Development of floating-leaved vegetation in three lakes of varied trophy (Leczna-Włodawa Lakeland)

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Abstract: Nymphaeids are a typical component of littoral vegetation in European lakes. In different types of water bodies they create large stands. This group of macrophyte species grows not deeper than 3 metres, but depending on clarity and depth. The aim of this study was to determine the percentage share and biomass of nymphaeids in investigated lakes with varying trophy and way of use. Furthermore, another aim of the study was a comparative analysis of morphometric features among dominant species of nymphaeids. The studied lakes are a group of eutrophic lakes, in various stages of its advancement from the low eutrophic Lake Płotycze Sobiborskie, through the eutrophic Lake Płotycze Urszulińskie to the highly eutrophic Lake Zienkowskie. In the studied lakes, nymphaeids formed a large part of the phytolittoral as well as macrophyte biomass, the smallest in the strongly eutrophic lake, the largest in the eutrophic lake. In the studied lakes appeared both *Nymphaea candida* species as well as intermediate forms. Neither the use of the lake nor habitat conditions affected the differentiation of the analysed characteristics of *Nuphar lutea*, while the most sensitive species was *Nymphaea candida*.

Key words: nymphaeids, *Nymphaea candida*, macrophytes, morphometric features

Introduction

Nymphaeids are aquatic plants which possess mainly floating leaves, have their flowers above or floating on the water surface and are rooted in the bottom. They represent different families of vascular plants such as Menyanthaceae, Nymphaeaceae, Potamogetonaceae, etc. They are a typical component of littoral vegetation in European lakes. In different types of water bodies they create large stands mainly dominated by one species (Szańkowski and Kłosowski 1999). Among seven nymphaeid communities found in Poland, the most common in our waters are *Nymphaeetum candidae* MILJAN 1958, *Potametum natantis* Soó 1923, *Polygonetum natantis* Soó 1923, *Nupharo-Nymphaeetum albae* TOMASZ. 1977. Some of them are typical of clean, less fertile water, while others have a wide range of tolerance to habitat conditions (Kłosowski 2001). Structurally nymphaeids can be considered as intermediate between helophytes and submerged aquatic plants. In general, this group of

macrophyte species grows not deeper than 3 metres, but depending on clarity and depth of water they can settle some metres deeper, but then are usually not able to form floating leaves (van der Velde 1980).

The aim of this study was to determine the percentage share and biomass of nymphaeids in investigated lakes with varying trophy and way of use. Furthermore, another aim of the study was a comparative analysis of morphometric features among dominant species of nymphaeids.

Material and methods

The study was conducted in the years 2009-2010 on three lakes, situated in the Łęczyńsko-Włodawskie Lakeland. The different habitat conditions of those lakes permitted a comparison of changes in species composition of flora, resulting from the different eutrophy level of waters.

The investigated lakes were diverse in terms of water surface, depth, usage, and eutrophy level (Table

Table 1. Basic morphometric data and depth of macrophyte occurrence for lakes under study acc. Michalczyk and Wilgat 1998, (*own research)

Feature		Lake Płotycze Sobiborskie	Lake Płotycze Urszulińskie	Lake Zienkowskie
length	[m]	650	390	373
surface area	[ha]	15.8	10.6	7.6
width	[m]			
	max.	400	365	285
	mean	255	272	204
shape index	[nd]	0.39	0.70	0.55
shore line	[m]	1775	1185	1113
depth	[m]			
	max.	8.1	n.det.	4.9
	mean	2.2	1.7*	2.7
depth of macrophyte occurrence*	[m]	1.5	1.7	1.2
usage		Nature Reserve, Natura 2000, Landscape Park	Natura 2000	Landscape Park

1). The lakes were covered by various forms of nature conservation. Lake Zienkowskie, through which flows the Piwonia Północna river, serves also as an intermediate receiver of urban waste water from nearby settlements. The main uses of the catchment area are as meadows and pastures. Lake Płotycze Sobiborskie is the largest among the studied lakes. Surrounded mostly by forest catchment, it is situated in a nature reserve "Three Lakes". Dominant ways of use of the catchment area of Lake Płotycze Urszulińskie are meadows, pastures, forests and land used intensively for agriculture.

The phytolittoral surface and participation of various plant communities, with particular emphasis on nymphaeids were described. Specified the phytolittoral surface and participation of various plant communities, with particular emphasis on nymphaeids. In phytosociological investigations, Braun Blanquet's method (1951) was used. Phytosociological units were distinguished on the basis of a systematic system and follow Matuszkiewicz's nomenclature (2008). The phytolittoral surface was determined according to field investigations and aerial photos using the Macrostation vr. 8 programme.

In order to verify the presence of *Nymphaea candida* Nowak's method was used based on 10 characteristics, verified in fresh material (Nowak and Nowak 2007). Moreover the investigations included qualitative analysis of macrophytes (determination of the area covered by plants), quantitative analysis (determination of total biomass of macrophytes and in-

dividual vegetation groups, assessment of plant diversity). Emergent macrophytes were analysed using the floristic rake, while the submerged macrophytes using the floristic anchor (Bernatowicz 1960). The total macrophyte biomass (TMB) in the lake was estimated by the following equation (Canfield et al. 1983):

$$TMB = SA \times C \times B$$

where: SA = lake surface area, C = percentage cover of submersed and floating-leaved aquatic macrophytes, and B = average biomass collected with a sampler.

Variation in morphometric traits, density and biomass among the dominant species of nymphaeids in the studied lakes was also determined. Samples of nymphaeids were taken at a water depth of 50-100 cm at a distance of 3m from banks by means of a 80 x 80 cm frame made of PVC tubes. A surface of 0.64 m² per sample was dug out. Twelve samples were taken in the vegetative period in 2009, as well as in 2010. The length and in the case of leaf blades also the width were measured and the number of leaves was counted. The plant material was cleaned as well as possible by washing with tap water. The density of nymphaeids was determined by the formula πr^2 , where r – radius, and the surface of each leaf blade was calculated by the formula (van der Velde et al. 1979):

$$\pi (l+w/4)^2$$

l – is the leaf length measured from the leaf tip to the tip of the basal lobe

w – is the maximum width of the leaf.

Physical and chemical factors of the water were analysed such as pH, temperature, electrolytic conductivity, oxygen content, total P, total N. The following instruments were used for the determination of physical and chemical properties of water: OXI 330 oxymeter (oxygen content, temperature), electronic conductivity meter (electrolytic conductivity), microchip Slandi SP300 pH-meter (water reaction). The content of biogenic nitrogen and phosphorus compounds was determined using the microchip Slandi photometer LF 205. For all lakes Carlson's (1977) *Trophic State Index* (TSI) was calculated, based on the *visibility of a Secchi disk* (SD), nitrogen (TN) and phosphorus (TP) content.

Results and discussion

The studied lakes represent eutrophic lakes at different stages of their advancement. This is confirmed by the Carlson index, Lake Zienkowskie – highly eutrophic; Lakes Płotycze Urszulińskie – eutrophic; and Sobiborskie – moderately eutrophic (Table 2).

According to some authors Lake Płotycze Sobiborskie is classified as a type of mesohumic lake (Chmiel 2008). In the investigated lakes N:P ratio was higher than 16, which points to relative phosphorus deficiency (Table 2). Such a situation, from one side, is conducive to low trophic status, but on the other it could indicate instability of the ecosystem (Hillbricht-Ilkowska and Wiśniewski 1994).

The area occupied by plants in all studied lakes was different and averaged 47% of their surface, which puts them above the average for other Polish lakes (Kłosowski 1999). The largest phytolittoral occurred in Lake Płotycze Urszulińskie and the smallest in Lake Zienkowskie. The number of plant communities creating the phytolittoral was also varied. The most communities developed in Lake Płotycze Sobiborskie – 12 – while in Lake Zienkowskie only 6 (Table 3).

Nymphaeids played a significant part in creating the phytolittoral in the studied lakes. The largest area occupied by plants with floating leaves was in Lake Płotycze Urszulińskie, the smallest in Lake Zienkowskie. Almost half of the phytolittoral – 48% – was formed by nymphaeids in Lake Płotycze Sobiborskie. In other lakes, Zienkowskie and Płotycze Urszulińskie, nymphaeids occupied respectively 37% and 30%.

Rushes were the most numerous in all studied lakes. The least numerous were submerged plant communities. There were no submerged plant communities in Lake Zienkowskie (Table 3). Among seven nymphaeid associations distinguished in Poland, 3 occurred in the investigated lakes of the Łęczyńsko-Włodawskie Lakeland: *Potametum natantis* Soo 1927, *Nupharo-Nymphaeetum albae* Tomasz. 1977, *Nymphaeetum candidae* Miljan, 1958. Most of them had already appeared in the 1950s in the studied lakes (Fijałkowski 1959). These communities have developed on the edge of the rushes in Lakes Płotycze Urszulińskie and So-

Table 2. Physical and chemical characteristics of water in investigated lakes and trophic state indices (mean values)

Feature	Lake Płotycze Urszulińskie	Lake Zienkowskie	Lake Płotycze Sobiborskie
Temperature [°C]	26.3	26.1	23.8
Visibility [m]	1.2	0.2	1.05
Water reaction [pH]	7.3	7.6	7.2
Conductivity [$\mu\text{S cm}^{-1}$]	196.6	260.4	44.9
Dissolved oxygen [mg dm^{-3}]	2.9	1.5	8.2
Oxygen saturation [%]	33.7	20.2	108.1
Total nitrogen [mg dm^{-3}]	1.99	2.95	1.49
Total phosphorus [mg dm^{-3}]	0.069	0.179	0.055
Hardness [mg dm^{-3}]	3.56	6.39	1.27
TSI(SD)	58.6	83.2	59.3
TSI(TP)	65	79	62
TSI(TN)	47	75	27
Carlson's TSI	57	79	50
N:P	29	16	27
Trophy	eutrophy	highly eutrophic	moderately eutrophic

Table 3. Phytolittoral surface and particular plant associations in investigated lakes

Group of water plants	Plant associations	Lake Płotycze Sobiborskie		Lake Płotycze Urszulińskie		Lake Zienkowskie	
		[ha]	[%]	[ha]	[%]	[ha]	[%]
emergent	<i>Phragmitetum australis</i>	1.9	11.4	1.6	15.1	0.68	8.9
	<i>Typhetum latifoliae</i>	1.1	6.6	1.6	15.1	0.16	2.1
	<i>Elocharitetum palustris</i>	0.1	0.6				
	<i>Scirpetum lacustris</i>	0.3	1.8				
	<i>Caricetum elatae</i>	0.3	1.8	0.2	1.9		
	<i>Caricetum paniculatae</i>	0.2	1.2				
	<i>Thelypteridi – Phragmitetum</i>			0.3	2.8		
	<i>Equisetum fluvatile</i>			0.4	4.8		
	<i>Caricetum vesicariae</i>	0.1	0.6				
	<i>Salicetum pentandro-cinereae</i>					0.2	2.6
	total	4	12.6	4.1	39.7	1.04	13.6
submerged	<i>Scorpidio – Utricularietum minoris</i>	0.1	0.6				
	<i>Nitellopsidetum obtusa</i>			1.6	15.1		
	total	0.1	0.6	1.6	15.1	0	0
Pleuston	<i>Hydrocharitetum morsus-ranae</i>					0.13	1.7
	<i>Lemno minoris – Salvinietum natantis</i>	0.4	2.4	0.2	1.9		
	total	0.4	2.4	0.2	1.9	0.13	1.7
Plant with floating leaves	<i>Potametum natantis</i>	1.2	7.2			0.02	0.3
	<i>Nupharo – Nymphaeetum albae</i>	1	6	2.3	21.7	0.47	6.2
	<i>Nymphaeetum candidae</i>	0.2	1.2	1.2	11.3		
	total	2.4	14.4	3.5	33	0.49	6.5
Phytolittoral surface		6.9	30	9.4	89.7	1.66	21.8

biborskie in contact with submerged vegetation, while in Lake Zienkowskie in open water. *Nymphaea candida* C. Presl is a Euro-Siberian species with the western range limit on the line of the Rhine; in Poland, it occurs only in the north-west (Wayda 2000). There are some data about its occurrence in different places in this region of Poland, among them in some parts of the Łęczyńsko-Włodawskie Lakeland (Nowak et al. 2010).

The preliminary study conducted on the occurrence and taxonomical differentiation of *Nymphaea* genus is the first step towards species recognition in the investigated lakes. Optimum development of communities with *Nymphaea candida* occurs in mesotrophic waters with an acidic medium, fairly rich in organic substances (Kłosowski 2001). *Nymphaea candida* and intermediate forms (*Nymphaea alba* x *N. candida*) based on the analysis of 10 features were found in the studied lakes. Intermediate forms occurred in Lakes Płotycze Urszulińskie and Zienkowskie.

The analysis of morphometric features based on three dominant species distinguished communities of *Nymphaea alba*, *Nuphar lutea* and *Nymphaea candida*. In Lake Zienkowskie *Nymphaea candida* did not create communities; there were only single specimens.

The density of nymphaeid leaves floating on the water surface was varied in the studied lakes, among the species tested. The largest concentration in all the lakes was exhibited by *Nymphaea alba*, while the smallest by *Nymphaea candida* (Table 4). A similar trend occurred in oxbow lakes of the River Waal in the Netherlands; however, their density was greater (van der Velde 1980).

Generally, participation of macrophytes in plant biomass production is different than their share of the phytolittoral surface. The largest producer of biomass in water ecosystems is rush vegetation, then nymphaeids (Kraska 1988; Sender 2010a,b). *Nuphar lutea* reached the highest values of biomass in the investigated lakes, while *Nymphaea candida* the lowest (Table

Table 4. Mean density and biomass of some nymphaeids in investigated lakes

Lake	<i>Nymphaea alba</i>			<i>Nymphaea candida</i>			<i>Nuphar lutea</i>		
	density (ind m ⁻²)	biomass (g _{sm} m ⁻²)	B:D ratio	density (ind m ⁻²)	biomass (g _{sm} m ⁻²)	B:D ratio	density (ind m ⁻²)	biomass (g _{sm} m ⁻²)	B:D ratio
Plotycze Urszulińskie	8.7±1.3	208.6	24	6.4±1.6	168.5	26	7.2±1.7	355.0	49
Plotycze Sobiborskie	7.1±1.1	196.4	28	5.1±1.4	61.4	12	6.5±1.6	304.4	47
Zienkowskie	7.9±1.5	297.6	38	3.6±0.5	174.2	49	5.5±1.3	592.2	108

Table 5. Mean biomass of particular parts of investigated species (±stand. deviation)

Lake	<i>Nymphaea alba</i>		<i>Nymphaea candida</i>		<i>Nuphar lutea</i>	
	leaf	petiole	leaf	petiole	leaf	petiole
Plotycze Urszulińskie	136 ±12	125±9.0	111±21	92±2.4	235±15	264±24
Plotycze Sobiborskie	123±17	56±6.4	35±3.4	46±3.5	198±14	133±16
Zienkowskie	120±15	88±5.7	109±27	109±18	555±70.1	378±42

4). In Lake Zienkowskie all analysed species reached the highest values of biomass, while in Lake Plotycze Sobiborskie the lowest (Table 5).

For values of biomass, especially *Nymphaea alba* and *N. candida* visibility had a significant influence ($r = 0.98$, $p < 0.05$); in the case of *Nuphar lutea* this correlation was less significant ($r = 0.11$, $p < 0.05$). A high correlation between the density of nymphaeids and biomass values was found only in moderately and highly eutrophic lakes ($r = 0.9$, $p < 0.05$); in Lake Plotycze Urszulińskie, where the phytolittoral occupied over 80% of the water surface, such a relationship was not significant ($r = 0.1$, $p < 0.05$). The bulk of the biomass of nymphaeids is leaves along with stalks; other parts such as flowers or buds have no material effect on the plant mass (Kraska 1988). The largest mass of leaves and petioles occurred in *Nuphar lutea*, while the smallest in *Nymphaea candida* in all of the studied lakes (Table 5). On average, leaf biomass was two times greater than the biomass of petioles.

The greatest diversity among nymphaeid species occurred in Lake Plotycze Urszulińskie, while the smallest in Lake Plotycze Sobiborskie. The most numerous were pleustonic plants as well as plants with floating leaves (Table 6). Habitat conditions of nymphaeid associations were discussed by Szańkowski and Kłosowski (1999). Studies have also been conducted on the ecology of some nymphaeid species diverse in terms temperature conditions (Kraska 1988), as well as phenology, production and decomposition of floating leaves (van der Velde 1980; Malthus et al. 1990).

An analysis of selected morphometric features of 3 nymphaeid species in eutrophic lakes shows certain tendencies. In all the studied lakes *Nymphaea alba*

developed the largest number of leaves but with a small area. The largest area is displayed by leaves of *Nuphar lutea* (Table 7). All parts of this plant reached the highest value, regardless of the type of use of the lake. The studied features of *Nymphaea candida* evolved differently depending on the lake. Smaller values of the analysed features in the lake were attained in Plotycze Sobiborskie; in the other lakes, these values were higher than for *Nymphaea alba* (Table 7). The longest petioles in most of the analysed species have evolved in Lake Zienkowskie. The reason for this could be the difference in water level due to its rate flow.

In the studied lakes, the shape indicator was important as well as the degree of development of both belts of rushes and plants with floating leaves. This is confirmed by the high correlation index value $r = 1.00$, $p < 0.05$. The ratio of the development of rushes to nymphaeids was three times higher, while in Lake Zienkowskie more than 4 times larger $r = 0.91$, $p < 0.05$.

Conclusions

The studied lakes are a group of eutrophic lakes, in various stages of advancement from the low eutrophic Lake Plotycze Sobiborskie, through the eutrophic Lake Plotycze Urszulińskie to the highly eutrophic Lake Zienkowskie. In the studied lakes, nymphaeids formed a large part of the phytolittoral as well as macrophyte biomass, the smallest in the strongly eutrophic lake, the largest in the eutrophic lake. Neither the use of the lake nor the habitat conditions affected the differentiation of the analysed characteristics of *Nuphar lutea*, while the most sensitive species was *Nymphaea candida*.

Table 6. Species composition and contribution of macrophytes in selected stands of nymphaeids

Group of macrophyte species	Lake Płotycze Sobiborskie	Lake Płotycze Urszulińskie	Lake Zienkowskie
Helophyte/emergent			
<i>Equisetum limosum</i>		+	
<i>Schoenoplectus lacustris</i>	+	+	
<i>Phragmites australis</i>			+
<i>Typha latifolia</i>			+
Pleustonie and plants with floating leaves			
<i>Lemna minor</i>	+	++	++
<i>Lemna trisulca</i>		+	+
<i>Potamogeton natans</i>	+	+	++
<i>Hydrocharis morsus-ranae</i>	+	+	+
<i>Nuphar lutea</i>	+	++	++
<i>Nymphaea alba</i>	+	+	++
<i>Nymphaea candida</i>	++	+	+
<i>Polygonum amphibium</i>	+		
<i>Utricularia vulgaris</i>		+	
<i>Spirodella polyrrhiza</i>		+	+++
Elodeids/submerged			
<i>Stratiotes aloides</i>		++	+
<i>Ceratophyllum demersum</i>		++	+
<i>Elodea canadensis</i>		+	
<i>Myriophyllum spicatum</i> , <i>Scorpidium scorpioides</i>	+	+	
<i>Batrachium circinatum</i>		+	
total	9	16	12

(+) – to 25%, (++) – 25-50%, (+++) – above 50%

Table 7. Mean biometrical values of leaves and petioles of investigated nymphaeid species

Lake	nymphaeid species		Petiole diameter [mm]	Leaf width [cm]	Leaf length [cm]	Leaf mass [g]	Mass of 1 m of petiole [g]	Petiole length [m]
Płotycze Sobiborskie	<i>Nymphaea alba</i>	x	5.0	20.5	13.3	19.0	8.7	1.80
		SD	0.0	0.3	0.6	0.7	0.4	
	<i>Nymphaea candida</i>	x	3.3	13.2	8.4	7.0	5.2	1.87
		SD	0.6	1.8	1.2	1.7	0.9	
	<i>Nuphar lutea</i>	x	7.2	21.7	20.0	28.0	18.8	1.67
		SD	0.9	2.8	3.0	8.3	10.8	
Płotycze Urszulińskie	<i>Nymphaea alba</i>	x	5.2	17.8	12.2	15.7	8.3	1.64
		SD	0.6	1.5	1.1	2.4	1.6	
	<i>Nymphaea candida</i>	x	5.7	19.0	13.0	17.3	9.0	1.66
		SD	0.2	2.7	1.7	6.4	2.0	
	<i>Nuphar lutea</i>	x	9.2	22.6	20.4	32.5	16.5	1.45
		SD	1.2	1.1	0.6	2.2	7.3	
Zienkowskie	<i>Nymphaea alba</i>	x	5.9	21.9	14.0	21.7	16.0	1.86
		SD	2.1	8.6	5.7	1.2	11.9	
	<i>Nymphaea candida</i>	x	6.2	25.7	17.4	30.3	18.3	1.68
		SD	0.3	6.4	8.5	1.5	1.5	
	<i>Nuphar lutea</i>	x	7.3	26.3	25.8	70.0	37.7	1.73
		SD	2.5	45.4	34.0	17.8	29.7	

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