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Preventing Eutrophication: Scientific Support for Dual Nutrient Criteria

Summary

Nutrient pollution resulting from excess nitrogen (N) and phosphorus (P) is a leading cause of degradation of U.S. water quality. The scientific literature provides many examples that illustrate the effects of both N and P on instream and downstream water quality in streams, lakes, estuaries, and coastal systems. Development of numeric nutrient criteria for both N and P can be an effective tool to protect designated uses in the nation's waters. The purpose of this fact sheet is to describe the scientific basis supporting the development of criteria for both N and P to prevent eutrophication and the proliferation of harmful algal blooms.

Background

Nitrogen and phosphorus together support the growth of algae and aquatic plants, which provide food and habitat for fish, shellfish and other organisms that live in water. Excess N and P in aquatic systems can stimulate production of plant (including algae and vascular plants) and microbial biomass, which leads to depletion of dissolved oxygen, reduced transparency, and changes in biotic community composition -- this is called eutrophication [[1]]. In addition to the impacts on aquatic life, excess nutrients can also degrade aesthetics of recreational waters [[2],[3],[4]], and increase the incidence of harmful algal blooms, which may endanger human health through the production of toxins that can contaminate recreational and drinking water resources[[5],[6]].

Under the Clean Water Act, states and authorized tribes are responsible for establishing water quality standards that specify appropriate designated uses, establish criteria to protect those uses, develop anti-degradation policies and implementation methods, and provide for the protection of downstream waters. Numeric nutrient criteria are an important element of water quality standards and are an effective tool for preventing nutrient pollution, for example, in helping to derive numeric limits in discharge permits. Development of numeric nutrient criteria is one aspect of a coordinated and comprehensive approach to nutrient management [[7]]. EPA has published several guidance documents to assist states and authorized tribes in deriving numeric nutrient criteria for both N and P to protect aquatic systems [[8],[9],[10],[11],[12]].

Why develop criteria for both N and P?

Nutrient management efforts have traditionally focused on controlling a single limiting nutrient (i.e., N or P) based on a paradigm that assumes primary production is N-limited in marine waters and P-limited in freshwaters. Conceptually, the assumption is that if the key limiting nutrient is controlled, primary production is limited and the cascading effects of eutrophication do not occur. In practice, however, there are scientific reasons that make this an overly simplistic model for management of nutrient pollution as described below.

Trophic status may vary both spatially and temporally.

The scientific literature demonstrates that nutrient concentrations vary across a landscape as a result of a multitude of factors, including climate, flow, geology, soils, biological processes, and human activities. This variability in concentration means that the relative contribution of and limitation by N and P can change spatially and temporally - even within the same watershed.

There are numerous examples in the scientific literature documenting exceptions to the conventional nutrient limitation theory. For example, N limitation has been shown to occur in lakes with small watershed areas relative to size [[13]], streams have demonstrated temporal and spatial changes in nutrient limitation [14,15], many estuaries show seasonal shifts from P limitation in spring to N limitation in summer [16,17], and co-limitation is commonly observed across freshwater and marine systems [18,19]. Because of the highly variable nature of nutrient limitation in aquatic systems, numeric criteria for both N and P provide the greatest likelihood of protecting aquatic systems.

Aquatic flora and fauna have a diverse set of nutritional needs.

The concept of single nutrient limitation relies on the assumption that at any moment in time the growth of all organisms will be limited by the nutrient in shortest supply. However, the scientific literature demonstrates that aquatic flora and fauna have different nutritional needs. Some species may exhibit N limitation while others show P limitation or co-limitation by both N and P [20, 21, 22, 23,24]. Because of the diversity of nutritional needs amongst organisms, numeric criteria for both N and P are more likely to protect aquatic systems.

N fixation does not fully offset N deficiency.

Arguments for controlling P only in freshwaters have relied on the idea that reductions in N are compensated by cyanobacterial N fixation. It has been suggested that this process undermines N control and serves to maintain P limitation [25]. This theory has also been extended to marine waters [26], yet scientific evidence indicates that N fixation is not able to fully offset N deficiency in either fresh or marine waters [27,28,29,30]. Because N fixation is highly variable across waterbody types, numeric criteria for both N and P are likely to be more effective in protecting aquatic systems.

Both N and P have a role in protecting downstream waters.

Focusing on only the perceived limiting nutrient in upstream waters can enhance export of the uncontrolled nutrient downstream. For example, limiting P in streams can reduce phytoplankton biomass, which, in turn, can make N more available for transport downstream [31]. Waters where N and P concentrations exceed saturation thresholds are particularly vulnerable to becoming nutrient sources [32, 33,34].

Both N and P are important to consider when assessing downstream impacts at any scale (e.g., 10 miles, 100 miles, or 1000 miles from the source). For example, nutrient concentrations in streams may not trigger an adverse effect until some distance downstream where other factors - light, temperature, substrate, or velocity - no longer suppress the response to nutrients [35,36,37,38,39]. Lakes with a nutrient limitation status sufficiently different from that of upstream waters may also be impacted by upstream nutrient loads [40]. Estuarine and coastal waters are especially sensitive to upstream sources given that they are physically, chemically, and biologically distinct from freshwater systems [41,42].

Research in the Northern Gulf of Mexico highlights the importance of considering both N and P when assessing downstream impacts. Increasing N inputs from the Mississippi River into the Gulf of Mexico have been observed to change the trophic status of the Gulf, over time forcing P limitation [43]. In 2007, EPA's Science Advisory Board (SAB) recommended that reduction strategies for both N and P be implemented to protect downstream waters in the Gulf [44,45]. The SAB recommendation has been supported by more recent research demonstrating that reductions of both N and P to the Gulf of Mexico should be implemented to protect aquatic habitat and limit further expansion of the low dissolved oxygen zone [46].

Controlling only P may not effectively prevent the occurrence of harmful algal blooms in freshwaters.

P control has achieved reductions in algal biomass over the last several decades in some waters. However, as explained above, P management may be only half the solution to the eutrophication problem. As sources of N and P have increased and watersheds have built up an ever greater nutrient pool, the role of N control in protecting freshwater resources has become increasingly clear, especially in preventing the occurrence of harmful algal blooms.

Recent scientific evidence has demonstrated that certain harmful algal taxa thrive, and are even potentially more toxic, in conditions where N is disproportionately available relative to P.

Several studies have shown that toxic algae such as cyanobacteria possess unique physiological characteristics that allow them to out compete other species in N-rich/P-poor conditions. They may do this by either utilizing novel forms of available N and P (e.g., urea, particulate or organic P) or substituting other elements for physiological P requirements (e.g., using sulfur instead of P during lipid synthesis) [[47],[48],[49],[50],[51],[52]]. Toxin production has also been shown to increase under conditions of nutrient imbalance [[53],[54]]. Several field and laboratory studies, for example, have found the production of microcystin, a common cyanotoxin that is linked to human illness, to be strongly associated with N concentration [[55],[56],[57],[58]]. More recent analysis of lakes across the U.S. found similarly strong associations between N concentrations and high levels of microcystin [[59]].

Conclusion

Nutrient pollution is a major cause of degradation in U.S. waters. Given the dynamic nature of aquatic systems, the need to protect downstream waters, and the threat of harmful algal blooms, the weight of the scientific evidence supports the development of nutrient criteria for both N and P.

For More Information

Additional information on the development of numeric nutrient criteria is available on our website:

http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/guidance_index.cfm

Contact Brannon Walsh at the EPA Office of Water at 202-566-1118 or walsh.brannon@epa.gov

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