Climate Impact on Phytoplankton Blooms in Shallow Lakes
Data-Based Model Approaches and Model-Guided Data Analyses

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Summary

Lake ecosystems across the globe have responded to climate warming of recent decades and are expected to further change in the future. Anticipating impacts that are detrimental to water quality is critically important given that lakes constitute a major part of the earth's freshwater resources. A central concern is the climate impact on phytoplankton, including algae and cyanobacteria, since it forms the basis of the food chain and decisively influences water quality.

Climate impacts on freshwater phytoplankton are far from clear yet. Correctly attributing observed changes to altered climatic conditions is complicated by multiple anthropogenic influences. Due to successfully implemented measures to contain eutrophication, many lakes have simultaneously experienced increases in water temperature and reductions in nutrient load in the recent past.

With this thesis, I contribute to a better understanding of the climate impacts on phytoplankton in shallow lakes. The results shed light on i) mechanisms underlying warming induces changes in the seasonal timing of the phytoplankton spring bloom (phenology shifts), in particular under varying nutrient availability (trophic state); ii) the risk that climate change disrupts the temporal coupling of predator and prey (zooplankton and phytoplankton) in spring; iii) the question whether summer heat wave events favour nuisance blooms of cyanobacteria; and iv) the influence of seasonal warming patterns on cyanobacteria via effects on thermal stratification and food web interactions.

I also examine two different approaches to model phytoplankton spring phenology and focus on disentangling effects of climate change and nutrient enrichment.

My analyses were, for the most part, based on a long-term data set of physical, chemical and biological variables of Müggelsee, a shallow, polymictic lake in north-eastern Germany, which was subject to a simultaneous change in climate and trophic during the past three decades. To analyse the data, I constructed a dynamic simulation model, implemented a genetic algorithm to parameterize models, and applied statistical techniques of classification tree and time-series analysis.

Results achieved with the dynamic simulation model indicated that the mechanisms driving phytoplankton spring phenology in shallow lakes depend on the trophic state. They also suggested that nutrient enrichment amplifies the temporal advancement of the phytoplankton spring bloom, triggered by high winter and spring temperatures. Also, warming decoupled the phytoplankton from the zooplankton spring peak only under high nutrient supply. However, in contrast to observations in other studies, this temporal predator-prey mismatch did not cause the subsequent decline of the predator.

A novel approach to model phenology, which allows generating analytical prediction, was parameterized based on experimental data. It proved useful to assess the timings of

population peaks of an artificially forced zooplankton-phytoplankton system. Mimicking climate warming by lengthening the growing period advanced algal blooms and consequently also peaks in zooplankton abundance.

Investigating the reasons for the contrasting development of cyanobacteria during two recent summer heat wave events, I found that anomalously hot weather did not always promote cyanobacteria in the nutrient-rich lake studied. The seasonal timing and duration of heat waves determined whether critical thresholds of thermal stratification, decisive for cyanobacterial bloom formation, were crossed.

In addition, the temporal patterns of heat wave events influenced the summer abundance of some zooplankton species, which as predators may serve as a buffer by suppressing phytoplankton bloom formation. Inter-annual differences in water temperature during specific temporal windows explained most of the contrasting responses of two zooplankton subgroups (cyclopoid copepods and bosminids) to recent heat wave events.

In conclusion, this thesis adds to the growing body of evidence that lake ecosystems have strongly responded to climatic changes of recent decades. It reaches beyond many previous studies of climate impacts on lakes by focussing on underlying mechanisms and explicitly considering multiple environmental changes. Key findings show that while nutrients remain the primary agents that determine the magnitude of phytoplankton blooms future climate change may counteract successfully implemented measures to fight lake eutrophication, e.g., by favouring cyanobacteria. They also indicate that climate impacts are more severe in nutrient-rich than in nutrient-poor lakes. Hence, to develop lake management plans for the future, limnologists need to seek a comprehensive, mechanistic understanding of overlapping effects of the multi-faceted human footprint on aquatic ecosystems.