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The Regional Distribution of Nutrient Loading and Hydrology Influence Lake Restoration

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Commentary

Globally, excessive nutrient loading and changes in natural hydrology are degrading the water quality of aquatic ecosystems. Increasing coastal water flow, sediments, and nutrients, for example, contribute to the destruction of coral reefs, while increased nutrient enrichment causes the appearance of hazardous algal blooms in lakes. Human-caused changes to natural hydrology, as well as altered channels for all ochthonous nutrient input, are at the root of this widespread degradation of aquatic ecosystems. Many efforts are made to restore damaged ecosystems by reducing allochthonous nutrient input, such as in coastal regions, as well as addressing water movement, such as by restoring natural hydrology. Unfortunately, rehabilitation of damaged aquatic ecosystems has only been partially effective, and meeting UN Sustainable Development Goals (SDG) such as clean water, as defined in SDG6, remains a challenge. Nutrient loading occurs from both external sources (allochthonous nutrient intake) and from nutrient recycling inside the eco-system (autochthonous nutrient input). There are several sources of allochthonous nutrient inputs, including atmospheric wet and dry deposition, as well as loading via water flows such as groundwater, rivers, and tidal. Furthermore, animal motility, such as fish and bird migration, is an often-overlooked source of nutrition. These diverse allochthonous nutrition input sources are typically classified into two major load types: point and diffuse nutrient sources. Here we define nutrient point sources as local foci of nutrient input into lakes, which include nutrient inputs via rivers or pipelines. We characterised diffuse sources as nutrient input to lakes that is widely spread, resulting in spatially more uniform nutrient intake. Atmospheric nutrient deposition and groundwater seepage are two examples of diffuse nutrient sources. The distinction between point and diffuse sources is that the former enters a lake at a single spot, whilst the latter is geographically distributed throughout the lake. This difference influences the spatial heterogeneity of resource availability within eco-systems, resulting in spatial patterns in the aquatic food web. Hydrology influences nutrient spatial heterogeneity through transport processes. Relatively fast transport rates limit biological nutrient conversion and allow nutrients to spread further. Because of the low transit rates, local nutrient retention is significant, and fewer nutrients are disseminated further in the aquatic ecosystem. The sources of water entering the ecosystem, like the sources of nutrients, might be localised or widely spread, determining the eventual distribution of resources in the water body.

This distinction in hydrological types is often denoted in water by designating them as drain-age and seepage, respectively. To properly understand the biological and physical dynamics of lakes, it is necessary to untangle the many nutrient and hydrology types. According to one study, variations in hydrology and fertiliser intake can have a significant impact on water quality. Furthermore, it was demonstrated that the velocity of water impacts how local regime shifts propagate through aquatic systems. To our knowledge, a complete study that elucidates the influence of different types of nutrient load and hydrology is currently lacking. In this paper, we hypothesise that the efficiency of lake restoration techniques is critically dependent on hitherto underappreciated geographical variability in nutrient availability driven by varying nutrient loading and hydrological types. Importantly, a good restoration technique favours preferred primary producers, such as macrophysics in shallow lakes, over undesirable primary producers, such as cyanobacteria.

Primary producers respond to restoration in a spatially heterogeneous manner. Because primary producers rely on available nutrients, this may be explained by the geographical heterogeneity of re-sources within lakes, which vary for point and diffuse nutrient sources and is influenced by hydrology. Using lake types with differing nutrient loading and hydrology, we used a modelling technique to assess how the success of lake restoration measures is affected by geographic variability in nutrient availability. First, we investigate how spatial patterns in incoming nutrient loading and movement within lakes affect spatial heterogeneity in primary producers and the prevalence of alternative-stable states. Then, in the contrasting lakes, we compare the effect of conventional lake restoration strategies (load reduction, flushing, and bio manipulation). Finally, we provide real-world examples of different lake types to demonstrate the predicted trends and the efficacy of restoration approaches. We show that assessing the loading type and transit of nutrients is critical for planning successful lake ecosystem restoration. We separated point and disperse nutrition sources for allochthonous nutrient load types. We used Lake Hydrology to study nutrient transfer inside the lake.

We classified drainage and seepage lakes as Lake Hydrology categories, which are determined by the type of water intake. Drainage lakes are lakes that receive most of their water from rivers. The primary water flow in drainage lakes with one water inflow point and one outlet will constitute a spatially homogeneous mass flux of water between the inflow and outlet, according to the law of conservation of mass. Seepage lakes, on the other hand, acquire water mostly from dispersed sources such as groundwater and precipitation. As additional water is poured over the whole spatial extent of the lake, the primary water flow in seepage lakes will build up mass flux of water towards the exit. The fundamental difference between drainage and seepage lakes is thus the direction of the main water flow toward the outflow point, which is likely to alter nutrient delivery and distribution. When the two allochthonous nutrient load types are combined with the two hydrology types, four separate lake types result. In the discussion, we will replicate these four lakes using lake types at the extremes of the nutrient and hydrological spectrum, but we will also address the ramifications for lakes that do not fit into these distinct and rigid categories.

Each of these lake kinds is discussed below, along with an example of a real-world lake. These real lakes will be used as examples to demonstrate the horizontal patterns discovered for the four lake types included in our model study. The first form of lake is a drainage lake, which receives nutrients as well as water from allochthonous point sources such as an inflowing river, stream, or ditch. These point-loaded drainage lakes include lowland lakes that are part of a river catchment with nutrient-rich rivers as a result of urban, industrial, and agricultural activities.

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