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Increasing DOC concentrations in surface waters of boreal lakes and possible consequences for hypolimnetic element cycling

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Natural organic matter (NOM) has received increasing attention within limnology over the past few decades as it influences many aspects of lake physiochemical properties and ecosystem functioning. The chromophoric part of NOM absorbs sunlight and re-emits the energy as heat. This influences the vertical light and heat distribution in lakes, thus modulating the climate regulated thermal regime. Changes in lake water NOM concentrations will likely influence lake thermal structure and possibly the duration of stratification, which may exacerbate hypolimnetic anoxia. The overall aim of this study was to examine if boreal lakes that are affected by rising dissolved organic carbon (DOC) concentrations are experiencing changes in bottom water dissolved oxygen (DO) concentrations. As a follow up question, we assessed long-term trends and seasonal patterns in bottom water ammonia (NH4-N), total phosphorus (TP), silica and DOC concentrations, all of which are hypothesized to be affected by DO status. To this end, monitoring data (1988-2015) from 13 Swedish lakes that are minimally affected by anthropogenic disturbance (other than forestry) were assessed. Surface (0.5 m) and bottom (1 m above sediment level) water chemistry data were evaluated, and long-term trends were determined (Mann-Kendall trend tests). The results showed that surface water (0.5 m) DOC concentrations have significantly increased in 8 lakes. In 6 of these lakes (and in 1 with no change in surface water DOC), yearly median bottom water DO concentrations have significantly decreased over time. Moreover, significant rising trends in bottom water NH4-N concentrations were only observed in the 7 lakes with declining yearly median DO. Rising DOC levels were more prevalent in bottom waters, as bottom water DOC has significantly increased in all but the northernmost study lake. In several lakes, we observed pronounced seasonal peaks in bottom water DOC, without equivalents in the respective surface waters. The pronounced bottom water DOC peaks coincided with drops in DO and subsequent periods of anoxia. Similarly, as DO levels dropped, NH4-N and TP also peaked, further pointing to DO as the main driver of changes in bottom water chemistry. The underlying cause of the peaks in hypolimnetic DOC during periods of anoxia might be reductive dissolution of iron oxides and release of associated organic carbon, as has previously been experimentally demonstrated. Our observations indicate that more frequent or longer durations of hypolimnetic anoxia, possibly caused by stronger or longer thermal stratification associated with a warmer climate and / or increasing surface water DOC concentrations may result in less efficient carbon burial in periodically anoxic northern lakes. The hypothesized positive feedback between increased inputs of terrestrial NOM and the consequent increased internal loading of lake sediment derived organic matter, phosphorus and nitrogen needs to be further evaluated. Moreover, the relative quantitative importance of sediment derived material compared to recent inputs from lake catchments needs to be assessed and quantified for improved understanding of coupled element cycling.