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# Effects of changing anthropogenic pressures on water quality and plankton dynamics in three Swiss lakes - Long-term simulations with the biogeochemical-ecological lake model BELAMO

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Water quality and plankton dynamics, important indicators for the ecological state of a lake, are affected by many influence factors. To understand the behaviour of a lake under changing driving forces (such as nutrient loads or climatic change), modelling is an important resource. A model used for this purpose should represent the quantitative understanding of the dominant biogeochemical and ecological processes within a lake and be as universal as possible.

With the Biogeochemical Ecologial LAke MOdel (BELAMO) it was tried to combine the description of biogeochemical processes in the lake with an ecological model. The results of its application to the lakes Greifensee (eutrophic), Lake Zurich (mesotrophic) and Walensee (oligotrophic) indicate that already a relatively simple plankton sub-model can lead to a quite high degree of universality (in the sense of applicability of the same model and parameter values to lakes of different trophic state). The box version of the model distinguishes the four mixed compartments epilimnion, hypolimnion and 2 sediment layers. It aims at a joint calculation of mass balances of nutrients, oxygen, organic particles, one group of phytoplankton and one group of zooplankton in a lake in all four compartments. The model was designed to explicitly describe the sediment processes, instead of considering their effect by source and sink terms at the bottom of the lake for substances exchanged between lake water and the sediment.

Therefore the different mineralisation processes had to be quantified. Difficulties compassed the identification of aerobic, anoxic and anaerobic mineralisation rates while representing jointly the measured concentrations of oxygen, nitrate and organic material in the lake. The description of the lake by mixed compartments enhanced this difficulty, because the depth of the sediment layers determines maximal diffusion gradients for the entry of substances into the sediment.
One further problem we had to cope with was the availability of concentration data only. The same concentrations can result from different fluxes that drive the dynamics in the lake. Different concentrations can have quite different sensitivities to external changes. An example for this are phosphate and algae. While the phosphate concentration responds quite fast to a decrease in phosphate input loading, the algae might not show this decrease directly. This is due to the ability of adaptation of the algal community and a parallel reaction of zooplankton. For this reason, the reduced turnover rates of phosphate do not necessarily lead to much smaller plankton concentrations. On a shorter time scale, phytoplankton and zooplankton can show faster variability than can be detected by monthly data. This makes it impossible to get a realistic description of short-term algal dynamics.

To handle this problem when improving the model we conducted parameter calibrations that fit smoothed model results to smoothed data. This calibration technique avoids fitting the model to uncertain data peaks as well as rejecting parameter combinations resulting in model outputs that do not represent individual data peaks, but cover the main patterns of the measurements correctly. This pattern fitting technique led to a much better performance of the fit algorithm than fitting to the original data, which often resulted in simulations that covered some data peaks, but missed the basic annual and long-term pattern.

In the end, long-term simulations for 20-30 years (depending on data availability for the different lakes) showed that good simulations are possible despite significantly changing driving forces. This is an indication of the good mechanistic representation of the processes in the lake. Nevertheless, as this behaviour depends critically on the chosen model parameter values, the predictive power of the model still needs further improvement.