LETTER

Coastal marine eutrophication: Control of both nitrogen and phosphorus is necessary

Whole-lake experiments by Schindler and others since 1971 have conclusively shown that phosphorus is the major cause of eutrophication in freshwater lakes (1). In response, in the 1970s governments began to reduce phosphorus inputs, and water quality in many lakes improved dramatically. However, eutrophication has increased in many coastal marine ecosystems since the 1970s, including the Chesapeake Bay, Long Island Sound, and the Gulf of Mexico "Dead Zone." Why? Nitrogen contributes to eutrophication in these ecosystems, and nitrogen pollution has grown tremendously since the 1970s (2, 3).

Unfortunately, Schindler *et al*. (1) generalize their lake results to estuarine and coastal ecosystems, suggesting that the controls on eutrophication in lakes and coastal waters are the same. If this is true, reducing nitrogen in coastal systems could cause blooms of nitrogen-fixing cyanobacteria, as occurs in many lakes. Substantial research over 2 decades demonstrates that this premise is wrong, and in most estuaries and coastal waters worldwide with salinities exceeding 6–8‰, planktonic, nitrogen-fixing cyanobacteria do not occur because their growth is controlled by factors other than phosphorus supply (2–4). At least 1 of these other controls (grazing) apparently is relaxed in offshore waters such as the Mid-Pacific Gyre in which *Trichodesmium* fixes significant quantities of nitrogen. But the nitrogen fixers are missing from most estuaries and coastal seas.

For decades, governments relied on phosphorus controls alone to solve coastal eutrophication. That experiment failed, and a strong consensus of estuarine and coastal scientists has for more than a decade stated the need to control both nitrogen and phosphorus (2, 3, 5).

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LETTER

Reply to Howarth and Paerl: Is control of both nitrogen and phosphorus necessary?

As we stated in our paper (1), extrapolation of our results to estuaries should be done with caution. In response to Howarth and Paerl (2) we believe that the many similarities between responses of freshwater and estuarine systems that we discuss should not be totally ignored. Controlling nitrogen is a costly process, and we should expect conclusive evidence that it is effective.

Salinity per se does not limit nitrogen fixation. It, and nitrogen-fixing Cyanobacteria such as *Nodularia* are common in highly saline lakes (3, 4). Bacteria (5, 6) and phytobenthos (7, 8) are also known to fix atmospheric nitrogen. Nitrogen-fixing Cyanobacteria are reported from the Adriatic, at salinities near full-strength seawater (8), and N fixation of global significance occurs in tropical and subtropical pelagic oceans (9). If estuaries are not hospitable to nitrogen fixers, it must be for some reason autocorrelated with salinity rather than salinity alone.

Other recent studies indicate deficiencies in our understanding of the marine nitrogen cycle. Estimated denitrification in coastal oceans is double the known input of nitrogen (10). If runoff is measured reasonably well, considerable nitrogen fixation is being missed in marine systems. Recent studies have shown high benthic nitrogen fixation in an eastern estuary, exceeding the sum of inputs from land and the atmosphere (6). Others report similar results (8, 11).

As we discuss, at least one low-salinity estuary, the Stockholm Archipelago, showed greatly reduced abundance of algae in response to reduction of phosphorus inputs. In a recent review of the Baltic Sea (12), we found little evidence to support claims that some of the sites had responded to nitrogen control. The only clear response was in Himmerfjärden, where the diazotroph *Aphanizomenon* increased many-fold in response to reduced inputs of nitrogen, i.e., an undesirable outcome consistent with the Lake 227 experiment. To properly evaluate the ability of an ecosystem to resolve nitrogen deficiencies, whole-ecosystem experiments of several years' duration are necessary. Such experiments are yet to be done in estuaries.

Finally, we note that in many studies the conclusion that nitrogen must be controlled to reduce eutrophication is based on many of the same indicators (dissolved nutrient ratios, short-term bioassays) that gave misleading results in Lake 227 (13). The assumption that nitrogen control will recover coastal waters from eutrophication deserves a second look.

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LETTER

Coastal eutrophication: Whether N and/or P should be abated depends on the dynamic mass balance

Whether nitrogen (N) and/or phosphorus (P) should be abated to counteract coastal eutrophication remains controversial. System-wide lake experiments presented in PNAS have shown that P control was essential for dampening algal blooms whereas N control only strengthened the competitive advantage of cyanobacteria and increased fixation of dissolved N_2 from the atmosphere (1).

We have recently found that P concentrations and fluxes in all basins of the Baltic Sea could be dynamically modeled with good results using a general set of calibration constants and that key operational bioindicators, such as chlorophyll concentration and Secchi depth, may be predicted from modeled P concentrations without taking N loadings into account. N models for this area either provide poor predictions in some basins or require basin-specific calibration, which fundamentally undermines the credibility of their predictions. Many major N fluxes are also highly variable and uncertain (2).

This issue involves high societal stakes. An abatement plan for the Baltic Sea, which will cost $4 billion per year (3), was signed by all Baltic Sea countries in 2007. According to calculations by the Swedish Department of Agriculture, N reductions in the plan cannot be fulfilled unless a large part of Swedish agriculture would be permanently shut down (4). However, upgrading urban sewage treatment of P in the catchment could decrease the trophic state of the Baltic Sea to levels of the years 1900–1920 (2). Conversely, N abatement is a very expensive shot in the dark that may favor cyanobacteria instead of the water quality.

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LETTER

Reply to Bryhn and Håkanson: Models for the Baltic agree with our experiments and observations in lakes

As Bryhn and Håkanson state (1), their mass-balance modeling yields results that agree with our observations (2) based on a long-term lake experiment and a recovery in part of the Baltic resulting from phosphorus control (3). Other recent papers (4) also support our conclusion that phosphorus control deserves a second look in coastal systems, at least those containing brackish water. As the authors (1) point out, control of nitrogen in runoff could be costly enough to cripple agriculture in some areas. We agree with them that until ecosystem-scale evidence is obtained, "N abatement is a very expensive shot in the dark that may favor cyanobacteria instead of the water quality."

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