

Physical pathways of nutrient supply in a small, ultraoligotrophic arctic lake during summer stratification

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Abstract

During the ice-free period in the Arctic, the thermal structure and mixing dynamics of small lakes change with the passing of air masses. In Toolik Lake, Alaska, stable warm air masses during the ice-free season were associated with lake warming, daily winds were maximally 4–7 m s⁻¹ for less than 12 h duration, lake numbers (L_N) varied daily between 2 and 80, and values of the coefficient of vertical eddy diffusivity ranged from molecular to 10⁻⁶ m² s⁻¹. For the 3-week warming period following ice-off, vertical mixing, which occurred primarily near the lake's sloping boundaries, supplied inorganic nitrogen only to phytoplankton in the chlorophyll maxima and only at rates sufficient to support 10–22% of their daily needs. In the upper water column, chlorophyll concentrations and primary productivity decreased by a factor of three relative to the maximum at ice-off. In contrast, during transitions between warm and cold air masses or the converse, wind speeds exceeded 5 m s⁻¹ for over 1 d and L_N decreased to values of 3 or lower for periods of 1–2 d. In consequence, turbulence increased by one to two orders of magnitude, dispersing the chlorophyll maximum into multiple layers and increasing solute concentrations in hypolimnetic waters. Increased precipitation accompanied cold air masses, and in one case stream discharge of ~30 times base flow led initially to an overflow and subsequently to a metalimnetic intrusion with loading of inorganic nitrogen 10 times the daily needs of phytoplankton. Overall, the frequency with which frontal systems moved through the region determined the temporal variance in nutrient supply. Spatial variability within the lake was generated by the degree of penetration of incoming streams and the vertical layering of intrusions. These temporal events and the layers induced are hot spots of activity important for sustaining growth in oligotrophic lakes.

Small, dimictic lakes are a major feature of the landscape in the northern temperate zone and the Arctic. Numerous studies have focused on these lakes (e.g., Fee et al. 1992, 1994; Schindler et al. 1996; O'Brien et al. 1997), but few

studies have tried to elucidate and quantify the major pathways for nutrient flux under variable weather conditions. Deciphering these pathways and determining the frequency of events that induce them is critical for understanding a variety of ecosystem processes, such as mixing dynamics and primary production.

A number of pathways have been identified for nutrient and particle transport in lakes (reviewed in MacIntyre and Jellison 2001). For internal pathways, wind-induced vertical mixing across the thermocline has often been assumed to be critical for nutrient flux, but its role varies with development of the internal wave field and gradients in nutrient concentration (Robarts et al. 1998; MacIntyre et al. 1999; MacIntyre and Jellison 2001). Tracer experiments (Quay et al. 1980) and calculated fluxes (Fee et al. 1994) in small, stratified lakes show the coefficient of vertical eddy diffusivity K_z within the thermocline to be on the order of molecular diffusivity of heat, implying limited flux of nutrients by turbulent mixing. However, in tundra regions, average wind speeds are typically higher than in the

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