Teka Kom. Ochr. Kszt. Środ. Przyr. – OL PAN, 2015, 12, 120–127

EFFECTS OF SUBMERGED MACROPHYTES ON THE CONCENTRATIONS OF PHOSPHOROUS AND CHLOROPHYLL A UNDER EXPERIMENTAL CONDITIONS

Monika Tarkowska-Kukuryk, Wojciech Pęczuła, Tomasz Mieczan, Wojciech Płaska, Jacek Rechulicz

Department of Hydrobiology, University of Life Sciences in Lublin
B. Dobrzańskiego str. 37, 20-262 Lublin, monika.kukuryk@up.lublin.pl

Abstract. The role of two submerged macrophyte species (*Ceratophyllum demersum* and *Potamogeton pectinatus*) as biological factor affecting concentrations of P and chlorophyll a concentrations was tested under laboratory conditions. In general, after four weeks exposition, the significant reduction of TP, P-PO_4 and chlorophyll a was observed in all experimental variants (aquaria with *P. pectinatus*, *C. demersum* and *P. pecinatus* + *C. demersum*), but the highest decrease of phosphorous compounds (TP, P-PO_4) was noted in aquarium with *C. demersum*, whereas the highest decline of chlorophyll a concentration (biomass of phytoplankton) was observed in aquarium with *C. demersum* + *P. pectinatus*. Together with the reduction of chemical parameters the biomass of macrophytes as well mean length of plant shoots significantly increases. The highest growth of shoots and biomass showed *C. demersum*.

Key words: macrophytes, shallow lakes, trophic conditions, eutrophication

INTRODUCTION

The distribution and occurrence of macrophyte communities in lake ecosystems are determined by a group of environmental parameters, such as water chemistry [Heegaard *et al*. 2001, Takamura *et al*. 2003], lacustrine topography [Duarte and Kalff 1986], water level fluctuations [Hudon *et al*. 2000] and substrate composition [Power 1996]. Submerged vegetation plays an important role in forming a clear water state in shallow lakes by reducing resuspension of bottom sediments, competing with algae for nutrients and releasing allelopathic substances, toxic for algal growth [Barko and James 1998, Gross *et al*. 2003]. One of the most important way in which macrophytes affect the lake status is their role in nutrients cycling. Due to production of high biomass, aquatic plants have high capacity to accumulation of biogenic compounds [Clarke and Wharton 2001, Abdo and daSilva 2002]. From eutrophication point of view, the most important are inorganic phosphorous compounds, P is considered as major determinant of primary production in lakes, particularly for phytoplankton [Schindler 1977, Kalff 2001]. Thus intensive growth and development of macrophytes may diminish concentration of inorganic phosphorous compounds in lake water, reduce development of phytoplankton and positively affect water transparency and oxygen content [van den Berg *et al*. 1997].

The role of soft vegetation as a "trap" for phosphorous compounds can be used as a tool in restoration of shallow hypertrophic lakes. Most of the lakes are influenced by intensive catchment phosphorous loads that originates from human activities and exceed natural loading by several orders of magnitude [Falkowski *et al*. 2000]. Eutrophication is a human induced factor affecting trophic status of lake ecosystems of Polesie Lubelskie region [Kornijów and Radwan 2000, Smal *et al*. 2005]. Intensive external loads of nutrients come from catchments, used mainly for agriculture purpose, animal production and recreational activity and caused deterioration of water quality of many lakes. Highly productive lakes are often characterized by permanent and long lasting cyanobacterial blooms. Thus, there is a need of a complex studies on the relations between phosphorous concentrations with the biomass of macrophytes and phytoplankton in highly eutrophic ecosystems.

In the present study we assume that: 1) introduction of macrophytes to lake water may substantially reduce concentrations of inorganic phosphorous compounds (TP, P-PO_4) and phytoplankton biomass (concentration of chlorophyll a) and 2) decrease of phosphorous in the water is the result of its incorporation into the macrophyte biomass. We test these hypothesis under laboratory experiment.

The aims of the study were: a) to measure control and final concentrations of chlorophyll a, TP and P-PO_4; b) to determine the growth of plant shoots and their biomass after four weeks exposition; c) to evaluate the relations between macrophytes and studied chemical parameters.

STUDY AREA, MATERIAL AND METHODS

Experiment was conducted under laboratory conditions. For the purpose of the study we used glass aquaria (20 cm × 24 cm × 40 cm) and two species of submerged macrophytes, rigid hornwort (*Ceratophyllum demersum* L.) and sago pondweed (*Potamogeton pectinatus* L.). Both macrophytes were successfully used in constructed wetlands and wastewater treatment experiments. Plant shoots as well the water for experiment were taken from highly eutrophic Lake Krzczeń (Łęczyńsko-Włodawskie Lakeland). The aquaria were prepared in three variants: 1) *Ceratophyllum* (CER) – 10 shoots, 2) *Ceratophyllum* (5 shoots) + *Potamogeton* (5 shoots) (CER + POT) and 3) *Potamogeton* (POT) – 10 shoots; each variant was prepared in three replicates to enable statistical analysis of the data. At the beginning of experiment all plant shoots were gently washed under tap water to remove periphyton, measured and weighted. Next were put into aquaria filled with water. To provide similar conditions prevailing in the lake (light conditions, water movement) aquaria were aerated using a standard pump and illuminated using fluorescent lamps. Concentrations of total phosphorous (TP) and P-PO_4 were determined at the laboratory, using spectrophotometric methods according Hermanowicz *et al*. [1999]. The concentration of chlorophyll a was analyzed by spectrophotometric method following a 24-h extraction with 90% acetone in the dark [Golterman 1969]. The analysis was made in 1 day, 14 day and 28 day of experiment. All the plants shoots were measured and weighted at the same days as the concentrations of chemical parameters.

The influence of time, macrophyte species and biomass on the concentration of phosphorous and chlorophyll *a* were verified using repeated measures ANOVA. Test of Shapiro-Wilk was used to compare significant ($P < 0.05$) differences between means. The analysis was performed by means of Statistica 7.0 Software.

RESULTS AND DISCUSSION

During the experiment we observed positive influence of macrophyte species on the concentrations of phosphorous compounds as well chlorophyll a in all variants (Fig. 1, 2, 3). High control concentrations of all the studied parameters, typical for eutrophic lakes, showed significantly lower values in 28 day of experiment (ANOVA, Table 1). This observation confirm the role of time and macrophyte species as determinants of phosphorous and chlorophyll *a* concentrations in lake water which has been previously stressed by the other studies [Rorslett 1991, Rooney and Kalff 2003, Shilla *et al*. 2006]. Total phosphorous showed the decrease from the concentration of 231 µg dm^{-3} (control) to the 74 µg dm^{-3} (28 day, CER+POT aquaria). The lowest final P-PO_4 concentration, 27 µg dm^{-3}, was noted in POT aquarium, in comparison to the control concentration of 54 µg dm^{-3}. The concentrations of chlorophyll a showed the highest decrease from 154.75 µg dm^{-3} in control to 3.27 µg dm^{-3} in CER+POT aquaria.

Macrophyte biomass and mean length of plant shoots changed significantly during the experiment (Table 1). The total biomass of macrophytes increased from 37.5 g WW to 78.4 g WW and depended on the type of aquarium (Fig. 4). The highest growth of plant biomass was noted in CER aquaria. It can be concluded that the decline of P-PO_4 in these aquaria caused its incorporation into plant biomass. *Ceratophyllum demersum* is an unrooted submerged macrophyte species, which required nutrient uptake from the water and may successfully compete with phytoplankton for nutrients [Denny 1987, Mjelde and Faafeng 1997]. The mean length of plant shoots increased in all variants, the highest significant differences between control and final results were observed in CER aquaria (Fig. 5).

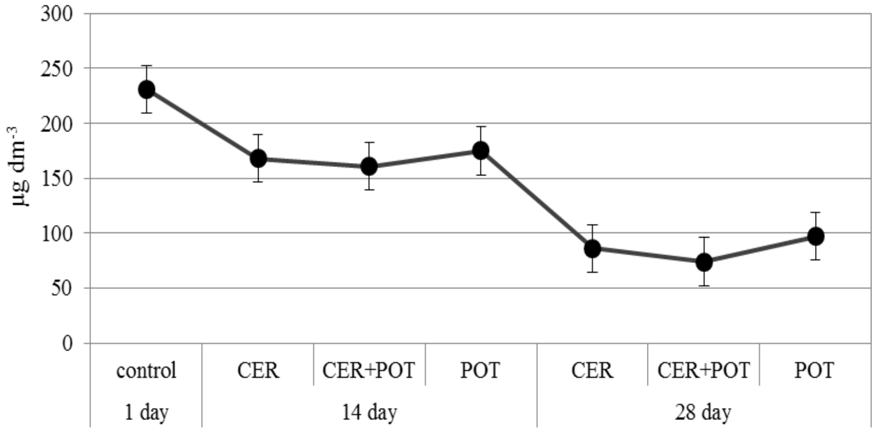

Fig. 1. Mean concentrations of TP (±SE) in aquaria during the experiment. CER – aquaria with *Ceratophyllum demersum*, POT – aquaria with *Potamogeton pectinatus*, CER+POT – aquaria with *C. demersum* and *P. pectinatus*

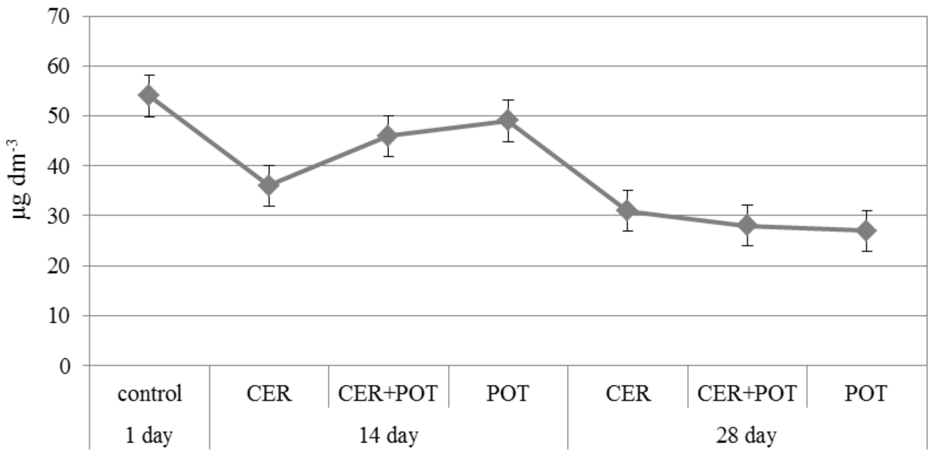

Fig. 2. Mean concentrations of P-PO_4 (±SE) in aquaria during the experiment. Abbreviations as on Fig. 1

In these aquaria mean length of *C. demersum* shoots increased from 19.1 cm (control) to 35.6 cm (28 day). The slowest growth of shoots was observed in POT aquaria, mean length of *P. pectinatus* shoots raised from 14.4 cm (control) to 22.6 cm (28 day). These results, similarly to the studies of Gao *et al*. [2009] and Wang *et al*. [2008] confirm high efficiency of *C. demersum* to phosphorous removal from water.

Studies showed that submerged macrophytes (*C. demersum*, *P. pectinatus*) have positive effect on the trophic conditions of lake water, although clearly better results were obtained in implementing *C. demersum* alone. Both macrophyte

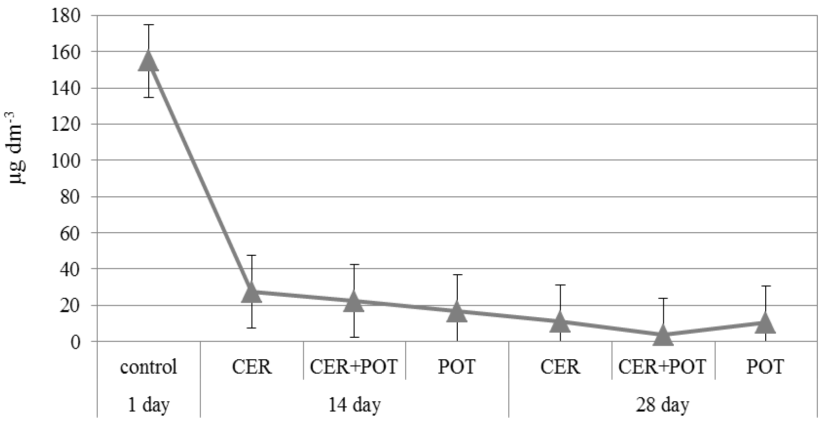

Fig. 3. Mean concentrations of chlorophyll *a* (±SE) in aquaria during the experiment. Abbreviations as on Fig. 1

Table 1. Results of repeated measures RM ANOVA on concentrations of TP, P-PO_4 and chlorophyll a testing for the effect of time (days of exposition) and macrophyte (biomass, species) (n = 27)

Specification		df	SS	MS	*F*	*P*
TP	time	2	0.092	0.046	7.94	<0.001**
	macrophyte biomass	2	0.007	0.009	103.02	0.003*
	macrophyte species	2	0.46	0.003	74.31	0.045*
P-PO_4	time	2	0.003	0.002	125.13	<0.001**
	macrophyte biomass	2	0.006	0.004	2.54	0.101
	macrophyte species	2	0.044	0.037	35.43	0.006*
Chlorophyll a	time	2	1168.54	584.3	27.85	<0.001**
	macrophyte biomass	2	104.8	52.4	719.1	0.007*
	macrophyte species	2	178.7	48.1	12.7	0.011*
Macrophyte biomass	time	2	76.87	38.44	12.91	<0.001**
Length of shoots	time	2	1577.82	788.91	9.59	0.005*

*significant at $P < 0.05$
**significant at $P < 0.01$

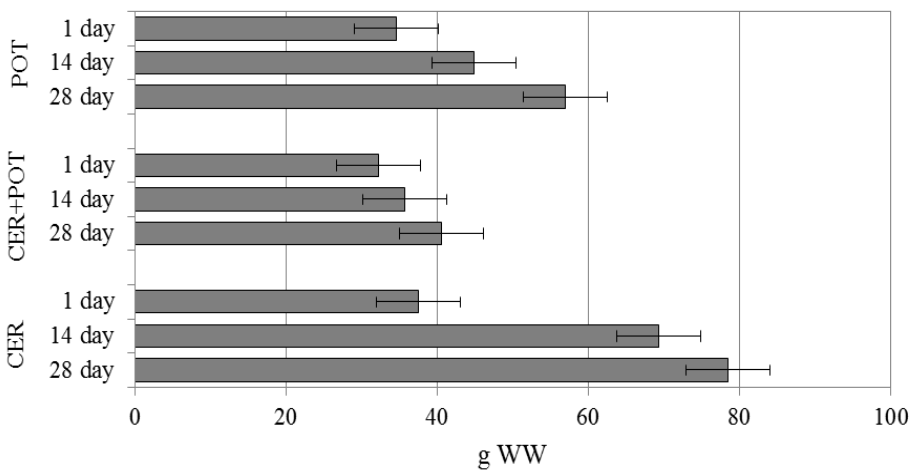

Fig. 4. Changes of mean biomass (±SE) of studied macrophyte species in experimental aquaria. Abbreviations as on Fig. 1

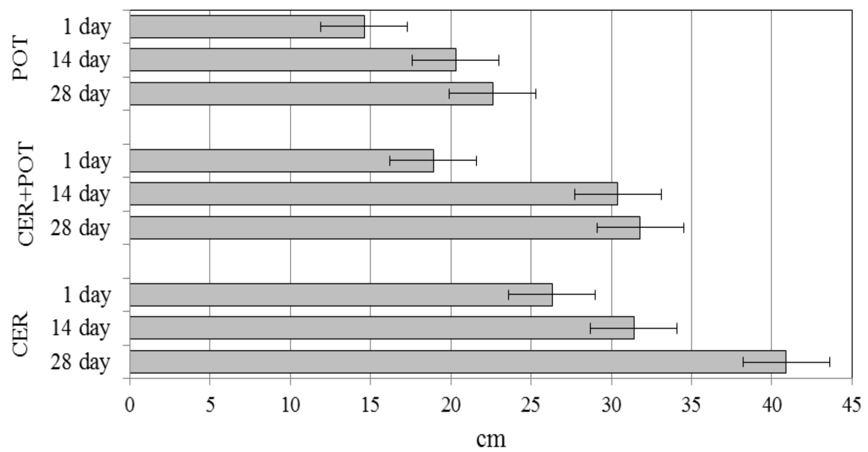

Fig. 5. Mean lenght (±SE) of shoots of studied macrophyte species in experimental aquaria. Abbreviations as on Fig. 1

species positively affect conditions for primary production in water; visibly reduce concentrations of chlorophyll a (biomass of phytoplankton), TP and P-PO_4. Studied macrophyte species can be tested in the field and implemented under hypertrophic conditions within restoration of lake ecosystems.

REFERENCES

Abdo M.S.A., Da Silva C.J., 2002. Nutrient stock in the aquatic macrophytes *Eichhornia crassipes* and *Pistia stratiotes* in the Pantanal, Brazil, in: Lieberei R., Bianchi H.K., Boehm V., Reisdorff C. (eds.), Neotropical ecosystems. Proceedings of the German-Brazilian Workshop, Hamburg 2000, GKSS-Geesthacht, 875–880.

Barko J.W., James W.F., 1998. Effects of submerged aquatic macrophytes on nutrient dynamics, sedimentation and resuspension. Ecol. Stud. 131, 197–214.

Clarke J.S., Wharton G., 2001. Sediment nutrient characteristic and aquatic macrophytes in lowland English rivers. Sci. Total Environ. 266, 103–112.

Denny P., 1987. Mineral cycling by wetland plants – a review. Arch. Hydrobiol. 27, 1–25.

Duarte C.M., Kalff J., 1986. Littoral slope as a predictor of the maximum biomass of submerged macrophyte communities. Limnol. Oceanog. 31, 1072–1080.

Falkowski P., Scholes R.J., Boyle E., Canadell J., Canfield D., Elser J., 2000. The global carbon cycle: a test of our knowledge of earth as a system. Science 290, 291–296.

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.

Golterman H.L., 1969. Methods for chemical analysis of freshwaters. IBP Handbook No. 8, Blackwell Scientific Publications, Oxford–Edinburgh.

Gross E.M., Erhard D., Ivanyi E., 2003. Allelopathic activity of *Ceratophyllum demersum* L. and *Najas marina* ssp. *intermedia* (Wolfgang) Casper. Hydrobiologia 506–509, 583–589.

Heegaard E., Birks H.H., Gibson C.E., Smith S.J., Wolfe-Murphy S., 2001. Species-environmental relationships of aquatic macrophytes in Northern Ireland. Aquat. Bot. 70, 175–223.

Hermanowicz W., Dojlido J., Dożańska W., Kosiorowski B., Zerbe J., 1999. Fizyczno-chemiczne badanie wody i ścieków. Wyd. Arkady, Warszawa, ss. 556.

Hudon C., Lalonde S., Gagnon P., 2000. Ranking the effects of site exposure, plant growth form, water depth, and transparency on aquatic plant biomass. Can. J. Fish. Aquat. Sci. 57: 31–42.

Kalff J., 2001. Limnology. Upper Saddle River (NJ): Prentice Hall, pp. 592.

Kornijów R., Radwan S., 2002. Zasady zrównoważonego użytkowania i ochrony jezior położonych na obszarach wiejskich, w: Radwan S. (red.), Problemy ochrony i użytkowania obszarów wiejskich o dużych walorach przyrodniczych. Wyd. UMCS, Lublin, 63–70.

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 Biol. 37, 355–365.

Power P. 1996. Effects of current velocity and substrate composition on growth of Texas wildrice (*Zizania tezana*). Aquat. Bot. 55, 199–204.

Rooney N., Kalff J., 2003. Submerged macrophyte-bed effects on water-column phosphorous, chlorophyll *a*, and bacterial production. Ecosystems 6, 797–807.

Rorslett B., 1991. Principal determinants of aquatic macrophyte richness in northern European lakes. Aquat. Bot. 39, 173–193.

Schindler D.W., 1977. Evolution of phosphorous limitation in lakes. Science 195, 260–262.

Shilla D.A., Asaeda T., Kian S., Lalith R., Manatunge J., 2006. Phosphorous concentration in sediment, water and tissues of three submerged macrophytes of Myall Lake, Australia. Wetlands Ecol. Manage. 14, 549–558.

Smal H., Kornijów R., Ligęza S., 2005. The effect of catchment on water quality and eutrophication risk of five shallow lakes (Polesie Region, Eastern Poland). Pol. J. Ecol. 53, 313–327.

Takamura N., Kadono Y., Fukushima M., Nakagawa M., Kim B.H.O., 2003. Effects of aquatic macrophytes on water quality and phytoplankton communities in shallow lakes. Ecol. Res. 18, 381–395.

Van den Berg M.S., Coops S., Meijer M.L., Scheffer M., 1997. Clear water associated with a dense *Chara* vegetation in the shallow and turbid Lake Veluwemeer, The Netherlands, in: Jeppesen E.,

Sondrergaard Ma., Sondergaard Mo., Christoffersen K. (eds.), The structuring role of submerged macrophytes in lakes. Ecological studies. Springer-Verlag, New York, 339–352.
Wang Ch., Yan X., Wang P., Chen Ch., 2008. Interactive influence of N and P on their uptake by four different hydrophytes. Afric. J. Biotechnol. 19, 3480–3486.

WPŁYW MAKROFITÓW ZANURZONYCH NA STĘŻENIA FOSFORU I CHLOROFILU A W WARUNKACH EKSPERYMENTALNYCH

Streszczenie. W warunkach laboratoryjnych analizowano wpływ dwóch gatunków makrofitów zanurzonych (*Ceratophyllum demersum* oraz *Potamogeton pectinatus*) na stężenia nieorganicznych form fosforu i chlorofilu a w wodzie jeziornej. Po czterech tygodniach ekspozycji zaobserwowano istotny spadek stężenia fosforu ogólnego, fosforanowego oraz chlorofilu a we wszystkich wariantach eksperymentu (akwaria z *C. demersum*, *P. pectinatus* oraz *C. demersum* + *P. pectinatus*). Największy spadek nieorganicznych form fosforu odnotowano w akwariach z rogatkiem sztywnym, podczas gdy największy spadek chlorofilu a (wskaźnika biomasy fitoplanktonu) obserwowano w akwariach, w których umieszczono dwa gatunki makrofitów, rogatka sztywnego i rdestnicę grzebieniastą. Podczas trwania eksperymentu odnotowano również istotny wzrost biomasy makrofitów oraz średniej długości pędów roślin. Największe istotne zmiany dotyczyły *C. demersum*.

Słowa kluczowe: makrofity, płytkie jeziora, eutrofizacja