Moderation of water-column nutrient concentrations by sediment-water exchange in lakes

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Background

Mass balance studies suggest that phytoplankton production in lakes may be subsidized by nutrients released from the sediments. Epilimnetic sediments, which directly underlie the lake's surface mixed layer, are likely to be particularly important in this regard. However, the role of these sediments in epilimnetic nutrient dynamics is not well understood.

Nutrient exchange across the epilimnetic sediment-water interface (SWI) likely is regulated by a zone of laminar flow, the diffusive boundary layer (DBL), located just above the sediment surface. Because mass transfer of solutes through the DBL is governed by molecular diffusion, rates of diffusive interfacial mass transfer should be regulated by the interfacial solute concentration gradient and the DBL thickness. By regulating DBL thickness, turbulence should play an important role in facilitating interfacial solute exchange, but its role in sediment-water nutrient fluxes in lakes has not been well-described.

The goals of this ongoing research are to develop methods to simulate realistic DBL thickness, to evaluate how DBL thickness may influence interfacial nutrient exchange, and to determine whether epilimnetic sediments are capable of moderating water-column nutrient concentrations in lakes.

Study Site

Figure 1. Grand Lake is a deep (Z_{mean} = 41 m), 243-ha oligotrophic glacial lake located on the west slope of the Rocky Mountains in Grand County, Colorado, USA. It is the largest natural lake in Colorado.

Methods

During 2005 and 2006, epilimnetic sediment cores (~20-30cm) were taken from Grand Lake at depths of 2, 4, 5, 7 and 10m. Sediment cores were incubated with turbulence generated by oscillating gridded disks (Orlins and Gulliver 1999) under 30cm water columns of filtered lake water. Cores were incubated with ambient water column concentrations of PO_4^{3-}, NH_4^+, and NO_3^- and with nutrient-amended water columns.

DBL thicknesses were calculated from gypsum dissolution (Santschi *et al*. 1988) and correlated to grid-generated turbulence estimates (Orlins and Gulliver 1999). DBL thicknesses generated in the laboratory-incubated cores were representative of the range of values calculated from gypsum incubation *in-situ* and published estimates (~100 -2500um).

Individual experiments were conducted to establish relationships between sediment-water nutrient exchange and DBL thickness, incubation temperature, and interfacial nutrient concentration gradients.

Results

• Sediment cores from Grand Lake released P, but the magnitude of release did not change significantly with depth and sediment composition. Alternatively, shallow cores were powerful sinks for nitrate and important sources of ammonia. Deeper cores were important sources of nitrate but did not release substantial ammonia (Figure 2).

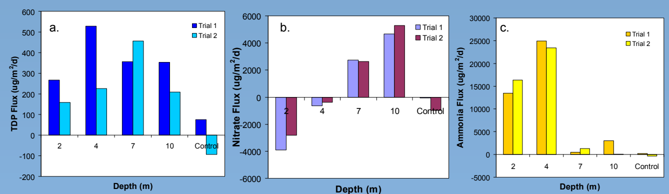

Figure 2. Epilimnetic sediments in Grand Lake released total dissolved P (2a.) when DBL conditions were set to simulate those observed in the lake. Shallow epilimnetic sediments (2 and 4m) sequestered nitrate (2b.) but released substantial quantities of ammonia (2c.) while deeper sediments (7 and 10m) released substantial quantities of nitrate (b.), but ammonia release was low (2c.).

• Within published and observed ranges, the DBL thickness did not substantially influence the net magnitude or direction of nutrient fluxes across the SWI, but turbulence did maintain an oxidized sediment-water interface, preventing nutrient release due to anoxia.

•Within the range of temperatures observed in Grand Lake during summer stratification (8-16°C), no protracted nutrient fluxes were observed when cores were pooled by depth of sampling, but a threshold for release appeared when incubation temperatures were increased to 19°C (Figure 3).

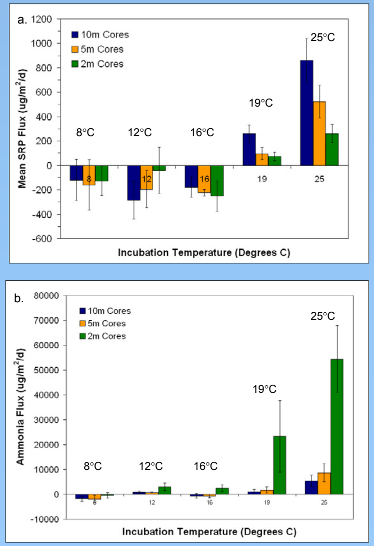

Figure 3. The cumulative mass flux of soluble P (3a.) and ammonia (3b.) increased when temperatures exceeded 19 °C, and increases grew more substantial as incubation temperature reached 25 °C. Average maximum temperature in the Grand Lake epilimnion is 16-17°C.

• When incubated at 12°C with nutrient-amended water-columns, epilimnetic sediments sequestered P and NH_4^+(Figure 4a and b). Only minute fluctuations in water column P were observed when nutrient concentrations in the water-column were near seasonal averages for the lake, and sediments tended to release P when initial water-column nutrient concentrations were below seasonal averages.

•Based upon initial water-column nutrient concentrations, sediments either sequestered or released P until the mass of dissolved P in the water-column approached the seasonal average.

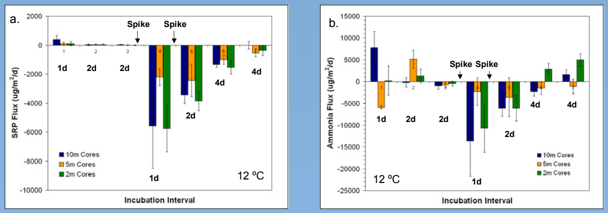

Figure 4. Cores incubated with nutrient-amended water-columns tended to sequester soluble P (4a.) and ammonia (4b.). Declining uptake over time is a function of declining water-column nutrient concentrations and longer intervals across which fluxes were time-averaged.

Implications and Future Directions

Although oxidized lake sediments often have been thought to act as long-term nutrient sinks, our research suggests a more dynamic interaction between nutrient pools in the water-column and in the sediments. During periods of nutrient abundance, epilimnetic sediments may sequester nutrients, potentially restricting the nutrient supply for phytoplankton in the water-column. Conversely, during periods of nutrient scarcity, epilimnetic sediments may release stored nutrients, subsidizing epilimnetic phytoplankton production when nutrients are in critically short supply. Epilimnetic lake sediments may play a more crucial role in the regulation of primary production in lakes than previously expected.

The existence of a temperature threshold for nutrient release from epilimnetic sediments has broad implications for primary production in freshwater lakes. At a temperature not far above the seasonal maximum, this threshold appears to inhibit the role of epilimnetic sediments as a buffer for water-column nutrient fluctuations. Rather, the sediments become sources for both ammonia and phosphorus, with release presumably continuing until a new equilibrium between sediment and water-column nutrient pools is established, thereby increasing epilimnetic productivity. If such thresholds are common and occur at similar temperatures, climate change could have important implications for the trophic status of many nutrient-poor oligotrophic lakes, particularly at high elevations or high latitudes, where temperature increases driven by climate change are likely to be the most dramatic.

Ongoing research goals include:

•Further evaluation of the role of the DBL thickness in sediment-water nutrient dynamics.

•Elucidating the mechanisms contributing to the temperature-mediated threshold of nutrient release.

•Quantifying the magnitude of nutrient sequestration and subsequent release relative to other nutrient sources and sinks for the epilimnion.

References

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