The relationship between land management and the nature of helophytes in small lakes (Eastern Poland)

Joanna Sender¹, Magda Grabowski²

¹ Department of Landscape Ecology and Nature Conservation, University of Life Sciences in Lublin, Dobrzańskiego B.str. 37, 20-267 Lublin, Poland, e-mail: joanna.sender@up.lublin.pl (corresponding author)

² Graduate Degree Program in Ecology, Colorado State University, 1177 Campus delivery, Fort Collins, CO 80523-1177, United States

Abstract: The aim of this study was to determine the relationship between the development of rush zones in small lakes and the utilization and condition of surrounding lands. Generally, the width of the helophyte zone increased along shores with gentle slopes ($>5^\circ$) that were covered with vegetation. The most favourable conditions for rush development and spread were along sloped areas bordered by farmlands and rural developments. In addition, pasturelands that developed on top of peat accumulation adjacent to lakes were found to facilitate the development of rushes. We observed a positive effect of anthropogenic development, especially agriculture and infrastructure, on stem density and total biomass of *Phragmites australis* populations in the lakes studied. However, individual stem biomass of plants was lower. In different parts of the studied lakes, macrophyte distribution patterns were influenced by environmental conditions including nutrient availability, wind exposure, and bottom slope. The poorest macrophyte communities were found in areas within the lakes that were shaded by trees growing on neighboring banks and where slopes were forested rush zones were absent altogether.

Key words: small lakes; helophytes; buffer zone; plant biomass; land management, landform

Introduction

Emergent aquatic macrophytes are a group of helophytes, or aquatic plants, that are rooted in the substrate of shallow waters and extend above the water's surface. As macrophytes inhabit the zone between the water's surface and the shore they are sensitive to environmental conditions along shorelines and surrounding land areas (Thiebaut et al. 2002). Macrophytes serve as biofilters for surface flow (Bai et al. 2012) and influence lower trophic levels in lakes (Bakker et al. 2010). Macrophyte vegetation also prevents erosion of the lakeshore and provides shelter for fish and waterfowl (Engloner 2009). Understanding the interactions between surrounding land areas and macrophyte communities is imperative for developing sustainable management practices that promote functioning ecosystems. Macrophytes, are important components of the water systems we studied because they provide diverse habitats for aquatic fauna and buffer lake systems against outside influences.

Lake morphometry, water and sediment chemistry, as well as biotic interactions all effect the development of macrophyte communities. Generally, small and shallow lakes have higher numbers of macrophytes when compared to large and deep lakes (Lacoul and Freedman 2006; Sender 2012). Water level fluctuation, lake basin shape, and nutrient loading are important factors affecting macrophyte development (Feldman and Noges 2007). Riparian areas also affect water systems by removing pollutants, sediment, and nutrients from inflowing surface and ground water. Uplands slow runoff, infiltrate water, and filter sediment. Little is known about the influence of shoreline conditions on the development and persistence of macrophyte communities (Feldman and Maemets 2004; Van Geest et al. 2005; Feldmann and Noges 2007; Tağil 2007; Wei et al. 2014).

Emergent macrophytes transpire large amounts of water and play an important role in regulating the water budget of lakes (Sytsma and Anderson 1993). They grow quickly, are key successional species, and

in some cases overgrow reservoirs. Even though macrophytes can multiply quickly, under natural conditions complete lake overgrowth is a slow successional process. The rate of this process can, however, be altered and accelerated by anthropogenic disturbances. Anthropogenic changes have been shown to both limit (Radomska and Goemana 2001) and stimulate (Cheruvilil and Soranno 2008) the growth of macrophytes. Certain anthropogenic influences such as changes in the hydrologic regime and nutrient loading can initially stimulate macrophyte development but are often followed by the disappearance of macrophytes, especially those which are submerged (Søndergaard et al. 2010). The condition and utilization of terrestrial lands surrounding lakes may have significant influences on the biotic structure of these ecosystems and their associated emergent macrophyte communities.

Rushes, a group of emergent macrophytes, grow along shorelines (Coops et al. 1994, 1996) and impact trophic interactions by providing habitat refuges and reproduction sites for fish, birds, and other wildlife. *Phragmites australis*, a rush species, is one of the most abundant species of emergent macrophytes in all types of water ecosystems. *P. australis* communities are capable of purifying water directly and indirectly. Ciliates, protozoa and other epiphytic organisms, colonize the stems of *Phragmites australis* and reduce the concentration of bacteria in the water. Due to their ecological importance, areas in Europe containing *P. australis* are protected under the Ramsar Convention of 1972 and are also occasionally protected by local laws. Ecological studies of the biocoenosis of these systems are needed to improve lake management and to develop a deeper understanding of the factors driving recent declines of *P. australis* vegetation throughout Europe (Van der Putten et al. 1997; Bresciani et al. 2007). Long-term and large scale monitoring of *P. australis* communities is imperative for developing adaptive management plans for these valuable resources (Farnsworth and Meyerson 1999; Marks et al. 1994; Sinnassamy and Mauchamp 2001; Bresciani et al. 2009; Clevering 1998; Mauchamp et al. 2001; Russell and Kraaij 2008; Sawtschuk and Bioret 2012).

Understanding how colonization depth of emergent macrophytes varies among lakes of similar trophic status but varied depth, topography, and land use could shed valuable insights into the drivers of helophyte dynamics and current community declines. The aim of this study was to determine the relation-

ship between the development of helophytes in small lakes and the environmental conditions of adjacent terrestrial lands. Specifically, we sought to better understand which natural landscapes and anthropogenic developments stimulate or impede helophyte development and spread. In addition to surveying existing conditions of macrophyte communities, we used data that was collected 25 years ago to better understand how the macrophyte communities in these lakes has changed over the last two decades.

Material and Methods

The study included four lakes situated in the north-western part of the Łęczna-Włodawa Lakeland in eastern Poland (Fig. 1). In the Lake District there are currently 63 lakes, representing all trophic types. It is estimated that over the last 50 years out of 68 lakes, five or more have disappeared; two have decreased in size to below 1 ha (Chmielewski 2009) and others have been or are being overtaken by macrophyte communities.

The lakes we surveyed are very similar in area, approximately 25 ha. Two are defined as deep (18.2 m), while two are considered shallow (5.4 m) (Table 1). They are eutrophic lakes (Harasimiuk et al. 1998) and three of them (Ściegienne, Czarne and Bialskie) are connected by waterways.

In this study, buffer zones included uplands, the riparian zone, as well as the shallow littoral zone extending to the end of the maximum depth inhabited by emergent macrophytes. The upland areas extended approximately 500 m from the lakeshore in all the studied lakes.

The study included only emergent macrophytes because plants with floating leaves were not present in any of the studied lakes and submerged macrophytes were not present in all of the lakes or were present in quantities insufficient for analysis. Data from all four lakes were collected in August 2012 and 2013. Measurement of helophyte density and abundance and dominant species biomass were collected from vegetated belts within the lake area. Data regarding lake surroundings, landform types, and management regimes were collected from transects reaching approximately 500 m from the lakeshore outward, or what we consider the buffer zone. Transects radiated out from the lake and were placed 100 m apart. The total number of transects established per lake was determined with respect to shoreline radius, the variety of land-

Fig. 1. Localization of studied lakes

forms, and structures present along each shoreline. For example, where buffer zones were vegetated and buildings and forest were also present more transects were surveyed to account for the range of influence of these different landforms. Percentage cover of specific land use types (i.e. buildings, agricultural fields) was calculated within the surveyed area. Four main landforms in the buffer zone around the lakes were identified as: peat accumulation (lacustrine or peatbog basin), slopes, undulating upland, or flat upland. Lake basin slope was calculated according to the bathymetry maps established by Wilgat (1963). Maximum

depth and GPS location were determined using the sonar Elite no. 5 of LOWRENCE.

Aquatic transects radiated inward towards the centre of the lake for the length of helophyte occurrence and were uniformly distributed along the entire coastline every 100m. Macrophyte density was measured using a floristic frame with a sampling area of 0.25 m² placed randomly along transects. Data on species composition, biomass of dominant species, and density and width of helophyte belts were collected and the calculated means were used in analysis. Helophyte belts were measured using a measuring tape and

Table 1. Morphometrical data of studied lakes (*according to Harasimiuk et al. 1998)

Parameter		Lake			
		Bialskie	Czarne Uścimowskie	Głębokie Uścimowskie	Ściegienne
GPS location		N 51°32'09.33" E 23°00'54.90"	N 51°29'09.74" E 22°56'33.58"	N 51°28'34.27" E 22°55'23.72"	N 51°30'21.34" E 22°57'16.35"
Total area [ha]	2013	31.5	24.0	20.1	27.0
	1991*	31.7	24.8	20.5	27.4
Width [m]	max	526	512	452	565
	mean	435±12	416±14	350±17	390±14
Shape Indicator*		0.60	0.70	0.60	0.56
Shoreline [m]	length	2038	1823	1650	2112
	development	1.02	1.03	1.03	1.14
Depth [m]	max	18.2	10.3	7.1	5.4
	mean	6.8±0.5	3.7±0.2	3.4±0.2	2.8±0.3
Depth ratio*		0.37	0.36	0.48	0.52
Volume [dam ³]*		1258	915	689	756
Mean slope*		3°45'	2°20'	2°10'	1°45'
Lake basin slope [unitless]		4.66	6.7	6.03	9.79

the rangefinder BOSCH DLE 50 Professional. Plant communities were characterized by dominant species according to the Matuszkiewicz nomenclature (2008). To determine the biomass of emergent macrophytes, five individuals of each species present were randomly collected from ten sites within each lake. Aerial parts of plant were collected, washed to remove periphyton detritus, and dried for 24 h in a dryer at a temperature of 60°C to obtain their dry weight. The macrophyte biomass was calculated as grams of dry weight per square metre ($g_{DW} m^{-2}$). Lake sediment type was assessed at the time of macrophyte sampling by visual inspection at each sample site.

Littoral zone areas of the lakes and their buffer zone were determined by interpretation of aerial photos, orthophotomaps, and topographic maps. Orthophotomaps from 2013, in the scale 1:10000 were purchased by the Department of Landscape Ecology and Nature Conservation at the University of Life Sciences in Lublin. On the orthophotomap land-use forms around the lakes were mapped. Topographic maps were obtained from www.geoportal.gov.pl service topographic maps at a scale of 1:7000 to carry out analyses of landforms. Analyses were performed using the MicroStation PowerDraft V8i program. Habitat and landform diversity was estimated using the Shannon-Wiener diversity index (Magurran 1988).

The arithmetic mean and standard deviation (SD) of individual stems and total helophyte biomass, land covered with helophytes, density of helophytes, average width of helophyte belt, and depth of helophyte occurrence were determined for each lake, development type, and surrounding landform type. The statistical significance of differences in rush communities based on biomass, richness of helophytes, colonization depth and coverage between lakes was assessed using the t-test or two-way repeated measures ANOVA. Statistical analyses on the data were completed in the Statistica For Windows Package version 11. For correlation analysis between the percentage of features of the main categories and properties of helophytes the nonparametric a Spearmann's rank correlation was used. P-values were considered statistically significant at the 0.01 and 0.05 level. The correspondence analysis was performed with the Biodiversity Professional (Version 2) software.

Results

Patterns of land use around the four lakes were diverse. Around Lake Bialskie the largest area was covered with forests (48%) and only 8% of the study area was dominated by infrastructure (Table 2). Farmlands dominated buffer zones of the other three lakes, cover-

ing from 39% (Lake Czarne) to 51.5% (Lake Głębokie). In addition, in the buffer zone of Lakes Głębokie and Ściegienne, shrublands constituted a substantial share, 17% and 18%, respectively (Table 2). In all the studied lakes sediment deposits of varied thickness covered sand layers.

Natural landforms adjacent to the lakes were not diverse and were distinguished as uplands, hill-sides (slopes), and peat accumulations. In each of the lakes, the ratio of these landform types varied. Hill-sides surrounded the greatest portion of all lakes studied but were absent around lakes where shorelines had been transformed. The gentlest slopes occurred around Lake Bialskie, surrounding almost the entire lake. More than 50% of the buffer zone in Lake Czarne was covered with peat accumulation and was characterized by fishponds. Uplands contributed to the largest share of land around the two remaining lakes, Lake Ściegienne and Lake Głębokie (Table 3).

In the studied lakes macrophytes often reached beyond the aquatic zone. While these patterns may result from changes in lake surface, processes associated with depth reduction and succession may also explain

these observations. Comparative analysis of vegetation from the 1990's to the present confirms slight reductions in lake area of all four lakes (Fig. 2).

Fig. 2. Lake surface and rush vegetation cover in studied lakes in years 1991 and 2013: 1 – lake surface in 1991, 2 – lake surface in 2013, 3 – rush surface in 2013, 4 – rush surface in 1991

Table 2. Habitat diversity and land use in the buffer zone of studied lakes

Land use feature	Lake							
	Bialskie		Czarne Uścimowskie		Głębokie Uścimowskie		Ściegienne	
	[ha]	[%]	[ha]	[%]	[ha]	[%]	[ha]	[%]
Lake	31.5	17	24	18	20.1	19	27	11
Infrastructure	18	9	0.6	0.4	14	12	28	11
Shurbs	12	6.1	4.5	3.6	16.4	15.8	46	18
Other water bodies	3	2	53	38	0.6	0.5	13	5
Fields	17	9	55.4	39.6	58.4	51.5	97	39
Forests	93	48	–	–	–	–	–	–
Recreational buildings	16	8	–	–	–	–	–	–
Meadows and pastures	2	0.9	0.5	0.4	1.6	1.2	39	16
H' habitat diversity	0.73		0.52		0.54		0.69	

Table 3. Landform diversity and landform structure in buffer zone of studied lakes

Landform	Lake							
	Bialskie		Czarne Uścimowskie		Głębokie Uścimowskie		Ściegienne	
	[ha]	[%]	[ha]	[%]	[ha]	[%]	[ha]	[%]
Peat accumulation	40	17.5	102	62	25	16	46	29
Gentle slope	143	63	11	7	15	10	34	21
Undulating uplands	2	1	12	7	40	26	24	15
Flat uplands	43	18.5	40	24	75	48	57	35
H' landform diversity	3.59		3.47		2.27		1.80	

Helophytes occurred in all the studied lakes. They included four species: *Phragmitetum australis*, *Typhetum latifoliae*, *T. angustifoliae* and *Eleocharitetum palustris*. The least diverse according to the Shannon-Weaver index in terms of the number of species were found to be Bialskie and Ściegienne lakes (Table 4).

The area occupied by rush vegetation in the studied lakes ranged from 2.8 ha in Lake Bialskie to 11 ha in Lake Czarne (8.8 and 44% of lake area respectively). In Lake Głębokie and Lake Ściegienne this was very similar and reached respectively 5.04 ha and 5.88 ha (24 and 21% of lake area). The lowest ratio of rush vegetation compared to the lake surface area was found at Lake Bialskie, whereas the largest was in Lake Czarne. In three of the lakes rush cover has increased between 1991 and 2013, while in Lake Ściegienne it has decreased, by 13% (Fig. 2). Although these changes are interesting, they were not statistically significant ($F_{2,30} = 1.09$, $p < 0.35$). The depth of helophyte occurrence was lower in deep lakes and reached up to 1.1 m, while in shallow lakes they reached up to three metres. In the studied lakes, there was no significant correlation between the range of depth and the area that they occupied.

Populations of *Phragmites australis* dominated the phytolittoral zones that were covered with emergent macrophytes. Populations of *Typhetum angustifoliae*, were also abundant in Lakes Ściegienne and Czarne Uścimowskie and comprised approximately 27% of the helophyte community. Analysis confirmed

that in all the studied lakes *Phragmitetum australis* has been replacing other rush communities since 1991 (Fig. 3). The greatest statistically significant changes ($F_{1,16} = 19$, $p < 0.001$) occurred in Lake Bialskie.

Fig. 3. Share of different communities in phytolittoral of studied lakes in years: A – 1991 and B – 2013

Table 4. Characteristics of the shoreline and rush vegetation

Shoreline		Lake			
		Bialskie	Czarne Uścimowskie	Głębokie Uścimowskie	Ściegienne
Transformations of shoreline [%]	changed	18	100	19	23
	natural	82	0	81	77
Length of shoreline covered with helophytes [%]	2013	17±2	100±0	83±2.9	49±1.7
	1991	15±3	100±0	80±2.5	43±1.9
Density of helophytes [ind. per m ²]	max	44±6	96±11	68±7	108±16
	min	25±5	49±9	28±9	34±7
Mean width of rushes [m]		16.9±19.1	67.5±43.6	29.3±23.2	40.7±24.6
Helophyte biomass in lake [$g_{DW} m^{-2}$]		338.1±23.7	1254±38.5	744±31.1	1157.3±43.7
Mean biomass of <i>P. australis</i> stem [g_{DW}]		9.8±1.2	17.3±5.7	15.4±4.2	16.3±3.3
Depth of helophyte occurrence [m]	max	1.1±0.2	1.2±0.7	2±0.4	3±0.4
	mean	0.75±0.1	1.0±0.2	1.65±0.3	2.5±0.7
	min	0.4±0.1	0.9±0.1	1.3±0.2	1.1±0.1
Height of helophytes [m]	max	1.95±1.0	2.03±1.4	2.75±1.3	2.30±1.6
	mean	1.83±0.4	1.99±1.1	2.13±1.5	2.05±1.1
	min	0.8±0.1	1.50±1.1	1.62±0.9	0.7±0.3
Shannon index		1.2	1.36	1.46	0.37

The longest shoreline appeared in Lake Bialskie, while the shortest in Lake Głębokie Uścimowskie. Transformations of the coastline were associated with the construction of the drainage system in the Łęczna-Włodawa Lakeland which was carried out in the 1960's. In Lake Czarne, embankments accounted for 100% of the coastline. Lakes Głębokie and Bialskie (Table 4) were the most natural and have undergone the least anthropogenic transformation.

In the studied lakes, helophytes occupied from 17 to 100% of shorelines. The percentage occupancy of helophytes tended to decrease as the extent of shoreline transformation increased. Lake Czarne, having undergone the highest degree of shoreline transformation, was completely inhabited by emergent macrophytes. Across all the lakes, shoreline transformation was strongly correlated with all helophyte characteristics: width of helophyte belt ($r_s = 0.87$, $p < 0.01$), helophyte surface ($r_s = 0.87$, $p < 0.05$), helophyte density ($r_s = 0.89$, $p < 0.01$), and helophyte biomass ($r_s = 0.67$, $p < 0.05$). In addition, the slope of the lake bottom was correlated with all helophyte characteristics as well: width of helophyte belt ($r_s = -0.76$, $p < 0.01$), helophyte surface ($r_s = -0.77$, $p < 0.01$), helophyte density ($r_s = 0.72$, $p < 0.05$), and helophyte biomass ($r_s = 0.74$, $p < 0.01$).

In every studied lake the widest belt of emergent macrophytes occurred on the north-west shores. The helophyte belt was narrowest on southeast shores. The density and biomass of helophytes also varied between lakes. A positive correlation was observed between the width of the rush belt and density as well as biomass of individual helophyte stems (statistically significant $F_{1,16} = 5.75$, $p < 0.023$, $F_{1,16} = 3.15$, $p < 0.003$, respectively). However, where rush belts were narrow, density remained high (t-test: $t = -3.31$, $p < 0.001$) but biomass of individual stems decreased ($t = -4.61$, $p < 0.001$).

The six environmental variables used in the Canonical Correspondence Analysis (CCA) explained 31% of the total variance in helophyte composition of the investigated lakes. The first two axes of CCA ordination explained the species – environment relationship well and accounted for 52% of the variation. The first axis was strongly correlated with infrastructure ($R = 0.27$) and forest ($R = -0.29$) and the second axis with fields ($R = 0.46$). Agricultural fields, infrastructure, and forests had the greatest influence on the variability of distribution. Where forests were present on flat uplands in the buffer zone variation in

the diversity of helophytes increased. Density, height, and biomass values of *P. australis* were highest where gentle slopes were utilized as agricultural fields. Infrastructure, especially buildings on undulating uplands had the greatest influence on all helophyte biomass. In addition, peat accumulations that were most often overgrown by meadows or pastures had the greatest influence on helophyte range and cover (Fig. 4).

Fig. 4. Canonical Correspondence Analysis ordination for investigated features of helophytes and environmental variables: Infr – infrastructure (buildings, roads and recreational bulidings), Gslp – gentle slope, Fld – fields, Mdw – meadows and pastures, Frst – forests (shrubs and forests), Wre – water reservoirs, Fup – flat uplands, Uup – undulating uplands, Pacc – peat accumulation, CD – buffer zone diversity index, HW – width of helophytes, HD – helophyte density, HB – helophyte biomass, PhB – *P. australis* biomass, DH – depth of helophytes, HC – cover of helophytes, HH – height of helophytes, LsH – length of shoreline covered with helophytes SI – Shannon index

Discussion

The results presented here help to identify factors affecting the growth of emergent macrophytes in small lakes. Generally, the width of the helophyte zone increased in lake areas that were adjacent to vegetated buffers that were utilized for agriculture as fields or for infrastructure and had gentle slopes of less than 5°. In addition, where peat accumulation was covered with pasture grasses the range of helophytes tended to increase. This may be due to the emergent macrophytes acting as a filter of nutrients from incoming runoff. Nutrient filtering from runoff by helophytes can stimulate growth that can subsequently lead to faster overgrowth of lakes and potentially hinder the devel-

opment of other groups of macrophytes (Sender et al. 2012). In two of the lakes, Ściegienne and Głębokie, vegetated buffer zones were lacking and agricultural fields and infrastructure dominated the shoreline. In addition, at both of these lakes, flat uplands dominated. At these locations the biomass of all helophytes and depth were the greatest and plants were overgrowing the lakes.

Within one lake, Bialskie, helophyte vegetation (density, biomass, belt width) was clearly differentiated. The most depauperate emergent macrophyte communities were found adjacent to sloped areas covered with trees or forests. Helophytes were absent in areas where trees were dense and shading extended to cover the lake's surface. While forests provide biofiltration of runoff water, they can also potentially shade riparian vegetation (Ali et al. 2011) and impede development of this group of emergent macrophytes.

Generally, the proportion of the littoral zone covered with macrophytes declines with increasing depth and lake size (Zingel et al. 2006). In this study, however, the depth and size of the lakes was not related to the surface occupied by helophytes. It is also important to consider the relationship between the depth of the lakes and macrophyte occurrence. Sharp declines in lake depth have negative effects on the development of emergent macrophytes. This is of great importance in landscape protection, especially of ecosystems in agricultural landscapes because without macrophyte barriers nutrients are not filtered from runoff and directly enter the aquatic system.

According to the bathymetry of shallow lakes and the ranges of colonization depth macrophytes could potentially colonize 95% of a lake area, but in reality colonize only 19% (Zingel et al. 2006). The average area occupied by emergent macrophytes in the eutrophic lake region we studied was 25% while in the 1970's, just north of our location in the Polish Masuria region, helophytes occupied from 9.34 to 12.3% (Bernatowicz and Wolny 1974). Among lakes from the Łęczna-Włodawa Lakeland, in the 1990's 35% of lake surface was covered with emergent macrophytes (Sender 2009b).

Phragmites australis (Gams 1927; Schmale 1939), the common reed, belongs to the most common association of emergent macrophyte vegetation (Pełechaty 2004; Zingel et al. 2006). It was the most abundant species found and dominated the littoral zone of the studied lakes, as is frequently the case in many other water ecosystems from the area of the Łęczna-Włodawa Lakeland (Sender 2009a).

Eutrophication, lower water levels, toxic putrefactive substances, reduced ventilation, low genetic variability and ecophysiological constraints have all been attributed as causes of common reed dieback in Europe (Koppitz 1999). Poland and North America have not experienced the dieback phenomenon. Rather, in many areas, common reed expansion is occurring and has led to overgrowth and degradation of aquatic ecosystems (Wilcox et al. 2003; Boszke et al. 2005; Próchnicki 2005). Common reed overgrowth that often includes the formation of monolithic reed beds has resulted in the displacement of other aquatic plant species and reduced biodiversity.

Although in some places *P. australis* is defined as an invasive species and overtakes aquatic systems in Eastern Europe it is a native species and ubiquitous in aquatic systems. The over-proliferation of the reeds in waters, however, can be considered a problem, often indicating poor water quality, facilitated by pollution and human disturbance in lake regions. Understandably reed management is complex and in some cases it may be necessary to cut or contain the reed community to open up space for other species or to alter the dynamics of water currents. However, in other cases, reeds serve important filtration and habitat roles in aquatic systems (Bresciani et al. 2009) and these stands should be maintained and managed.

Another emergent helophyte, *Schoenoplectus lacustris* (Coops et al. 1996b), was also found in the studied lakes and occurred at depths of up to 3m, although only individuals of *S. lacustris* were found, not whole populations, and this species did not create distinct patches of vegetation. This is contrary to a finding from lakes in Estonia in which *P. australis* has reached the greatest depth among emergent macrophytes (Zingel et al. 2006).

The domination of certain species depends on environmental factors as well as on the historical development of the vegetation. In the lakes studied in this research, in the 1950s *Typha angustifolia* dominated shorelines but several reed and bulrush species were also present. They also covered a much smaller space than they currently occupy (Fijałkowski 1959). Eutrophication of aquatic habitats often leads to the displacement of *Typha* stands by reed communities (Matuszkiewicz 2008; Mäemets et al. 2010).

In the studied lakes, anthropogenic development, agriculture and infrastructure in the buffer zone were correlated with the highest density of stems and biomass of all helophytes, including *Phragmites*. A

similar situation has been observed in large lakes in Estonia (Liira et al. 2010). In the small lakes we studied, the belt widths of helophytes were much smaller than in the large Estonian lakes, although their density was much higher.

Generally, differences in environmental conditions (nutrient availability, sediment type, wind exposure and bottom slope) create a large diversity of macrophyte distribution patterns in different parts of lakes (Chambers et al. 2008). In our study, the helophyte belts were widest in the north-western part of the studied lakes. This may suggest spatial variation in habitat conditions or dominance of west and southwesterly winds. It may also potentially be attributed to anthropogenic buffer zone pressures including infrastructure and agriculture or natural upland forms. In these areas riparian vegetation was present. The narrowest belts were generally found in the eastern portions of the studied lakes that were characterized by agricultural fields but riparian vegetation was lacking. Introduced waters from irrigation ditches and other drainages also seemed to affect emergent macrophyte communities. Another general trend appeared to be that the relative area of lakes occupied by rushes increased as the irregularity of the surrounding shoreline increased; for example where infrastructure, agriculture, and pasture were all present. Our floristic measurements and analysis confirmed that highly irregular lakes might have a higher proportion of vegetation zones compared with lakes that have less complex shorelines or those that have been altered by humans.

Conclusion

In the four lakes studied, width of rushes was most influenced by irregular shorelines (specifically other water catchments) and shoreline transformation. Total biomass, density, individual stem biomass, and colonization depth of helophytes were most influenced by lake depth, presence of agricultural fields and infrastructure in the buffer zone. Undulating uplands and slopes also influenced helophyte characteristics. Forest presence, flat uplands, peat accumulations with meadows or pastures did not influence helophyte characteristics in the studied lakes. Greater diversity of land use in the buffer zone around the lakes significantly limited surface, density, and biomass of emergent macrophytes.

In the studied small, deep, and shallow lakes the main factor driving the size and condition of the

emergent macrophyte zones seemed to be the state and type of land use in the adjacent buffer zones. Preserving a vegetated buffer zone, ideally of native riparian plants, of at least 200 m is imperative for maintaining vital lake ecosystem processes and function. Buffer zones should be appropriately managed and sustainable land use practices should be emphasized to prevent eutrophication and degradation while simultaneously promoting diverse aquatic plant communities and functioning ecosystems. To prevent overgrowth by common reed communities and associated decreases in biodiversity, management practices should focus on maintaining riparian vegetation and natural landforms within the buffer zones surrounding lakes. These buffer zones need to be preserved or developed to filter runoff and nutrient rich water from entering aquatic systems.

References

- Ali M.M., Hassan S.A., Shaheen A.M., 2011, Impact of riparian trees shade on aquatic plant abundance in conservation islands, *Acta Bot. Croat.* 70(2): 245-258.
- Bai X., Chen K., Ren K., Huang W., Chen X., 2012, Impact of four emergent macrophytes on sediment nutrient loading, *J. Freshwater Ecol.* 27(4):4 81-493.
- Bakker E.S., van Donk E., Declerck S.A. J., Helmsing N.R., Hidding B., Nolet B., 2010, Effect of macrophyte community composition and nutrient enrichment on plant biomass and algal blooms, *Basic Appl. Ecol.* 11(5): 432-439.
- Bernatowicz S., Wolny P., 1974, *Botanika dla limnologów i rybaków* (Botany for limnologists and fishermen), PWRiL Warszawa, 518 pp (in Polish).
- Boszke P., Bociąg K., Szmeja J., 2005, Population structure and regeneration of *Phragmites australis* (Cav.) Trin. ex Steud. in flood control ditches in the depression wetland (Żuławy Wiślane, Northern Poland), *Pol. J. Ecol.* 53(1): 3-12.
- Bresciani M., Fila G.L., Stroppiana D., Giardino C., 2007, Project Rizoma: remotely sensing data for wetlands and common reed monitoring in the Garda lake, 27th EAR-SEel Symposium, Bolzano, Italia, 7-9 June: 361-366.
- Bresciani M., Stroppiana D., Fila G.L., Montagna M., Giardino C., 2009, Monitoring reed vegetation in environmentally sensitive areas in Italy, *Ital. J. Remote Sens.* 41(2): 125-137.
- Brix H., 1994, Functions of macrophytes in constructed wetlands, *Water Sci. Technol.* 29(4): 71-78.
- Chambers P.A., Lacoul P., Murphy K.J., Thomaz S.M., 2008, Global diversity of aquatic macrophytes in freshwater, *Hydrobiologia* 595: 9-26.
- Cheruvilil K.S., Soranno P.A., 2008, Relationships between lake macrophyte cover and lake and landscape features, *Aquat. Bot.* 88(3): 219-227.

- Chmielewski T.J. (ed.), 2009, *Ekologia krajobrazów hydro-genicznych Rezerwatu Biosfery "Polesie Zachodnie"* (Ecology of hydrogenic landscapes of the "West Polesie" Biosphere Reserve), Wydaw. UP Lublin, Lublin, 344 pp. (in Polish).
- Clevering O. A. 1998, An investigation in to the effects of nitrogen on growth and morphology of stable and die-back populations of *Phragmites australis*, *Aquat. Bot.* 60(1): 11-25.
- Coops H., Geilen N., Van der Velde. G., 1994, Distribution and growth of the helophyte species *Phragmites australis* and *Scirpus lacustris* in water depth gradients in relation to wave exposure. *Aquat. Bot.* 48(3-4): 273-284.
- Coops H., Geilen N., Verheij H.J., Boeters R., Van der Velde G., 1996, Interactions between waves, bank erosion and emergent vegetation: an experimental study in a wave tank, *Aquat. Bot.* 53(3-4): 187-198.
- Coops H., Van den Brink F. W., Van der Velde G., 1996b, Growth and morphological responses of four helophyte species in an experimental water-depth gradient, *Aquat. Bot.* 54(1): 11-24.
- Engloner A. I., 2009, Structure, growth dynamics and biomass of reed (*Phragmites australis*): A review, *Flora* 204: 331-346.
- Farnsworth E. J., Meyerson L. A., 1999, Species composition and inter-annual dynamics of a freshwater tidal plant community following removal of the invasive grass, *Phragmites australis*, *Biol. Invasions* 1(1-2): 115-127.
- Feldman T., Mäemets H., 2004, Macrophytes. [in:] Haberman J., Pihu E., Raukas A. (eds.), *Lake Võrtsjärv, Estonian Encyclopaedia Publishers, Tallinn*: 185-205.
- Feldmann T., Noges P., 2007, Factors controlling macrophyte distribution in large shallow Lake Vortsjarv, *Aquat. Bot.* 87(1):15-21.
- Fijałkowski D., 1959, Szata roślinna jezior Łęczyńsko-Włodawskich i przylegających do nich torfowisk (The vegetation cover of Łęczna-Włodawa lakes and the adjacent peatbogs), *Ann. UMCS B* 14(3): 131-206 (in Polish).
- Harasimiuk M., Michalczyk Z., Turczyński M. (eds), 1998, Jeziora Łęczyńsko-Włodawskie. *Monografia przyrodnicza* (The Łęczna-Włodawa lakes. Environmental monograph), Biblioteka Monitoringu Środowiska, Wydaw. UMCS-PIOŚ, Lublin, 176 pp. (in Polish).
- Koppitz H., 1999, Analysis of genetic diversity among selected populations of *Phragmites australis* world-wide, *Aquat. Bot.* 64(3-4): 209-221.
- Lacoul P., Freedman B., 2006, Environmental influences on aquatic plants in freshwater ecosystems, *Environ. Rev.* 14(2): 89-136.
- Liira J., Feldmann T., Maemets H., Peterson U., 2010, Two decades of macrophyte expansion on the shores of a large shallow northern temperate lake: A retrospective series of satellite images, *Aquat. Bot.* 93(4): 207-215.
- Magurran A. E., 1988, *Ecological diversity and its measurement*, Princeton University Press, Princeton, 192 pp.
- Marks M., Lapin B., Randall J., 1994, *Phragmites australis* (*P. communis*): threats, management and monitoring, *Nat. Areas J.* 14: 285-294.
- Matuszkiewicz W., 2008, *Przewodnik do oznaczania zbiorowisk roślinnych Polski* (Guide-book for determination of plant communities in Poland), Wydaw. Nauk. PWN, Warszawa, 531 pp. (in Polish).
- Mauchamp A., Blanch S., Grillas P., 2001, Effects of submergence on the growth of *Phragmites australis* seedlings, *Aquat. Bot.* 69(2-4): 147-164.
- Mäemets H., Palmik K., Haldna M., Sudnitsyna D., Melnik M., 2010, Eutrophication and macrophyte species richness in the large shallow North-European Lake Peipsi, *Aquat. Bot.* 92(4): 273-280.
- Pelechaty M., 2004, Can reed stands be good indicators of environmental conditions of the lake littoral? A synecological investigations of *Phragmites australis* – dominated phytocenoses, *Pol. J. Environ. Stud.* 13(2):177-183.
- Próchnicki P., 2005, The expansion of common reed (*Phragmites australis* (Cav.) Trin ex Steud.) in the anastomosing river valley after cessation of agriculture use (Narew River Valley, NE Poland), *Pol. J. Ecol.* 53(3): 353-364.
- Radomska P., Goemana T.J., 2001, Consequences of human lakeshore development on emergent and floating-leaf vegetation abundance, *N. Am. J. Fish. Manage.* 21(1):46-61.
- Russell I.A., Kraaij T., 2008, Effects of cutting *Phragmites australis* along an inundation gradient, with implications for managing reed encroachment in a South African estuarine lake system, *Wetl. Ecol. Manag.* 16: 383-393.
- Sawtschuk J., Bioret F., 2012, Analyse diachronique de la dynamique spatiale de la végétation de l'estuaire de la Loire, *Photo-Interprétation Eur. J. Appl. Remote Sen.* 48(3): 15-28.
- Sender J., 2009a, Changes in structure of macrophyte communities in the chosen lakes of Łęczna-Włodawa Lake District, *Ecohydrol. Hydrobiol.* 9(2-4): 237-245.
- Sender J., 2009b, Hydrobotanical characteristic of lakes used for recreational purposes of Łęczna-Włodawa Lakeland, *Teka Kom. Ochr. Kszt. Środ. Przyr.* 6: 277-284.
- Sender J., 2012, Quantitative investigations of vascular flora in deep and shallow eutrophic Lakes, *Teka Kom. Ochr. Kszt. Środ. Przyr.* 9: 206-214.
- Sender J., Chmielewski T.J., Kolejko M., Grzywna A., 2012, Functioning conditions of small watercourse, supplying water to the recreational reservoir and opportunities to improve its quality (JanówLubelski, south-east Poland), *Inż. Ochr. Środ.* 15(1): 17-31.
- Sinnassamy J.M., Mauchamp A., 2001, Roselières: gestion fonctionnelle et patrimoniale, *Atelier Technique des Espaces Naturels (ATEN), ATEN Cahiers Techniques* 63: 1-96 (in French).
- Søndergaard M., Johansson L.S., Lauridsen T.L., Jørgensen T.B., Liboriussen L., Jeppesen E., 2010, Submerged macrophytes as indicators of the ecological quality of lakes, *Freshwater Biol.* 55(4): 893-908.

- Sytsma M.D., Anderson L.W.J., 1993, Transpiration by an emergent macrophyte: source of water and implications for nutrient supply, *Hydrobiologia* 271: 97-108.
- Tagil S., 2007, Quantifying the Change Detection of the Uluabat Wetland, Turkey, by Use of Landsat Images, *Ekoloji* 16(64): 9-20.
- Thiebaut G., Guerold F., Muller S., 2002, Are trophic and diversity indices based on macrophyte communities pertinent tools to monitoring water quality?, *Water Res.* 36(14): 3602-3610.
- Van der Putten W. H., Peters B. A. M., Van den Berg M. S., 1997, Effect of litter on substrate conditions and growth of emergent macrophytes, *New Phytol.* 135: 527- 537.
- Van Geest G.J., Wolters H., Roozen F.C.J.M., Coops H., Roijackers R.M.M., Buijse A.D., Scheffer M., 2005, Water-level fluctuations affect macrophyte richness in floodplain lakes, *Hydrobiologia* 539: 239-248.
- Wei H., Cheng S., Liang W., Wu Z., 2014, Growth responses and adaptations of the emergent macrophyte *Acorus calamus* Linn. to different water-level fluctuation, *J. Freshwater Ecol.* 29(1):101-115.
- Wilcox K.L., Petrie S.A., Maynard L.A., Meyer S.W., 2003, Historical distribution and abundance of *Phragmites australis* at long point, Lake Erie, Ontario, *J. Great Lakes Res.* 29(4): 664-680.
- Wilgat T., 1963, Budowa geologiczna, rzeźba i wody Polesia lubelskiego (The geological structure, relief and water conditions within the region of Polesie Lubelskie), [in:] Wilgat T. (ed.), *Polesie Lubelskie (The Polesie Lubelskie region)*, Wydaw. Lubelskie, Lublin: 9-30 (in Polish).
- Zingel P., Nöges P., Tuvikene L., Feldmann T., Järvalt A., Tönno I., Agasild H., Tammert H., Luup H., Salujõe J., Nöges T., 2006, Ecological processes in macrophyte- and phytoplankton- dominated shallow lakes, *Proc. Estonian Acad. Sci. Biol. Ecol.* 55(4): 280-307.