Asking the Right Questions about Nutrient Control in Aquatic Ecosystems

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Eutrophication remains the greatest stressor affecting freshwater ecosystems across North America and Europe. However, over the past five years, the scientific literature has seen a resurrection of the debate over causes of eutrophication,1,2 with resulting confusion in management circles. This debate has been poorly defined, fractious, and oftentimes counterproductive.

Eutrophication has been defined as the process leading to increased algal productivity in lakes through time. It can be a natural process, as lakes age; or, in the case of cultural eutrophication, it can be facilitated by anthropogenic nutrient inputs. Management concern about eutrophication centers on a change from a desirable—often clear water state, to an undesirable state, exemplified by issues of low hypolimnetic dissolved oxygen, nuisance algal productivity, and in many cases, production of algal toxins. Unfortunately, this may not be a linear change through time, but instead can occur as a state shift or regime change3. More unfortunate, is that although eutrophication is reversible, it can take decades or centuries to induce a shift back from a degraded eutrophic state into a more natural, desirable condition.

It is this state change and associated degradation of key ecosystem services that matters most to stakeholders and policy makers. Rarely are managers concerned about small, incremental changes in productivity that are of significant interest to science (Figure 1, arrow 1), yet these incremental changes, also correctly termed ‘eutrophication’ are where much of the debate appears to derive. The question fundamental to eutrophication control is not “what is the limiting nutrient”, nor is it “can we induce a decrease in algal productivity”, but how can we prevent a state shift into an undesirable state, and how can we push an ecosystem back from a degraded state via nutrient control.

If we subscribe to the assumption that a single nutrient is limiting to primary producers, then control of that nutrient will reduce productivity until productivity becomes limited by some other resource. So, where researchers argue that control of nitrogen (N) will reduce algal productivity, this is often correct in ecosystems like many agriculturally impacted prairie landscapes, where phosphorus (P) is replete. However, it remains to be seen whether N control could induce a shift to a desirable state. Although productivity may be controlled, changes may be small, incremental shifts of little interest to managers (e.g., Figure 1, arrow 3). Indeed, to date, it has not been clearly demonstrated that N addition in freshwaters can induce a change to a highly degraded state. More research on this topic is surely forthcoming, and will help clarify the role of N in eutrophication of inland lakes, and the potential importance of N control in remediating eutrophic systems.

While the case for N in lake eutrophication, and N control in helping induce a shift back to desired conditions has yet to be made in lakes, the case for N control at a landscape or watershed scale is nuanced, but stronger. Our understanding of responses of rivers to different nutrients is even poorer than our ability to understand responses of divergent lake types. Variable light and flow regimes, temperatures, sediment composition, and nutrient delivery make streams and rivers a more complex mosaic of shifting limitation and variable drivers of eutrophication. As in lakes, there is no question that N affects the algal community, and other aspects of the ecosystem, and the effects of N are likely to vary with N species (nitrate, ammonia, or organic N). Nutrient limitation bioassays (admittedly not at the spatial or temporal scale necessary to fully understand the role

Figure 1. Nutrient additions driving shifts from desirable to degraded ecosystem states. Initially, incremental changes (→ 1) minimally impact ecosystem services. This can be followed by a state change to a degraded state (→ 2). The goal of remediation is a state change back to desirable conditions, not incremental improvements (→ 3).

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of limiting nutrients in eutrophication-driven “state changes”, but more suited to understanding incremental changes in productivity) tend to frequently reflect an important role for N in algal growth in streams and rivers.4

Although this may help argue for N control, the strongest argument for N control relates to aquatic ecosystem connectivity. Riverine N that reaches estuaries leads to coastal eutrophication. Nowhere is the need to control N inputs to inland waters more clear than in the Mississippi River basin, where high N inputs associated, for example, with cultivation of corn in the Midwestern U.S., contribute to algal blooms and loss of fisheries hundreds of kilometers downstream in the Gulf of Mexico.

Here, we have a clear-landscape difference that is important to decisions regarding eutrophication control. In lake-rich, postglacial landscapes like much of Canada, not only are distances (travel times) for N to reach the sea very high, leading to a high proportion of N removal via denitrification, but in these lake-rich landscapes, a large proportion of nutrients may be retained via sedimentation in lakes. As a result, these natural buffers can help prevent coastal eutrophication. As such, N control in inland areas of Canada may be less important than in highly connected landscapes where a greater proportion of N reaches sensitive coastal ecosystems. In riverine, lake-poor landscapes common in much of the U.S. and Europe, nutrients are transmitted much more efficiently, making a strong case for N control due to the sensitivity of these downstream coastal zones. P control is also necessary, given evidence that P can induce a state shift to degraded conditions. However, additional ecosystem-scale manipulation of P across geological regions and ecosystem types would be beneficial.

The question of whether N or P should be controlled to manage eutrophication is one that must be viewed within the lens of regional ecology, geology, geomorphology, and management objectives. The question of small incremental increases, or decreases in productivity — as is may be implied by the use of the term “eutrophication” or “eutrophication control” is one of limited interest to managers. Given the high cost of managing both N and P, the question of whether we can stay in (or shift back to) a desired state across all connected aquatic ecosystems, is the most critical consideration in management decisions regarding eutrophication control. Phosphorus control is clearly supported. Nitrogen control, while still debated for poorly connected inland waters, may be just as crucial as phosphorus control where inland waterways are effective conduits of nitrogen to sensitive coastal ecosystems.

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Notes
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