EKOLOGIJA. 2007. No. 53. No. 2. P. 51–55

Lake Žuvintas water quality analysis employing PCLake model

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Since 1937, the reservation regime has been established in Lake Žuvintas. Nevertheless the basin of the lake was reorganized for the requirements of agriculture and fishing industry. The reorganization of the basin and natural processes have resulted in an even more intensive eutrophication and overgrowth of the lake by submerged vegetation. The objective of the present study was to estimate the impact of hydrological regime and nutrient load on the water quality and ecosystem structure of the lake. The shallow, not stratified lake eutrophication model PCLake was used. The model suggests that the best measure to increase Lake Žuvintas water quality and to stop its overgrowth is to reduce pollution by nutrients and stabilize the water level. The lower nutrient load stabilizes the amount of submerged vegetation and results in lower concentrations of nitrogen and phosphorus in the lake water and in the top layer of sediments.

Key words: eutrophication, water quality, modeling

INTRODUCTION

The reservation regime in Lake Žuvintas and surrounding wetland was established in 1937. After some years of intensive monitoring, very rapid changes of morphometric parameters were noticed. The area and depth of the lake decreased and an intensive process of eutrophication was observed.

The area of Lake Žuvintas decreased by about 0.2 ha per year in the period 1934–1960. The decrease was caused by overgrowth with microphytes and by intensive silting. The volume of water decreased almost by half (Bieliukas, Stanaitis, 1962). In the above-mentioned period there were no significant sources of anthropogenic pollution that could increase the eutrophication of the lake. Therefore, the rapid overgrowth and shallowing of the lake were considered as natural evolutional processes (Garunkštis, 1962).

It was considered that bogging up of the lake can be slowed down by water regime regulation. This idea was implemented in the late sixties of the 20th century. The system of sluices was established and water level in lakes Dusia, Simnas and Žuvintas was raised. However, the desirable effect was not achieved. The eutrophication and bogging up of the lake was still intense (Tamošaitis et al., 1986). Almost at the same time the hydrographical network of the Lake Žuvintas basin was reorganized for requirements of agriculture and fishing industry, fishing ponds were established near the Simnas town. The current water quality in the lake is the outcome of a considerable anthropogenic stress and natural processes in the lake ecosystem.

The objective of this study was to estimate the impact of the hydrological regime and nutrient load on the lake's water chemistry and ecosystem structure and to suggest the suitable measures to improve water quality in Lake Žuvintas.

DATA AND METHODS

The PCLake model was used to estimate the effect of hydrological regime and nutrient load on the eutrophication of Lake Žuvintas.

PCLake is the ecological model designed to estimate eutrophication of shallow (non-stratified) lakes (Puijenbroek, 2004). The model calculates such water quality parameters as concentration of nutrient, chlorophyll-a, transparency, the biomass of submerged macrophytes and phytoplankton. It also calculates the distribution and fluxes of the nutrients in water and the top sediment layer.

Dimensions of the lake (mean depth and size), hydrological regime and nutrient load are the main model inputs.

PCLake is a one-dimensional model and does not describe the spatial distribution of water quality parameters, so the surface of Lake Žuvintas was transformed into a rectangular configuration more suitable for the model. The long axis of this rectangular is 5000 m and the short one 1900 m. The average depth of the lake is 1.1 m. The area and volume of the transformed lake is almost equal to the real values – 934.3 ha and 10502 thousand m^3, respectively (Žuvinto..., 1997).

Regular discharge measurements in the Lake Žuvintas basin were made only for a short period (January 1969 – August 1971) and only at one site. For the present study, daily inflow discharges modeled with the SIMGRO model for a period from 01-01-1994 to 01-05-2005 were used (Povilaitis, 2005). Lake water level was also calculated by the SIMGRO model for the same period (Povilaitis, 2005).

Lake Žuvintas is macrophyte-dominant. The predominant family of submerged vegetation is pondweeds. The most common species is shining pondweed (Potamogeton lucens). The module of macrophytes was parameterized according to the characteristics of this species (Janse, Puijenbroek, 1997).

There were not enough data to parameterize food web modules, so the default parameters were left. These default parameters were estimated during a multi-lake study of 20 shallow lakes and represent a "typical shallow" lake (Janse, Liere, 1995).

The main boundary conditions for PCLake are the nutrient loads to the lake. The sampling data do not show the recognizable annual pattern of nutrient concentration in the inflow water, therefore the long-term average was used (Table 1). The constant concentration of nutrients in the inflow was used for the whole period of modelling.

To estimate the impact of hydrological regime on Lake Žuvintas eutrophication, we hypothesised that the water level of the lake could be raised by 0.5 and 1.0 m. and then the average water depth will be 1.6 m and 2.1 m.

Theoretically, it is possible to reduce the concentrations of nutrients to the natural (without anthropogenic influence) level. We made an assumption that the concentration of nutrients in the upper part of the Spernia River (an outflow of Lake Dusia) is close to the natural values. The same concentrations would be found in the Lake Žuvintas inflow Bambena River if there was no pollution by nutrients in the section between lakes Dusia and Žuvintas

In reality, it is impossible to reduce the whole pollution by nutrients in the section Lake Dusia – Lake Žuvintas, so we also made calculations for reduction by 25% and 50% (Table 1).

RESULTS AND DISCUSSION

Model implementation

The national lake water quality monitoring and expedition data were used for model verification. The model suggests that the concentrations of nitrogen are maximum in spring and the minimum late in summer. The measured data mostly define the transition between the maximum and the minimum. Therefore the collected data did not explain the whole possible range of the concentrations (Figs. 1, 2).

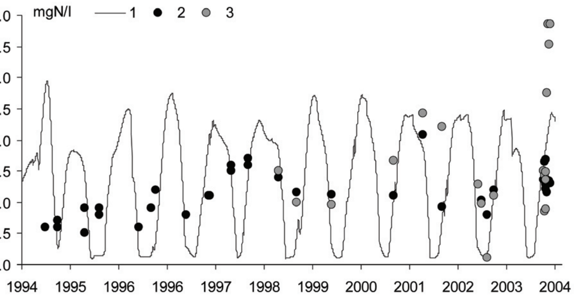

Fig. 1. Total nitrogen concentrations calculated with PCLake and measured in Lake Žuvintas and its outflow Dovinė

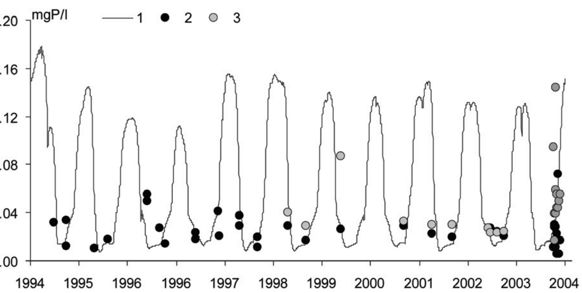

Fig. 2. Total phosphorous concentrations calculated with PCLake and measured in the Lake Žuvintas and its outflow Dovinė

The results of modeling could be more accurate if there were more data on the concentrations of nutrients in the inflow water. The nitrogen and phosphorus load may be overestimated in the inflow water during spring floods, if the concentrations are constant. As a result, the modeled concentration of nutrients in the lake could be higher than real.

The maximum concentrations of nutrients in the lake are highly correlated with the spring flood discharge. When the discharge is greater, phosphorus concentration in the lake is higher (Fig. 3), but the nitrogen concentration is lower (Fig. 4). The opposite relationship between inflow discharge and nutrients is explained by the different proportion of nitrogen and phosphorus in inflow water and in the lake. Phosphorus concentration in inflow water is higher than in the lake. Nitrogen concentration

Table 1. **Measured concentrations of nutrients in the Bambena and the Spernia rivers and estimated concentrations in the Bambena when pollution in Dusia–Žuvintas section is reduced by 25%, 50% and 100%**

Nutrient	$N_{org.}$	NO_3	NH_4	$N_{b.}$	$P_{org.}$	PO_4	$P_{b.}$
	mgN/l				mgP/l		
Bambena (Lake Žuvintas inflow)	1.09	0.24	0.37	1.7	0.07	0.13	0.2
Spernia (Lake Dusia outflow)	0.57	0.05	0.04	0.66	0.03	0.01	0.04
Difference (Bambena – Spernia)	0.53	0.19	0.33	1.04	0.04	0.12	0.16
Pollution reduced by 100%	0.57	0.05	0.04	0.66	0.03	0.01	0.04
Pollution reduced by 50%	0.83	0.15	0.21	1.18	0.05	0.07	0.12
Pollution reduced by 25%	0.96	0.19	0.29	1.44	0.06	0.10	0.16

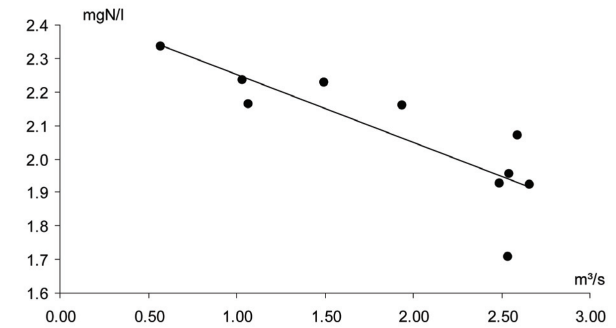

Fig. 3. Relationship between average January–April total phosphorus concentration in the lake and average inflow discharge

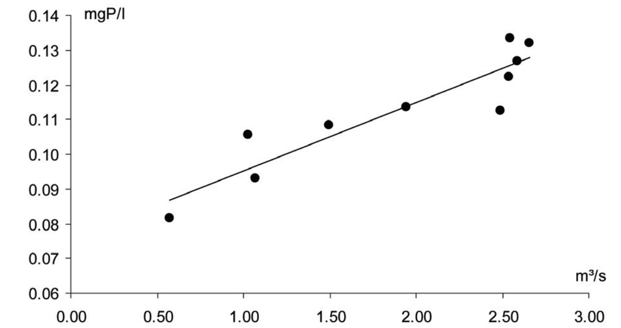

Fig. 4. Relationship between average January–April total nitrogen concentration in the lake and average inflow discharge

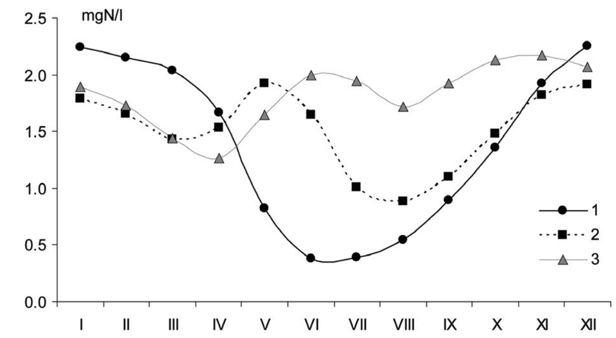

Fig. 5. Total nitrogen concentration in the Lake Žuvintas at different water levels (*1* – water level 1.1 m, *2* – water level 1.6 m, *3* – water level 2.1 m)

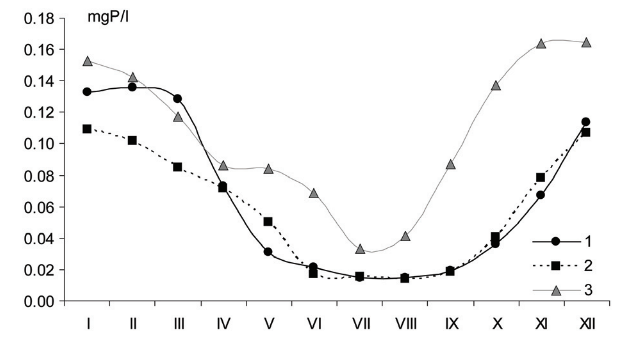

Fig. 6. Dry weight of submerged vegetation at different water levels (*1* – water level 1.1 m, *2* – water level 1.6 m, *3* – water level 2.1 m)

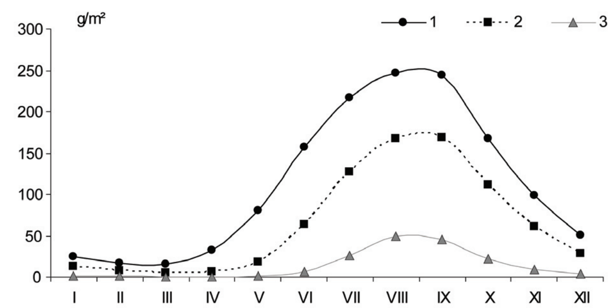

Fig. 7. Dry weight of phytoplankton at different water levels (*1* – water level 1.1 m, *2* – water level 1.6 m, *3* – water level 2.1 m)

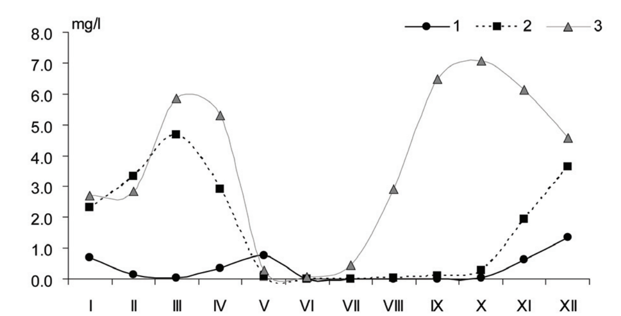

Fig. 8. Total phosphorous concentration in the Lake Žuvintas at different water levels (*1* – water level 1.1 m, *2* – water level 1.6 m, *3* – water level 2.1 m)

in inflow water is lower than in the lake, so the lake water is "diluted" in the case of nitrogen.

Hydrological regime

When the water level is increased, the seasonal variation of nitrogen in the lake water is reduced (Fig. 5). It is mainly caused by the smaller amount of submerged vegetation in the lake. (Fig. 6). Reduction of submerged vegetation is determinated by the increase of water turbidity in the beginning of shoots growing period. Water turbidity is the outcome of large amounts of phytoplankton (Fig. 7). The ecosystem structure of Lake Žuvintas changes with the increase of the average water level. Lake Žuvintas becomes phytoplankton-dominant instead of macrophyte-dominant.

The phosphorus concentration variation differs less than nitrogen, because phosphorus is the growing limiting element and its minimum concentrations are almost the same for all scenarios (Fig. 8).

There are a lot of diatoms in spring when the average water depth is increased by 0.5 m. Diatoms use the dissolved forms of nitrogen and phosphorus and decrease the maximum concentration of these nutrients. The concentrations of nitrogen and phosphorus increase again when diatoms dye (early summer). When the average depth of the lake is increased by 1.0 m, there are lots of phytoplankton in late summer and autumn. When phytoplankton dies, large amounts of organic nitrogen and phosphorus are released into water.

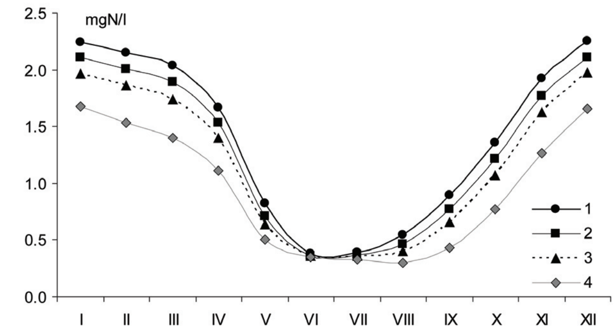

Fig. 9. Total nitrogen concentration in the Lake Žuvintas at different pollution by nutrients (*1* – current conditions, *2* – pollution reduced by 25%, *3* – pollution reduced by 50%, *4* – pollution reduced by 100%)

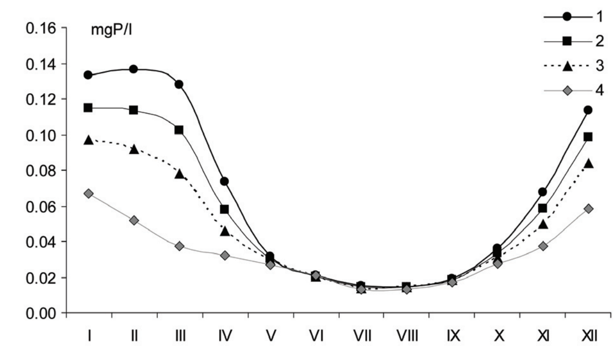

Fig. 10. Total phosphorus concentration in the Lake Žuvintas at different pollution by nutrients (*1* – current conditions, *2* – pollution reduced by 25%, *3* – pollution reduced by 50%, *4* – pollution reduced by 100%)

age of nutrients in the water is compensated by their resources in the sediments.

CONCLUSIONS

The concentration of phosphorus and nitrogen is maximum in December through April and is very closely correlated with the concentration of phosphorus and nitrogen in the inflow water.

The dry weight of submerged vegetation does not decrease significantly with the reduction of nutrient load. When this load is reduced, the nitrogen / dry weight and phosphorus / dry weight ratios decrease, but the amount of vegetation in the lake is almost the same.

It seems that the best measure to improve water quality in Lake Žuvintas is to reduce the pollution by nutrients from the basin and to leave the current (or close to it) water level regime. When the water level of the lake is raised, the amount of submerged vegetation decreases, but the amount of phytoplankton increases. The phytoplankton and submerged vegetation are less sensitive to nutrient load changes when the water level is high. When the pollution is reduced, the amount of submerged vegetation does not change significantly, at least it does not increase.

Table 2. **Change of total nitrogen and phosphorous storage in the top sediment layer when pollution by nutrients in the Dusia–Žuvintas section is reduced by 100%**

Average depth of lake, m	1.1	1.6	2.1
Total nitrogen, %	–7.7	–7.5	–18.4
Total phosphorous, %	–5.8	–2.6	–3.0

Table 3. **Change of concentration in Žuvintas Lake and its inflow when pollution by nutrients in Dusia–Žuvintas section is reduced**

Nutrient	Reduction of pollution, %	Change of concentration, %			
		Inflow	Average depth of lake, m		
			1.1	1.6	2.1
Total nitrogen	100	–60	–34	–29	–23
	50	–30	–16	–15	–11
	25	–15	–8	–7	–5
Total phosphorus	100	–80	–49	–48	–26
	50	–40	–27	–27	–12
	25	–20	–14	–14	–7

The amount of phytoplankton may be overestimated in the cold season, because the PCLake model does not estimate the effect of ice cover to the extinction of the light.

Nutrient load

Reduced pollution by nutrients results in a drop of nutrient concentration in lake water and in the top sediment layer (Tables 2, 3). The difference is largest in winter and early spring when the inflow discharge is the greatest (Figs. 9, 10). The influence of pollution reduction is more significant when the water level is lower, because the volume of the lake is also less.

The amount of submerged vegetation does not change significantly with the reduction of pollution. The main reason is a more intensive exchange of nutrients between the water column and the top sediment layer. The shortage of nutrients in the water is compensated by their resources in the sediments. On the other hand, it results in lower maximum concentrations of nutrients in the lake water and a decrease of nutrient stores in the sediments.

Received
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References

1. Bieliukas K., Stanaitis A. 1962. Žuvinto ežero morfometrinių rodiklių kitimas. *Moksliniai pranešimai. Ežerotyra*. Nr. 14(2). P. 39–62.
2. Bukantis A. 1994. *Lietuvos klimatas*. Vilnius
3. Garunkštis A. 1962. Pagrindinės Dusios, Simno ir Žuvinto ežerų skirtingo užaugimo priežastys. *Moksliniai pranešimai. Ežerotyra*. Nr. 14(2). P. 63–96.

4. Janse J. H., Liere van L. 1995. PCLake: a modelling tool for the evaluation of lake restoration scenarios. *Water Science and Technology*. No. 31(8). P. 371–375.
5. Janse J. H., Puijenbroek van P. J. T. M. 1997. *PCDitch, een model voor eutrofierinf en vegetatie – ontwikkeling in sloten*. RIVM rapport No. 703715004.
6. Povilaitis A. 2005. *Hydrological modeling of the Dovine River basin to evaluate various water management alternatives*. PIN-Matra project ref. No. 2003/040 (final report).
7. Puijenbroek van P. J. T. M., Janse J. H., Knoop J. M. 2004. Integrated modelling for nutrient loading and ecology of lakes in The Netherlands. *Ecological Modelling.* No. 174. P. 127–141.
8. Tamošaitis J., Klimkaitė I., Lasinskas M. 1986. Antropogenizacijos įtaka Žuvinto ežero režimui. *Geografijos metraštis*. Nr. 22–23. P. 167–171.
9. *Žuvinto užtvenkto ežero naudojimo ir priežiūros taisyklės*. 1997. LR Aplinkos apsaugos ministerijos Hidrografinio tinklo tarnyba.

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ŽUVINTO EŽERO VANDENS KOKYBĖS TYRIMAS PCLAKE MODELIU

Santrauka

Nuo 1937 m. Žuvinto ežere buvo įvestas rezervacinis režimas, nors juridiškai rezervatas buvo įteisintas tik 1946 m. Nepaisant ežero rezervacinį statuso, jo baseinas buvo pertvarkomas žemdirbystės, žuvininkystės ir vandens tiekimo Marijampolės miestui poreikiams. Dėl pokyčių ežero baseine ir natūralių procesų Žuvinto ežero eutrofikacija stiprėjo per visą stebėjimų laikotarpį. Viena svarbiausių eutrofikacijos sukeltų problemų yra ežero ploto ir tūrio mažėjimas dėl užaugimo makrofitais. Šio darbo tikslas – PCLake modeliu nustatyti ežero hidrologinio režimo ir azoto bei fosforo prietakos iš baseino poveikį ežero vandens kokybei ir ekosistemos struktūrai. Remiantis gautais modeliavimo rezultatais, galima teigti, kad maksimalios azoto ir fosforo koncentracijos ežere labai priklauso nuo šių elementų prietakos iš baseino. Pakėlus ežero vandens lygį sumažėja makrofitų, tačiau jų vietą užima fitoplanktonas, o ežero vandens skaidrumas labai sumažėja. Panašu, kad geriausias būdas pagerinti Žuvinto ežero vandens kokybę ir pristabdyti ežero užaugimą yra sumažinti azoto ir fosforo prietaką iš baseino, o vandens lygį palikti artimą dabartiniam. Sumažėjus biogeninių medžiagų prietakai, pristabdomas makrofitų plitimas, sumažėja azoto ir fosforo koncentracijos ežero vandenyje bei paviršiniame nuosėdų sluoksnyje, tad ežeras bent iš dalies apsivalo.

Raktažodžiai: eutrofikacija, vandens kokybė, modeliavimas