Christophe Rouleau-Desrochers

Outline of Proposed Research

Title: Fueling Next Year's Growth of Trees with Carbon and Nitrogen

Context: In temperate and boreal forests, temperature plays a crucial role in setting the boundaries for the seasonal physiological activity. Thus, with rising temperatures from anthropogenic climate change, the climatically possible growing season has lengthened in many ecosystems worldwide by up to 11 days (Körner & Basler, 2010; Menzel & Fabian, 1999). Plants have tracked this through shifts in phenology—the study of recurring life history events—which are expected to continue with increasing temperatures (Wolkovich and al., 2012). In particular, trees have shifted earlier in the spring, and may use this opportunity to fix more carbon and grow more during the current growing season (Keenan and al., 2014; Wang and al., 2020). Trees have also delayed autumn events (e.g., leaf senescence) but the impacts on tree fitness are not well understood. Both extended spring and fall events are likely to affect the next growing season, though this is rarely tested.

Research Question: How do extended growing seasons affect tree growth across different species both immediately (in the same year as the extended season) and in subsequent years?

Hypothesis : I hypothesize that an extension of the growing season could modify a tree's capacity to fill carbon and nitrogen storage pools (Chapin and al., 1990; Lawrence & Melgar, 2018). Trees that use this opportunity by fixing more carbon may experience increased growth in the subsequent growing season (Landhäusser and al., 2012; Martens and al., 2007). Thus, species capable of accumulating nutrients, like nitrogen, after leaf senescence, might exhibit growth increment in the following growing season (Schott and al., 2013).

Objectives: First, I aim to assess the tree species potential to prolong or stretch their activity schedule. Second, I will determine whether trees can absorb nutrients beyond their theoretical growing season. I will also examine if increased carbon storage pools translate into growth increment in the following growing season. Finally, I will investigate potential variations in these responses across deciduous and evergreen tree species, aiming to discern whether different patterns emerge within these distinct groups.

Methodology: To investigate the impact of manipulated spring and autumn temperatures on phenological responses, I will conduct experiments across nine different tree species under controlled conditions. For deciduous trees, I have selected seven species spanning both fast and short-life strategies (e.g., *Alnus rubra*) and slow growth and longer lifespan species (e.g., *Quercus macrocarpa*). Since phenological monitoring is more difficult and trends are less likely to be observed for evergreen trees, only two of the nine species will be conifers (Jönsson and al., 2010). I plan a full factorial experiment of spring and fall warming with two levels each (control/warmed) resulting in four treatments: spring or autumn warming, or both, and a control. To test that responses are not limited by nutrient depletion later in the season, I plan two additional nutrient enrichment treatments (6 total treatments across the whole experiment). For this, I will add liquid nutrients to the treatment trees in regular and warmer autumn temperature treatments. I plan on a minimum of 10 replicates per species, adhering to the standards in tree phenological monitoring, which generally require 5-10 replicates (Siegel, 2009).

Throughout the summer of 2024, I will continuously monitor radial growth using magnetic micro-dendrometers and track phenology every 2-3 days. In fall 2025, after the trees have grown in ambient temperatures for the season, I will assess growth on the individual (total biomass) and the cellular level (number of cells and their characteristics).

Research outreach: Given the widespread impacts of climate change on ecosystems, understanding how forest communities respond to prolonged growing seasons is crucial. Observing the reactions of deciduous and conifer species to extended season and nutrient supplementation may reveal potential benefits for some species and harm for others. These shifts are likely to influence forest stand dynamics across North America.

Bibliography and citations

Chapin, F. S., Schulze, E., & Mooney, H. A. (1990). The Ecology and Economics of Storage in Plants. *Annual Review of Ecology and Systematics*, *21*(1), 423–447. https://doi.org/10.1146/annurev.es.21.110190.002231

Jönsson, A. M., Eklundh, L., Hellström, M., Bärring, L., & Jönsson, P. (2010). Annual changes in MODIS vegetation indices of Swedish coniferous forests in relation to snow dynamics and tree phenology. *Remote Sensing of Environment*, *114*(11), 2719–2730. https://doi.org/10.1016/j.rse.2010.06.005

Keenan, T. F., Gray, J., Friedl, M. A., Toomey, M., Bohrer, G., Hollinger, D. Y., Munger, J. W., O'Keefe, J., Schmid, H. P., Wing, I. S., Yang, B., & Richardson, A. D. (2014). Net carbon uptake has increased through warming-induced changes in temperate forest phenology. *Nature Climate Change*, *4*(7), Article 7. https://doi.org/10.1038/nclimate2253

Körner, C., & Basler, D. (2010). Phenology Under Global Warming. *Science*, *327*(5972), 1461–1462. https://doi.org/10.1126/science.1186473

Landhäusser, S. M., Pinno, B. D., Lieffers, V. J., & Chow, P. S. (2012). Partitioning of carbon allocation to reserves or growth determines future performance of aspen seedlings. *Forest Ecology and Management*, *275*, 43–51. https://doi.org/10.1016/j.foreco.2012.03.010

Lawrence, B. T., & Melgar, J. C. (2018). Variable Fall Climate Influences Nutrient Resorption and Reserve Storage in Young Peach Trees. *Frontiers in Plant Science*, *9*. https://doi.org/doi: 10.3389/fpls.2018.01819.

Martens, L. A., Landhäusser, S. M., & Lieffers, V. J. (2007). First-year growth response of cold-stored, nursery-grown aspen planting stock. *New Forests*, *33*(3), 281–295. https://doi.org/10.1007/s11056-006-9027-2

Menzel, A., & Fabian, P. (1999). Growing season extended in Europe. *Nature*, *397*(6721), Article 6721. https://doi.org/10.1038/17709

Schott, K. M., Pinno, B. D., & Landhäusser, S. M. (2013). Premature shoot growth termination allows nutrient loading of seedlings with an indeterminate growth strategy. *New Forests*, *44*(5), 635–647. https://doi.org/10.1007/s11056-013-9373-9

Siegel, J. A. (2009). Collaborative Decision Making on Climate Change in the Federal Government. *Pace Environmental Law Review*, *27*, 257. https://doi.org/10.58948/0738-6206.1007

Wang, H., Wang, H., Ge, Q., & Dai, J. (2020). The Interactive Effects of Chilling, Photoperiod, and Forcing Temperature on Flowering Phenology of Temperate Woody Plants. *Frontiers in Plant Science*, *11*. https://doi.org/10.3389/fpls.2020.00443

Wolkovich, E. M., Cook, B. I., Allen, J. M., Crimmins, T. M., Betancourt, J. L., Travers, S. E., Pau, S., Regetz, J., Davies, T. J., Kraft, N. J. B., Ault, T. R., Bolmgren, K., Mazer, S. J., McCabe, G. J., McGill, B. J., Parmesan, C., Salamin, N., Schwartz, M. D., & Cleland, E. E. (2012). Warming experiments underpredict plant phenological responses to climate change. *Nature*, *485*(7399), Article 7399. https://doi.org/10.1038/nature11014