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Spatial heterogeneity in critical nutrient loads of large shallow lakes: implications for Lake Taihu (China)

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Usually, biogeochemical processes in lakes are spatially heterogeneous. In the first place this is caused by internal heterogeneity in lake characteristics. For instance characteristics such as depth, sediment type and fetch may vary largely. Second, spatial heterogeneity in biogeochemical processes is caused by variation in external pressures from the lake's environment. An example of heterogeneity in external pressures are nutrient point sources which are local foci of nutrient input to a lake and thus cause locally higher eutrophication. Due to spatial variation in internal and external factors, primary producers show spatial heterogeneity as well. For instance, phytoplankton blooms can occur frequently in certain parts of a lake whereas they are rare in other parts.
With a novel modelling approach called Spatial Ecosystem Bifurcation Analysis (SEBA), the effect of a changing environmental pressure (e.g. nutrient load) to an ecosystem state (e.g. phytoplankton biomass) can be evaluated spatially. An important aspect of SEBA is that the method accounts for the heterogeneity in internal factors and external pressures. Given a management goal, e.g. the maximum allowable chlorophyll-a concentration, SEBA produces a map showing critical nutrient loads for different locations within a lake. Here we defined the critical nutrient load as the maximum nutrient load that can be absorbed, while remaining in a good ecological state.
In our study we evaluated the spatial heterogeneity in critical nutrient loads for Lake Taihu (China) using SEBA. Lake Taihu (Southeast China) is a large shallow lake with an average depth of 2 m. In its pristine state, nutrient loads per unit area of lake surface were below 0.4 gP/m2/yr and 8 gN/m/2/yr. Macrophytes were established at the shores and in the bays, whereas they were absent in the lake's centre due to strong wind forces. In recent decades, the nutrient load rose above 0.93 gP/m2/yr and 19 gN/m2/yr resulting in excessive phytoplankton blooms that threaten millions of people depending on Taihu. These blooms occur mainly in the north and centre part of the lake, while in the east part macrophytes still flourish.
With SEBA a map of critical nutrient loads for Lake Taihu is produced. This map shows a large spatial variability. Consequently, the response of phytoplankton to changing nutrient loads will be spatially different within the lake. The north and middle part of Lake Taihu showed to be most sensitive to increasing nutrient loads. According to our model, total nutrient loads need to be more than halved to reach chlorophyll-a concentrations of 30-40 mg/L in most sections of the lake. To prevent phytoplankton blooms with 20 mg/L chlorophyll-a throughout Lake Taihu, both phosphorus and nitrogen loads need a nearly 90% reduction. These insights help lake managers in realizing spatially explicit management goals. We envision that our approach can be of great value to determine critical nutrient loads of lake ecosystems such as Lake Taihu and likely of spatially heterogeneous ecosystems in general.