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DIFFERENTIATION OF THE MACROPHYTES STRUCTURE IN THE BASINS OF FLOW AND INFLOW LAKES

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Abstract. The aim of this study was to analyze the influence of water movement on both qualitative and quantitative occurrence of macrophytes in lakes. We studied four lakes differentiated in respect of water supply (two flow and two inflow).The investigation included: determination of the buffer zones of lakes, analysis of land use forms and layout of the buffer zone, floristic characteristic of lakes littoral, characteristic of phytolittoral types, analysis of physical and chemical parameters of lakes. The buffer zone of the flow lakes was dominated by farmland, but there was no land meadow. In the inflow lakes co-dominated fields and forests in the buffer zone. The inflow lakes characterized by greater species diversity, density and biomass of emergent macrophytes. In all investigated lakes, in the zone of water supply, analyzed features of macrophytes, and selected chemical parameters of water, reached the highest value.

Key words: flow lakes, inflow lakes, emergent macrophytes, usage of buffer zone

INTRODUCTION

Stable hydrological conditions in lakes is a main factor affecting maintenance of lake biodiversity [Zohary and Ostrovsky 2011, Soszka *et al*. 2012, Hrivnak *et al*. 2014]. On the hydrological regime consists among other, greatness and dynamics of flow, It affects the water level in the reservoir which determines the littoral range and the lake depth. Changes in water levels cause coastal erosion, impact thermal and oxygen conditions, transform availability of light and habitats and shape the nutrient management [McParland and Barrett 2009]. In natural reservoirs, the most common cause of changes in water level is water supply and natural hydrological and climatic conditions. If the lake is sup-

plied with waters from altered or disturbed rivers the lake may experience significant changes in physical and chemical parameters, as well as changes in the structure of fish fauna or plankton [Huszar and Reynolds 1997]. In lakes without flow conditions of biotic and abiotic factors are considered more stable, and created by local conditions [Kasten 2003].

Macrophytes are a group of aquatic organisms inhabiting the littoral zone and therefore very sensitive to changes in water level [Keto *et al*. 2006]. Changes in the water level may result in changes in species richness and distribution. The aim of this study was to analyze the influence of water movement on both qualitative and quantitative occurrence of macrophytes in lakes. We studied four lakes differentiated in respect of water supply (two flow and two inflow).The investigation included: determination of the buffer zones of lakes, analysis of land use forms and layout of the buffer zone, floristic characteristic of lakes littoral, characteristic of phytolittoral types, analysis of physical and chemical parameters of lakes.

STUDY AREA AND METHODS

The study was conducted in four lakes: two flow (Gumienek and Ściegienne), located in the Tyśmienica river basin, and two inflow lakes (Lipieniec and Święte), located in the Włodawka river basin. The research was conducted during the summer in July in the years 2014 and 2015.

Lake Gumienek covers an area of 8,1ha, with a depth of 7.8 m. To the lake from the south side of the Bobrówka (Piwonia) river flows. From the lake water flows out in northern part. It is the tributary to the Bobrówka river. Previously this river flows through the complex ponds, adjacent to the lake.

Lake Ściegienne is the largest among the surveyed lakes – 24.7 ha but shallow, with a maximum depth of only 5.4 m. From the western side of the lake there is a tributary, which drainage out of the meadow Ścionki. Through the lake flows the river Bobrówka (Piwonia), which flows into the lake from the south and flows out in the western part.

Lake Lipieniec is very small, its area is 4.1 ha, and reaches a depth of 7.1 m. From the north-western part of the lake there is a canal, periodically supplying waters from meadows overgrown with bushes.

Lake Święte has an area of 5.7 ha and a depth of 9.6 m. The lake was supplied by two water draining canals, one of them was located on the east side, the other from the south. Strongly reduced water level caused that the channel, periodically, did not supply waters to the lake.

The study of macrophytes and the physical and chemical parameters of water were done in transects, two in each of the lakes. One transect was established where water flows into the lake (the inflow), the other where water flows out of the lake (outflow).

The aim of aquatic plants analysis was to determine the qualitative composition, range of distribution, density of emergent macrophytes and their biomass. In studies of vegetation was used: the florist anchor (species diversity especially submerged macrophytes), the sonar Elite no. 5 (distribution, range of occurrence), the floristic fork (density of emergent macrophytes) and the floristic sickle (cutting of emergent plants) and the Vibra balance (wet and dry weight of emergent macrophytes). In order to determine the biomass of emergent macrophytes collected from every position, five shoots of each species were collected, washed with periphyton, then dried for 12 hours at 60°C. After drying, all shoots were weighed to determine a dry weight (g_{dw}/m^2).

In the littoral zone analysis of physical and chemical parameters of lake waters were carried out. They included: water temperature, water reaction (pH), electrolytic conductivity, the content of phosphates $P\text{-}PO_4$ and nitrate$N\text{-}NO_3$ (spectrophotometer) and visibility (Secchi disk).

All the cartographic analyzes were done using raster maps, topographical and orthophoto-maps (origin: www.geoportal.gov.pl, ver. 2013). We determined layout and land use of the buffer zones, which have been designated 500 m from the shoreline of the lake. Maps were developed on a scale of 1 : 5000. Cartographic analysis was done using the MicroStation PowerDraft V8i.

RESULTS

The buffer zones, in investigated lakes, differed in size. In Lake Gumienek it covers an area: 116.46 ha, in Lake Ściegiene 206.43 ha, in Lake Lipieniec 105.55 ha, and in Lake Święte 109.21 ha. Lay of the land in the buffer zones of all lakes was similar. Three of the studied lakes were located at the same height – 158 m above sea level, only Ściegienne lake was situated slightly below – 157 m above sea level. Absolute altitude in the buffer zone of lakes ranged between 157 m asl and 163 m asl.

In the studied lakes there were natural and anthropogenic forms of management in the buffer zone. In three of them anthropogenic forms dominated. The exception was lake Lipieniec where natural forms dominated. The buffer zone of flow lakes was dominated by farmland, but there were no meadows. The buffer zone of inflow lakes were co-dominated by farmland and forests. In the buffer zone of Lake Gumienek were summer resort buildings (Table 1).

Analyzed physico-chemical parameters differed slightly in individual lakes. Especially electrolytic conductivity in the Lake Święte was very small and reached 49.75 μS/cm. In most lakes water reaction (pH) was alkaline but in lake Święte was slightly acidic. The parameter which significantly differentiate two groups of lakes was the Secchi disc visibility, which was significantly higher in the inflow lakes (Table 2).

Table 1. The share of individual forms of land development in the buffer zones of investigated lakes

Specifications	Gumienek		Ściegienne		Lipieniec		Święte	
	ha	%	ha	%	ha	%	ha	%
Lake	7.58	6.50	20.66	10.15	3.63	3.44	4.89	4.48
Watercourses	1.11	0.95	1.55	0.61	0.36	0.34	0.46	0.42
Other reservoirs	28.86	25.64	6.28	3.08	1.04	0.99	0.11	0.10
Forest	23.57	22.75	26.73	12.17	50.79	48.11	33.70	30.86
Farmland	41.2	38.24	103.77	50.88	33.87	32.11	57.55	52.69
Building	8.03	0.71	34.97	17.18	5.81	5.50	5.42	4.96
Roads	2.11	1.81	2.45	1.02	1.58	1.49	0.96	0.86
Meadow	-		-		3.92	3.71	0.46	0.42
Wet meadow	-		-		2.22	2.10	3.17	2.90
Summer resort buildings	1.97	1.69	-		-		-	
Bushes	2.03	1.74	9.97	4.90	2.33	2.21	2.49	2.28
Totally	116.46	100	206.43	100	105.55	100	109.21	100

Table. 2. Physico-chemical parameters in the studied lakes (D – tributary, W – outflow, B – bank)

Specifications	Gumienek		Ściegienne		Lipieniec		Święte	
Position feature	D	W	D	W	D	B	D	B
Temperature, ºC	24	26	23.2	24	23	25	25	27
Oxygen, mg O_2/l	13	12.01	10	9.9	7.6	6.5	8.9	7.7
Oxygen, %	135	129	118	116	98	87	108	102
Water reaction pH	7.62	7.8	8.1	8.0	7.75	7.5	5.2	7.1
Electronic condactivity, $\mu S \cdot cm^{-1}$	288	234	314	302	298.35	287	49.75	66.5
Sechi disc visibility, m	0.91	1.5	0.8	1.3	2.0	2.2	1.1	1.5
N-NO_3, mg N/l	0.99	0.51	0.21	0.17	0.23	0.20	0.48	0.42
P-PO_4, mg P/l	0.1	0.02	0.09	0.07	0.02	0.012	0.042	0.040

The structure of macrophytes, in the studied lakes, was also varied. In all investigated lakes 3 groups of macrophytes occurred: emergent, submerged and with floating leaves. Emergent vegetation was the most numerous in each investigated lake. It formed a belt along the shoreline of lakes. Plants with floating leaves and submerged macrophytes formed patches or occurred individually (Table 3).

In relation to the total lake surface macrophytes occupied various areas. In the flow lakes Gumienek and Ściegienne, macrophytes occupied respectively 21.8% and 15.44% of the surface lake. However, in the inflow lakes macrophytes inhabited 31.57% or the surface area in lake Lipieniec and 19.7% in Lake Święte. Among all of the lakes together a total of 17 plant communities made up the phytolittoral zone, which included 25 species. In each the flow lakes there were 10 macrophyte communities, while in the inflow lakes there were 8 com-

munities in lake Lipieniec and only 5 in Lake Święte. There was no submerged macrophyte community in Lake Święte (Table 3).

Table 3. Plant communities occurring in the studied lakes

Plant community	Gumienek	Lipieniec	Ściegienne	Święte
Lodeetum canadensis (Ping. 1953) Pass. 1964		o 1		
Ceratophylletum demersi Hild. 1956	o 4	o 2	o 2	
Potametum perfoliati Koch 1926 em. Pass. 1964	o 1			
Nupharo-Nymphaeetum albae Tomasz. 1977	o 2	o 2	o +	o 2
Hydrocharitetum morsus-ranae Langendonck 1935		o 1		
Eleocharitetum palustris Šennikov 1919	. +			o +
Phragmitetum australis (Gams 1927) Schmale 1939	/ 4	/ 5	/ 5	/ 3
Typhetum angustifoliae (Allorge 1922) Soo1927	/ 2		/ 1	
Typhetum latifoliae Soo 1927		/ 1	/ 1	
Scirpetum lacustris (Allorge 1922) Chouard 1924	/ 1	o +		
Caricetum elatae 1926			/ 1	o +
Thelypteridi-Phragmitetum Kuiper 1957			/ 2	/ 1
Cariicetum rostratae Rübel 1912			/ 1	
Glycerietum maximae Hueck 1931	/ +		/ 1	
Salicetum pentandro-cinereae (Almq. 1929) Pass. 1961	o +			
Sagittario-Sparganietum emersi R.Tx. 1953	o +		o 1	
ass. with *Utricularia vulgaris* L.		. +		

/-belt, o – patch, .- single; cover: 1. 0–10%, 2. 11–30%, 3. 31–50%, 4. 51–80%, 5. 81–100%

In the flow lakes, average width of phytolittoral ranged from 31 m in the lake Ściegienne to 36.6 m in the lake Gumienek. However, in the inflow lakes the range amounted 21.5 in the lake Lipieniec to 23.1 m in the lake Święte. The maximum depth of macrophytes occurrence was differentiated in studied lakes. In the flow lake the maximum depth of the macrophyte occurrence reached 1.8 m (lake Gumienek), and in the inflow lakes 2.1 m (lake Lipieniec).

Higher diversity, density and biomass of emergent macrophytes occurred in the inflow lakes. In flow lakes the analyzed features of emergent macrophytes differed depending on the test stands. In places where the water flow into the lakes halophytes showed particularly large values of density and biomass (Table 4).

Table 4. The structure of emergent macrophytes in studied lakes

Specifications	Gumienek		Ściegienne		Święte		Lipieniec	
Test site	D	W	D	W	D	B	D	B
Number of species	5	4	4	3	7	4	11	6
Surface of emergent macrophytes, %	16.8		12.8		18.3		16.5	
Max. depth of occurrence, m	1.4	1.0	1.2	0.9	1.3	1.1	1.3	1.3
Density, ind./m^2	74	54	78	40	182	61	108	96
Biomass, g_{dw}/m^2	318.7	133.8	250.9	40.4	568.2	482.6	756.4	120.2
Dominant species	*Phragmites australis*	*Typha angustifolia*	*Typha latifolia*	*Typha angustifolia*	*Typha latifolia*	*Phragmites australis*	*Phragmites australis*	*Phragmites australis*

Macrophytes can create different type of phytolittoral lake. In the studied lakes there were three types of phytolittoral. In the Gumienek lake, from the northern side of the lake, close to the beach occurred, small-lake type of phytolittoral, which occupied 40% of the shoreline, while pond type of phytolittoral occupied 60% of the shoreline. In the lake Ściegienne occurred on the entire length of the shoreline small-lake type of phytolittoral. In the lake Lipieniec occurred only pond type of phytolittoral. However, in the Święte lake macrophytes formed fading- type of phytolittoral.

DISCUSSION

The study included small but relatively deep lakes. Lakes of this type are more vulnerable to the impact of the catchment area [Jennings *et al*. 2003]. The water table of the lakes investigated from 50 s [Wilgat 1954] was subjected to significant changes, as evidenced by a reduction in their surface (Gumienek 0.52 ha, Ściegienne 4.04 ha, Lipieniec 0.47 ha, Święte 0.81 ha). The disappearance of lakes in the Łęczna-Włodawa Lake District is caused mainly by, reclamation works conducted in the 50s of the last century, which resulted in lowering of the groundwater level, and the intensification of agriculture that increased the amount of nutrients flowing in and caused overgrowth [Czachorowski 1995, Radwan 1994]. Drainage also led to the elimination of septic areas and mixing of different origin and quality waters [Janiec 1992].

Changes in the water level of lakes usually have a negative impact on the species diversity of macrophytes [Hellsten *et al*. 1996] and the habitats of their occurrence [Blindow *et al*. 1993]. Particularly unfavourable are high and rapid changes in water level [Hellsten 2000]. Small fluctuations, according to the theory of "moderate disturbance", increase their diversity [Rorslett 1991]. The studied lakes can be counted among the lakes undisturbed hydrological relations. In case of studied lakes, seems more important factor is connected with introduction, into the lakes, alien waters. The supply of such waters, usually highly eutrophic, can destabilize the ecosystem [Solis 2012]. In all investigated lakes either species diversity and density, as well as the biomass of macrophytes reached higher values in positions where alien water flow into the lake. In inflow lakes the examined features were even higher.

The flow of river water through the reservoir reduced retention time, causing, on the one hand the increase of lake trophy, and on the other reducing the algal biomass by the mechanical elution [Huszar and Reynolds 1997]. At that time macrophytes win the competition for light and nourishment. It is very important because this group of organisms is attributed to the decisive role in the restoration of lakes [Diehl and Kornijów 1997, Lacoul and Freedman 2006].

Land-use of the buffer zone has a large impact on water quality of the lake and the structure of macrophytes. As the buffer zones in most investigated lakes

had anthropogenic influences, this should not be ruled out its negative impact. Particularly unfavorable is impact of agricultural land and peatlands subjected of mineralization processes [Misztal and Smal 1992].

In the lake Gumienek an additional incentive stimulating the spread of the macrophytes and their relatively high biomass appears to be the presence of fishponds. Water from the ponds is supplied into the lake. Rich in organic matter and the suspension waters from ponds [Bonisławska *et al*. 2016] stimulate the growth of aquatic vegetation [Broyer and Curtet 2011, Daniel *et al*. 2005]. While, thanks to the movement of the water does not occur overgrowing lakes.

CONCLUSIONS

1. The buffer zone of the flow lakes was dominated by farmland, but there was no land meadow. In the inflow lakes co-dominated fields and forests in the buffer zone.

2. The inflow lakes characterized by greater species diversity, density and biomass of emergent macrophytes.

3. In all investigated lakes, in the zone of water supply, analyzed features of macrophytes, and selected chemical parameters of water, reached the highest value.

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ZRÓŻNICOWANIE STRUKTURY MAKROFITÓW W MISACH JEZIOR PRZEPŁYWOWYCH I DOPŁYWOWYCH

Streszczenie. Celem pracy była analiza wpływu ruchu wody na jakościowe oraz ilościowe występowanie makrofitów w jeziorach. Do badań zostały wybrane dwa jeziora przepływowe oraz dwa jeziora dopływowe. Badania obejmowały: wyznaczenie stref buforowych jezior i analizę form zagospodarowania terenu i ukształtowania, inwentaryzację florystyczną litoralu jezior, charakterystykę typów fitolitoralu, analizę parametrów fizyczno-chemicznych wód jezior.

Strefa buforowa jezior przepływowych zdominowana była przez agrocenozy, nie występowały tu łąki. W strefie buforowej jezior dopływowych współdominowały agrocenozy i lasy. Jeziora dopływowe charakteryzowały się większą różnorodnością gatunków, a także zagęszczeniem i biomasą makrofitów wynurzonych. We wszystkich badanych jeziorach stanowiska usytuowane przy dopływie wody do jeziora charakteryzowały się większymi wartościami analizowanych parametrów wśród roślinności oraz wybranych parametrów fizyczno-chemicznych wody.

Słowa kluczowe: jeziora przepływowe, jeziora dopływowe, makrofity wynurzone, użytkowanie strefy buforowej