www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES OF ENVIRONMENTAL PROTECTION

vol. 39 no. 3 pp. 33 - 46 2013

VERSITA

PL ISSN 2083-4772

DOI: 10.2478/aep-2013-0029

EFFECT OF PHOSPHOROUS LOADINGS ON MACROPHYTES STRUCTURE AND TROPHIC STATE OF DAM RESERVOIR ON A SMALL LOWLAND RIVER (EASTERN POLAND)

MONIKA TARKOWSKA-KUKURYK

University of Life Science, Department of Hydrobiology
Dobrzańskiego 37, 2-262 Lublin
Corresponding author's e-mail: monika.kukuryk@up.lublin.pl

Keywords: Dam reservoir, river, phosphorous, eutrophication.

Abstract: The main objective of the study was to evaluate if macrophytes structure and trophic status of dam reservoir Kraśnik on a small lowland river Wyżnica are determined by phosphorous loadings. Studies were conducted seasonally in May, July and October during the years 2008–2009. Samples were taken at four sites: Site 1 – inflow of the Wyżnica River to pre-dam, Site 2 − pre-dam, Site 3 − dam reservoir and Site 4 – outflow of the Wyżnica River from dam reservoir. Physical and chemical parameters (temperature, Secchi disc depth, dissolved oxygen, pH, conductivity, total suspension, chlorophyll-*a*, TP and P-PO_4) were measured in water samples. Together with water parameters there were estimated biomass of phytoplankton and species composition and biomass of emergent, floating-leaved and submerged macrophytes. Concentrations of TP, chlorophyll-*a* and Secchi disc depth were used to calculate trophic state index of Carlsson for dam reservoir and its pre-dam. Based on mean water current, mean residence time of water in dam reservoir and concentrations of TP and P-PO_4 loadings (g m^{-2}) flowing into dam reservoir with the Wyżnica River were calculated. The results showed visible negative effect of phosphorous loadings on both macrophytes composition and trophic state of the reservoir. The marked changes concerned soft vegetation. High P loadings (7.74 g m^{-2} of TP and 6.03 g m^{-2} P-PO_4) during the spring of 2008 caused the disappearance of characeans meadows. In 2009, the presence of rigid hornwort (*Ceratophyllum demersum* L.), the species typical for eutrophic lakes was noted. This unrooted submerged plant uptakes dissolved orthophosphates directly from the water column.

Values of Carlsson index ($51.4 \leq TSI \leq 68.2$) indicate the eutrophic state of dam reservoir Kraśnik. During summer season in dam reservoir there were observed algal blooms (biomass of phytoplankton exceed 10 mg WW dm^{-3}) and low water transparency (Secchi disc depth ranged from 0.4 to 0.65 m). During the two-year studies in dam reservoir Kraśnik a high reduction of P loadings, mostly dissolved orthophosphates was observed. Dependently on season, reduction of P-PO_4 loadings ranged from 52% (July 2008) up to 91% (May 2009). The reduction of TP was lower and reached values from 15% (May 2008) to 48% (July 2009).

INTRODUCTION

Phosphorus is a key limiting factor controlling primary production in river ecosystems [40, 30, 20]. Enhanced inputs of phosphates from human sources (together with other nutrients such as nitrates) may stimulate the process of eutrophication. In lentic ecosystems this process can promote intensive growth of planktonic algal biomass which led to decrease of oxygen content and a subsequent decrease in diversity of water biocenosis as well the reduction of the economical and aesthetic values of the reservoir (surface scums, production of toxins, bad taste of water) [34, 38]. The major sources of P entering rivers are sewage/industrial effluents (point sources) and agricultural runoff (diffuse sources) [15]. Sewage is one important route by which inorganic phosphorous compounds may enter rivers. The principal sources of phosphates in sewage are human faeces and urine, food wastes (together around 75% of phosphates in sewage), detergents and industrial effluent that are discharged to reservoirs [14, 23].

In pre-dams and dam reservoirs the concentrations of phosphorous compounds may be reduced substantially, the process lead to improve the quality of inflowing water [25, 26]. In the reservoirs phosphorous loadings are diminished under two main processes: settling of particles and adsorbed phosphorous and incorporation of dissolved orthophosphates into phytoplankton biomass, which is then eliminated from the water by sedimentation [18, 34]. The negative, frequently observed effect of P loadings is increase of trophic status of reservoir. As a consequence, algal blooms, decrease of water transparency and biomass of soft vegetation are observed in the reservoir [31, 13]. The most vulnerable for eutrophication process are newly created reservoirs. Such reservoirs are intensively colonized by different phyto and zoocenosis, thus the trophic structure of the ecosystems is very unstable [11].

The main objective of the study was to recognize the influence of high P loadings on macrophytes structure and trophic status of a new man-made dam reservoir.

SRUDY AREA, MATERIALS AND METHODS

The dam reservoir Kraśnik (50° 56' 32.23" N, 22° 11' 37.06" E) and its pre-dam are small and shallow reservoirs (Table 1), created on the Wyżnica River near the town of Kraśnik (eastern Poland). The Wyżnica River is a right-bank tributary of the Vistula River and is about 42,5 km long. Water current shows seasonal variability and rangs from 0.11 to 0.42 m^3s^{-1} (mean 0.29 m^3s^{-1}) [3]. The river catchment covers 508 km^2 and it is dominated by arable lands and pastures. The main problems of water quality of the Wyżnica River are high loads of sewage from district dairy of Kraśnik, diffuse sewage sources (runoff from intensively managed agricultural lands) and storm runoffs.

The dam reservoir Kraśnik was created in 2006 for the purpose of water discharge, recreation and fishery management. All banks of the reservoir are rampart, except for the south side, where the natural slope of river valley was retained. The reservoir was built on the area comprised by meadows, pastures and fishery ponds. One year after filling algal blooms appeared in the reservoir, which was closed for recreation use. High constant supply of organic matter and nutrients (mostly P-PO_4) caused remarkable reduction of water transparency and deterioration of water quality.

The studies were conducted during the years 2008–2009 at four sites (Fig. 1): Site 1 – inflow of the Wyżnica River to pre-dam; Site 2 – pre-dam; Site 3 – dam reservoir; Site 4 – outflow of the Wyżnica River from dam reservoir. Water samples were taken in spring (May), summer (July) and autumn (October).

Water temperature, pH, conductivity and dissolved oxygen were measured *in situ* using YSI 556 MPS electrode. Total suspension content was estimated by gravimetric method. Concentrations of chlorophyll-a were determined by spectrophotometric method following

Table 1. Main hydrological parameters of pre-dam and dam reservoir Kraśnik

	pre-dam	dam reservoir
Volume (m^3)	11600	996000
Surface (ha)	2.3	39.06
Mean depth (m)	0.5	2.5
Maximum length (m)	330	1180
Maximum width (m)	75	570
Water residence time (days)	40.2*	

* according Pęczuła and Suchora [28]

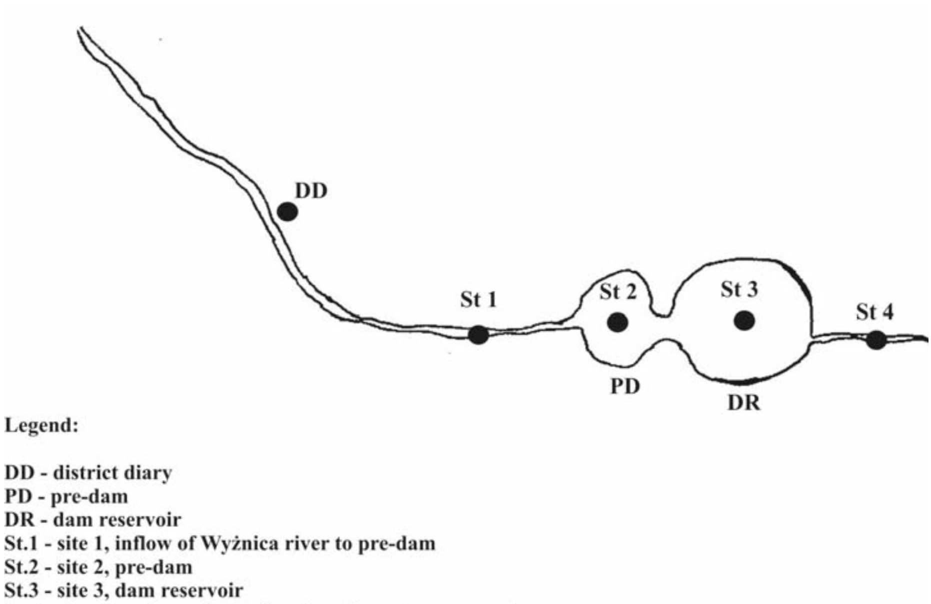

Fig. 1. Location of studied sites on WyżnicaRiver, pre-dam and dam reservoir Kraśnik

a 24 h extraction with 90% acetone in the dark [10]. The concentrations of P compounds were estimated using spectrophotometric method with ammonium heptamolybdate [29]. For the analysis one liter of water was filtered (3 replicates at each site).

Trophic status of pre-dam and dam reservoir were evaluated by calculating Trophic State Index (TSI) of Carlsson [5].

Loadings of TP and P-PO_4 were estimated using Vollenveider [41] criteria, including concentrations of total phosphorous and dissolved orthophosphates in pre-dam and dam reservoir, mean water current and mean water residence time.

Biomass of phytoplankton was estimated in 100 ml water samples preserved with Lugol's liquid. Algal biomass was calculated using the lengths and widths of algal cells and common geometric equations [32].

The species structure of macrophytes was estimated along horizontal transects [16] starting from the land-water ecotone and ending at the depth of macrophytes occurrence. In pre-dam, due to its small area, transects ranged between banks. In pre-dam 5 transects were marked and in dam reservoir – 18 transects. Along the transects macrophytes were sampled at points located every 20 m using floristic fork. The plant material was collected for species identification. Species identification was done according to Kłosowski and Kłosowski [17] and Pełechaty and Pukacz [27]. The density of emergent macrophytes (helophytes) was estimated at 10 randomly chosen sites by counting the shoots on the area of 0.25 m^2 limited by a floristic fork. The biomass of floating-leaved (nympheids) and submerged vegetation (elodeids) was estimated using Bernatowicz rake [2] of the area 0.16 m^2 and calculated per m^2 of bottom surface.

All data collected during field studies were analyzed statistically. The influence of the water of the Wyżnica River on physical and chemical parameters of pre-dam and dam reservoir was analyzed by means of two-way ANOVA (site, season). For pre-dam and dam reservoir Pearson's correlation coefficients between biomass of phytoplankton and macrophytes and environmental variables were calculated. All analysis were performed by STATISTICA 6.0.

RESULTS

Physical and chemical water parameters

During the years 2008–2009 physical and chemical parameters of the water of the Wyżnica River, pre-dam and dam reservoir Kraśnik differed between studied sites and seasons (Table 2). Most of studied parameters showed a significant variability (Table 3). Temperature of water, independently on site and season, showed the lowest values at Site 1 (inflow of the Wyżnica River to pre-dam). The highest water temperature, in spring and summer, was observed at Site 4 (outflow of the Wyżnica River from dam reservoir); in autumn at Site 3 (dam reservoir). Values of pH ranged from 7.35–8.65. In 2008 the highest values of pH were noted in summer (July) and the lowest in spring (May). In 2009 the highest pH was observed in spring (May) and the lowest in autumn (October). Secchi disc visibility in pre-dam in all studied seasons reached the bottom and rose from spring to autumn from 0.9 to 1.1 m. In dam reservoir an opposite pattern was observed, the highest water transparency, 1.5 m (2008) and 1.1 m (2009) was noted in spring (May). During summer and autumn seasons, Secchi disc depth rapidly decreased and amounted to 0.65 and 0.4 m (2008) and to 0.5 and 0.9 m (2009). The highest concentrations of dissolved oxygen (10.74–16.47 mg dm^{-3}) were observed in spring, while the lowest, dependently on the year in summer (4.93–10.11 mg dm^{-3}) or in autumn (5.66–7.02 mg dm^{-3}). Conductivity, in both studied years, reached the highest values (404–642) in spring and the lowest in summer (351–483). Concentrations of total suspension ranged from 3.3 to 52.2 mg dm^{-3}. In 2008, the lowest amounts were noted in spring and the highest in autumn. In general, the content of total suspension was about 2–4 times lower in the outflow of the Wyżnica River from dam reservoir than in the water of the Wyżnica River inflowing to pre-dam. In 2009, the lowest content of total suspension was noted at most sites in autumn and the highest in summer. Concentrations of chlorophyll-*a* showed high variability, dependently on season and site. The lowest concentration of chlorophyll-*a*, 1.85 μg dm^{-3} was observed in July

Table 2. Seasonal variations of physical and chemical water parameters at studied sites on WyżnicaRiver, pre-dam and dam reservoir Kraśnik during the years 2008–2009

	2008												2009											
	Stanowisko 1			Stanowisko 2			Stanowisko 3			Stanowisko 4			Stanowisko 1			Stanowisko 2			Stanowisko 3			Stanowisko 4		
	Maj	Lip	Paź	Maj	Lip	Paź	Maj	Lip	Paź	Maj	Lip	Paź	Maj	Lip	Paź	Maj	Lip	Paź	Maj	Lip	Paź	Maj	Lip	Paź
Temperature (°C)	12.1	17.7	11.9	13.9	19.4	12.7	14.4	21.8	12.9	15.1	22.1	12.4	12.7	18.0	8.6	13.1	23.5	9.4	13.9	22.3	9.9	16.2	25.2	9.2
Secch disc depth (m)	-	-	-	0.9*	1.0*	1.1*	1.5	0.65	0.4	-	-	-	-	-	-	1.0*	1.1*	1.2*	1.1	0.5	0.9	-	-	-
pH	7.58	7.69	7.72	7.35	7.63	7.56	7.72	8.65	8.30	7.60	7.78	7.53	8.39	7.79	7.77	8.39	7.77	7.74	8.40	8.18	7.91	8.39	8.50	7.79
Dissolvedoxygen (mg dm^{-3})	14.74	7.21	7.15	12.87	5.85	5.66	11.90	11.69	7.02	10.74	4.93	6.89	16.47	8.32	10.16	11.78	7.73	8.57	10.92	10.11	13.97	9.87	8.45	12.14
Conductivity (µS cm^{-1})	544	483	525	541	455	528	444	360	350	421	351	376	642	445	504	524	455	495	434	360	387	404	354	370
Total suspension (mg dm^{-3})	19.0	29.0	28.4	8.2	13.6	15.8	11.4	52.2	53.0	4.1	7.0	9.0	8.7	19.0	13.4	12.1	11.8	7.1	19.6	21.2	6.3	24.8	13.7	3.3
Chlorophyll-a (µg dm^{-3})	6.63	16.38	16.87	11.87	10.22	7.52	10.95	72.45	31.11	10.88	17.91	19.4	10.36	5.62	16.87	14.33	1.85	9.82	24.43	10.39	35.02	22.90	17.91	11.38
TP (mg dm^{-3})	0.327	0.335	0.245	0.461	0.509	0.205	0.149	0.274	0.161	0.194	0.216	0.141	0.176	0.274	0.174	0.194	0.352	0.213	0.177	0.197	0.212	0.149	0.141	0.119
P-PO4 (mg dm^{-3})	0.195	0.261	0.101	0.278	0.419	0.129	0.063	0.082	0.086	0.054	0.125	0.034	0.078	0.130	0.101	0.066	0.224	0.131	0.018	0.023	0.036	0.007	0.019	0.031
TSI	-	-	-	59.7	58.6	51.3	51.4	68.2	62.3	-	-	-	-	-	-	54.5	50.3	52.9	55.4	56.9	58.4	-	-	-

Site 1 – inflow of Wyżnica River to pre-dam; Site 2 – pre-dam; Site 3 – dam reservoir; Site 4 – outflow of Wyżnica River from dam reservoir; TSI – Trophic State Index; * – to the bottom

2009 at Site 2 (pre-dam) and the highest – 72.45 μg dm^{-3} in July 2008 at Site 3 (dam reservoir).

Concentrations of total phosphorous and dissolved orthophosphates in all studied seasons were visibly higher at Site 1 (the inflow of thge Wyżnica River to pre-dam) than at Site 4 (the outflow of the Wyżnica River from dam reservoir) (Table 2). During the years 2008–2009 the highest decrease of concentration of P-PO_4 was noted in spring (May); in 2008 the concentration of P-PO_4 decreased 4-times, from 0.195 mg dm^{-3} to 0.054 mg dm^{-3} and in 2009 as many as 11-times, from 0.078 mg dm^{-3} to 0.007 mg dm^{-3}. Differences in total phosphorous concentrations along the studied sites were much lower. In 2008, the highest decrease of TP concentration was observed in spring (May); from 0.327 mg dm^{-3} (Site 1) to 0.194 mg dm^{-3} (Site 4). In 2009, the highest difference of concentration of TP was noted in summer (July), from 0.274 mg dm^{-3} (Site 1) to 0.141 mg dm^{-3} (Site 4).

Table 3. Results of two-way ANOVA (site, season) for selected physical and chemical parameters of water of Wyżnica River, pre-dam and dam reservoir Kraśnik

Parameter	Season	Site
Temperature	$F = 129.68; p < 0.001$	ns
Secchi disc depth	ns	$F = 3.25; p = 0.034$
pH	ns	$F = 3.19; p = 0.037$
Dissolved oxygen	$F = 15.17; p < 0.001$	ns
Conductivity	$F = 4.88; p = 0.012$	$F = 45.59; p < 0.001$
Total suspension	ns	$F = 4.67; p = 0.044$
Chlorophyll-*a*	$F = 4.16; p = 0.021$	$F = 10.79; p < 0.001$
TP	$F = 5.62; p = 0.006$	$F = 6.89; p < 0.001$
P-PO_4	$F = 0.55; p = 0.016$	$F = 5.01; p = 0.010$

N = 72; ns – not significa

Phosphorous loadings

Loadings of TP and P-PO_4 introduced to dam reservoir Kraśnik with the Wyżnica River showed visible seasonal variability (Fig. 2). In 2008, the highest loadings of phosphorous inflow to the reservoir were in spring and summer and amounted to 7.56 g m^{-2} TP and 4.49 g m^{-2} P-PO_4 in May and to 7.74 g m^{-2} TP and 6.03 g m^{-2} P-PO_4 in July. In 2009, the highest loadings were observed in July, 3.08 g m^{-2} P-PO_4 and 6.33 g m^{-2} TP. In all studied seasons in dam reservoir Kraśnik important reduction of P loadings was observed. The highest retention of P-PO_4 was noted in May; 72% in 2008 and 91% in 2009. Reduction of TP loadings was much lower. In 2008, the highest, 42% reduction of TP was observed in October and in 2009 in July – 48%.

Biomass of phytoplankton

During the years 2008–2009 biomass of phytoplankton in dam reservoir was from 1.5 up to 26-times higher than in pre-dam. Observed differences were significant (ANOVA, $F = 5.17; p = 0.042$). In pre-dam, in both studied years, the lowest phytoplankton biomass was observed in July, 1.07 and 1.23 mg WW dm^{-3}. The highest biomass of planktonic

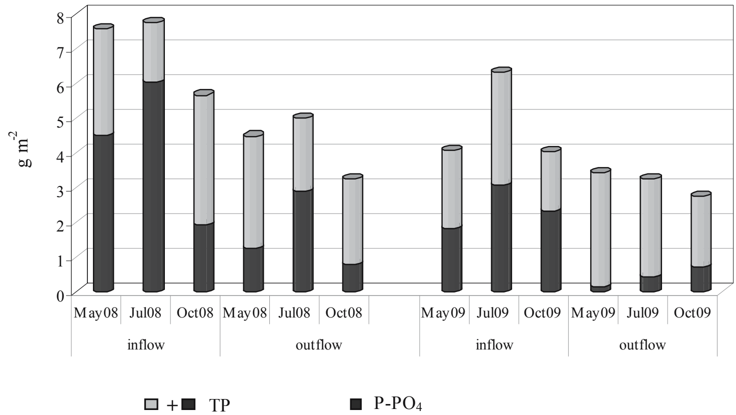

Fig. 2. Loadings of total phosphorous (TP) and dissolved orthophosphates (P-PO_4) in inflow and outflow of Wyżnica River to dam reservoir Kraśnik in studied seasons during the years 2008–2009

algae in 2008 was noted in May (3.68 mg WW dm^{-3}) and in 2009 in October (2.71 mg WW dm^{-3}). The biomass of phytoplankton was negatively correlated with water temperature ($r = -0.62$; $p = 0.006$) and pH ($r = -0.71$; $p = 0.001$) and positively with conductivity ($r = 0.72$; $p = 0.001$).

In dam reservoir the highest biomass of planktonic algae, in both studied years, was observed in summer, 32.97 mg WW dm^{-3} (2008) and 23.41 mg WW dm^{-3} (2009) and the lowest in spring, 5.24 mg WW dm^{-3} (2008) and 3.77 mg WW dm^{-3} (2009) (Fig. 3). All the differences were significant (ANOVA, $F = 7.87$; $p = 0.011$). The biomass of phytoplankton was positively correlated with water temperature ($r = 0.84$; $p < 0.001$), total suspension ($r = 0.67$; $p = 0.003$) and concentrations of TP ($r = 0.48$; $p = 0.013$) and P-PO_4 ($r = 0.73$; $p = 0.001$). Also, biomass of planktonic algae was negatively affected by Secchi disc depth ($r = -0.64$; $p = 0.004$).

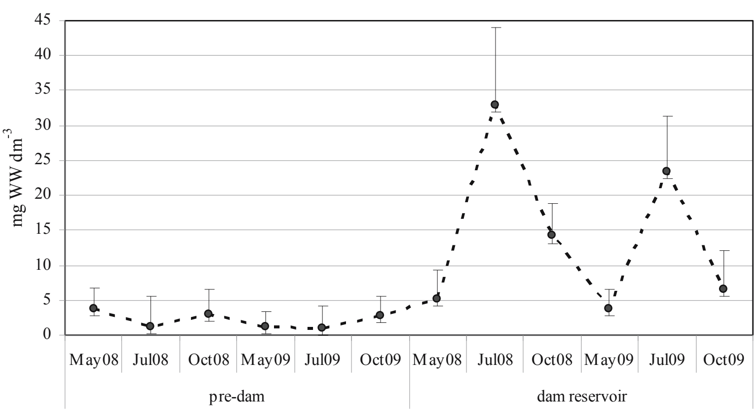

Fig. 3. Biomass of phytoplankton (mean values, +SD) in pre-dam and dam reservoir Kraśnik in studied seasons during the years 2008–2009

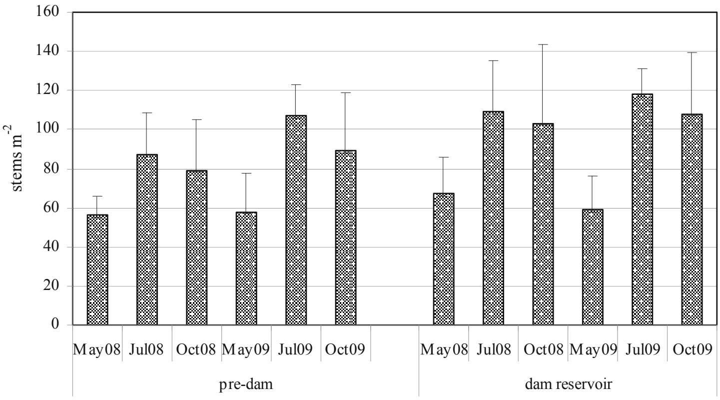

Fig. 4. Density of emergent macrophytes (mean values, +SD) in pre-dam and dam reservoir Kraśnik in studied seasons during the years 2008–2009

Structure of macrophytes

In pre-dam and dam reservoir, during two-year studies 11 macrophyte species were noted (Table 4). In pre-dam the number of species was constant through the sampling period and included 2 species of emergent macrophytes, 2 floating-leaved species and 1 species of submerged macrophytes. In dam reservoir the structure of submerged macrophytes varied between studied years and seasons. In 2008, the highest number of species was noted in May (10 species) in remaining two seasons the number of species was lower (7 species). In spring season, in reservoir there were presented characean meadows formed by *Chara tomentosa* L., *Chara rudis* (A. Braun) Leonh. and *Chara intermedia* A. Braun. In 2009, submerged macrophytes were represented by 8 species. Instead of characeans rigid hornwort (*Ceratophyllum demersum* L.) appeared.

Density of emergent macrophytes, in both studied years, differed significantly between seasons (ANOVA, $F = 7.96$; $p = 0.002$) (Fig. 4). The highest density of emergent vegetation, in pre-dam and dam reservoir was observed in summer (mean 87–118 stems m^{-2}) and the lowest in spring (mean 56–67 stems m^{-2}). In pre-dam the density of emergent macrophytes was negatively correlated with pH ($r = -0.65$; $p = 0.004$) and dissolved oxygen content ($r = -0.52$; $p = 0.027$) and positively with concentrations of TP ($r = 0.49$; $p = 0.036$) and P-PO_4 ($r = 0.63$; $p = 0.005$). In dam reservoir there was noted a negative correlation of emergent plant density with Secchi disc depth ($r = -0.64$; $p = 0.004$) and conductivity ($r = -0.80$; $p = 0.001$) and a positive correlation of helophytes density with chlorophyll-*a* concentration ($r = 0.61$; $p = 0.006$), TP ($r = 0.64$; $p = 0.004$) and phytoplankton biomass ($r = 0.57$; $p = 0.013$).

A significant influence of season was observed also for the biomass of floating-leaved (ANOVA, $F = 5.07$; $p = 0.035$) and submerged macrophytes (ANOVA, $F = 5.12$; $p = 0.015$) (Fig. 5). During two-year studies, the highest biomass of nympheids, in both reservoirs was noted in May (mean 156.3–386.4 g WW m^{-2}) and the lowest in July (mean 419.3–722.8 g WW m^{-2}). In pre-dam the biomass of floating-leaved plants was positively correlated with total suspension ($r = 0.71$; $p = 0.001$) and P-PO_4 ($r = 0.59$; $p = 0.011$) and negatively correlated with dissolved oxygen ($r = -0.83$; $p < 0.001$). In

Table 4. Species structure of macrophytes in pre-dam and dam reservoir Kraśnik during the years 2008–2009

	2008						2009					
	PD			DR			PD			DR		
	May	Jul	Oct	May	Jul	Oct	May	Jul	Oct	May	Jul	Oct
Emergent macrophytes												
Phragmites australis (Cav.) Trin. ex Steud	+	+	+	+	+	+	+	+	+	+	+	+
Typha latifolia L.	+	+	+	+	+	+	+	+	+	+	+	+
Alisma plantago-aquatica L.				+	+	+				+	+	+
Floating-leaved macrophytes												
Lemna minor L.	+	+	+	+	+	+	+	+	+	+	+	+
Polygonum amphibium L.	+	+	+	+	+	+	+	+	+	+	+	+
Potamogeton natans L.				+	+	+				+	+	+
Submerged macrophytes												
Potamogeton filiformis Pers.	+	+	+	+	+	+	+	+	+	+	+	+
Ceratophyllum demersum L.										+	+	+
Chara tomentosa L.				+								
Chara rudis (A. Braun) Leonh.				+								
Chara intermedia A. Braun				+								
Ogółem liczba gatunków	5	5	5	10	7	7	5	5	5	8	8	8

PD – pre-dam, DR – dam reservoir

dam reservoir, the concentrations of chlorophyll-a ($r = 0.53$; $p = 0.026$) and TP ($r = 0.51$; $p = 0.031$) positively affected the biomass of floating-leaved macrophytes, also conductivity showed negative correlation with biomass of these plants ($r = -0.52$; $p = 0.027$).

Submerged macrophytes in pre-dam, in both years, showed the highest biomass in summer (mean 861.3 g and 979.8 g WW m^{-2}) and the lowest in spring (mean 447.8 g and 555.6 g WW m^{-2}). Biomass of submerged plants was negatively correlated with dissolved oxygen ($r = -0.66$; $p = 0.003$) and positively with total suspension ($r = 0.58$; $p = 0.011$) and concentrations of TP ($r = 0.61$; $p = 0.007$) and P-PO_4 ($r = 0.78$; $p < 0.001$). In dam reservoir the highest biomass of elodeids, in both years, was observed in May (mean 2675.9 g and 1841.2 g WW m^{-2}) and the lowest in October (mean 541.8 g and 694.3 g WW m^{-2}). The biomass of submerged plants was positively affected by Secchi disc depth ($r = 0.90$; $p < 0.001$) and conductivity ($r = 0.92$; $p < 0.001$) and negatively by pH ($r = -0.52$; $p = 0.031$), total suspension ($r = -0.54$; $p = 0.021$), concentration of TP ($r = -0.56$; $p = 0.016$), chlorophyll-*a* ($r = -0.59$; $p = 0.019$) and phytoplankton biomass ($r = -0.58$; $p = 0.012$).

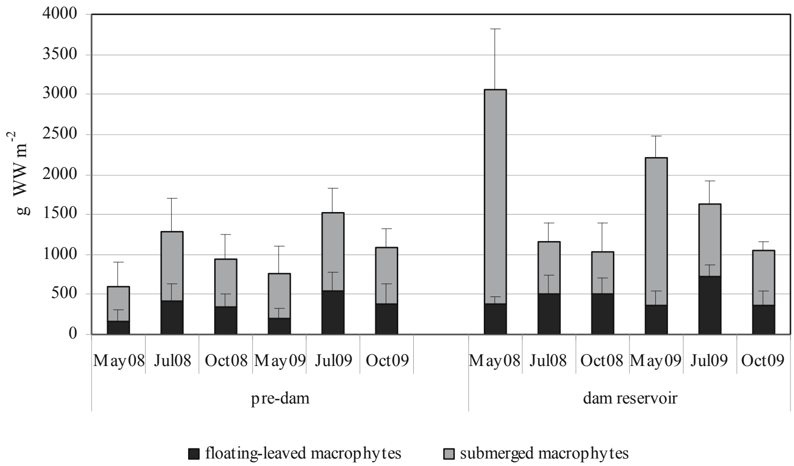

Fig. 5. Biomass (mean values, +SD) of floating-leaved and submerged macrophytes in pre-dam and dam reservoir Kraśnik in studied seasons during the years 2008–2009

Trophic state

Values of Carlsson index calculated for pre-dam and dam reservoirs, for both years and all seasons indicate the eutrophic state of both reservoirs (Table 2). For pre-dam the values of TSI ranged from 50.3 to 59.7 and for dam reservoir, dependently on season, index of Carlsson reached higher values, from 51.4 to 68.2.

The observed changes of TSI index for dam reservoir Kraśnik seem to be related to the share of P-PO_4 in total P loadings. The highest value of Carlsson index, 68.2, was noted in July 2008, at time the highest loading of P-PO_4 (6.03 g m^{-2}) inflow the reservoir and they amounted to 78% of TP loading. The lowest value of TSI, 55.4, was calculated in May 2009, the P-PO_4 loading amounted to 1.82 g m^{-2} and reached 44% of loading of TP.

DISCUSSION

Phosphorous loadings into dam reservoir Kraśnik with the Wyżnica River caused the process of eutrophication of the reservoir and negative changes of species composition and biomass of vegetation.

Studies began at spring 2008, two years after the creation of dam-reservoir, thus low diversity of macrophytes in the reservoir and its pre-dam resulted from initial stage of succession. Usually similar structure of vegetation is observed in newly man-made reservoirs [37]. In dam reservoir, among submerged vegetation characeans were noted. These plants are usually the pioneer community in newly created habitats [39]. However, in July 2008, due to high P loadings (4.5–6.0 g m^{-2} of P-PO_4 and 7.5 g m^{-2} of TP), in dam reservoir there were observed algal blooms (biomass of phytoplankton exceeded 30 mg MM dm^{-3}) and high decrease of water transparency (Secchi disc visibility reached only 0.4 m). At time characean meadows disappeared from the reservoir. Submerged macrophytes responded very quickly to eutrophication process and showed rapid decline of biomass and occurrence of more sensitive species [6, 36]. These relations confirmed significant negative correlations between submerged macrophytes biomass and chlorophyll-a concentration and phytoplankton biomass, as well as a positive correlation of plants biomass with Secchi disc depth. Also, in summer season, rapid development of emergent macrophytes density (form 67 up to 109 stems m^{-2}) was noted in dam reservoir. The community of helophytes was dominated by common reed (*Phragmites australis* (Cav.) Trin. ex Steud.). The intensive growth of emergent macrophytes could be related to vegetation period and to increasing concentration of phosphorous compounds in dam reservoir Kraśnik. This observation confirms positive correlation of helophytes density with concentration of TP. Rooted emergent plants utilize external P loadings during the growing season [20]. *P. australis* is an emergent species, sensitive to the increase of nutrients concentrations in water and shows a visible increase of its biomass and is a good indicator of eutrophication of water ecosystems [12, 24].

In 2009, in dam reservoir Kraśnik rigid hornwort, *Ceratophyllum demersum* L appeared. This unrooted, submerged plant shows ability to uptake dissolved orthophosphates directly from water column and may successfully conquer with phytoplankton [7, 8]. *C. demersum* was presented in all seasons of 2009 and reached the highest biomass (mean above 1600 g WW m^{-2}) in May. Relatively high biomass of rigid hornwort (mean above 700 g WW m^{-2}) was noted in July, despite high biomass of planktonic algae (above 23 mg WW dm^{-3}). Similar results were obtained by Melzer [21], who observed floating mats of *C. demersum* in highly eutrophic lakes.

During two-year studies, a high reduction of P-PO_4 loadings was observed in dam reservoir Kraśnik. The highest retention of dissolved orthophosphates was noted during spring season and amounted to 72% in 2008 and even to 91% in 2009. Usually the highest reduction of P-PO_4 (60–80%) in dam reservoirs is observed in summer [26, 33, 35]. High retention of P-PO_4 observed in May in dam reservoir Kraśnik was probably a consequence of rapid growth of soft vegetation. Due to the production of high biomass, submerged macrophytes, are able to accumulate high amounts of inorganic phosphorous in their tissues [1, 9] and affect the concentrations of phosphorous and chlorophyll-*a* in water column [8].

Trophic state of dam reservoir Kraśnik depended on season and main biological processes of P loadings elimination. During spring season, values of TSI were the lowest, at time P-PO_4 was incorporated mostly into macrophyte biomass and retention of P-PO_4 was the highest. Index of Carlsson raised in summer season, in July 2008, TSI amounted to almost 70, value typical for hypertrophic lakes. At time, due to high P-PO_4 loadings, in dam reservoir Krasnik a massive development of phytoplankton and algal blooms was observed.

CONCLUSIONS

Dam reservoir Kraśnik plays an important role in the reduction of high P loadings in the Wyżnica River, and led to improvement of quality of river waters. Dependently on season, the retention of total phosphorous ranged from 15 to 48% and dissolved orthophosphates from 52 up to 91%. In dam reservoir, a reduction of P-PO_4 loadings is determined by biological processes, phosphorous is incorporated mainly into biomass of macrophytes and planktonic algae. High loadings of P caused eutrophication of dam reservoir Krasnik. Increase of trophic state of reservoir resulted in blooms of planktonic algae and decrease in water transparency. Current loading of P influenced negatively species composition and biomass of macrophytes, mostly sort submerged plants. During two-year studies, the number of submerged macrophytes species was reduced by half and increased biomass of macrophyte species typical for nutrient rich habitats.

REFERENCES

[1] Barko, J.W., & James, W.F. (1998). Effects of submerged aquatic macrophytes on nutrient dynamics, sedimentation and resuspension. *Ecological Studies*, 131, 197–214.

[2] Bernatowicz, S. (1960). Methods of plants studies in lakes. *Rocznik Nauk Rolniczych*, t. 77, B 1, 61–79.

[3] BIPROMEL: Zbiornik retencyjny na rzece Wyżnicy w m-ci Suchynia gm. Kraśnik i miejscowości Kolonia Wyżnianka gm. Dzierzkowice. Projekt instrukcji gospodarowania wodą, Warszawa, 2007.

[4] Bowes, M.J., Smith, J.T., Hilton, J., Sturt, M.M., & Armitage, P.D. (2007). Periphyton biomass response to changing phosphorus concentrations in a nutrient-impacted river: a new methodology for phosphorus target setting. *Canadian Journal of Fisheries and Aquatic Sciences*, 64, 227–238.

[5] Carlson R.E. (1977). A trophic state index for lakes. *Limnology and Oceanography*, 22, 361–369.

[6] Carpenter, S.R., Kitchell, J.F., & Hodgson, J.R. (1985). Cascading trophic interactions and lake productivity. *Bioscience*, 35, 634–639.

[7] Denny P. (1987). Mineral cycling by wetland plants – a review. *Archiv für Hydrobiologie*, 27, 1–25.

[8] Faafeng, B.A., & Mjelde, M. (1998). Clear and turbid waters in shallow Norwegian lakes related to submerged vegetation. *Ecological Studies*, 131, 361–368.

[9] Gao, J., Xiong, Z., Hang, J., Zhang, W., & Mba, F.O. (2009). Phosphorous removal from water of eutrophic Lake Donghu by five submerged macrophytes. *Desalination*, 242, 193–204.

[10] Golterman, H.L. (1969). *Methods for chemical analysis of freshwaters*. IBP Handbook No. 8., Edinburgh: Oxford, Blackwell Scientific Publications, 1–188.

[11] Górniak, A. (2006). *Ekosystem Zbiornika Siemianówka w latach 1994–2004 i jego rekultywacja*. Białystok: Wydawnictwo Uniwersytetu w Białymstoku, 1–236.

[12] Hardej, M., & Ozimek, T. (2002). The effect of sewage sludge flooding on growth and morphometric parameters of Phragmites australis (Cav.) Trin. ex Steudel. *Ecological Engineering*, 18, 343–350.

[13] Jachniak E. (2011). Ładunki związków biogennych a stopień eutrofizacji zbiornika zaporowego Kozłowa Góra. *Nauka Przyroda Technologie*, 5, 4–55.

[14] Jarvie, H.P., Neal, C., Williams, R.J., Neal, M., Wickham, H.D., & Hill, L.K. (2002). Phosphorous sources, speciation and dynamics in the lowland River Kennet, UK. *Science of the Total Environment*, 282–283, 175–203.

[15] Jarvie, H.P., Neal, C., & Withers, P.J.A. (2006). Sewage-effluent phosphorus: a greater risk to river eutrophication than agricultural phosphorous? *Science of the Total Environment,* 360, 246–253.

[16] Jensen S. (1977). An objective method for sampling the macrophyte vegetation in lakes. *Vegetatio,* 33, 107–118.

[17] Kłosowski, S., & Kłosowski, G. (2001). *Flora Polski. Rośliny wodne i bagienne*. Warszawa: Multico Press, 1–333.

[18] Lind O.T., & Dávalos-Lind L. (1999). Suspended clay: its role in reservoir productivity. In. *Theoretical Reservoir Ecology and its Applications*. (Eds.) Tundisi, J.G., Straškraba, M., International Institute of Ecology, Brazilian Academy of Sciences and Backhuys Publishers 1999, 85–97.

[19] Lothar P. (2003). Nutrient elimination in pre-dams: results of long term studies. *Hydrobiologia*, 504, 289–295.

[20] Mainstone, Ch. P., & Parr, W. (2002). Phosphorous in rivers – ecology and management. *The Science of the Total Environment*, 282/283, 25–47.

[21] Melzer, A. (1999). Aquatic macrophytes as tools for lake management. *Hydrobiologia,* 395/396, 181–190.

[22] Mjelde, M., & Faafeng, B. (1997). Ceratophyllum, demersum (L.) hampers phytoplankton development in some small Norwegian lakes over a wide range of phosphorous level and geographical latitude. *Freshwater Biology*, 37, 355–365.

[23] Neal, C., Jarvie, H.P., Neal, M., Love, A.J., Hill, L., & Wickham, H. (2005). Water quality of treated sewage effluent in a rural area of the upper Thames Basin, southern England, and the impacts of such effluents on riverine phosphorous concentrations. *Journal of Hydrology*, 304, 103–117.

[24] Obarska-Pempkowiak, H., Ozimek, & T., Haustein, E. (2002). The removal of biogenic compounds and suspended solids in a constructed wetland system. *Polish Journal of Environmental Studies*, 11, 261–266.
[25] Paul, L., Schröter, K., & Labahn, J. (1998). Phosphorous elimination by longitudal subdivision of reservoirs and lakes. *Water Sciences and Technology*, 37, 235–243.
[26] Paul, L. (2003). Nutrient elimination in pre-dams: results of long term studies. *Hydrobiologia*, 504, 289–295.
[27] Pełechaty, M., & Pukacz, A. (2008). *Klucz do oznaczania gatunków ramienic (Characeae) w rzekach i jeziorach*. Warszawa: Biblioteka Monitoringu Środowiska, 1–80.
[28] Peczuła, W., & Suchora, M. (2011). Analiza przyczyn występowania złej jakości wody w zbiorniku retencyjnym w Kraśniku w pierwszych latach jego funkcjonowania. *Przegląd Naukowy – Inżynieria i Kształtowanie Środowiska*, 54, 321–332.
[29] PN-EN 1189: *Jakość wody. Oznaczanie fosforu. Metoda spektrofotometryczna z molibdenianem amonu*, 2000.
[30] Reynolds, C.S., & Davies, P.S. (2001). Sources and bioavailability of phosphorous fractions in freshwaters: a British perspective. *Biological Reviews,* 76, 27–64.
[31] Radwan, S. (2006). *Zalew Zemborzycki. Struktura ekologiczna, antropogeniczne zagrożenia i ochrona*. Lublin: Wydawnictwo Akademii Rolniczej w Lublinie, 1–98.
[32] Rott, E. (1981). Some results from phytoplankton counting intercalibrations. *Swiss Journal of Hydrology.* 43, 34–62.
[33] Ryding, S.O., & Rast, W. (1989). *The control of eutrophication of lakes and reservoirs*. UNESCO, Paris, 1989.
[34] Salvia-Castellvi, M., Dohet A, Vander-Borght P., & Hoffmann L. (2001). Control of the eutrophication of the reservoir of Esch-sur-Sûre (Luxembourg): evaluation of the phosphorus removal by pre-dams. *Hydrobiologia*, 459, 361–371.
[35] Sas H. (1989). *Lake restoration by reduction of nutrient loading: expectations, experiences, extrapolations*. St. Augustin: Academia-Verl. Richarz, 1–497.
[36] Scheffer M. (2001). Alternative attractors of shallow lakes. *The Scientific World*. 1, 254–263.
[37] Solimini, A.G., Ruggiero, A., Bernardyni, V., & Carchini, G. (2003). Temporal pattern of macroinvertebrate diversity and production in a new man made shallow lake. *Hydrobiologia*, 506–509, 373–379.
[38] Stutter, M.I., Demars, B.O.L., & Langan, S.J. (2010). River phosphorus cycling: separating biotic and abiotic uptake during short-term changes in sewage effluent loading. *Water Research*, 44, 4425.
[39] Wade, P.M. (1990). The colonisation of disturbed freshwater habitats by Characeae. *Folia Geobotanica Phytotaxonomica,* 25, 275–278.
[40] Van Nieuwenhuyse, E.E., & Jones, J.R. (1996). Phosphorus-chlorophyll relationship in temperate streams and its variation with stream catchment area. *Canadian Journal of Fisheries and Aquatic Sciences,* 53, 99–105.
[41] Vollenweider, R. (1976). Advances in defining critical loading levels for phosphorous in lake eutrophication. *Mem. Ist. Ital. Idrobiol.*, 33, 53–83.

WPŁYW ŁADUNKÓW FOSFORU NA STRUKTURĘ MAKROFITÓW I STATUS TROFICZNY ZBIORNIKA ZAPOROWEGO NA MAŁEJ RZECE NIZINNEJ

Celem badań była ocena czy ładunki fosforu dopływające z wodami rzeki Wyżnicy mogą mieć istotny wpływ na strukturę makrofitów i status troficzny zbiornika zaporowego w Kraśniku. Badania prowadzono w trzech sezonach, maj, lipiec i październik w latach 2008–2009. Próby pobierano na czterech stanowiskach; stanowisko 1 – wpływ rzeki Wyżnicy do zbiornika wstępnego; stanowisko 2 – zbiornik wstępny; stanowisko 3 – zbiornik zaporowy; stanowisko 4 – odpływ rzeki Wyżnicy ze zbiornika zaporowego. W wodzie oznaczano parametry fizyczne i chemiczne (temperatura, widzialność krążka Secchiego, tlen rozpuszczony, pH, przewodnictwo, zawiesina ogólna, chlorofil-a, fosfor ogólny, fosfor fosforanowy). Ponadto analizowano biomasę fitoplanktonu oraz skład gatunkowy i biomasę makrofitów wynurzonych, zanurzonych i o liściach pływających. Na podstawie stężenia fosforu ogólnego, chlorofilu-*a* oraz widzialności krążka Secchiego obliczono wskaźnik trofii Carlssona (TSI) dla zbiorników zaporowego i wstępnego. Na podstawie średnich przepływów, czasu retencji wody w zbiorniku oraz stężeń fosforu ogólnego i fosforanowego obliczono ładunki (g m^{-2}), które dopływają do zbiornika z wodami rzeki Wyżnicy. Uzyskane wyniki wskazują, że ładunki fosforu dopływające do zbiornika zaporowego oddziałują negatywnie zarówno na strukturę roślinności zbiornika, jak i jego stan troficzny. Naj-

bardziej widoczne zmiany dotyczą składu gatunkowego roślinności miękkiej. W 2008 roku na skutek wysokich ładunków fosforu, zwłaszcza fosforanowego (6.03 g P-PO_4 m^{-2}), ze zbiornika ustąpiły ramienice. W 2009 roku odnotowano występowanie rogatka sztywnego, gatunku typowego dla wód żyznych, posiadającego zdolności wiązania fosforu fosforanowego bezpośrednio z toni wodnej.

Wartości wskaźnika Carlssona ($51.4 \leq TSI \leq 68.2$), wskazują na eutroficzny charakter wód zbiornika Kraśnik. W sezonie letnim zbiornik charakteryzuje się zakwitami glonów (biomasa fitoplanktonu przekracza wówczas 10 mg MM dm^{-3}) oraz małą przezroczystością wody (widzialność krążka Secchiego waha się w granicach 0.4–0.65 m). W zbiorniku zaporowym Kraśnik następuje znaczna redukcja ładunków fosforu, przede wszystkim fosforanowego. W zależności od sezonu, redukcja fosforanowego wahała się w przedziale od 52% (lipiec 2008) aż do 91% (maj 2009). Redukcja ładunku fosforu ogólnego była znacznie niższa, osiągała wartości od 15% (maj 2008) do 48% (lipiec 2009).

www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES OF ENVIRONMENTAL PROTECTION

vol. 39 no. 3 pp. 47 - 59 2013

VERSITA

PL ISSN 2083-4772
DOI: 10.2478/aep-2013-0022

EVALUATION OF SUITABILITY OF *AMARANTHUS CAUDATUS* L. AND *RICINUS COMMUNIS* L. IN PHYTOEXTRACTION OF CADMIUM AND LEAD FROM CONTAMINATED SUBSTRATES

MACIEJ BOSIACKI[1] ,TOMASZ KLEIBER[1], JAKUB KACZMAREK[1]

[1]Department of Plants Nutrition, University of Life Sciences in Poznań,
Zgorzelecka 4, 60-199 Poznań, Poland, e-mail: mbos@up.poznan.pl

Keywords: Phytoextraction, phytoremediation, cadmium, lead, heavy metals, ornamental plants.

Abstract: The phytoextraction is a process that uses living plants for cleaning up the heavy metals from contaminated soil. The cadmium and lead contamination of soils results from the application of sludge or urban composts, fertilizers, pesticides, motorization, metallurgy, and different technological processes. In industrial terrain the content of cadmium and lead in soils has increased in the recent years. This study was undertaken to evaluate the potential of *Amaranthus caudatus* L. 'Atropurpureus' and *Ricinus communis* L. 'Sanguineus Apache' for phytoextraction of cadmium and lead. Two species of ornament plants, i.e. *Amaranthus caudatus* L. 'Atropurpureus' and *Ricinus communis* L. 'Sanguineus Apache', were planted in drainless containers in a substrate artificially polluted with cadmium and lead in order to evaluate their suitability for phytoremediation of soils or substrates contaminated with these metals. Cadmium was applied at increasing rates of 0, 1, 5 and 10 mg $Cd \cdot dm^{-3}$ in the form of cadmium sulfate $3CdSO_4 \cdot 8H_2O$, while lead was used at 0, 100, 500 and 1000 mg $Pb \cdot dm^{-3}$ in the form of lead acetate $(CH_3COO)_2Pb \cdot 3H_2O$. The applied doses of cadmium and lead in the experiment reflected different degrees of soil pollution. After five months of growth it was found that *Amaranthus caudatus* L. accumulated the biggest concentrations of cadmium and lead in leaves and the lowest concentrations in inflorescences. *Ricinus communis* L. accumulated the highest concentrations of cadmium in stems, while the lowest concentrations in inflorescences, whereas the biggest concentration of lead was accumulated in inflorescences and the least lead was accumulated in leaves. The biggest reduction of cadmium and lead concentrations after the completion of the experiment was found in substrates, in which *Amaranthus caudatus* L. was grown. The tested species of ornamental plants may be used in the phytoextraction of cadmium and lead from soils contaminated.

INTRODUCTION

The intensively developing civilization, next to numerous benefits, is also connected with contamination of the environment with heavy metals, including cadmium and lead [17, 21, 29]. The presence of these metals in polluted air, water and soil results in their uptake by plants, animal organisms and humans, causing many adverse effects. Soil contaminated with cadmium and lead becomes a source contaminating in turn all elements of the food chain. Thus for many years effective but cheap methods of purification of soil contaminated with heavy metals have been searched for. An increasing number of studies is being conducted worldwide on the dynamically developing field of bioremediation, such