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Patterns and drivers of carbon cycling in old-growth boreal forests

Hanna Axén

Academic dissertation

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Faculty opponent:
Professor Sebastiaan Luyssaert, Vrije Universiteit Amsterdam, The Netherlands

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Hanna Axén

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Abstract

Old-growth forests, defined by minimal human disturbance, provide natural baselines for understanding forest carbon (C) cycling, especially in the face of climate change. Although boreal forests are important C sinks that mitigate climate change, the climate benefits of old-growth forests remain debated. Declining boreal C sink strength makes understanding the processes sustaining C uptake increasingly urgent. Yet detailed measurements of these processes remain scarce, particularly in old-growth forests, limiting our ability to predict their future C balance.

To address these knowledge gaps, we established a network of 12 boreal old-growth forests spanning a broad climate gradient and varying hydrological conditions, where we measured key C cycling components.

The first study examined stem growth responses to warming and drought. Norway spruce in southern Sweden emerged as vulnerable to both, although wetter conditions buffered growth declines following the major 2018 drought.

The second study quantified belowground C stocks, inputs, and respiratory losses. Unexpectedly low root-associated inputs coincided with comparatively low soil respiration, resulting in a neutral C balance - indicating stable soil C stocks. We link the low soil respiration to cool soil temperatures, possibly maintained by insulating and water-retaining old-growth features such as dense understory vegetation and dead wood. Wetter parts held substantial belowground C stocks and further suppressed respiratory losses.

The third study integrated C fluxes into a budget, to estimate the net ecosystem production as a proxy for C balance. All studied old-growth forests were C sinks, sustained by high tree growth and low soil heterotrophic respiration. Net primary production increased more than respiratory losses across the climate gradient, suggesting that moderate climate warming may strengthen these sinks.

Together, these findings establish boreal old-growth forests as natural baselines that reveal ongoing C sequestration and show how species composition, soil wetness, and forest structure may shape its persistence in a warming climate.

Keywords: Boreal forests, old-growth forests, tree growth, drought, C cycling, C balance, C stocks, C allocation

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