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Editorial: The effects of benthic-pelagic coupling on shallow lake ecosystems: Implications for lake management

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Editorial on the Research Topic
The effects of benthic-pelagic coupling on shallow lake ecosystems: Implications for lake management

Excess nutrient loading due to anthropogenic activities increases nutrient availability and enhances phytoplankton production in pelagic habitats, which may have profound effects on processes in the benthic habitats of shallow lakes as the benthic primary production will decrease due to light intensity reduction, with implications also for the nutrient release from the sediment. Such changes in the benthic-pelagic coupling may result in a shift from a clear-water state dominated by submerged macrophytes to a turbid water state dominated by phytoplankton in shallow lake ecosystems. The aim of this Research Topic is to identify biotic and abiotic feedback mechanisms between pelagic and benthic habitats and their consequences and to discuss the important implications for shallow lake protection and restoration.

Reduction of both external and internal nutrient loading is needed to combat eutrophication and enhance the recovery of culturally eutrophic lakes. The effectiveness of controlling the external loading of nitrogen (N) to manage eutrophication of aquatic ecosystems is currently debated. A mesocosm study conducted in summer showed that N addition increased not only water N levels but also total phosphorus (TP) concentrations, which together elevated the phytoplankton biomass and caused strong dominance of cyanobacteria (He et al.). Addition of N significantly lowered the herbivorous zooplankton to phytoplankton biomass ratio. This study indicates that summer N loading may boost eutrophication *via* both changes in resource and grazing control in shallow lakes, and alleviation of eutrophication in such lakes requires a strategic approach to control both N and phosphorus (P) appropriately (He et al.). In addition to external nutrient loading, internal P loading is usually considered one of the most important factors determining nutrient levels in lake water. The underwater light may promote growth of phytoplankton and benthic algae and thereby increase dissolved oxygen (DO) and pH. DO inhibits P release from the sediment and pH promotes P release from the sediment (Zhang et al.). A 4-week mesocosm experiment revealed no significant difference among treatments with different light intensities in the effects on the accumulative P release flux for the whole study period, although it tended to be higher in the control (no light at the water-sediment interface) than in both the low and the high light treatments (Zhang et al.). Increasing concentrations of dissolved organic carbon (DOC) have been observed in many aquatic ecosystems due to increased human activities. DOC may affect the sediment P release *via* induced changes in DO and alkaline phosphatase (Dong et al.). The effects of DOC on sediment P release was evaluated in a 2-month mesocosm experiment where sodium acetate ($Na(CH_3COO)$) was added as DOC source. The results showed that DOC loading increased the labile P recorded for 7-cm-deep sediment and the flux of P across the sediment–water interface and consequently also the total P concentrations in the overlying water. DOC also stimulated the alkaline phosphatase activity, increased the proportion of P-solubilizing bacteria and decreased the dissolved oxygen concentration, which likely were the primary mechanisms behind the DOC-stimulated sediment P mobilization and release. These results provide insight into DOC promotion of sediment P release. Therefore, an increase in DOC concentrations in aquatic systems due to climate change and human activities may contribute to maintain aquatic ecosystems in a eutrophic state.

Loss of submerged macrophytes is one of the major mechanisms behind the shift from a clear-water state to turbid one in shallow lakes, and the recovery of submerged macrophytes often determines the success of lake restoration, not least in shallow lakes. Low light intensity is one of the main factors limiting macrophyte recovery. A long-term study conducted in the shallow oxbow lake Alte Donau (Austria) showed that sufficient light availability (12% surface ambient light) in benthic habitats rather than minimum light requirement (euphotic depth) triggered the recovery of submerge macrophytes and thus a clear-water state (Teubner et al.). The results of this study also support that macrophytes can act as a significant sink of P at least during the growing season. Moreover, degradation of sediment quality as a habitat for rooted macrophytes due to eutrophication can inhibit the growth of plants and thus delay the recovery of submerged vegetation. He et al. carried out an outdoor experiment and examined how the growth and anchorage of the widespread submerged macrophyte *Myriophyllum spicatum* L. responded to the enrichment of organic matter in the sediments. It was shown that low levels of enrichment with organic matter (≤7%) enhanced the growth of *M. spicatum*. In contrast, high levels of enrichment with organic matter (from 12% to 18%) slightly inhibited its growth. Although the anchorage force of *M. spicatum* slightly decreased with an increase in the content of organic matter in the sediment, it was much higher than the hydraulic drag force on plants at a relatively high current velocity (He et al.). Their study suggests that *M. spicatum* could be a potential species to use in restoration of eutrophic lakes where this species has been lost, since it can grow and anchor well in sediments with relatively high organic matter levels. The results suggest that native macrophyte species that promote sediment stabilization and grow under a range of conditions may be well suited as a restoration tool.

Climate warming can affect shallow ecosystems synergistically with eutrophication. Elevated temperatures might confer the competitive advantage to planktonic algae for light and nutrients over benthic algae and facilitate the development of turbid states in shallow lakes (Mei et al.). In a mesocosm study, Mei et al. found that elevated temperature increased the concentrations of total nitrogen, total phosphorus, and total suspended solids in the overlying water and enhanced the growth of planktonic algae (measured as chlorophyll a, Chl a) but decreased light intensity and benthic algal biomass (Chl a). These results indicate that, in a future warmer world, more efforts are needed (e.g., higher external nutrient loading reduction) to restore eutrophicated shallow lakes.

The transfer efficiencies of nutrients and nutritional chemicals between phytoplankton and zooplankton are important for understanding the structure and function of food webs in shallow lake ecosystems. Fish and zebra mussels may change these transfer efficiencies and thus the ecosystem functioning of lakes. Feniova et al. conducted a mesocosm experiment to determine how fish and zebra mussels altered the transfer efficiencies of essential substances including carbon (C), polyunsaturated fatty acids (PUFAs), total fatty acids (FAs), P, and N from phytoplankton to zooplankton. The study demonstrated that fish increased the transfer efficiencies of eicosapentaenoic acid 20:5 ω-3 (EPA), docosahexaenoic acid 22:6 ω-3 (DHA), and P relative to the control. In contrast, zebra mussels reduced the transfer efficiencies of EPA and DHA relative to the control treatment. However, zebra mussels did not have any impact on the transfer efficiencies of C, total FAs, N, and P. This study suggests that both zooplanktivorous fish and benthic mussels can significantly affect the functioning of pelagic food webs and thus the benthic-pelagic coupling.

The Research Topic of work presented in this Research Topic illustrates that manipulating benthic processes, e.g., by reducing sediment P release, increasing light condition, and enhancing the growth of native submerged macrophytes and mussels, may reduce P concentrations and phytoplankton biomass in the pelagic habitat and, thereby, be effective measures to restore the clear-water state in culturally eutrophic shallow lakes.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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