B4WarmED: Experimental warming and rainfall manipulation in a boreal ecotone reveal key responses and adjustments at plant, soil, and ecosystem scales

The B4WarmED experiment examines projected climate change impacts on plant and soil function at the boreal-temperate ecotone. The study includes juveniles of 11 tree species intermixed with native vegetation on 72 plots under two canopy conditions (open, understory) at two sites in northeastern Minnesota. Since 2009, plots received aboveground and belowground warming treatments (ambient, +1.7°C, +3.4°C), and since 2012 half the open plots received ≈45% less than ambient summer rainfall. Results provide insight into climate change impacts on boreal forest and general understanding of critical response functions that can inform earth system models.

Leaf respiration temperature response curves (>1,750) for 10 species had remarkably consistent Q_{10} values across warming treatments, sites, canopies, and seasons. Warming treatments and seasonal variation in temperature both resulted in pronounced acclimation of leaf respiration (responses were nearly homeostatic). Acclimation was greater than reported in prior studies (done mostly in shorter time frames or less realistic conditions). The high temperature tolerance of leaves in warmed treatments was also elevated via acclimation. Across six years, phenological response to warming resulted in a longer growing season, but more so in years with early springs.

Low rainfall had more negative effects on net photosynthesis, plant growth, and survival in warmed than ambient temperatures; suggesting that lower rainfall in a warming world will have increasingly negative impacts. Species responses varied as a function of their thermal histories and water-conductance traits. Boreal species, especially conifers, were consistently more negatively affected by heat, drought, and their combination in terms of photosynthesis, growth and survival, than temperate species. Temperate angiosperms exhibited greater ability to hydraulically acclimate (with wider conduits and greater specific hydraulic conductivity) to increases in temperature than boreal conifers.

Net nitrogen mineralization measured *in situ* across 2012-2013 was significantly higher with warming, but only in open canopy treatment. Surprisingly, warming effects on net nitrogen mineralization were greatest over winter, when the warming treatment was off. From 2009-2013, *in situ* warming increased soil CO_2 flux, but less so in latter years. The long-term temperature sensitivity (Q_{10}) of soil CO_2 flux was decreased by warming *in situ* and by drier soils in lab incubations. Impacts of treatments on ectomycorrhizae, and consequential impacts on plants and biogeochemistry, are a current major focus.

Results indicate mechanisms by which boreal species will likely perform poorly with future warming. They also provide generalized understanding and equations for better modeling of plant and soil carbon cycling processes.

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