MIDDLE POMERANIAN SCIENTIFIC SOCIETY OF THE ENVIRONMENT PROTECTION
ŚRODKOWO-POMORSKIE TOWARZYSTWO NAUKOWE OCHRONY ŚRODOWISKA

Annual Set The Environment Protection
Rocznik Ochrona Środowiska

Volume/Tom 20. Year/Rok 2018 ISSN 1506-218X 392-416

Preliminary Study for Water Quality Improving in Storage Reservoir by Introducing of Artificial Phytolittoral

Joanna Sender[*], Magda Garbowski[**],
Danuta Urban[*], Andrzej Demetraki-Paleolog[*]
[*]University of Life Sciences in Lublin
[**]Graduate Degree Program in Ecology, Colorado State University

1. Introduction

Eutrophication of waters is one of the main problems threatening its quality all over the world (Ilnicki 2002, Gałczyński 2008). Dam reservoirs are particularly vulnerable to eutrophication and require maintenance throughout their life-cycle for appropriate function and control (Prochal 1978, Ciepielowski 1999).

As the key building blocks of photoplankton cell walls, nitrogen and phosphorus compounds play major roles in the eutrophication process and the overabundance of phytoplankton in some lakes (Jachniak 2011). The pace of eutrophication depends primarily on the morphometric conditions of the aquatic ecosystem. The large surface area, low depth and an unfavorable shore structure increase lake susceptibility to eutrophication. Frequent mixing of lake waters further supplies phosphate from the bottom sediment. The location of the reservoir and the quality of river's water supplying the reservoir can also accelerate its degradation. On large loads of biogenes are the most exposed reservoirs located in urbanized and agricultural catchments (Koc et al. 2008, Kasza 2009, Pärn et al. 2012). Hydrological regimes in reservoirs, especially the time of water retention and fluctuations, greatly influence nutrient cycles (Soszka et al. 2012).

Zemborzycki reservoir is a small retention and recreation reservoir built on the Bystrzyca River within the borders of Lublin city and was put into use in 1974. It now protects the inhabitants of Lublin from floods and its associated hydropower plant generates energy for the surrounding areas. Since the 1990s, the reservoir has undergone unfavorable transformations from both natural and anthropogenic causes that hinder its recreational use. Anthropogenic factors including concrete banks, a lack of a littoral zone, adjacent farmland, and single family housing, as well as natural factors including small size and shallowness contributive to reservoir degradation (Sender 2007).

Littoral zones are often the richest areas of biodiversity within lake and are shaped by a variety of physical, morphological, chemical, and environmental factors (Penning et al. 2008, Khadija et al. 2015, Bolpagni & Piotti 2015). The littoral zone is also the only place where macrophytes occur.

Macrophytes are a morphologically diverse group of plants (Cook 1985, Wołek 1996). These include all national stonewort (*Charophyta*) species, some bryophytes (*Bryophyta*), a few pteridophytes (*Pteridophyta*) and a small group of seed plants (*Spermatophyta*) (Szmeja 2006). Most aquatic plant classification systems were established on the basis of growth criteria and can easily be categorized by growth form: submerged, emergent and floating-leaved.

The area of the littoral zone colonized by macrophytes in lakes is called the phytolittoral. This zone contributes greatly to the functioning of the entire reservoir. The influence this zone has on lake functioning is directly related to its diversity and size (Ozimek 1991, Thiebaut et al. 2002, Dhote & Dixit 2007, Pełechaty & Poronin 2015). Lake trophy within reservoirs greatly influences the species composition, the colonization depth and the biomass of macrophytes (Sender 2009a). The composition of aquatic plant communities is variable in time and space, mainly due to the instability of such factors as: light, temperature, quantity and availability of nutrients, sediment type, substrate angle, hydrodynamic phenomena, human pressure (Szmeja 2006, Bucak et al. 2012).

The Zemborzycki reservoir has undergone a successive eutrophication since its creation resulting in blooms of cyanobacteria that prevent recreational use. Several factors have contributed to this degradation and have adversely effected its functioning. Its 12 km of shoreline are concrete or surrounded by steep banks fortified with stones which prevent the development of rushes. The average depth of reservoir does not exceed 1.5 m. The large surface of the reservoir (about 280 ha), predominant western winds and a lack of well-developed rushes zone lead to significant wave action. In addition, a large portion of the shoreline is surrounded by compact buildings and farmlands. The major contaminant sources of Zemborzycki reservoir are direct discharges of wastewater to the Bystrzyca River and its tributaries from six municipal wastewater treatment facilities. The Bystrzyca river catchment area above the Zemborzycki reservoir is under severe pressure from agricultural land, which creates diffuse sources of pollution (Smal et al. 2015).

In 2010, experimental lagoons, or artificial land surfaces we introduced throughout the reservoir. Various native species were transplanted on these lagoons to enrich biodiversity within the reservoir and to reduce phosphorus supply through the plant barrier. We postulated that should be distinct, within the Zemborzycki reservoir, natural and recreation zone. Our works on the experimental creation of lagoons were carried out in the so-called natural part of reservoir. The zone in which the lagoons were located was characterized by the impact of many factors (agriculture, buildings, regulated and transformed shoreline, lack of rushes belt, strong winds). The logistic aspect was also taken into account. The first experimental construction work began in 2010, and the first plantings of native species from previously prepared seedlings in spring 2011 (Sender 2013). In the same year, in the autumn, the construction of another fragment of lagoon was started and planted the following spring in 2012. Two of the these lagoon structures were connected to the edge the reservoir. The third lagoon, which was built in autumn 2012, was constructed approximately 15m from the shore. The substrate of each lagoon was sand and gravel. Plantings were dominated by emergent macrophytes: *Typha angustifolia* L., *T. latifolia* L., *Phragmites australis* (Cav.) Trin. ex Steud., *Glyceria maxima* (Hartm.) Holmb. By 2015, these species fully occupied two of the three lagoons. At the third lagoon, which was far from the shore, waves and insulation likely contributed to failed establishment (Sender 2013).

The purpose of this study was to determine the role of these artificially constructed lagoons and their associated vegetation on phosphorus reduction throughout the reservoir.To this end, the phosphorus load from surface flow, sources within the lake, the river flowing into the reservoir, and additional sources directly flowing into the reservoir was determined. In addition, phosphorus concentrations were measured from waters within naturally occurring vegetated areas and our artificially vegetated lagoons. The qualitative and quantitative structure of macrophytes within the reservoir was also measured prior to and post lagoon construction. In order to determine the influence of the lagoons and macrophytes on phosphorus within the reservoir data from before construction and post construction was compared. We wanted to find permanent and esthetical solution for water quality improving in storage reservoirs.

2. Study area and methods

The Zemborzycki dam reservoir (N 51˚10' 45.05", E 22˚31' 41.95) is located in the south-eastern part of the city of Lublin. It was created due to the dividing of the Bystrzyca River valley with a dam about 573m length. Its primary purpose is water regulation and retention but the reservoir is also utilized for recreational purposes. The south-eastern shore is comprised of mixed forests. The West bank is adjacent to agricultural fields and infrastructure of the Zemborzyce district. At the reservoir there are three resorts, including rope parks and playgrounds. There are harbors, sailing tracks and bike trails. The surface of the reservoir under normal damming is 278 ha, while at high water damming is 282 ha. The capacity under normal damming is 6.3 million m^3. The length of the reservoir is 3 km and the average width is 0.8 km.

Studies were conducted in the spring, summer, and fall of 2010, 2012 and 2015. Study sites were selected: on the Bystryca River, before reaching the reservoir; at the mouth of the river; in lagoons 1 and 2 at two points -along the shore and in a more near the centre, within the recreational zone; and at the river outlet (below the reservoir) (Fig. 1). At each study site, the biomass, density, as well as the species composition of macrophytes were monitored (Sender 2009b). The syntaxsonomic system was adopted according to Matuszkiewicz (2008). Macrophytes were measured along horizontal transects. The density of emergent macrophytes was estimated at five randomly chosen sites, then to determine their biomass from the area of 0.25 m^2, limited by floristic fork, counting the hit ground part of shoots (only in summer). The biomass of submerged macrophytes and pleustonic was estimated using Bernatowicz sampler of the area 0.16 m^2 and calculated per m^2 of bottom surface (Sender 2010). The visibility of the water was measured using Secchi disc. Phosphorus compounds were estimated using spectrophotometric method with ammonium heptamolybdate (PN-EN 1189) after samples were filtered three times. The reservoir trophic status was calculated using the Carlson formula (1977, behind Cooke et al. 2016).

Five piezometers from which groundwater was collected were also installed around the reservoir to assess P compounds flowing into the reservoir from ground water. The piezometers were placed at several sites: the edge of farmland (A), among the buildings (B), in the forest with buildings (D), and in the forest (E). Water was also sampled from the settler, in which ground water and rainfall collect and then enter the reservoir (C) (Fig. 1). Loading of TP and $P\text{-}PO_4$ were estimated using Vollenveider (1976) criteria, including concentration of total phosphorus and dissolved orthophosphates in reservoir, mean water current and mean residence time.

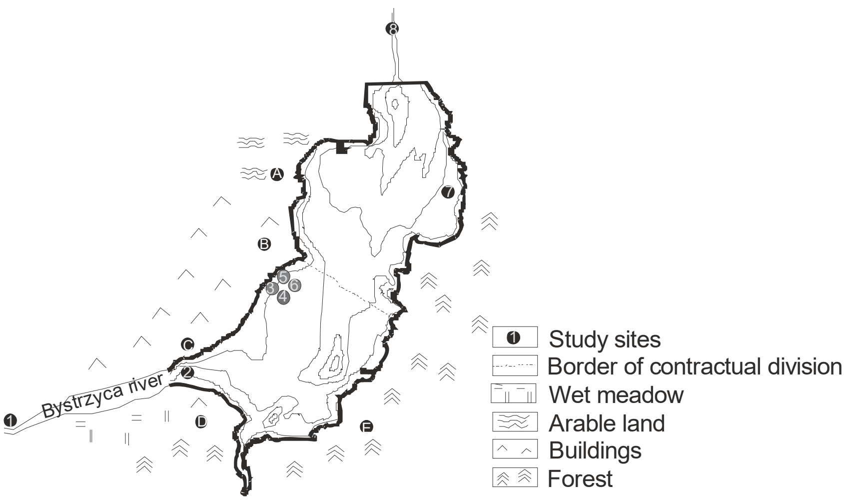

Fig. 1. Localization of study sites in investigated area: (1) the Bystryca River, before reaching the reservoir; (2) at the mouth of the river; (3, 4) in lagoons 1 and (5,6) in lagoons 2; (7) in a center zone of reservoir; (8) below the reservoir; and piezometers: (A) cultivated field, (B) compact development, (C) the settler, (D) in the forest with buildings, (E) in the forest.

Rys. 1. Lokalizacja stanowisk badań: (1) rzeka Bystrzyca przed wpłynięciem do zbiornika; (2) ujście rzeki; (3,4) laguna nr 1; (5,6) laguna nr 2; (7) środek zbiornika; (8) poniżej zbiornika; piezometry: (A) pola uprawne, (B) zabudowa zwarta, (C) osadnik, (D) las z zabudową, (E) las

The influence of the water of Bystrzyca river on biomass and density of macrophytes was analysed by means of two-way ANOVA. For dam reservoir Pearson's correlation coefficients between biomass of macrophytes and P concentration was calculated. We tested P-values were considered statistically significant at the 0.01 and 0.05 level. All analysis were performed by STATISTICA program (ver.10, Statsoft). The correspondence analysis was complete in the Biodiversity Professional Version 2.

3. Results

3.1. Phosphorus concentration

The highest concentrations of total phosphorus (TP) and orthophosphates ($P\text{-}PO_4$) were found in the Bystrzyca River above Zemborzycki reservoir (point 1) but both declined from 2010 to 2015 from 0.8 mg $dm^{-3}$to 0.36 mg dm^{-3} and 0.59 mg dm^{-3} to 0.34 mg dm^{-3},respectively. In the area of inflow the Bystrzyca river, TP and $P\text{-}PO_4$ concentration decreased significantly and ranged from 0.45 $mg \cdot dm^{-3}$ TP in 2010 to 0.26 $mg \cdot dm^{-3}$ TP in 2015.As macrophytes developed through time, phosphorus concentration within the lagoons shows a clear reduction, decreasing from 2010 to 2012 and from 2012 to 2015.

In the littoral zone naturally formed in the reservoir, the concentration of TP ranged from 0.08 mg dm^{-3} in 2012 to 0.215 $mg \cdot dm^{-3}$ in 2015. The lowest values both total TP and $P\text{-}PO_4$ concentrations were found in the Bystrzyca river below the reservoir and ranged from 0.05 $mg \cdot dm^{-3}$ $P\text{-}PO_4$ in 2010 to 0.14 $mg \cdot dm^{-3}$ $P\text{-}PO_4$ in 2015 and 0.06 mg dm^{-3} TP in 2010 to 0.1 $mg \cdot dm^{-3}$ TP in 2015 (Fig.2). Most of studied parameters showed significant variability among study sites and study years (Table. 1).

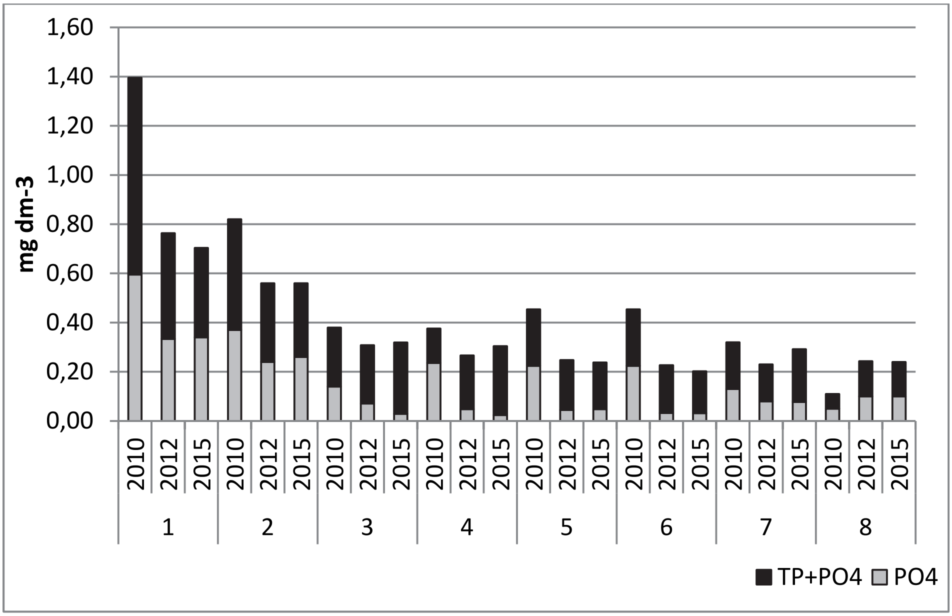

Fig. 2. Concentration of total phosphorous and dissolved orthophosphates in studied sites in particular years
Rys. 2. Stężenie fosforu całkowitego i rozpuszczonych ortofosforanów w badanych miejscach w poszczególnych latach

Table 1. Results of two-way ANOVA (site, year) for selected phosphorus concentration and macrophytes in Zemborzycki reservoir (n = 72; ns-not significant)
Tabela 1. Wyniki dwuczynnikowej analizy ANOVA (stanowiska, lata) dla wybranych, analizowanych cech makrofitów i koncentracji fosforu (n = 72; ns-nieistotne statystycznie)

	Site by site	site by year
TP	$F = 3.42$; $p = 0.001$	$F = 8.98$; $p < 0.001$
P-PO_4	$F = 17.07$; $p < 0.001$	ns
Secchi disc (SD)	$F = 11.3$; $p = 0.001$	ns
Biomass of emergent	$F = 5.62$; $p < 0.001$	$F = 6.87$; $p < 0.001$
Biomass all macrophytes	$F = 2.58$; $p < 0.001$	$F = 4.35$; $p = 0.001$
Number of species	$F = 2.86$; $p = 0.01$	$F = 6.16$; $p = 0.001$
Emergent density	$F = 25.8$; $p = 0.016$	$F = 0.59$; $p < 0.001$

3.2. Phosphorus loadings

Loadings of TP and P-PO_4 introduced to Zemborzycki reservoir with the Bystrzyca River showed variability (Fig. 3). With the Bystrzyca River into the reservoir 4.29 g m^{-2} P-PO_4 and 5.77 g m^{-2} TP in 2010 was introduced. In all studied years there was a reduction in reservoir P loadings. The highest retention, 66% of P-PO_4 was noted in 2010, but in 2015 only 2%. Reduction of TP loadings was differentiated. In 2010 the highest reduction, 70% was observed and in 2012 only 25%.

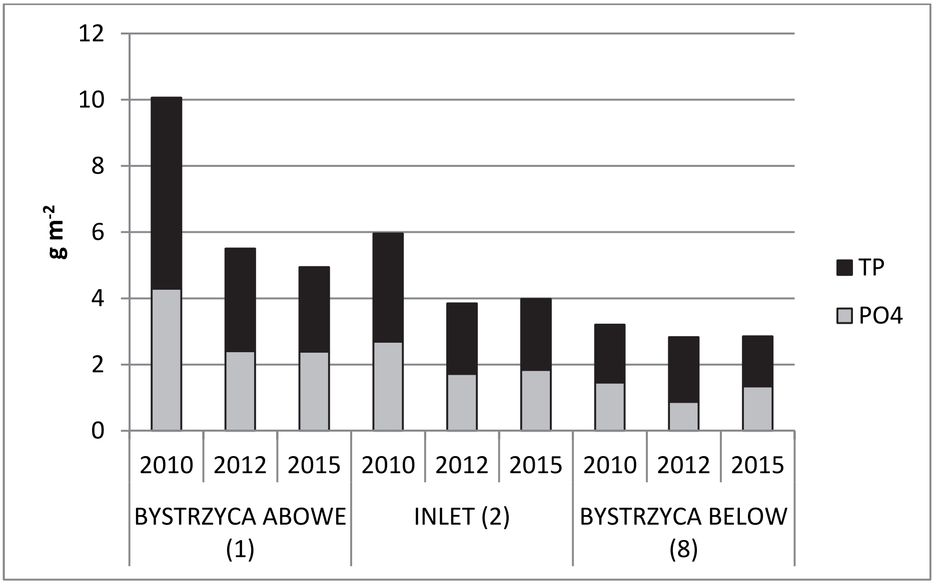

Fig. 3. Loadings of total phosphorus (TP) and dissolved orthophosphates (P-PO_4) in inflow (1, 2) and outflow (8) of Bystrzyca river to Zemborzycki reservoir during the years 2010, 2012, 2015
Rys. 3. Ładunek fosforu całkowitego (TP) oraz ortofosforanów (P-PO_4) na dopływie rzeki Bystrzycy do zbiornika Zemborzyckiego (1,2) oraz odpływie (8), poniżej zbiornika, w latach 2010, 2012, 2015

3.3. Phosphorus load of the reservoir from external sources

The highest concentrations of total phosphorus and orthophosphates were found in groundwater from arable land (A from Fig. 1, Table 2) and remained high throughout study years: 5.1 mg dm^{-3} P-PO_4 and 5.3 mg dm^{-3} TP in 2010 to 4.8 mg dm^{-3} P-PO_4 and 4.9 mg dm^{-3} TP in

2015.Within the points sampled around the reservoir, relatively high concentrations of phosphorus were also found in groundwater from the buffer zone with infrastructure development(B from Fig.1, Table 2). The lowest concentrations of both forms of phosphorus were found in ground waters from a forest-covered buffer zone (E from Fig. 1, Table 2). Waters that were collected from the girdling ditch within the settler, were characterized by very high values of both phosphorus concentrations (Table 2). The ditch flowed in the immediate vicinity of the buildings, and then the water flowed into the Zemborzycki reservoir.

Table 2. Phosphorus concentrations in ground waters of the buffer zone of the Zemborzycki reservoir
Tabela 2. Stężenia fosforu w wodach gruntowych strefy buforowej Zalewu Zemborzyckiego

Sampling Point	$P\text{-}PO_4$ mg dm^{-3}			TP mg dm^{-3}		
	2010	2012	2015	2010	2012	2015
Piezometer – Arable land (A)	5.120	4.964	4.880	5.330	5.227	4.950
Piezometer – Infrastructure (B)	3.689	2.996	3.850	4.410	5.581	3.252
Piezometer – Settler (C)	3.668	3.224	2.992	3.470	3.648	3.874
Piezometer – Forest (E)	0.145	0.106	0.132	0.990	0.547	0.214
Piezometer – Infrastructure in forest (D)	3.953	3.823	2.897	3.510	2.859	2.114

3.4. Buffer zone utilization

Forests dominated in the buffer zone of the Zemborzycki reservoir, covering over 40% of surrounding areas. More than 24% of this area was covered by compact development. The smallest area was occupied by cultivated fields and meadows, covering about 11% of the buffer zone (Fig. 4).

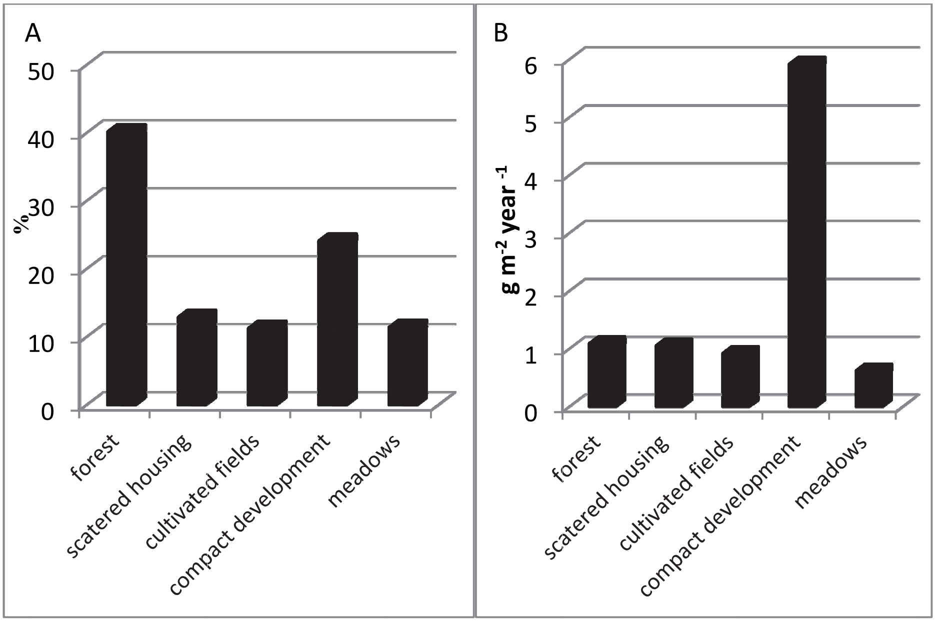

Fig. 4. A) Use of buffer zone; B) phosphorus load supplied from different type of a buffer zone
Rys. 4. A) użytkowanie strefy buforowej; B) ładunek fosforu dostarczany z poszczególnych form użytkowania strefy buforowej

The total supply of phosphorus from the buffer zone was 96.62 kg $ha^{-1}year^{-1}$. The largest supply of phosphorus comes from the area covered by buildings and amounted to 5.92 g m^{-2} $year^{-1}$. The lowest concentrations of phosphorus flowed from the meadow area, about 0.62 g m^{-2} $year^{-1}$ (Fig. 4).

3.5. Macrophytes structure

In 2015 macrophytes occupied 70 hectares in the Zemborzycki reservoir, which constituted 25.1% based on aerial photographs. Emergent macrophytes covered 43 ha and submerged covered 27 ha. When measured with cover grids at the reservoir, the average cover of the reservoir bottom with submerged macrophytes was low and amounted to 50%. The area occupied by macrophytes on lagoons was about 85 m^2 in 2015, 47% of total lagoon area.

3.6. Species diversity

The richest study sites in terms of number of species of macrophytes was the Bystrzyca River above the reservoir. In this area 13 to 20 plant species were present. Slightly fewer species were also found in the estuary of the river to the reservoir. The smallest number of species was found in the littoral zone of the reservoir within the recreational areas and where only two or three species were found (Table 3).

Species numbers were low in constructed lagoon areas prior to plantings in 2010 with only 1-5 species present. After planting in 2015, this number increased up to 15 species (Table 2).

3.7. Species biomass

Increases in macrophyte species richness did not necessarily correlate with increases in macrophyte biomass. The highest biomass values of macrophytes occurred in the estuary zone and ranged from 553 g_{DW} m^{-2} in 2010 to 1330 g_{DW} m^{-2} in 2015. The lower biomass values in this zone in 2012 were caused by construction work related to the shaping of the bicycle path. This project resulted in the destruction of the shoreline and macrophytes occurring there. High biomass values were also found in the lagoon zone during the last year of the study (from 1200 g m^{-2} to 1500 g m^{-2}). The lowest values of biomass occurred in the residual but typical for the Zemborzycki reservoir phytolittoral (from 102 g m^{-2} to 239.1g m^{-2}) (Fig. 5).

There was a high positive correlation between increasing biomass of macrophytes and decreasing concentration of total phosphorus and orthophosphates ($r = 0.72$, $p < 0.05$).

Table 3. Macrophytes composition in study sites + – often, cover < 50%; ++ – very often, cover > 50%
Tabela 3. Skład gatunkowy makrofitów na badanych stanowiskach; + – często, pokrycie < 50%; ++ – bardzo często, pokrycie > 50%

study site	1			2			3,4			5,6			7			8		
year species	2010	2012	2015	2010	2012	2015	2010	2012	2015	2010	2012	2015	2010	2012	2015	2010	2012	2015
Phragmites australis (Cav.) Trin. ex Steud	+	+	+	+				+	++		+	++					+	+
Urtica dioica L.									+			+						+
Galium aparine L.		+	+	+					+			+						
Hydrocharis morsus-ranae L.					+	+												
Glyceria maxima (Hartm.) Holmb.	++	++	++	++	+	++	+	+	++	+	+	++				+	+	+
Lemna minor L.	+	+	+	+		+	+		+			+						
Typha latifolia L.				+		+	+	+	++		+	++					+	
Phalaris arundinacea L.	+	+	+	+		+	+	+	+		+	+					+	+
Stuckenia pectinata (L.) Börner		+	+	+	+	++		+	+		+	+	+	+	+		+	+
Potamogeton praelongus Wulfen				+	++	++			+			+	+	+	+	+	+	+
Sparganium erectum L. em. Rchb.s.s.	+	+	+	++	+	++			+							+	+	+
Sagittaria sagittifolia L.		+	+	+	+	+											+	+
Lycopus europaeus L.	+	+	+	+		+			+			+					+	
Salix cinerea L.					+	+												

Table 3. cont.
Tabela 3. cd.

study site	1			2			3,4			5,6			7			8		
year species	2010	2012	2015	2010	2012	2015	2010	2012	2015	2010	2012	2015	2010	2012	2015	2010	2012	2015
Salix pentandra L.			+		+	+												
Alnus glutinosa (L.) Gaertn.	+	+	+		+	+												
Salix viminalis L.	+	+	+															
Impatiens noli-tangere L.			+															
Ranunculus repens L.	+	+	+															
Elodea canadensis Michx.		+	+	+	+													
Veronica beccabunga L.	+	+	+	+	+													
Epilobium hirsutum L.	+	+	+						+							+	+	+
Iris pseudacorus L.	+	+	+	+			+		+			+						
Typha angustifolia, L.																		
Rumex hydrolapathum Huds.				+		+												
Mentha aquatica L.		+	+	+					+									
Carex pseudocyperus L.																		
Scirpus sylvaticus L.	+	+	+	++	+	++			+			+			+		+	+
Myriophyllum spicatum L.					+	+												
Potamogeton acutifolius Link ex Roem. & Schult.				+									+					
	13	18	20	18	13	16	5	5	15	1	5	12	3	2	3	4	11	10

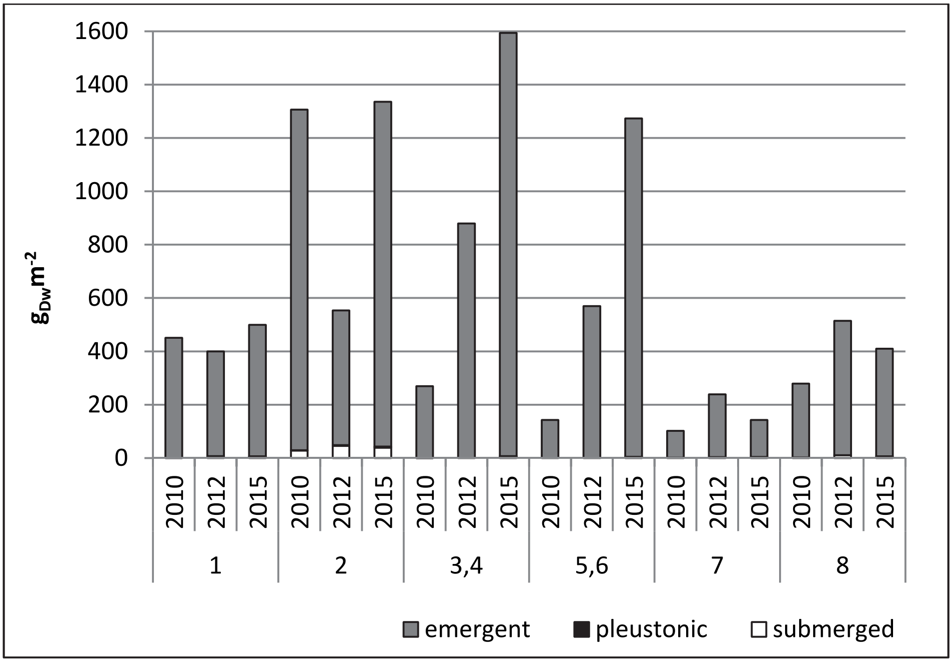

Fig. 5. Biomass of macrophytes at individual study sites in subsequent years of research

Rys. 5. Biomasa makrofitów na poszczególnych stanowiskach w kolejnych latach badań

Among the emergent macrophytes, the species that reached the highest values of biomass was *Glyceria maxima* (Hartm.) Holmb. *Sparganium erectum* L. em. Rchb.s.s. and *Phalaris arundinacea* L. also had a high biomass in the Bystrzyca river above the reservoir and in the estuary zone. Since 2012 the lagoons were also dominated by *Phragmites australis* (Cav.) Trin. ex Steud. Below the reservoir, *Sparganium erectum* L. em. Rchb.s.s.*,* had the highest values of biomass (Fig. 6).

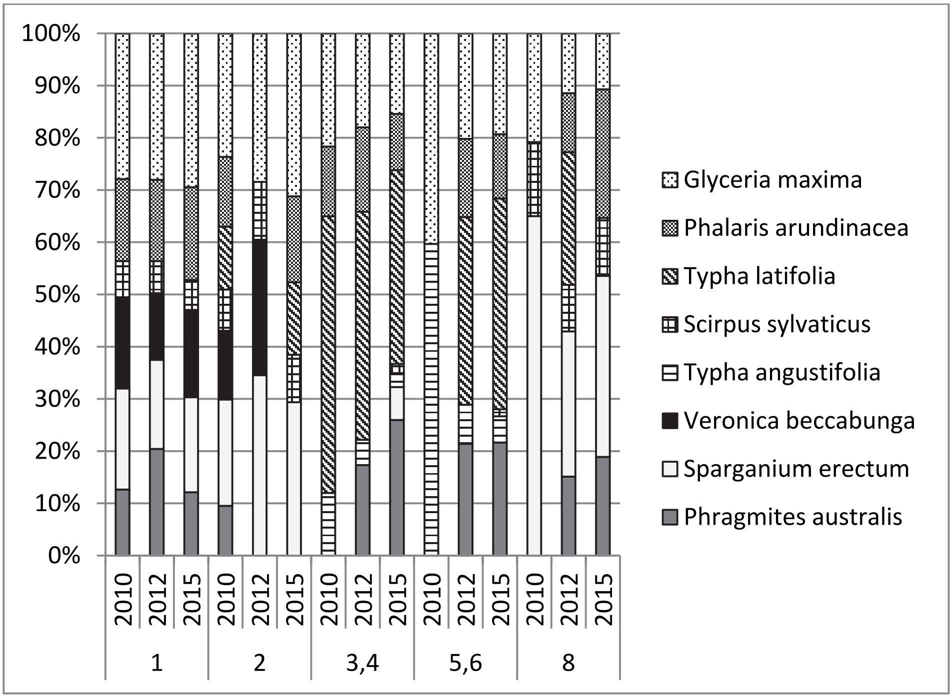

Fig. 6. Share of individual species of emergent macrophytes in biomass
Rys. 6. Udział procentowy poszczególnych gatunków makrofitów wynurzonych w ich biomasie

In spite of their large share in the surface of the Zemborzycki reservoir, submerged macrophytes achieved significantly lower biomass values. The highest were in the estuary zone and amounted to only 43 g_{Dw} m^2 in 2015. *Elodea canadensis* Michx. contributed the most to submerged macrophytes biomass above the reservoir, and *Potamogeton praelongus* Wulfen predominated in the reservoir and below it (Fig. 7).

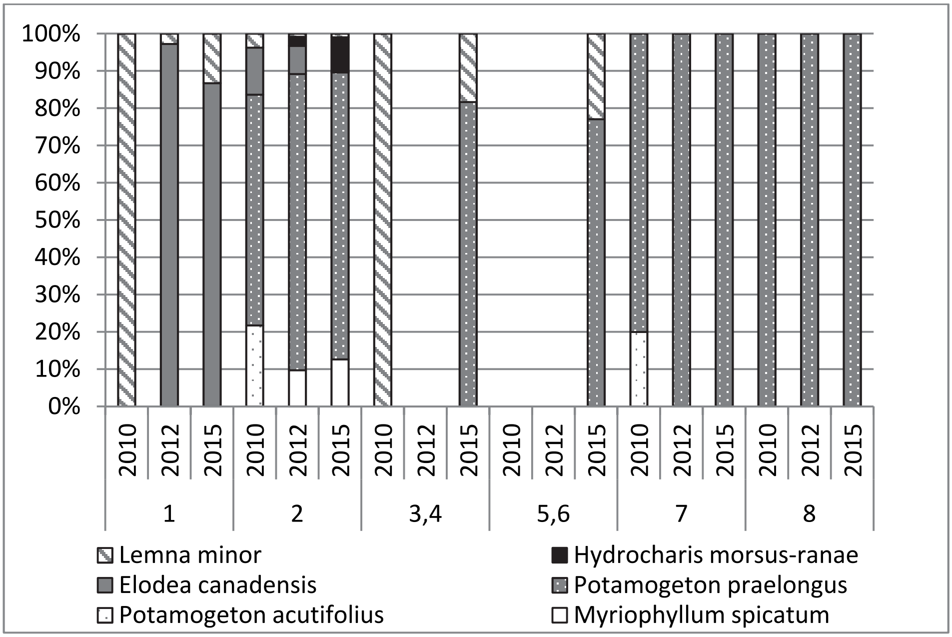

Fig. 7. Participation of individual species of submerged macrophytes in biomass
Rys. 7. Udział procentowy poszczególnych gatunków makrofitów zanurzonych w ich biomasie

Within the artificially created lagoons, submerged macrophytes established only in 2015 and *Potamogeton praelongus* Wulfen dominated in biomass (Fig. 7).

Total inertia is 0.487. Two dimensions explain 64% of the total inertia (axis 1 – 42% eigenvalue 0.188, Axis 2 – 22%, the eigenvalue 0.124). Analyzing the distribution of points it can be concluded that emergent macrophyte biomass (EB), pleustonic biomass (PB), submerged biomass (SB) were the most correlated with the concentration of phosphorus (TP and $P\text{-}PO_4$). Independent of the concentration of phosphorus in water were number of species (SN) and the density of emergent macrophytes (ED). Visibility had a relatively small effect on the variation in variable distributions (Fig. 8).

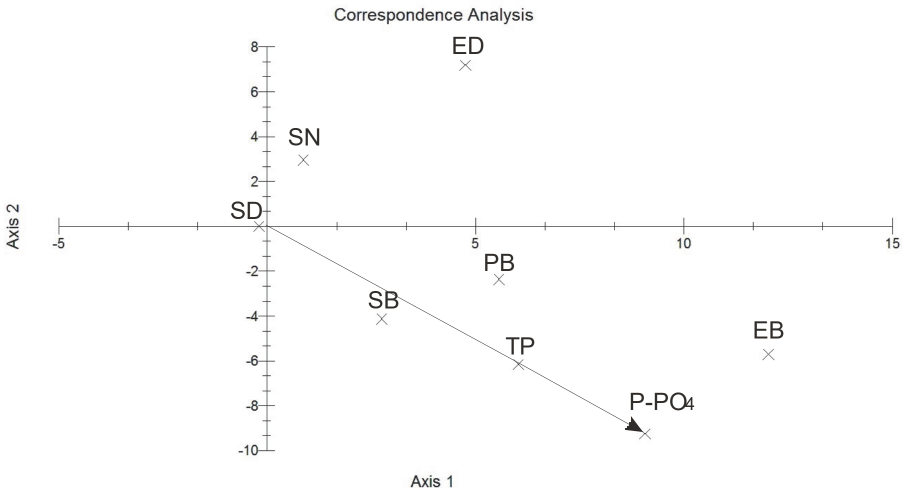

Fig. 8. Correspondence analysis SD – Secchi disc visibility, SN – Species number, ED emergent macrophytes density, PB – pleustonic biomass, EB – emergent macrophyte biomass; SB – submerged biomass; TP – total phosphorus; $P\text{-}PO_4$ - orthophosphates

Rys. 8. Analiza korespondencji, SD – widzialność krążka Secchiego, SN – liczba gatunków, ED – zagęszczenie makrofitów wynurzonych, PB – biomasa roślin pleustonowych, EB – biomasa roślin wynurzonych, SB – biomasa roślin zanurzonych, TP – fosfor całkowity, $P\text{-}PO_4$ – ortofosforany

4. Discussion

All water reservoirs are located in depressions and are a natural receiver of substances flowing from catchments. Still, the greatest threat to aquatic ecosystems are runoff from agricultural and urbanized areas in catchments (Kajak 2001). The natural cycling of nutrients in retention reservoirs is slower than in natural lakes (Kasza 2009). This process involves the conversion of compounds from organic into inorganic through microbial processes under aerobic conditions (Tranvik 1998) and the interception and capturing of nutrients by water plants (Chudyba & Kalwasiński 1998). With its low floristic diversity and biomass, the Zemborzycki reservoir is limited in its ability to cycle nutrients. Overall vegetation and diversity of species decreased in the last decade (Sender 2007). There are many causes of this phenomenon, among others, mechanical damage of macrophytes with large waves, large fluctuations in water level, restoration work of the shore and frontal dam, very low visibility associated with the progressive eutrophication of the reservoir (Bucak et al. 2012, Stefanidis & Papastergidou 2013).

Zemborzycki reservoir is affected by water rich in phosphorus. Up to 4.29 $g \cdot m^{-2}$ $P\text{-}PO_4$ and 77 $g\ m^{-2}$ TP are charged. In the estuary zone which hosts a developed phytolittoral zone with macrophytes phosphorus load is significantly reduced. In the lagoon area there was also a marked reduction in phosphorus concentration in study years, along with the progressive colonization of plants. In the littoral zone of Zemborzycki reservoir, with very low plant density, the concentration of phosphorus was much higher than in the lagoon zones. The lowest values were in the water of the Bystrzyca River below the reservoir. This means that a large proportion of phosphorus is deposited in the reservoir, mainly in bottom sediments. However, because of the unfavourable morphometry of this reservoir nutrients are re-suspended and waters undergo further eutrophication. Another negative factor is the supply of nutrients from external sources to the reservoir. It turns out that most of the phosphorus flows into the reservoir from the development area even though only 24% of surrounding areas are utilized for development.

The Zemborzycki reservoir along the almost entire shoreline is completely devoid of a natural buffer zone (except for the eastern part, covered with forest), as well as rushes. The presence of a natural buffer zone would allow for bioaccumulation in riparian plant, preventing the flow of phosphorus rich waters into the reservoir. The edges of the reservoir should be properly managed, to create well functioning buffer zones. Well developed and functioning vegetation zones occurring between terrestrial and aquatic ecosystems and display a gradient of biophysical conditions, ecological processes and a rich composition and diversity of organisms (Izydorczyk et al. 2013, Ryszkowski 1992, Correll 1997). Their most significant function is the buffering and filtering of pollutants between land and water ecosystems (Izydorczyk et al. 2015). If a buffer zone is lacking, rushes become the primary filters of nutrients (Sender & Grabowski 2016). Currently, in the Zemborzycki reservoir rushes are limited. The significant reduction of phosphorus compounds in the artificial phytolittoral zone confirms the necessity of such zones.

Macrophytes and associated periphyton are competing for phytoplankton, which is frequently represented in the waters of the Zemborzycki reservoir (Pawlik-Skowrońska & Toporowska 2011), in the uptake of nutrients. Moreover macrophytes strengthen bottom sediments, reduce the re-suspension of nutrients, and discharge metabolites which have the ability to inhibit the growth of phytoplankton, especially among *Chara* meadows (Gross 2003).

Currently emergent macrophytes are the dominant group of plants in the reservoir. This group also serves an important roles including: the stabilization of the lake bottom; reduction of wave undulation; oxygenation of sediments and the associated inactivation of phosphorus compounds; and they create the base for other living organisms (Cazzanelli et al. 2008, Thomaz & Cunha 2010, Ławniczak 2010).

The worsening ecological status of the reservoir and the disappearance of macrophytes, especially submerged macrophytes, indicate the need for corrective action. The life-cycle of dam reservoirs is closely related to the preservation of a specific capacity but as a result of reservoir silting up this, decreases with age. In the case of small water bodies it ranges from 10 to a maximum 50 years (Bąk et al. 2011, Michalec 2012). The capacity of the small reservoir does not exceed 5 million m^3 and the area 10 ha (Michalec 2012). The capacity of the Zemborzycki reservoir was 6.3 million m^3, with an area of over 280 ha. In the current form the Zemborzycki reservoir will not be able to function as a reservoir for recreational purposes. Hence, it becomes reasonable to divide it into a recreational area and a natural area which could also act as initial reservoir. Initial reservoirs allow the elimination of phosphates loads (as a limiting factor for primary production (Koc & Skwierawski 2004, Bechmann et al. 2005, Jarząbek 1998). They will also significantly reduce the muddying of the whole reservoir (Bąk et al. 2011). Removal of bottom sediments should be considered as a last resort, because removing bottom sediments does not always bring expected results (Gołdyn et al. 2003).

Storage reservoirs are artificially created and in order to function properly, require constant human interference. As they are extremely valuable the natural and economic role of retention reservoirs (Czamara 2001) requires constant attention to maintaining them in a sustainable way. Management should primarily involve activities such as biomanipulation, development of buffer zones and artificial phytolittoral zones, and well managed catchment areas. If these activities fail then more invasive methods should be considered. Abandoning any action will lead to ecosystem degradation and loss of its basic functions.

5. Conclusions

With limited possibilities of forming a buffer zone, special care should be taken to develop artificial phytolittoral to create artificial substrates, allowing them to develop in regulated shorelines to reduce the phosphorus compounds in the water. At present, the negative ecological potential of the Zemborzycki reservoir and its declining natural and recreational values, it seems justified to separate the so-called natural zone in a reservoir that would serve as a natural biofilter. However, the most important action is to regulate incoming wastewater in the catchment area of the Bystrzyca river and the reservoir as phosphorus loads entering the reservoir are highest from area with buildings and infrastructures.

The studies were performed within a Research Project no 77/OŚ/13,
Financed by the Lublin City Council,
Department of Environmental Protection.

References

Bąk, Ł., Dąbkowski, S.L., Górski, J. (2011). The method of predicting silting of a water reservoir based on a peat measurement. [in Polish]. *Woda-Środowisko-Obszary Wiejskie*, *11,* 19-29.

Bechmann, M.E., Berge, D., Eggestad H.O., Vandsemb S.M. (2005). Phosphorus transfer from agricultural areas and its impact on the eutrophication of lakes – two long-term integrated studies from Norway, *Journal of Hydrology*, *304(1)*, 238-250.

Bolpagni, R. & Piotti, A. (2015). Hydro-hygrophilous vegetation diversity and distribution patterns in riverine wetlands in an agricultural landscape: a case study from the Oglio River (Po plain, Northern Italy), *Phytocenologia, 45*, 69-83.

Bucak, T., SaraoĞL, E., LEVİ E., Nihan Tavşanoğlu Ü., Idil Çakiroğlu A., et al. (2012). The influence of water level on macrophyte growth and trophic interactions in eutrophic Mediterranean shallow lakes: a mesocosm experiment with and without fish, *Freshwater Biology*, *57(8)*, 1631-1642.

Cazzanelli, M., Warming, T.P., Christoffersen, K.S. (2008). Emergent and floating-leaved macrophytes as refuge for zooplankton in a eutrophic temperate lake without submerged vegetation, *Hydrobiologia*, *605(1)*, 113-122.

Chudyba, H. & Kalwasinski, K. (1998). Self-cleaning of water. [in Polish]. Nowoczesne Rolnictwo. Nauka, Doradztwo, Praktyka, 5, 6.

Ciepielowski, A. (1999). Basics of water management. [in Polish]. Publisher of SGGW Warsaw.

Cook, Ch.D.K. (1985). Aquatic plants endemic to Europe and the Mediterranean, *Bot. Jahrb.Syst.*, 103.

Cooke, G.D., Welch, E.B., Peterson, S., Nichols, S.A. (2016). Restoration and management of lakes and reservoirs, CRC press.

Correll, D. (1997). Buffer Zones: Their Processes and Potential in Water Protection, (eds) Haycock N. Burt T, Goulding K, Pinay G (Quest Environmental, Hertfordshire, UK), 7-20.

Czamara, W. (2001). The use of initial reservoirs to protection of dam reservoirs. [in Polish]. *Zeszyty Naukowe Akademii Rolniczej we Wrocławiu. Inżynieria Środowiska*, *12*, 257-262.

Dhote, S. & Dixit, S. (2007). Water quality improvement through macrophytes – a review, *Environmental Monitoring and Assessment 154*, 1-4, 149-153, DOI: 10.1007/s10661-008-0303-9

Gałczyński, Ł. (2008). Water eutrophication: the problem of civilization. [in Polish]. *Gaz, Woda i Technika Sanitarna*, 34-37.

Gołdyn, R., Joniak, T., Kowalczewska-Madura, K. & Kozak, A. (2003). Trophic state of a lowland reservoir during 10 years after restoration, *Hydrobiologia*, *506(1-3)*, 759-765.

Gross, E.M. (2003). Alleopathy of aquatic autotrophs, *Critical reviews in plant sciences. 22(3-4)*, 313-339.

Ilnicki, P. (2002). Causes, sources and course of surface water eutrophication. [in Polish]. *Przegląd komunalny 2*, 35-49.

Izydorczyk, K., Frątczak, W., Drobniewska, A., Cichowicz, E., Michalska-Hejduk, D., et al. (2013). A biogeochemical barrier to enhance a buffer zone for reducing diffuse phosphorus pollution – preliminary results, *Ecohydrology & Hydrobiology, 13*, 104-112

Izydorczyk, K., Michalska-Hejduk, D., Frątczak, W., Bednarek, A., Łapińska, M., et al. (2015). Buffer zones and ecohydrological biotechnologies in the reduction of area pollution. [in Polish]. *European Regional Center for Ecohydrology of the Polish Academy of Sciences*, Łódź, 145.

Jachniak, E. (2011). Loads of biogenic compounds and the degree of eutrophication of the Kozłowa Góra dam reservoir. [in Polish]. *Nauka Przyroda Technologie*, *5, 4, 55*, 1-9.

Jarząbek, A. (1998). Changes in the charge of phosphates when flowing through small reservoirs, *Zesz. Probl. Post. Nauk Rol. 458*, 389-396. (in Polish).

Kajak, Z. (2001). Hydrobiology-limnology: inland water ecosystems. [in Polish]. PWN Scientific Press Warsaw.

Kasza, H. (2009). Dam reservoirs: meaning-eutrophication-protection. [in Polish]. Wyd. Akademii Techniczno-Humanistycznej, Bielsko-Biała, 366.

Khadija, S.A., Francis, R., Bernard, T. (2015). Trend Analysis in Ecological Status and Macrophytic Characterization of Watercourses: Case of the Semois-Chiers Basin, Belgium Wallonia, *J. Water Res. Prot. 7*, 988-1000.

Koc, J., Duda, M., Tucholski, S. (2008). The importance of the retention reservoir to protect the lake against phosphorus runoff from the agricultural catchment. [in Polish]. *Acta Sci. Pol., Formatio Circumiectus*, *7(1)*, 13-24.

Koc, J. & Skwierawski, A. (2004). Phosphorus in the waters of agricultural areas. [in Polish]. *Zeszyty Nauk. AE Wrocław, Chemia, 1017*, 165-182.

Ławniczak, A. (2010). The role of emergent macrophytes in nutrient cycling in Lake Niepruszewskie (western Poland), *Oceanological and Hydrobiological Studies*, *39(2)*, 75-83.

Matuszkiewicz, W. (2008). Guide for the determination of plant communities in Poland. [in Polish]. PWN Scientific Press Warsaw, 537.

Michalec, B. (2012). Determination of the viability of small water reservoirs. [in Polish]. *Infrastruktura i Ekologia Terenów Wiejskich*, *3(4)*, 119-129.

Ozimek, T. (1991). Macrophytes as bio-filters in the wastewater treatment process [in Polish]. Wiad. Ekol. *38*, 13-34.

Pärn, J., Pinay G. & Mander U. (2012). Indictors of nutrients transport from agricultural catchments under temperate climate: a review, *Ecological Indicators*, *22*, 4-15.

Pawlik-Skowrońska, B. & Toporowska, M. (2011). Blooms of toxin-producing Cyanobacteria – A real threat in small dam reservoirs at the beginning of their operation, *Oceanological and Hydrobiological Studies*, *40(4)*, 30-37.

Pełechaty, M. & Pronin, E. (2015). The role of water and rush vegetation in the functioning of lakes and assessment of the condition of their waters. [in Polish]. *Stud. Lim. Tel.*, *9(1)*, 25-34.

Penning, E., Mjelde, M., Dudley, B., Hellsten, S., Hanganu J., et al. (2008). Classifying aquatic macrophytes as indicators of eutrophication in European Lakes, *Aquatic Ecology, 42*, 237-251.

Prochal, P. (1978). Water construction. [in Polish]. PWRiL Press, Warsaw, 306.

Ryszkowski, L. (1992). Ecological principles of shaping agricultural areas to ensure sustainable and sustainable development of agriculture. [in Polish]. in: Protection and rational use of water resources in agricultural areas in the Wielkopolska region, Kosturkiewicz A. (Ed.), Committee on Environmental Protection Department in Poznań PAN, 85-106.

Sender, J. (2007). Sources of the threats and the directions of the macrophytes structure changes in the Zemborzycki Reservoir, *TEKA Ochr. i Kszt. Środ. Przyr.*, *4*, 221-228.

Sender, J. (2009a). Changes in structure of macrophyte communities in the chosen lakes of Łęczna-Włodawa Lake District, *Ecohydrology & Hydrobiology*, *9(2)*, 237-245.
Sender, J. (2009b). Analysis of succession changes occurring in water phytocoenoses and macrophyte flora of the studied lakes in 1960 and 2009. in: Ecology of hydrogenic landscapes of the Biosphere Reserve ": Polesie Zachodnie". [in Polish]. Chmielewski T.J. (Ed.), University of Life Sciences in Lublin Press, 161-190.
Sender, J. (2010). Long-term changes of macrophytes structure in macrophyte-dominated lakes from the Łęczna-Włodawa Lake District. [in Polish]. *Ann. UMCS sec E Agricultura*, *65(2)*, 58-67.
Sender, J. (2013). Monitoring of ecological effects of three phytolittal lagoons in the Zemborzycki Reservoir in 2013. [in Polish]. (typescript).
Sender, J. & Grabowski, M. (2016). The relationship between land management and the nature of helophytes in small lakes (Eastern Poland), *Limnological Review*, *16(1)*, 51-62.
Smal, H., Ligęza, S., Wójcikowska-Kapusta, A., Baran, S., Urban, D., Obroślak, R., Pawłowski, A. (2015) Spatial distribution and risk assessment of heavy metals in bottom sediments of two small dam reservoirs (south-east Poland), Archives of Environmental Protection, *41(4)*, 61-70.
Soszka, H. (2010). Assumptions of the project concerning restrictions on the use of lake waters and the use of their catchment. [in Polish]. in: Protection and reclamation of lakes, Wiśniewski R. (Ed.), Polish Association of Sanitary Engineers and Technicians in Toruń, 115-127.
Soszka, H., Pasztaleniec, A., Koprowska, K., Kolada, A., Ochocka, A. (2012). Influence of hydromorphological transformations of lakes on water organisms – Literature review. [in Polish]. *Ochrona Środowiska i Zasobów Naturalnych*, *51*, 24-52.
Stefanidis, K. & Papastergiadou, E. (2013). Effects of a long term water level reduction on the ecology and water quality in an eastern Mediterranean lake, *Knowledge and Management of Aquatic Ecosystems 411*, 1–14.
Szmeja J. (2006). Guide to the study of aquatic vegetation. [in Polish]. Gdańsk University Press, 467.
Thiebaut, G., Guerold, F. & Muller, S. (2002). Are trophic and diversity indices based on macrophyte communities pertinent tools to monitor water quality? *Water Research, 36*, 3602-3610
Thomaz, S.M. & Cunha, E.R.D. (2010). The role of macrophytes in habitat structuring in aquatic ecosystems: methods of measurement, causes and consequences on animal assemblages' composition and biodiversity, *Acta Limnologica Brasiliensia, 22(2)*, 218-236.

Tranvik, L.J. (1998). Degradation of dissolved organic matter in humic waters by bacteria, Aquatic humic substances. Springer Berlin Heidelberg, 259-283.
Vollenweider, R.A. (1976). Advances in defining critical loading levels for phosphorus in lake eutrophication, *Mem. 1st. Ital. Idrobiol.*, *33*, 53-83.
Wołek, J. (1996). Occurrence and distribution of aquatic and rush plants in the area of Czorsztyn-Nidzica Sromowe Wyżne water reservoirs before water accumulation. [in Polish]. *Fragm. Flor. Geobot.* Ser. Polonica, *3*, 189-203.

Wstępne badania nad poprawą jakości wody zbiornika zaporowego poprzez wprowadzenie sztucznego fitolitoralu

Streszczenie

Zbiorniki retencyjne, utworzone przez człowieka, dla prawidłowego funkcjonowania wymagają ciągłej jego ingerencji. Zbiornik Zemborzycki ulega sukcesywnej eutrofizacji. W roku 2010 zapoczątkowane zostało tworzenie na obszarze zbiornika sztucznych powierzchni roślinnych dla wzbogacania bioróżnorodności. Ich powstanie miało także na celu wyhamowanie wody wpływającej do zbiornika i przez ich przepływ przez powierzchnię roślinną ograniczenie dostaw fosforu.

Celem badań było określenie roli sztucznie ukształtowanego fitolitoralu w redukcji fosforu. W tym celu określono ładunek fosforu dopływający do zbiornika ze źródeł powierzchniowych, z wodami rzecznymi oraz ze źródeł zewnętrznych. Do zbiornika wpływa woda bogata w fosfor. W strefie ujściowej rzeki Bystrzycy, w której znajduje się rozwinięta strefa naturalnego fitolittoralu, ładunek fosforu jest znacznie zmniejszony. W strefie lagun odnotowano również znaczne zmniejszenie stężenia fosforu w kolejnych latach badań, wraz z postępującą kolonizacją ich przez rośliny. Znacząca redukcja związków fosforu w sztucznej strefie fitolitoralu potwierdza konieczność ich istnienia.

Przy obecnym, złym potencjale ekologicznym zbiornika Zemborzyckiego i obniżających się walorach przyrodniczych oraz możliwościach jego rekreacyjnego wykorzystania, uzasadnione wydaje się wydzielenie tzw. strefy przyrodniczej w zbiorniku, która pełniłaby rolę naturalnego biofiltra. Jednak najważniejszą jest uregulowana gospodarka ściekowa w zlewni rzeki Bystrzycy i zbiornika. Badane sztuczne podłoża dla roślin, chociaż wolno, ale sukcesywnie zasiedlane są przez rośliny, mogą stanowić narzędzie wspomagające oczyszczanie wód zbiorników zaporowych. Są jednocześnie trwałe i mogą być dowolnie kształtowane, co może stanowić dodatkowy atut – estetyczny.

Abstract

Storage reservoirs are artificially created and in order to function properly, require constant human interference. Zemborzycki reservoir has undergone a successive eutrophication. In 2010, an experimental artificial land surfaces were developed throughout the reservoir. Various native species were transplanted on these lagoons to enrich biodiversity within the reservoir and to reduce phosphorus supply through the plant barrier. The aim of this study was to determine the role of these artificially constructed lagoons and their associated vegetation on phosphorus reduction throughout the reservoir. The reservoir is affected by water rich in phosphorus. In the estuary zone which hosts a developed phytolittoral zone with macrophytes phosphorus load is significantly reduced. In the lagoon area there was also a marked reduction in phosphorus concentration in study years, along with the progressive colonization of plants. The significant reduction of phosphorus compounds in the artificial phytolittoral zone confirms the necessity of such zones. At present, the negative ecological potential of the reservoir and its declining natural and recreational values, it seems justified to separate the so-called natural zone in a reservoir that would serve as a natural biofilter. However, the most important action is to regulate incoming wastewater in the catchment area of the Bystrzyca River.

Studied artificial substrates for plants (sand and gravel), although slowly, but gradually settled by water plants, can be a tool supporting the purification of dam reservoir waters. They are also durable and can be shaped in any way, which can be an additional asset – aesthetic.

Słowa kluczowe:
zbiornik zaporowy, eutrofizacja, makrofity, związki fosforu, sztuczny fitolitoral

Keywords:
storage reservoir, eutrophication, macrophytes, phosphorus compounds, artificial phytolittoral