0.0023$ ) were noted, between those measured in the habitat of ass. *Nymphaeum albae* and ass. *Trapetum natantis* ( $P = 0.001$ ), and between ass. *Nymphaeum albae* and ass. *Nymphaeum albo-luteae* ( $P = 0.002$ ), Tab. 3.

Alkalinity significantly differentiated the analyzed associations (Tab. 2, Fig. 3). The highest mean value was measured for the sites populated by the stands of ass. *Nymphaeum albae* (5.310), which are also the most tolerant to alkalinity variations (min = 2.745, max = 6.893). These are followed by the bicarbonate content of water in which the stands of ass.

*Trapetum natantis* (3.507) and ass. *Nymphoidetum peltatae* (3.114) develop, and finally by the values associated with water dominated by stands of ass. *Nymphaeum albo-luteae* (2.844), Fig. 2. Statistically highly significant differences were observed between the habitat alkalinity values of the ass. *Nymphaeum albae* and *Nymphaeum albo-luteae* stands ( $P = 0.001$ ), and between ass. *Nymphaeum albae* and ass. *Nymphoidetum peltatae* ( $P = 0.009$ ), as well as statistically significant differences between water alkalinity in habitats ass. *Nymphaeum albae* and ass. *Trapetum natantis* ( $P = 0.013$ ), Tab. 3.

The highest mean chemical oxygen demand value COD-MnO<sub>4</sub> (11.7 mg/l) and its greatest variation was noted in stands of *Nymphaeum albae* (Fig. 2). In the water where stands of ass. *Nymphaeum albo-luteae* develop, the mean value of 7.927 was obtained, whereas for ass. *Trapetum natantis* and ass. *Nymphoidetum peltatae* habitats, the mean COD-MnO<sub>4</sub> values of 7.272 and 6.927 were noted, respectively. Statistically highly significant differences in terms of COD-MnO<sub>4</sub> were found between localities populated by ass. *Nymphaeum albae* and ass. *Trapetum natantis* stands ( $P = 0.001$ ), as well as between the stands of *Nymphaeum albae* and *Nymphaeum albo-luteae* ( $P = 0.003$ ), and between the *Nymphaeum albae* and *Nymphoidetum peltatae* ( $P = 0.001$ ), Tab. 2, Tab. 3.

The obtained mean values of BOD<sub>5</sub> – slightly above 2 mg O<sub>2</sub>/l in water where the stands of ass. *Nymphaeum albae* (2.1775) and ass. *Nymphaeum albo-luteae* (2.488) develop – indicate moderate water pollution. On the other hand, higher mean BOD<sub>5</sub> values obtained for water populated by ass. *Trapetum natantis* stands (3.808), with the extremes exceeding 7 mg/l, are indicative of polluted water. At the border between a relatively clean and moderately polluted waters are the sites where ass. *Nymphoidetum peltatae* stands develop (mean value 1.70). Overall, the results indicate a “good ecological status” (BOD<sub>5</sub> below 6 mg/l) in the category of artificial water bodies, for the majority of sites where the analyzed stands develop, with the exception of a few sites at which stands of ass. *Trapetum natantis* are found (Fig. 2).

The differences in the ammonium ion content of the investigated stands were not statistically significant. The lowest values were noted at localities populated by ass. *Nymphaeum albo-luteae* stands (mean value 0.245), while the highest were obtained for those characterized by presence of ass. *Nymphaeum albae* stands (mean value 0.437; Fig. 2). Of particular significance is the ammonium ion content on some localities populated by stands of ass. *Trapetum natantis*, reaching max = 0.62, and thus indicating that the quality of water is poor (Fig. 2).

The water nitrate content analysis revealed that development of ass. *Nymphoidetum peltatae* stands favors water richer in these compounds (mean value 1.217), compared to the other stands (Fig. 2). Stands of *Trapetum natantis* (mean value 0.874), *Nymphaeum albo-luteae* (mean value 0.827) and *Nymphaeum albae* (mean value 0.68) were also characterized by relatively high nitrate content. No statistically significant differences were noted in the water nitrate content where the analyzed stands develop (Tab. 2).

In the studied aquatic ecosystem, nitrite content had no significant effect on the differentiation of *Nymphaeion*

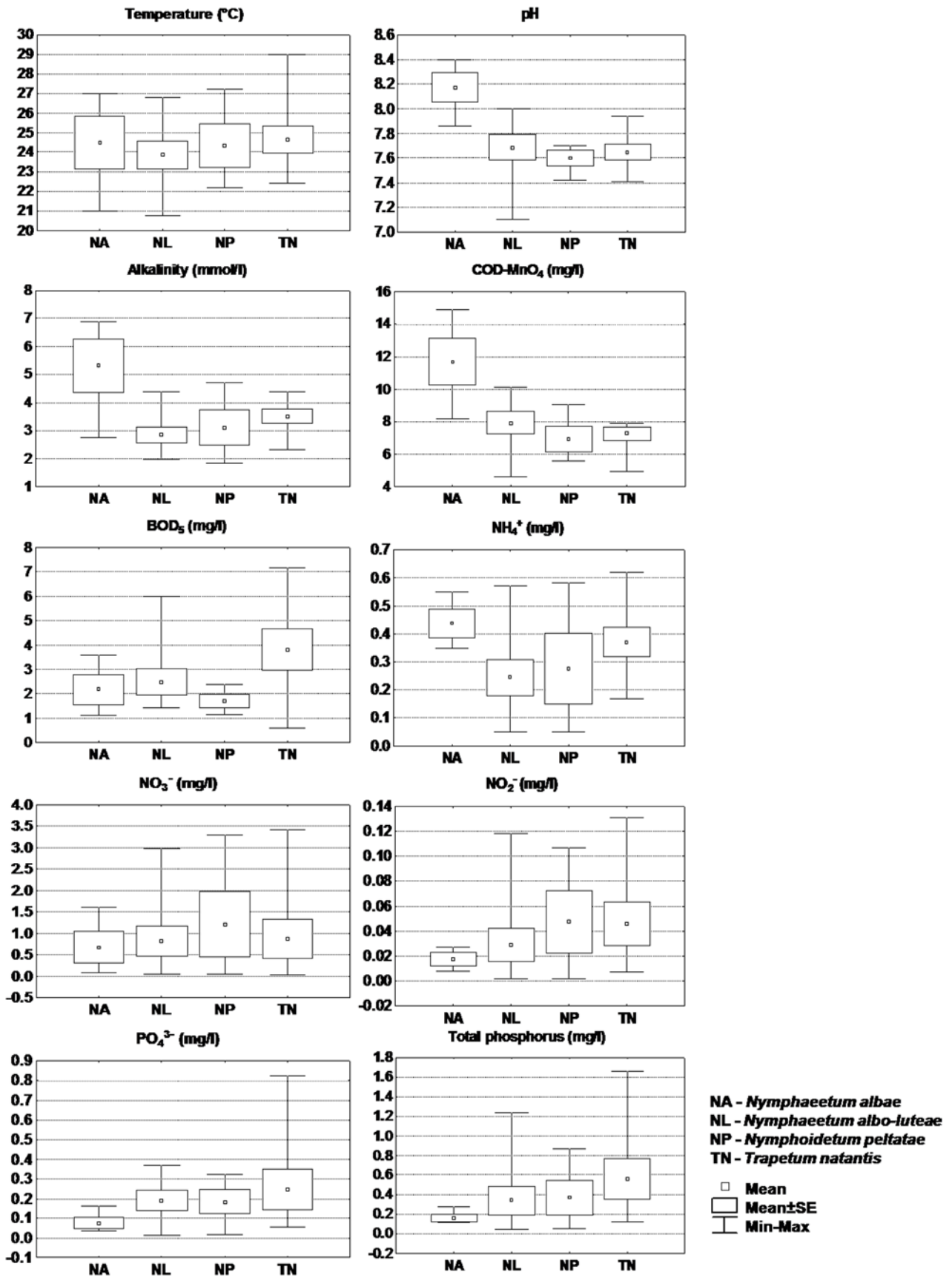


Fig. 2 The main physical-chemical water parameters of the *Nymphaeion* alliance phytocenoses habitat.

**Tab. 2** Significance of differences between studied phytocenoses compared to the analyzed water properties (ANOVA).

Variable	SS effect	df effect	MS effect	SS error	df error	MS error	F-ratio	P-value
Temperature	2.677	3	0.892	93.169	20	4.658	0.191	0.901
pH	0.916	3	0.305	1.067	20	0.053	5.725	0.005**
Alkalinity	17.134	3	5.711	23.439	20	1.172	4.873	0.010*
COD-MnO <sub>4</sub>	62.933	3	20.978	68.225	20	3.411	6.149	0.004**
BOD <sub>5</sub>	15.172	3	5.057	61.969	20	3.098	1.632	0.214
NH <sub>4</sub> <sup>+</sup>	0.129	3	0.043	0.608	20	0.030	1.414	0.268
NO <sub>3</sub> <sup>-</sup>	0.638	3	0.212	27.512	20	1.375	0.154	0.925
NO <sub>2</sub> <sup>-</sup>	0.003	3	0.001	0.035	20	0.002	0.585	0.632
PO <sub>4</sub> <sup>3-</sup>	0.078	3	0.026	0.808	20	0.040	0.641	0.597
Total phosphorus	0.445	3	0.148	3.999	20	0.200	0.743	0.539

SS – sum of squares; df – degrees of freedom; MS – mean squares. \*  $P < 0.05$ ; \*\*  $P < 0.01$ .

alliance phytocenoses. Mean values ranged from 0.017 in *Nymphaeetum albae* stands to 0.047 in *Nymphoidetum peltatae* stands (Fig. 2).

The water-dissolved phosphorus content analysis revealed that the stands of ass. *Trapetum natantis* formed in water with a higher dissolved phosphorus content (mean value 0.246). The dissolved phosphorus mean content in water with ass. *Nymphaeetum albo-luteae* stands was 0.191, whereas 0.185 was measured for water with ass. *Nymphoidetum peltatae* (Fig. 2). Stands of ass. *Nymphaeetum albae* developed in water with a much lower dissolved phosphorus value in comparison to the other stands (mean value 0.08), where minimum variation in the measured values was also noted.

Although notable, the differences in the total phosphorus content for different localities are not statistically significant (Tab. 2). Stands of *Trapetum natantis* developed in water relatively richer in phosphates (mean value 0.556), compared to the other analyzed phytocenoses, in which a wide range of values was noted (min = 0.123, max = 1.662). These are followed by habitats in which ass. *Nymphoidetum peltatae* (mean value 0.371), ass. *Nymphaeetum albo-luteae* (mean value 0.350) and ass. *Nymphaeetum albae* (mean value 0.164) develop.

**Tab. 3** Significant of differences in water properties between studied phytocenoses (Fisher LSD-test).

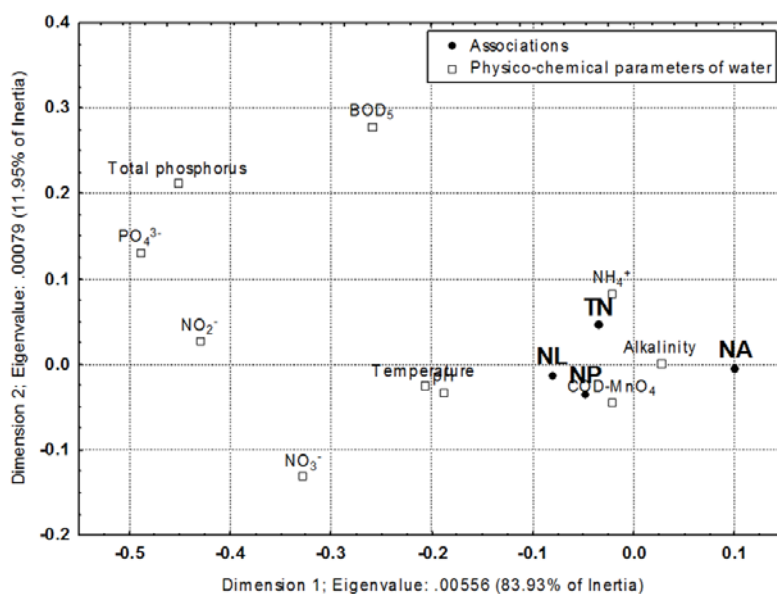
Water properties	NA-NL	NA-NP	NA-TN
pH	0.002	0.002	0.001
Alkalinity (mmol/l)	0.001	0.009	0.013
COD-MnO <sub>4</sub> (mg/l)	0.003	0.001	0.001

NA – *Nymphaeetum albae*; NL – *Nymphaeetum albo-luteae*; NP – *Nymphoidetum peltatae*; TN – *Trapetum natantis*. The differences between NL-NP, NL-TN and NP-TN are insignificant.

## Discussion

Among the water properties analyzed as a part of this study, pH, alkalinity and COD-MnO<sub>4</sub> are the most significant, and are the main contributors to the differentiation of phytocenoses *Nymphaeetum albae*, *Nymphaeetum albo-luteae*, *Nymphoidetum peltatae* and *Trapetum natantis* (Tab. 2, Fig. 3). Dawson and Szoszkiewicz [23] also reported that, in British rivers, pH and alkalinity, in addition to total phosphorus, are the key environmental parameters that significantly affect the differentiation of aquatic phytocenoses. In many European river systems, the role of alkalinity and pH is crucial in the differentiation and development of macrophytes, i.e., these parameters are directly correlated with the macrophyte distribution and abundance [42].

In the stands of *Nymphaeetum albae*, the highest mean pH value in relation to other *Nymphaeion* alliance phytocenoses, as well as the measured extreme values, are in accordance with the results reported by Szańkowski and Kłosowski [6] for aquatic ecosystems in Poland. However, all measured values are below the limits that define a “good ecological status” for artificial water bodies. High water alkalinity levels, as well as wide ecological amplitude for this parameter, were noted by Smits et al. [43] and Dimopoulos et al. [24] in the ass. *Nymphaeetum albae* stands. The highest average COD-MnO<sub>4</sub> value and ammonium ion content, relative to other phytocenoses, indicates that these stands are periodically exposed to water laden with organic matter (attributed to the close proximity of the food industry factories). The lowest nitrate, nitrite, dissolved and total phosphorus content compared to other analyzed stands characterizes the conditions in which these stands develop as mesotrophic [44], which is in accordance with the previously reported results [24,45,46]. Lukács et al. [45] found that this association prefers water with markedly poor organic matters, and the stands of this phytocenosis are vulnerable in waters rich in nutrients. Mesotrophic status is confirmed by the significant



**Fig. 3** Correspondence analysis between the identified *Nymphaeion* alliance associations and physical-chemical water quality parameters.

presence of *M. spicatum* in the stands of this community (Tab. 1). As *M. spicatum* growth decreases with further increases in the trophic level, it appears to act as its growth modulator [47,48]. This premise is supported by the highest abundance and coverage values for this macrophyte in the ass. *Nymphaetum albae* stands, in relation to the other analyzed phytocenoses developing in waters characterized by higher trophic levels (Tab. 1, Fig. 2).

Our results, as well as the data reported in pertinent literature [6,49], confirm that the habitat conditions in which ass. *Nymphaetum albo-luteae* stands develop are subject to a wide range of variation. Slightly lower pH value and wide ecological valence of the *Nuphar lutea* edifier is confirmed by Kočić et al. [7] and Jabłońska and Kłosowski [8]. In the studied stands, the lowest alkalinity was noted, in comparison with the water in which stands of other phytocenoses develop. BOD<sub>5</sub> value is in the range of “good ecological status” (below 6 mg/l) [50]. Lower nitrate content in the water in which the stands of *Nuphar lutea* develop was also found in the rivers of neighboring Croatia [7]. The dissolved and total phosphorus values define these habitat conditions as moderately eutrophic [44], as confirmed by the data reported in pertinent literature [9,11,51,52]. Moreover, the species of the *C. demersum* characteristic group, which forms thick “underwater meadows” in the analyzed stands, is an indicator of eutrophic habitat conditions, in line with the results reported for other studies [9,11,12,24,26,45,49,53,54].

In the stands of ass. *Nymphoidetum peltatae*, the lowest pH and the narrowest range of variation of this parameter were recorded. Szańkowski and Kłosowski [6] reported similar pH value for water flows in Poland. Bicarbonate values (min = 1.830, max = 4.734) are in the range of variation noted by Smits et al. [43] most likely to allow development of edifier *Nymphoides peltata*. Significantly, the lowest COD-MnO<sub>4</sub> and BOD<sub>5</sub> values, as well as very narrow range of variation in these parameters, was noted in comparison to other analyzed phytocenoses. The highest nitrate and nitrite content

in ass. *Nymphoidetum peltatae* habitats, in comparison to other analyzed phytocenoses, is in line with the findings reported by other authors [6,46,53]. The dissolved and total phosphorus values are in the range of eutrophic status, as indicated by the results of previous studies [6]. In addition to being an edifier, *H. morsus-ranae*, which was highly abundant in these stands, is also an indicator of eutrophic status [11,55]. On the other hand, according to Sýkora [51], development of this association is unaffected by water quality.

The most widespread floating-leaved vegetation in the canal network, ass. *Trapaetum natantis*, is one of the most thermophilic aquatic phytocenoses [21,56,57]. The study findings indicate that the analyzed phytocenosis stands prefer neutral water, which is consistent with the results reported by other authors [6,27]. In contrast to the high COD-MnO<sub>4</sub> values recorded by Szańkowski and Kłosowski [6], and low values determined by Kočić et al. [7], our results indicate that the habitats on which the analyzed stands form are moderately loaded with organic substances. Periodically measured, BOD<sub>5</sub> values significantly higher than the “good ecological status” limit [50] are typically due to organic pollution caused by the discharge of untreated sewage, industrial effluents and leaching from agricultural land. These conditions are confirmed by the presence of *Potamogeton pectinatus*, which often develops in polluted waters, rich in phosphates [7,9,23,58]. Of particular significance is the ammonium ion content that, in certain localities, reaches max = 0.62, indicating that the water in which the stands developed is of impaired quality. *Trapaetum natantis* stands developed in waters laden with phosphates, characterizing these conditions as eutrophic [44]. The highest dissolved and total phosphorus content, and very wide ecological amplitude of this important parameter, as an indicator of eutrophication, is characteristic of stands in other regions [6,11,45]. In addition to the edifier, hydrophytes *S. polyrrhiza* [9,12,21,51,54,59], *H. morsus-ranae*, *C. demersum* and *L. minor* [21,51,59] are also well adapted to the eutrophic

levels and are widely represented. Within *Nymphaeion* alliance phytocenoses, the mean value of phosphorus significantly exceeds the limit of “good ecological status” only in habitats of *Trapa natantis* stands [50]. Moreover, the ability of *T. natans* to tolerate significant water level fluctuations in the studied hydromelioration facility, in conjunction with the physical-chemical water parameters, is driving its expansion [21].

Comparative analysis of the physical-chemical water parameters at the localities where the ass. *Nymphaeion* stands develop revealed that most phytocenoses are closely

linked to specific habitat conditions. Water parameter values measured at most localities are the consequence of the anthropogenic eutrophication process. Owing to these adverse effects, it is likely that the biodiversity and survival of ass. *Nymphaeion* phytocenoses will be jeopardized [12]. Given that the phytocenoses that are endangered and vulnerable in most of the Europe have developed in this anthropogenic hydroecosystem, it is of paramount importance that its ecological equilibrium is maintained, in order to achieve “good ecological status” and preserve the stands of these immensely valuable phytocenoses.

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## Authors' contributions

The following declarations about authors' contributions to the research have been made: wrote the paper: DD; field research: DD, BLM, LN; phytosociological analyses: DD; chemical analysis: DD, BLM, LN; preparation of distribution map: BLM; statistical analysis: BLM.

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