Trophic state of the Great Masurian Lakes system in the past, present and future – causes, mechanisms and effects of changes

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The study was carried out at a pelagic zone of 17 lakes of the Great Masurian Lake system (GML-system) in North-Eastern Poland. Majority of the lakes are deep dimictic lakes and have a stratified structure during summer months. The GML-system is divided to two areas: the northern part belongs to the Pregoła catchment and the southern to the Pisa catchment. Although the area has been a site of extensive ecological study for many decades, the data has been scattered and scarce.

The main goals of this study were (i) to gather up and review previously scattered existing results and construct a history of the ecological changes, which occurred during years 1990-2008, (ii) to investigate the present ecological state of the system (during years 2009-2011) and (iii) to identify, based on obtained results, the external and internal factors related to the ecosystems’s functioning and to examine the possibility to influence these factors for the purposes of ecosystem management and for controlling risks related to climate change.

Oligotrophication and current trophic status of the GML-system

The southern lakes of the GML-system were highly eutrophic during the 1980’s (average value of Carlson’s trophic state index, TSI was 72). After year 1990 multiple changes in agriculture (such as changes in usage of mineral fertilizers) and improved wastewater treatment led to decrease in the external input of nutrients into the GML-system, allowing the southern lakes of the system to begin oligotrophication (fig. 1). The oligotrophication progressed up to year 2004 in the southern lakes of the GML-system (which decreased the trophic state index to an average of 59). Since 2005 the
progress has stopped. In the northern lakes similar improvement of the trophic state was not observable.

Fig 1. Time series of mean Carlson’s trophic state index (TSI) values in the southern (A) and in the northern lakes (B) from years 1990-2011.

Due to the different development of the TSI between southern and northern lakes, the large gradient of eutrophication from oligo-mesotrophy to hypereutrophy, which used to be characteristic for the lake system, has now nearly disappeared. In year 2010 all lakes were classified as eutrophic, but during years 2009 and 2011 a gradient from mesotrophy to eutrophy was found.

**Factors influencing the present state of the GML-system**

*External and internal nutrient loading*

Main sources of external nutrient inputs in the GML-system are wastewater treatment plants in Giżycko, Ryn and Mikołajki and diffuse inputs from agriculture. Improvements done especially in the plants in Giżycko and Mikołajki have decreased the point source input to the lakes, according to Local Data Bank. Usage of mineral fertilizers decreased sharply after year 1990, but has in the Warmia-Masuria province increased significantly since year 2002 (Local Data Bank). It remains unclear whether decreased inputs from point sources were able to compensate for the recently increased agricultural inputs.

Seasonal means of pelagic total phosphorus concentrations in the southern lakes of the GML-system increased during spring and in August, indicating internal input of phosphorus during the spring overturn and possibly also during the summer stagnation period. In addition, the profundal zone of the southern lakes were regularly hypoxic during summer months, indicating a low redox-potential and a possibility of consequent release of phosphorus from sediments.
Entrainment did not explain how profundal phosphorus reached epilimnetic zone in the deep stratified lakes. Results obtained during present investigations allowed construction of an alternative model and it was found that the distance between the lower border of epilimnetic zone and the higher border of hypoxic water layer had to decrease to below 5 meters before increase in the phosphorus concentration in the epilimnion was observed (fig 2). This critical value of the “oxygenated buffer zone” (OBZ) was found to be a significant factor in regulating internal loading of phosphorus in the GML-system. As the stratification structure of lakes and strength of hypoxia are highly regulated by weather conditions, then consequently also intensity of internal loading can be influenced by weather and thus by climate change in the future.

![Fig 2. Increase in total phosphorus (TP) concentration in limnetic zone on a plane of changing thickness of the oxygenated buffer zone (OBZ) and profundal total phosphorus concentration.](image)

**Nutrient limitation**

The changes in the amounts of external and internal inputs of nutrients have also influenced the ratio between nitrogen and phosphorus concentrations. The obtained results show that in the GML-system the ratio increased significantly when oligotrophication was occurring. This meant that at low trophic states phosphorus limitation prevailed and at higher trophic states nitrogen limitation took over. Additionally, changes from the average ratio took place during several years (for
example in 2010). It was identified that a large decrease in the ratio in 2010 was related to unusually hot weather pattern and the consequent changes in OBZ and internal loading.

In order to estimate which factors influence the biomass of cyanobacteria in the GML-system a forward stepwise multiple regression analysis was utilized. The test entered variables trophic state index, ratio between nitrogen and phosphorus concentrations and algal biomass into the model. The results indicated that both lowering of the trophic status and manipulation of ratio between nitrogen and phosphorus concentrations would be appropriate approaches for limiting harmful cyanobacterial blooms in the future.

Microbial activity

In the GML-system the rate of gross primary production decreased more than the respiration rate on a scale of trophic states from eutrophy towards oligotrophy. This indicates that the functioning of the ecosystem changes with eutrophication; in eutrophic environments primary production rates become dominant over the microbial respiration rates, which causes an accumulation of organic matter. During the current studies were found indications about a decreased ratio of microbially regenerated nitrogen to phosphorus during eutrophication. This could potentially be an important difference in the functioning of oligotrophic and eutrophic aquatic ecosystems, but the results still require verification.

Future of the GML-system

The internal and external inputs are generally predicted to increase with climate change. Consequently, according to the results obtained during the present investigations, the GML-system will be under a pressure of eutrophication even if external nutrient inputs remain at the present level. However, based on obtained results the eutrophic status of the southern lakes was identified as reversible. Reversibility of eutrophic status means that further oligotrophication could be achieved immediately and in proportion to the decrease in phosphorus inputs. Thus, at least in the southern lakes ecosystem management practices such as construction of riparian buffer zones to protect the lakes from diffuse inputs could lead to immediate oligotrophication and improved resistance against impacts caused by climate change.