

Modelling plankton dynamics and community compositions in temperate lakes

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Abstract

Phytoplankton are microscopic, unicellular organisms playing a critical role in regulating water quality and in supporting food webs and ecosystem functions in aquatic environments. Water quality and ecosystem functions are vital to sustaining human societies' daily lives. In recent years, lakes have faced rising pressure from anthropogenic activities and climate warming, and the aquatic communities of some lake ecosystems are reshaping in ways that can form harmful algal blooms. It is crucial to understand how lake phytoplankton communities respond to environmental stressors under varying environmental conditions. The cell size of phytoplankton has multiple important implications for the dynamics, diversity, and productivity of a phytoplankton community. Empirical evidence shows that lake food webs are generally structured by organisms' body size, with predators systematically larger than their prey. The size composition of a phytoplankton community in lakes thus regulates the energy transfer through trophic levels, from phytoplankton to fish. Empirical investigations in lakes showed that the size composition of phytoplankton communities differs with inorganic nutrient conditions, grazing pressure (usually quantified by zooplankton abundance), and water temperature. Previous modelling studies highlighted that the interactions between inorganic nutrient concentrations and grazing pressure govern phytoplankton size structures. Ample evidence showed that the grazing of freshwater zooplankton on phytoplankton is size-selective. However, it is not clear how the size-specific grazing range of zooplankton grazers, composed primarily of specialists (grazing on a narrow range of cell sizes) and generalists (grazing on a wide range of cell sizes), shapes the size composition of lake phytoplankton. Additionally, substantial evidence suggested that water temperature constitutes another key factor in structuring phytoplankton communities with respect to size, but various empirical works showed contrasting results regarding how increasing temperatures impact the size compositions of phytoplankton. The relative contributions of these factors could not be clearly disentangled by observations.

Using size-based plankton modelling, this thesis will elucidate how a trade-off mechanism, originally proposed for marine environments and is dependent on inorganic nutrient availabilities and zooplankton size-specific grazing strategies shapes the dynamics, the size composition, and the exclusion pattern of phytoplankton in a generic temperate lake. In the final part of the thesis, the model will be recast to a specific Swiss

lake, Greifensee, located nearby Zurich, by using high-frequency data comprising phytoplankton cell size (biovolume) and plankton abundances.

The thesis is structured into three main projects. In the first project (Chapter 3), the main result showed that the size composition of phytoplankton is shaped by size-feeding strategies when nutrient levels are high, such that grazer communities dominated by specialist grazers push the phytoplankton community towards smaller sizes; whereas grazer communities dominated by generalist grazers push the phytoplankton community towards larger sizes. When nutrient concentration is low, the phytoplankton community is dominated by small phytoplankton cells, and grazing strategies have little or no impact. In the second project (Chapter 4), the main result showed that phytoplankton exclusion patterns (quantified by the average number of size classes present after a specified time period and the time it takes to exclude 80% of the size classes) are regulated by grazing strategies under high inorganic nutrient regimes. In such regimes, zooplankton communities that are dominated by generalist grazers sustain higher coexistence and longer exclusion time scales of phytoplankton size classes compared to when zooplankton communities are dominated by specialist grazers. Under low inorganic nutrient regimes, the impact of grazing strategies on the exclusion patterns of phytoplankton is negligible. Additionally, the effects of grazing strategies depend on the specific allometric scaling relationships considered in the model. The allometric parameters are thus non-trivial factors when examining phytoplankton competition and community assembly. In the final project (Chapter 5), the main result showed that, as Greifensee warms up, according to future warming scenarios, the nutrient concentrations in the epilimnion increase and promote phytoplankton communities characterized by larger biovolumes. The biomass peak of phytoplankton in early summer also occurs earlier in the spring.

In summary, the work presented in this thesis investigates the interactive effects of inorganic nutrient regimes and zooplankton grazing strategies on the dynamics and size compositions of lake phytoplankton and offers a glimpse into the future size compositions of phytoplankton and nutrient and plankton dynamics of Greifensee. These results not only advance our understanding of plankton communities in temperate lakes, but they also identify hypotheses related to zooplankton grazing strategies that can be further tested with laboratory, mesocosm, or in-situ enclosure experiments. By improving the scientific knowledge at the base of lake functioning, the data-driven modelling approach presented in this thesis can contribute to strategic conservation and management plans for mitigating the effects of ongoing environmental change.