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RESEARCH PAPER

Impact of the Drainage System on Water Vegetation of the Lowland Lakes (Eastern Poland)

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Abstract

The Wieprz–Krzna drainage and irrigation canal was created in the early 1960s highly complicated water relations and the hydrological systems of the Polesie region of Eastern Poland. The highest level of degradation occurred in the hydrogenic areas of the Łęczna–Włodawa Lake District. The aim of this study was to complete a qualitative and quantitative analyses of changes from 1959 to present of vascular plants in lakes influenced by the drainage system. In addition, an evaluation of the lakes' ecological status was conducted and comparisons between lakes transformed into reservoirs, embanked lakes, and natural lakes were made. Based on RI values that are used to determine ecological status, in 1959 all of the eight lakes reached good or high ecological status but in 2015 only two remained in this classification. The extensive changes observed in the macrophyte plant communities within all lakes in the study, indicates a progressive process of overgrowth in both natural and transformed lakes. Agricultural water inputs from the WKCS into lakes has lead to their slow but differentiated degradation. The greatest changes within the studied eutrophic and hypertrophic lakes studied have occurred in lakes converted to retention reservoirs.

Keywords: Embankment, macrophyte biomass, phytolittoral.

Introduction

As with many other places around the world, fresh water in Poland is a scarce resource and its quality is in many cases is poor. Intensive agriculture and industrial use puts pressure on Poland's fresh water resources which are already quite low, only 1600 m^3 per individual. Furthermore, Poland uses twice as much water per person than other EU countries, likely due to intensive agriculture. Approximately 70% of rivers in Poland fail to qualify as having good ecological status as outlined by the Water Directive of the European Union.Up to 66% of natural lakes, partially transformed lakes or embanked lakes, and reservoirs do not meet good ecological qualifications either.

Wetland drainage has been implemented on a large scale in Europe since the XIX century. Consequently, the number and area of wetlands in Europe has decreased dramatically. Furthermore, drainage of wetlands and bogs as well as intensified eutrophication spurred by agricultural nutrient inputs has led to decreased biodiversity. This in turn also had a negative impact on the landscape and the hydrological cycle (Billen & Garnier, 2000; Herzon & Helenius, 2008).

In Europe, the majority of the drained land has been converted to farmland. Poland, has drained 4.205.000 ha of land since the early 1900's and approximately 25% of agricultural lands in Poland have been acquired through drainage. In Poland, the Netherlands, and Finland surface drainage was utilized over subsurface drainage, as it was more efficient. An open system, with proper management may limit nutrient supply from surface flows (Scheffer & Van Nesü, 2007) and has a greater potential to enrich biodiversity (Schmieder, 1997) than closed systems.

Eastern Poland is one of the least economically developed regions in Europe. For 200 years wetland drainage has been implemented in the Polesie region as a way to increase agricultural production and ultimately improving the living conditions of the local population. Melioration activities intensified after the World War II and the most aggressive drainage began in 1954 as part of the Wieprz-Krzna Canal System (WKCS) that was completed in 1961 (Michalczyk, 1994; Wilgat, Michalczyk, Truczynski, & Wojciechowski, 1991). This project covered a significant part of the Polesie Lublin region, and stretching for 139.9 km it is the longest drainage system in Poland. Connecting the Middle course of the Wieprz River with the waters of the southern Krzna, the WKCS has impacted over 3.770 km^2 (Michalczyk, Mięsiak-Wójcik, Sposób, & Truczynski, 2012). Unsurprisingly, this project highly complicated water relations in the region. The largest scale of degradation was concentrated on hydrological areas in the Łęczna–Włodawa Lake District (Dawidek, Sbolewski, & Truczyński, 2004; Lorens, Grądziel, & Sugier, 2003). Implementation of the WKCS affected the river network as well as over 60 natural lakes in the area to different degrees. Many natural lakes in the region were converted into complete retention reservoirs while others were partially converted to using embankments on segments of the shoreline (Janiec, 1994; Radwan & Kornijów, 1991).

Drainage of wetlands contributed to increased runoff of surface waters, decreased groundwater levels, and lead to the transformation of peatlands into anaerobic peatbogs (Michalczyk, 2009). The influence of agricultural runoff into Łęczna-Włodawa Lake District has been studied across many different fields including hydrology, (Janiec, 1994; Sender, 2012), plant ecology (Lorens *et al.*, 2003) and aquatic flora and fauna (Radwan & Kornijów, 1991). There is, however, a lack of comprehensive research regarding the consequences of embanking lakes, developing reservoirs, and separating standing water bodies from their catchment areas on phytolittoral zone changes. In more than a 50-year-long history of the functioning of the WKCS, 13 lakes have been transformed into retention reservoirs and excluded from exploitation (e.g. Mytycze, Skomielno), while others had their recreational and ecological functions reduced or modified.

Macrophytes are one of the most important biological indicators of ecological status of reservoirs and their ecological processes and functions. The European Union's Water Framework Directive uses aquatic macrophyte species composition and abundance as a biological quality element for assessing the ecological functioning of aquatic ecosystems (Penning *et al.,* 2008; Velichkova & Sirakov, 2013). Macrophytes are generally have a positive influence on the functioning of the entire water ecosystem through filtration of pollutants (Feldmann & Noges, 2007; Sender, 2009) and create habitat for fauna.

Macrophyte communities naturally change through time and the speed of these changes varies among macrophyte types. Changes in emergent macrophytes are quite slow, usually spanning several years to decades (Lacoul & Freedman, 2006; Sender, 2008). Submerged ones however, particularly in shallow lakes, are sensitive to changes in habitat conditions and can change within a few years (Rooney, Kalff, & Habel, 2003; Schaumburg *et al.*, 2004). Changes in environmental conditions including differences in nutrients and seasonal temperature can influence the composition of submerged macrophytes (Kosten *et al*., 2009). Nevertheless, other important factors that influence macrophyte development include wind, water level fluctuations, and algal blooms (Lechmann & Lachavanne, 1999).

In lakes where the phytolittoral zone covers a small portion of total lake surface, macrophytes may only have local ecological impacts (Rosińska, Rybak, & Goldyn, 2016). Ecological processes within catchments greatly influence hydrological systems within the lakes. In the Łęczna–Włodawa Lake District two factors play a particular important role: a nearly horizontal location of the underground water table and a close-to-balanced amount of rainfall and potential evaporation (Wilgat *et al*., 1991).

The aim of the present study was twofold: to analyse the influences of the WKSC drainage system on vascular plants in reservoirs, embanked, and natural lakes and to compare them to data collected in the same areas from 1959 and to evaluate their ecological status based on the German evaluation index RI (References Index).

Materials and Methods

Characteristics of the Research Area

Eight lakes located within the Łęczna–Włodawa Lake District (Figure 1) were studied.

The studied lakes are interconnected and influenced by the WKSC in various ways. Three of them: Mytycze, Skomielno, and Tomaszne have been converted into complete reservoirs, whereas three others, Bikcze, Gumienek and Czarne Uścimowskie, have had embankments built to varying degrees. In addition, two additional two natural lakes were studied for comparative purposes, Uścimowskie and Ściegienne, to which waters are added from surrounding areas (Table 1). The lakes in question are highly dissimilar in surface area: the smallest, Lake Gumienek, is only 8.1 ha and the largest reservoir, Mytycze, 202 ha (Table 1).

Floristic Investigations

Basic physicochemical parameters tests and floristic studies were carried out between 2009 and 2015 during peak macrophyte growth each growing season. Vegetation studies were conducted in horizontal transects extending from the shoreline to the maximum depth of macrophyte occurrence (Saikkonen, Herzon, Lankoski, & Ollikainen, 2011). The number of transects for each lake studied varied from 6 in small lakes up to 10 in large lakes. Plant communities were examined and identified with the application of the Braun-Blanquet phytosociological methods (Dzwonko, 2007). The taxonomic system was adopted from Matuszkiewicz (2008). Macrophyte communities were classified as emergent, free-floating, or submerged. Plants were collected at all depths from transects to determine the total biomass of each of the macrophyte groups. First, emergent macrophyte density was calculated by counting individual stems from five m^2 frames alone each transect, then 15 shoots of each species were randomly harvested from each m^2 frame to determine biomass. Submerged macrophytes and free-floating plants were collected using the floral rake with a sampling area of $0.16m^2$. Collected biomass was washed and dried in order to determine the dry mass of each group. The Lowrance Elite-5 sonar and floral anchor were used to determine the occurrence and the depth ranges of macrophytes.

The phytolittoral surface and the length of the shoreline inhabited by macrophytes were derived from the method of retrospective photointerpretative

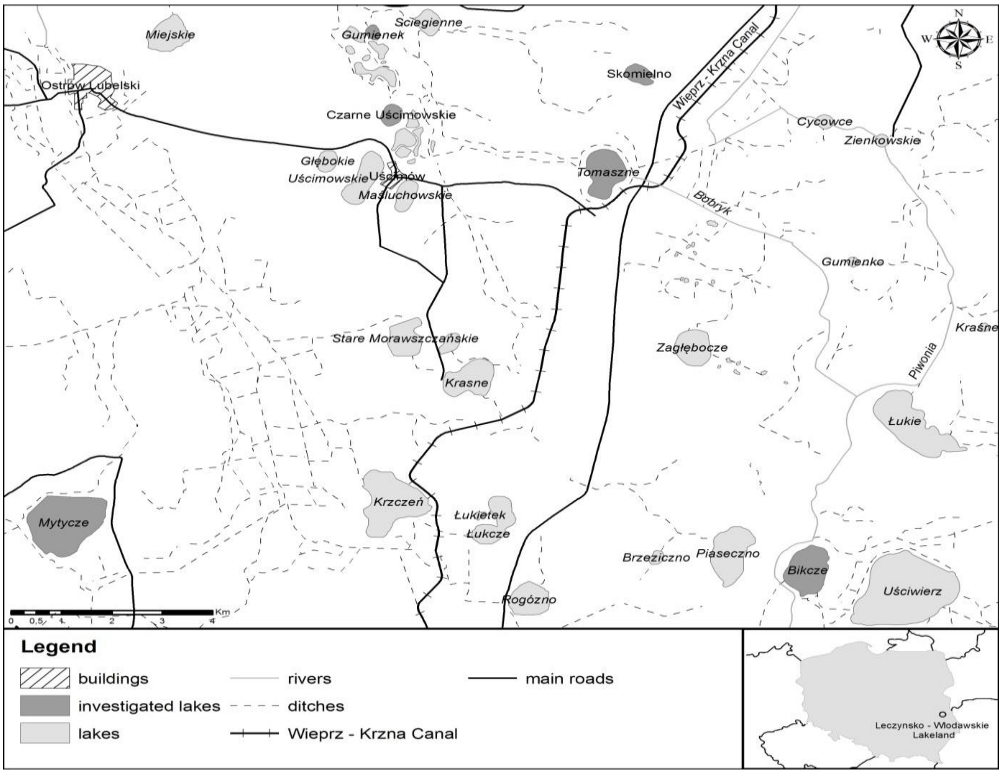

Figure 1. Locations of investigated lakes.

Table 1. Morphometric parameters (acc. to *Wilgat (1991)) (Lowrance sonar measurements), management of catchment area of investigated lakes and trophy (acc. to **Fijałkowski (1959)

	Embanked Lakes			Storage reservoirs			Natural lakes	
Lake Parameter	Bikcze	Gumienek	Czarne Uścimowskie	Mytycze	Skomielno	Tomaszne	Ściegienne	Uścimowskie
Surface (ha)	85	8.1	24.8	24.2	35.8	81.7	19,5	68,5
Area after change to reservoirs (ha)				202	74	95		
Max. depth (m)	3.3*	11.8	10.3*	1.2*	3.2	3.1	5,3	4.4
Mean depth (m)	1.5	3.8	3.7	0.5	1.6	1.8	2.8	2.7
trophy 50's**	eutrophy	eutrophy	eutrophy	dystrophy	eutrophy	oligotrophy	eutrophy	eutrophy
trophy 2015	eutrophy	eutrophy	eutrophy	hypertrophy	eutrophy	hypertrophy	eutrophy	hypertrophy
Lenth of shoreline (m)	3587	1014	1823	1958	2080	3859	1781	3904
Capacity (tys·m^{-2})*	1269	307	915	128	483	1435	756	1795
Capacity after change to reservoirs (tys·m^{-2})*				3092	750	2208		
Catchement area (ha)	183.32	21.5	150	72.2	552.68	331.5	87.5	318
Use of catchement area (%)(%)	A - 15 P - 85	A - 25 Pd – 50 F - 25	A - 50 Pd- 50	A - 75 F - 20 B -5	A - 40 F - 30 M - 30	A - 75 B - 15 F - 10	A - 30 B - 10 F – 30 M- 25 P - 5	A - 45 B - 10 F – 10 M- 35

P – peat-bogs, A – agrocenoses, F – forests, B – buildings M – meadows, Pd –ponds
** - catchment inside the banks surrounding the reservoir

analysis, using aerial photographs taken in 2007 as well as satellite images from Rapid Eye taken in 2013. The photographs were then converted into orthophotomaps, with one pixel representing 0.5 m in the field. Maps of current macrophyte cover and surrounding land management were developed with GIS software (ArcView, ArcInfo). The assessment of the ecological status of lakes was based on the German evaluation index RI (References Index) (Schaumburg *et al.* 2004). The Polish evaluation system was not used for the evaluation, as it is inappropriate for the "type specific" lakes in the Łęczna-Włodawa Lake District (Ciecierska, Kolada, Soszka, & Golub, 2006). Species diversity was estimated using the Shannon-Wiener diversity index (Magurran, 1988).

Physical and Chemical Parameters of Lake Waters

Physical and chemical water properties were determined for three positions: shallow littoral, littoral and profundal. All measurements were repeated along two transects in each lake, and the following parameters assessed: temperature, pH (water reaction), electrolytic conductivity, oxygen content, total P and N. The instrumentation used for determining physical and chemical properties of water was WTW Oxi 330 Oximeter (oxygen content, temperature), Hanna Electric Conductivity Meter (electrolytic conductivity) and Slandi SP300 pH-meter (water reaction). The content of biogenic nitrogen and phosphorus compounds was determined with the application of the Slandi photometer LF 205.

For the analysed lakes Carlson's Trophic State Index (TSI) was calculated, based on Secchi disk depth (SD), nitrogen (TN) and phosphorus (TP) content (Carlson, 1977).

A multivariate ANOVA was preformed assuming Wilks's lambda distribution to compare differences between given indices. To discern which abiotic factors influence macrophyte biomass and cover a RDA (Redundancy Analysis was conducted. All statistics were completed in Statistica 8.1. Similarities analysis for structure and density of macrophytes in studied lakes using the UPGMA method (Unweighted Pair-Group Method Using Arithmetic Averages) MVSP 3.2 Programme.

Results

Cultivated fields appeared within the vicinity of all the lakes but were particularly dominant around lakes converted into retention reservoirs (Table 1). The Carlson's correlation values indicate that the lakes are eutrophic and hypertrophic. Differences in physical and chemical parameters of lakes converted into storage reservoirs and the remaining ones were statistically significant the most significant were temperature, P-PO_4^{3-} (mg $PO_4 \cdot l^{-1}$), TSI (TP) and TSI Carlson's (Table 2).

In studied eutrophic natural lakes macrophytes typically covered 29% of the lakes surface area. In the studied embanked lakes the area occupied by macrophytes the average was 63.6%. The area covered by macrophytes in the reservoirs we studied averaged 18.9%. For specific averages see Table 3.

Emergent macrophytes occurred at deeper depths in reservoirs as compared to embanked and natural lakes. Submerged macrophytes displayed a reverse pattern, occurring at deeper depths in embanked lakes, with the exception of the reservoir, Lake Skomielno, where they occurred at a depth of up to 3m, despite light limitation past 2m (Table 3). Submerged macrophytes were dominant in the

Table 2. Selected physico-chemical parameters of waters in investigated lakes

Lake	Embanked Lakes		Reservoirs			Natural lakes			
	Bikcze	Gumienek	Czarne Uścimowskie	Mytycze	Skomielno	Tomaszne	Ściegienne	Uścimowskie	p-value
secchi disc visibility (m)	2.2	0.91	4.1	0.35	2	0.4	1.3	0.6	0.25
temperature (°C)	24.1	26.8	24.5	25	26.1	25.4	23.2	23.1	0.046*
oxygen concentration in water ($mgO_2 \cdot l^{-1}$)	10.3	12.01	9.7	12.5	9.9	13.6	9.9	15.4	0.09
electrolytic conductivity ($\mu S \cdot cm^{-1}$)	239	314	211	240	250	387	234	330	0.67
pH	8.2	7.62	8.2	9.1	7.5	8.5	8.1	8.15	0.15
% O_2	119	129	106	142	107	159	116	132	0.15
N-NH_4^+($mgN \cdot l^{-1}$)	0.15	0.51	0.13	0.17	0.21	0.66	0.17	0.74	0.62
N-NO_3^-($mgN \cdot l^{-1}$)	0.1	0.49	0.1	0.12	0.17	0.54	0.1	0.1	0.55
P-PO_4^{3-} (mg $PO_4 \cdot l^{-1}$)	0.024	0.01	0.018	0.033	0.359	0.015	0.07	0.354	0.002*
P total (mg $PO_4 \cdot l^{-1}$)	0.028	0.21	0.022	0.25	0.29	0.35	0.18	0.311	0.07
N total ($mgN \cdot l^{-1}$)	2.3	1.39	2.6	3.32	3.07	4.1	2.4	1.58	0.11
TSI SD	48.6	61.4	39.6	75.1	50	73.2	56.2	70	0.06
TSI (TN)	66.5	59.2	68.2	71.7	70.6	74.8	68	64	0.06
TSI(TP)	52.2	81.9	44.6	79.7	81.8	84.5	76.2	78	0.039*
TSI Carlson's	55.8	67.5	50.8	75.5	67.5	77.5	66.8	70.6	0.038*

phytolittoral zone of embanked lakes, whereas in retention reservoirs their share was negligible and in natural lakes was low (Table 3). Submerged macrophyte biomass values varied greatly between the lake types. In embanked lakes submerged macrophytes reached up 1,09 ton of dry matter per hectare of total surface area, while in retention reservoirs the biomass was low and reached only up to 0,02 ton of dry matter per hectare, and the differences were statistically significant ($p=0,017134 < 0,05$). In natural lakes, submerged macrophyte biomass per hectare reached 0.61 tons. Based on RI values that are used to determine ecological status, in 1959 all of the eight lakes reached good or high ecological status but in 2015 only two remained in this classification.

Currently, the number of plant communities creating the phytolittoral zone showed little dissimilarity and ranged between 6 and 13 in all lakes studied, however, with the exception of Lake Mytycze, where only 2 plant communities have developed (Table 4). A drastically decreased number of plant associations in the lakes under analysis indicated great transformations in the structure of plant communities. In virtually every one of the investigated lakes submerged macrophytes disappeared and were substituted, with a single exception of *Acotertm calami*, by emergent macrophytes; as exemplified by the appearance of *Ranunculetum circinati* in all lakes with *Charetum fragilis* and *Elodeetum canadensis* disappearing from most of them (Table 4).

In every type of the studied water bodies, the species diversity has changed. Reservoirs Tomaszne and Mytcze, underwent the greatest alterations while the smallest changes occurred in embanked lakes and the natural Lake Ściegienne (Figure 2).

Cluster analysis for plant assemblages in 8 lakes, performed on macrophytes coverage, biomass, and species composition let to divide studied lakes into two groups (Figure 3). The first group consisted storage reservoirs and the one natural lake Uścimowskie., All the lakes with the lakes in this group reaches poor or moderate ecological states with the exception of lake Skomielno which read a good ecological state. Within the group, the highest value of similarity index (0.91) showed macrophytes of lakes Uścimowskie and Skomielno. Lake Mytycze showed the highest separation from the other lakes (0.51). The second group included four lakes: the natural Lake Sciegienne and the three embanked lakes all of which reached good and moderate ecological state. Macrophytes in lakes Ściegienne and Czarne Uścimowskie (0.93) showed the highest similarity within this group. Values of the Pearsons correlation vacillated between 0.39 and 0.93 or 0.39% and 93%.

Results from the RDA analysis allowed for characterization of environmental factors that influence the biomass and surface cover of macrophytes. For embanked lakes, and the natural lake Ściegienne, visibility and lake surface drove high macrophyte cover. In lakes converted into reservoirs and the natural lake Uścimowske, nutrients and depth drove low macrophyte cover (Figure 4). High macrophyte biomass in Czarne Uścimowskie and Uścimowskie was most influences by management of the catchment area. Water inflow and outflow patterns as well as lake depth had the greatest impact on biomass in lakes Gumienek, Bikcze, Skomielno. Total phosphorous and visibility had the greatest impact on biomass in all of the reservoirs, respectively (Figure 4).

Discussion

The analysed lakes represented different ecological statuses based on the German index (References Index-RI). In 1959 six of the eight lakes possessed good ecological status and two, Bikcze and Mytycze were considered to be in very good ecological states. Presently, only two lakes in the

Table 3. Phytolittoral surface. biomass and RI index in investigated lakes (E-emergent. S- submerged. F – Floating leaved)

Lake		Embanked Lakes						Reservoirs						Natural lakes			
		Bikcze		Gumienek		Czarne Uścimowskie		Mytycze		Skomielno		Tomaszne		Ściegienne		Uścimowskie	
Year		1959	2015	1959	2015	1959	2015	1959	2015	1959	2015	1959	2015	1959	2015	1959	2015
phytolittoral surface (ha)	E	8.8	17.9	1.1	1.68	2.7	7.61	7.2	9.8	10.7	17	7.5	22.4	3.5	6.3	14	13
	F	2.1	6.7	0.4	0.6	0.4	3.51	1.6	0	0.2	0.7	0.6	0.6	1.4	0	2.2	1.3
	S	14.1	40.9	1.4	1.64	3	5.2	2.8	0	1.1	2.7	1.1	0.06	2.2	0.8	2.1	0.6
max. range of macrophyte occurrence (m)	E	1.1	1.2	1.2	1.2	1.2	1.2	1.3	1.4	1.3	1.3	1.5	1.4	1.2	1.3	1.2	1.3
	F	1.4	1.3	1.5	1.4	1.5	1.5	1.4	0	1.5	1.5	1.6	1.2	1.3	0	1.3	1.35
	S	2	2.1	2.2	2.1	4.5	4.4	1.5	0	3	3	2.5	1.4	1.5	1.55	1.5	1.45
% share of phytolittoral in lake		29.4	77.1	35.8	48.4	24.6	65.4	47.9	4.9	33.5	27.6	11.3	24.2	28.9	36.4	19.8	20.8759
dry weight (t) phytolittoral surface per 1 ha	E	-	2.07	-	1.77	-	1.62	-	2.5	-	2.34	-	2.2	-	1.8	-	1.6
	F	-	0.22	-	0.04	-	0.21	-	0	-	0.01	-	0.04	-	0	-	0.13
	S	-	1.5	-	1.85	-	0.51	-	0	-	0.14	-	0.01	-	0.99	-	0.4
dry weight (t) total lake surface per ha	E	-	1.6	-	0.74	-	1.06	-	1.02	-	1.33	-	1.26	-	0.77	-	1.14
	F	-	0.2	-	0.02	-	0.08	-	0	-	0.01	-	0.02	-	0	-	0.008
	S	-	1.09	-	0.85	-	0.43	-	0	-	0.02	-	0	-	0.61	-	0.14
RI index		**0.71**	**0.63**	**0.61**	**0.41**	**0.62**	**0.43**	**0.7**	**0**	**0.65**	**0.6**	**0.66**	**0.13**	**0.62**	**0.44**	**0.51**	**0.26**
ecological status		high	good	good	moderate	good	moderate	high	bad	good	good	good	poor	good	moderate	good	poor

Table 4. Plant associations occurring in the investigated lakes (+ indicates presence according to Fijałkowski (1959) and percent coverage given from 2015)

	plant association	Bikcze		Gumienek		Czarne Uścimowskie		Mytycze		Skomielno		Tomaszne		Ściegienne		Uścimowskie	
		1959*	2015	1959*	2015	1959*	2015	1959*	2015	1959*	2015	1959*	2015	1959*	2015	1959	2015
	Phragmitetum australis (Gams 1927) Schmale 1939	+	9.2	+	0.9	+	4.3	+		+	10.6	+	18.5	+	2.32	+	7.4
	Acoretum calami Kobendza 1948			+		+						+				+	0.75
	Typhetum latifoliae Soo 1927						1.37	+	6.9								
	Typhetum angustifoliae (Allorge 1922) Soo 1927		5.2	+	0.5	+	0.7	+	2.9	+	2.95	+	3.6	+	1.87	+	2.86
	Scirpetum lacustris (Allorge 1922) Chourard 1924	+		+		+	0.4	+		+	0.4	+		+		+	
	Thelypteridi-Phragmitetum Kupier 1957	+	2.1				0.6	+			2.8						
	Caricetum elatae Koch 1926	+					0.08								1.13		
	*Scirpetum sylvatici*Ralski 1931						0.06	+									
E	*Salicetum pentandro-cinereae* (Almq. 1929) Pass. 1961	+	1.3		0.1		0.1						0.3				
	Eleocharitetum palustris Šennikov 1919	+	0.1		0.04	+		+				+					
	*Caricetum paniculatae*Wangerin 1916																
	Cicuto-Caricetum pseudocyperi Boer et Siss. in Boer 1942							+			0.2						
	Sparganio-Glycerietum fluitantis Br.-Bl. 1925 n.n.				0.09			+									
	Epilobio-Juncetum effusi Oberd. 1957							+									
	Sagittario-Sparganietum emersi R.Tx. 1953				0.03					+	0.05	+		+	0.21		
	Glycerietum maximae Hueck 1931				0.02							+		+	0.67		
	Equisetetum fluviatilis Steefen 1931	+				+											
		-	**17.9**	**-**	**1.68**	**-**	**7.61**	**-**	**9.8**	**-**	**17**	**-**	**22.4**	**-**	**6.2**	**-**	**11.01**
	Plant with floating-leaf																
	Nymphaeetum candidae Miljan 1958	+		+		+	0.4			+	0.12	+		+		+	
F	*Potametum natantis* Soo 1923			+		+	0.21			+	0.06	+		+			
	Hydrocharitetum morsus-ranae Langendonck 1953	+	4				2.9			+					0.39		1.87

Table 4. Continued

	Nupharo-Nymphaeetum albae Tomasz. 1977	+	2.9	+	0.6	+				+	0.52	+	0.6	+		+	0.46
	Lenmominoris – Salvinietum natantis (Slavnić 1956) Korneck 1959							+							0.1		0.2
		-	**6.9**	**-**	**0.6**	**-**	**3.51**	**-**	**0**	**-**	**0.7**	**-**	**0.6**	**-**	**0.49**	**-**	**2.53**
	Submerged																
	Ceratophylletum demersi Hild. 1956	+	22.8	+	1.3	+	5.2	+		+	2.4		0.04	+	0.44		1.33
	Charetum fragilis Fijałkowski 1960	+	1.3							+		+					
	Elodeetum canadensis (Ping. 1953) Pass. 1964		6.7	+		+				+		+		+		+	
	Nitellopsidetum obtusae (Sauer 1937) Dąmbska 1961									+	0.3						
	Myriophyllo-Litorelletum Jaschke 1959											+					
S	*Potametum acutifolii* Segal 1961		7.4														
	Potametum pectinati Carstensen 1955		2.7													+	
	Potametum lucentis Hueck 1931									+		+					
	Potametum perfoliati Koch 1926 em. Pass. 1964	+			0.34					+		+		+			
	Myriophylletum spicati Soo 1927			+		+						+	0.02	+		+	
	Ranunculetum circinati (Bennema et West. 1943) Segal 1965	+		+		+						+		+			
		-	40.9	-	1.64	-	5.2	-	0	-	2.7	-	0.06	-	0.44	-	1.33
	Total number of plant associations	15	12	11	10	13	12	12	2	14	11	17	6	13	8	9	7

study, Bikcze and Skomielno represented good ecological status. Moderate ecological status was determined for the three lakes: Gumienek, Czarne Uścimowskie and Ściegienne. This situation could have resulted from the contact with foreign waters from adjacent fishponds for lakes Gumienek and Uścimowskie and from the WKK canal for lake Ściegienne. The remaining investigated lakes were characterized as having poor or bad ecological status. This index is based mainly on submerged macrophytes and floating-leaf plants, which are more sensitive to changes in water conditions (Radwan & Kornijów, 1991; Søndergaard *et al.,* 2010; Bolpagni, *et al.,* 2013). In lakes where index values were low, hence qualified as of poor ecological state, submerged macrophytes were virtually absent and frequent phytoplankton blooms occurred. Management of catchment areas greatly influence the functioning of reservoirs and may promote or inhibit degradation processes (Anastasiadis, 2004). In addition to catchment area management, the size of the catchment area, the ratio of shoreline to water volume, lake mean depth. Using indices developed by Bajkiewicz-Grabowska (1987) the studied lakes are found to be highly susceptible to degradation.

Most of the lakes studied were eutrophic. Considerable changes in lake trophy have occurred in lakes Mytycze, Tomaszne and Uścimowskie over the

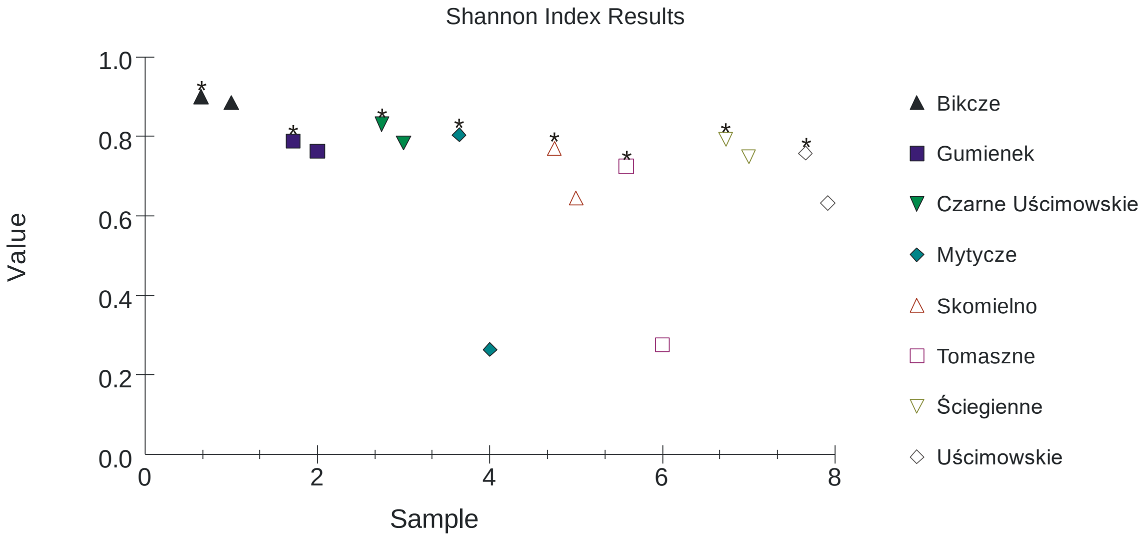

Figure 2. Shannon-Wiener index in years 2015 and 1959*.

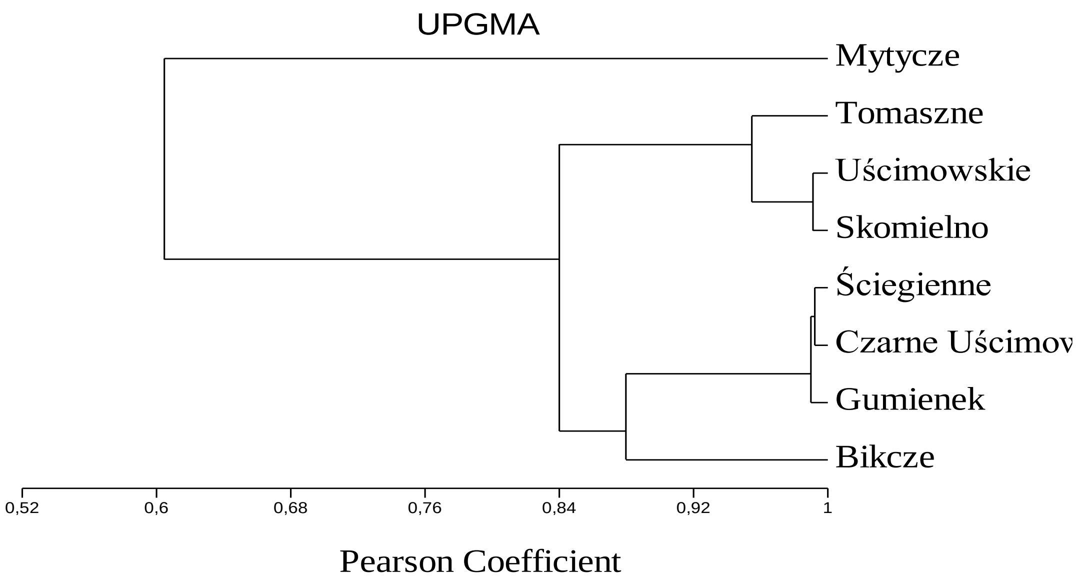

Figure 3. Cluster analysis (UPGMA). Qualitative and quantitative similarities in species diversity and density in studied lakes.

last half-century. Whereas the lakes were dystrophic and oligotrophic in the 1950s (Fijałkowski, 1959) recently they have become hypertrophic (Moss *et al.*, 2003; Sender, 2009; Lorens & Sugier, 2010). Embanking of lakes contributed to their separation from the catchment water supply, decreasing waters inputs from the catchment areas that intensify eutrophication processes. Lakes with the lowest plant diversity are lakes converted to storage reservoirs, especially those with runoff from the Wieprz-Krzna drainage system: Tomaszne and, to a lesser extent, Mytycze. The reservoir, Lake Skomielno, was an exception as it showed good ecological status in addition to well-developed macrophytes. The probable cause is the amount of external water supplied to the lake, which is 6 times less than in the case of Lake Tomaszne. Despite high susceptibility to degradation, Lake Bikcze has high ecological values. The reasons for that are may be because a predominantly small percentage of water exchanges, small recreational pressure and restriction of surface runoff by embanking. However, even embanking the systems may not protect lakes from natural degradation, as long as they are fed with external water of different water chemistry. This lake's good ecological condition could be attributed to the

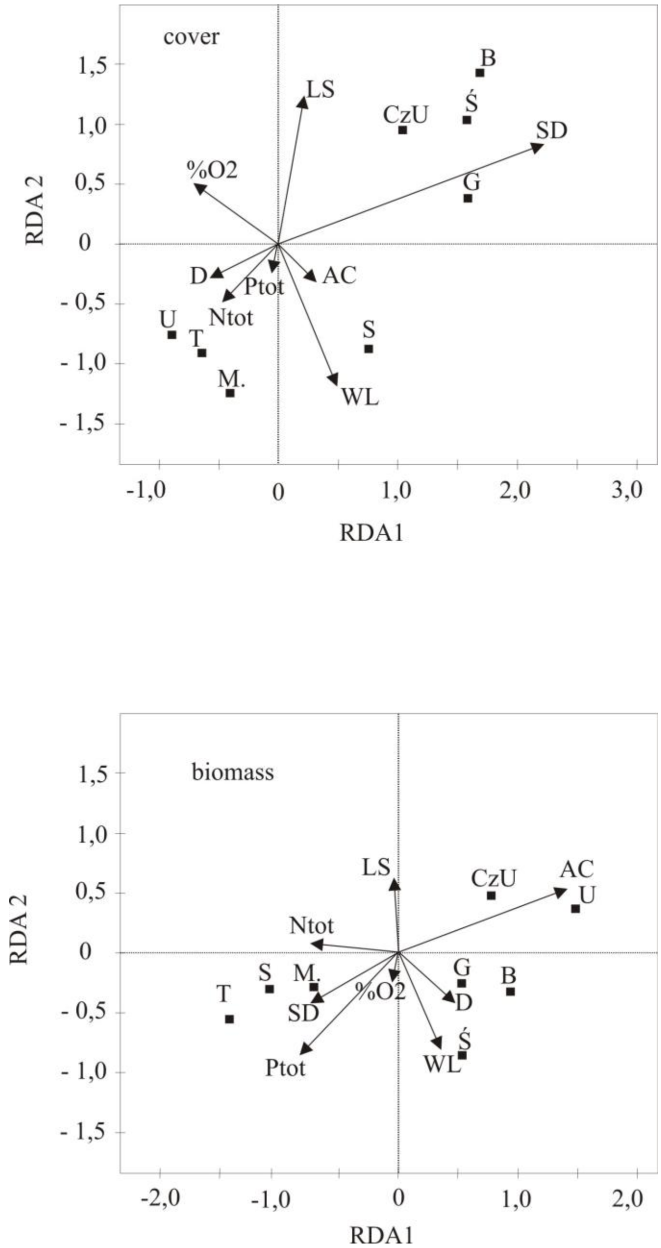

Figure 4. RDA for factors affecting cover and biomass of macrophytes in investigated lakes(cover- RDA1=17,36%, RDA2= 13,05%; biomass RDA1 =23,4%, RDA2= 14,7%). LS- lake surface, AC- anthropogenic use of catchment, D – lake depth, SD- secchi disc visibility, Ptot - P total, Ntot – N total, WL - Water inflow and outflow; T – Tomaszne, S – Skomielno, M – Mytycze, Ś – Ściegienne, G – Gumienek, B – Bikcze, CzU – Czarne Uścimowskie, U – Uścimowskie.

presence of peatlands in its catchment area, which act as a sink for nutrients (Wilpiszewska & Kloss, 2002). It was noted that several meters of a shoreline vegetation zone could reduce the supply of nitrogen and phosphorus from surface and ground waters by 20 % to 90 %. In lakes where even a part of a buffer zone was covered by riparian vegetation their ecological status was higher.

Lakes Mytycze, Skomielno and Tomaszne which are directly connected to the Wieprz–Krzna drainage system, have been converted into reservoirs and their water level has been managed through time. Similarly to lake Gumienek, these reservoirs are supplemented with waters from surrounding areas and waters from the reservoir source the WKK system. The water level in Skomielno have remained relatively stable because the addition of water from WWK canal are only introduced twice a year, once in the spring and autumn (Kornijów & Buczyński, 2012) while in Lake Tomaszne water is constantly being introduced and the water level fluctuates frequently. Within Lake Mytycze where water levels are relatively stable, plant communities have developed in littoral zones. Developing plant communities are also observed in lake Mytycze but are limited to areas were peatbogs once existed but were been excavated for fuel in 1950s. The banks of Lake Tomaszne are periodically mowed to remove rush vegetation. Drainage from the Wieprz-Krzna enters all of the lakes and increases nutrient concentrations within them. The two natural lakes analysed have not been embanked or converted into reservoirs. Waters from nearby drained pastures and agricultural fields are supplied to Lake Uścimowskie and there are no outputs. Lake Ściegienne similarly to Bikcze has both water inputs and outputs. Waters drained from nearby pastures and agricultural fields drain to Lake Ściegienne water whereas Bikcze is supplied with waters from a nearby lake. Only Lake Czarne Uścimowskie is not supplied with foreign waters but does supply water to surrounding ponds.

The extensive changes observed in the plant communities within all lakes in the study, indicates a progressive process of overgrowth. Agricultural water inputs into lakes within the drainage system has lead to their slow but differentiated degradation. For Łęczna-Włodawa Lake District the drainage has greatly altered the hydrological and ecological functioning of the region. In the majority of instances the reclamation of natural lands for agriculture has proven unprofitable. Management actions should be taken to prevent further ecological degradation of aquatic and hydrologic systems in the region.

As the main component of the phytolittoral zone, macrophytes exert direct effect on eutrophication processes, and have indirect influences on other organisms. The significance of the phytolittoral zone within lakes is determined by the ratio of its size to the extent of the limnetic zone and macrophyte biomass levels (Pieczyńska, 1993). Within lakes in Poland, on average, approximately 32.7% is covered with macrophytes. In Łęczna-Włodawa Lake District it is roughly 47.8% (Sender, 2009).

Presence of different groups of macrophytes is of considerable importance in developing a functioning phytolittoral zone. Submerged macrophytes in particular are good indicators of the ecological status of lakes and their disappearance indicates progressive degradation (Rooney *et al.*, 2003; Schmieder, 1997).

Macrophyte biomass is one of the most important indices of the ecological status of lakes (Kosten *et al.*, 2009). High values of biomass, especially of submerged macrophytes, indicate good condition of lakes. Nevertheless, low values of biomass along with low diversity suggest a progressive process of eutrophication.

High biomass and high phytolittoral surfaces may indicate that embanked lakes improve ecological conditions for development of this group of macrophytes, which are invaluable in the assessment and functioning of lakes. For eutrophic lakes from the Łęczna-Włodawa Lake District area (Sender, 2008, 2009), as well as the Masurian Lake District (Ozimek, 1983) biomass values were lower than in the studied lakes for all groups of macrophytes.

Changes in the surface area of the phytolittoral zone from the 50s confirmed the ecological transformations occurring in the all studied lakes. In lakes converted into retention reservoirs the phytolittoral surface dramatically decreased characterizing increasing eutrophication (Gertie, 2002). In embanked lakes, the area inhabited by macrophytes increased almost three fold. Increasing surface area but decreasing diversity is also the result of eutrophication, but slower than in the storage reservoirs.

At present, the phytolittoral zone in the majority of the studied lakes consists predominantly of emergent macrophyte communities. In lakes Bikcze and Skomielno communities of submerged macrophytes dominated, whereas in lakes changed into retention reservoirs the plant community composition and the biomass of all groups of macrophytes were similar to other retention reservoirs near Lublin, *e.g.* Zemborzycki Reservoir which is an entirely man-made structure (Sender 2007). Lake Tomaszne has seen rapid changes in both quality and quantity of the macrophyte structure; over the period of only 6 years populations of *Scirpetum lacustris* have disappeared and the surface of the phytolittoral slightly reduced in size (Sender, 2010). It is speculated that these changes result from grubbing and removal of vegetation growing on the reservoir's shoreline, as well as water level regulations (Solis, Pawlik-Skowrońska, & Kalinowska, 2016).

Lakes undergo slow processes of self-regulation. Improvements in water quality are primarily driven by biological processes completed by organisms within the water bodies (Yoder & Rankin, 1998). If the amount of nutrient enriched waters to the lakes would be limited such as in Lake Skomielno maintaining good ecological status of lakes is possible. Intensive and unregulated inflows of nutrient enriched waters from field and canals create great fluctuations in water level, which negatively influence macrophyte development (Tomaszne, Mytycze) (Krolová, Čížková, Hejzlar, & Poláková, 2013).

Several management actions could prevent further degradation of lakes. Firstly, maintaining permanent grassland or managed wetlands would slow and filter the flow of foreign waters and nutrients to lakes. Secondly managing nutrients inputs from ditches would prevent eutrophication and nutrient loading within the lakes. In its current form, maintenance of permanent grassland on land acquired for agriculture, management of ditches supplying water to the lakes and the maintenance or introduction of wetland vegetation in the vicinity of the lakes could significantly reduce or even inhibit degradation of lakes in the Wieprz-Krzna drainage system.

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