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Impact of multiple stressors on carbon cycling in northern lake ecosystems

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Environmental stressors as climate warming, nitrogen (N) deposition and forestry are regarded to have pronounced impact on the function of lake ecosystems. Still, the knowledge of the net effects of these stressors, alone or in combination, on lake ecosystems remains poor, largely due to a paucity of studies integrating all relevant ecosystem processes as well as the difficulties to carry out controlled experimental studies at the scale of whole ecosystems. Here we synthesize data on production of biomass and carbon dioxide (CO_2) from studies of boreal and subarctic lakes in northern Sweden. First, small scale experimental studies show that nutrients (N, phosphorus (P)), light and dissolved organic carbon (DOC) are important factors controlling different metabolic processes but also that these studies are unsatisfactory for our understanding and ability to predict the function of whole lake ecosystem. Then, by comparing whole lake ecosystems along a climate gradient with low N deposition and forestry we show clear changes in physicochemical properties, including concentration of DOC and nutrients. The function of the lake ecosystems show pronounced changes along the gradient with decreasing biomass production and increasing CO_2 production (net heterotrophy) when moving from cold to warm climate. These patterns seem to be mainly related to the export of terrestrial DOC along this gradient, and its effects on both autotrophic and heterotrophic metabolism in benthic and pelagic habitats. Nutrients and temperature, however, seem to play a subordinate role for the major patterns in carbon cycling observed along the gradient. Given expected effects of disturbance caused by N deposition and forestry on the physicochemistry of lake ecosystems, it can be expected that that these stressors may fundamentally alter the carbon cycling of natural systems. The different stressors are likely operate over different temporal and spatial scales in the landscape, emphasizing the need for large-scale and long-term experimental studies and modeling approaches in order to address and understand these expected complex interactions at relevant ecosystem scales.