Title:The effect of multiple short interval fires on community and functional trait-based regeneration in boreal Alaska

## Abstract:

Fire is a major driver of forest structure, composition, and age in boreal landscapes across spatial and temporal scales. Repeat short-interval fires in Interior Alaska (occurring within 50 years or less) are a departure from historic norms of fire intervals and drive ecological transitions from conifer-dominated to deciduous-dominated forests. The impact of short-interval reburning and its subsequent effects on overstory composition and structure on understory plant communities remains unknown. Here, we investigate how multiple short-interval fires alter understory plant communities via changes in stand structure and light availability in two sites of regenerating reburned stands in boreal Interior Alaska. Each site contains a mosaic of burn perimeters from fires that occured once, twice or three times in short-intervals (>30 years). We report ono understory community composition, overall species richness and differences in functional traits in reburned stands and examine the role of canopy structure and light availability in mediating or accelerating the impact of repeat reburning on regenerating plant communities. This work informs our ability to predict and manage impacts of repeat burning in boreal Interior Alaska forests and expands on our understanding of disturbance-driven ecological change in high-latitude boreal environments.

## Introduction

The boreal ecoregion is the largest forest ecosystem on the planet (Kuusela 1992), but contains relatively low vegetation diversity (Hart and Chen 2006). Understory plant communities in the boreal ecoregion are the primary source of plant diversity and act as a major forest ecosystem driver (Nilsson and Wardle 2005), shaping nutrient cycling (Webr and Vancleve 1981, Brumelis and Carleton 1989), wildlife (Gunnarsson et al. 204) and longer-term canopy succession trends (Messier et al. 1998). Despite their role in long-term forest dynamics, understory plant communities in the boreal remain less understood than their overstory counterparts, particularly in the context of recent shifts in modern fire regimes across the boreal. Rapidly warming temperatures across high latitudes have led to an increase in the frequency and severity of boreal wildfires (Balshi et al. 2009), amplifying short-interval fires across the region (Buma et al. 2021, *in prep*). Fire in the boreal is strongly linked to patterns of community composition and plant functional traits, but the impact of increased fire frequency on understory plant community dynamics remains unclear (Whitman et al. 2018).

Fires alter understory plant community composition by altering canopy cover which mediates understory microclimates (Hart and Chen 2006, Ma et al. 2010). [lots more to add]

To better understand the effects of multiple-short interval fires on ecosystem processes of modern boreal forest systems, it is necessary to 1) characterize the structure, composition, and functional traits of regenerating understory plant communities in reburned areas and 2) determine whether reburned areas support understory plant communities that differ significantly from similar communities regenerating in regions with different fire histories. Examining the success of specific functional traits within given community assemblages occurring after multiple short-interval fires builds a mechanistic understanding of the drivers of successional divergence in boreal Interior Alaska. Here, we investigate community regeneration in two reburned stands with comparable burn histories (1, 2 or 3 fires in <30 years).

This study evaluates patterns of understory plant community and functional trait regeneration across a gradient of reburns to investigate post-fire community regeneration and successional trends following multiple short-interval fires. To characterize community structure and drivers of that community structure, we compare understory plant species diversity, understory community composition and abundance of regeneration traits across varying fire histories and between two topographic positions with differing regenerating canopy composition and structures. We ask the following research questions: 1) what understory plant communities are present in regenerating reburned stands?, and 2) Does light availability, canopy structure or composition interact with fire history to alter overall diversity, community evenness and richness in reburned stands? We hypothesize that fire history will have the largest effect on diversity in reburned stands, overwhelming the effects of site conditions like canopy openness, topography, and solar radiation. Furthermore, we anticipate that single fires or reburns may lead to an initial increase in diversity in understory plant communities, but that communities will become less diverse with additional reburning, regardless of location. Finally, we hypothesize understory communities emerging in reburned stands will become more dissimilar to communities regenerating after single fires, and that communities will continue to become more dissimilar with additional reburns, independent of location.

## Methods

#### Study design

To examine the effects of short-interval disturbances on plant communities, we established a network of 50 plots in two topographic positions in Interior Alaska that contain a mosaic of unburned, burned and reburned stands. We sampled two locations: an upland region with well-drained soils and a lowland region with flatter topography and poorly drained soils.

Figure X. Map of study locations.

#### Field sampling

We sampled understory and overstory communities in field campaigns during the summer of 2018, 2019 and 2021. We counted vegetation above diameter breast height (DBH, 1.37 m) in 400-m2 sample spaces within each plot, though in denser stands, sample spaces were limited to 100m2 or 200 m2 randomly selected subsamples. For each individual above DBH, we recorded species, diameter at breast height (cm), canopy health (%) and the dominant corresponding understory species. We recorded seedlings and shrubs below DBH in 10 1-m2 subsets at each plot, and classified individuals above DBH but under 2.5 mm in diameter as saplings. Given the sensitivity of biodiversity metrics to sample size (Maurregan 2013), sample size was constrained specifically to a maximum of 400 m2  sub-samples of overstory vegetation and 100 m2 of understory vegetation.

We recorded species present and percent cover of understory vegetation within 5 1-meter2 subsamples within each plot in the upland site, and across 10 0.5-meter2 sub samples in the lowland. Species were identified according to regional guides (Mackinnon et al. 2004, Laursen and Seppelt 2010, Hulten 1968). When individuals were unidentifiable to the species level, the genus level was used. Due to difficulties in identifying moss species consistently across plots, we describe all moss data at the genus level.

To capture canopy openness as it relates to light availability, we took skyward hemispherical photographs at the center of each plot. Pixels were classified as “sky” or “non-sky” using Gap Light Analyzer (GLA) software, which was then used to quantity canopy openness (Frazer et al. 1999).

#### Data analysis

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To examine the specific drivers of community diversity in understories of upland reburned stands, we use multivariate regression models with Simpson’s diversity index as a dependent variable, and number of fires, organic layer depth (as a metric of disturbance severity), solar insolation, slope, and canopy openness as independent variables. Simpson’s index was calculated for upland and lowland plant communities according to reburn history using the ‘vegan’ package in R (Oskanen et al. 2017). This index provides a measure of diversity that considers both species richness and evenness of abundance by measuring the probability that two individuals randomly selected from an area will belong to the same species (Magurran 2013). Simpson’s diversity index was selected over the commonly used Shannon diversity index due to the stability of Simpson’s index at lower sample sizes (Magurran 2013, Gimaret-Carpentier et al. 1998). This model was used to compare the effect sizes and confidence intervals of the independent variables to evaluate the main drivers of diversity between a predefined set of frequency, severity and topographic characteristics.

To evaluate how plant communities in reburned stands differ according to reburn history or topographic context, we used presence/absence data of individual species to calculate Jaccard’s similarity index. Jaccard’s index uses the size of intersection and the size of the union of two finite sample sets to evaluate similarity (Magurran 2013). Once-burned species communities will be pooled and treated as one community. Jaccard’s index on its own is often a descriptive metric: to provide a quantitative estimate of community difference across reburns, we calculated Jaccard’s index comparing each plot experiencing either 2 or 3 fires to the pooled one-burn community. This approach produced a distribution of differences created from comparing each twice-burned plot index to the pool of once-burned plots. That distribution of differences is compared between 1-burn vs 2-burn and 1-burn vs 3-burn, providing a specific quantitative measure of whether additional reburns drives converging or diverging communities.

## Results

## Discussion

## Acknowledgements

## References

Balshi, M.S., McGUIRE, A.D., Duffy, P., Flannigan, M., Walsh, J. and Melillo, J., 2009. Assessing the response of area burned to changing climate in western boreal North America using a Multivariate Adaptive Regression Splines (MARS) approach. *Global Change Biology*, *15*(3), pp.578-600.

Castorani, M.C., Reed, D.C. and Miller, R.J., 2018. Loss of foundation species: disturbance frequency outweighs severity in structuring kelp forest communities. *Ecology*, *99*(11), pp.2442-2454.

Chapin, F.S., Oswood, M.W., Van Cleve, K., Viereck, L.A. and Verbyla, D.L. eds., 2006. *Alaska's changing boreal forest*. Oxford University Press.

Fraterrigo, Jennifer M., Aaron B. Langille, and James A. Rusak. 2020. Stochastic disturbance regimes alter patterns of ecosystem variability and recovery. *PloS one* 15(3): e0229927.

Frazer, G.W., Canham, C.D., and Lertzman, K.P. 1999. Gap Light Analyzer (GLA), Version 2.0: Imaging software to extract canopy structure and gap light transmission indices from true-colour fisheye photographs, users manual and program documentation. Copyright © 1999: Simon Fraser University, Burnaby, British Columbia, and the Institute of Ecosystem Studies, Millbrook, New York.

Gill, N.S., Jarvis, D., Rogan, J. and Kulakowski, D., 2020. Disturbance history modulates how litter and herbaceous cover influence conifer regeneration after fire. *International Journal of Wildland Fire*.

Gimaret‐Carpentier C, Pélissier R, Pascal JP, Houllier F. Sampling strategies for the assessment of tree species diversity. Journal of Vegetation Science. 1998 Apr;9(2):161-72.

Greene, D.F., Zasada, J.C., Sirois, L., Kneeshaw, D., Morin, H., Charron, I. and Simard, M.J., 1999. A review of the regeneration dynamics of North American boreal forest tree species. *Canadian Journal of Forest Research*, *29*(6), pp.824-839.

Hart, S.A. and Chen, H.Y., 2006. Understory vegetation dynamics of North American boreal forests. *Critical Reviews in Plant Sciences*, *25*(4), pp.381-397.

Hughes, A., Byrnes, J.E., Kimbro, D.L. and Stachowicz, J.J., 2007. Reciprocal relationships and potential feedbacks between biodiversity and disturbance. *Ecology letters*, *10*(9), pp.849-864.

Hultén, E., 1968. *Flora of Alaska and neighboring territories: a manual of the vascular plants* (Vol. 2193). Stanford University Press.

Hodson, J., Fortin, D. and Bélanger, L., 2011. Changes in relative abundance of snowshoe hares (Lepus americanus) across a 265-year gradient of boreal forest succession. *Canadian Journal of Zoology*, *89*(10), pp.908-920.

Hollingsworth, T.N., Johnstone, J.F., Bernhardt, E.L. and Chapin III, F.S., 2013. Fire severity filters regeneration traits to shape community assembly in Alaska’s boreal forest. PloS one, 8(2), p.e56033.

Howard, Janet L. 1996. Populus tremuloides. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer).

Johnstone, J.F. and Chapin, F.S., 2006. Fire interval effects on successional trajectory in boreal forests of northwest Canada. Ecosystems, 9(2), pp.268-277.

Johnstone, J.F., Hollingsworth, T.N., CHAPIN III, F.S. and Mack, M.C., 2010. Changes in fire regime break the legacy lock on successional trajectories in Alaskan boreal forest. *Global Change Biology*, *16*(4), pp.1281-1295.

Johnstone, J.F., Rupp, T.S., Olson, M. and Verbyla, D., 2011. Modeling impacts of fire severity on successional trajectories and future fire behavior in Alaskan boreal forests. *Landscape Ecology*, *26*(4), pp.487-500.

Kasischke, E.S., Rupp, T.S. and Verbyla, D.L., 2006. Fire trends in the Alaskan boreal forest. *Alaska’s changing Boreal forest*, pp.285-301.

Keeley, J.E., 2009. Fire intensity, fire severity and burn severity: a brief review and suggested usage. *International Journal of Wildland Fire*, *18*(1), pp.116-126.

Laursen, G.A. and Seppelt, R.D., 2010. *Common Interior Alaska Cryptogams: Fungi, Lichenicolous Fungi, Lichenized Fungi, Slime Molds, Mosses, and Liverworts*. University of Alaska Press.

MacKinnon, A., Pojar, J. and Alaback, P.B., 2004. *Plants of the Pacific Northwest coast*. Lone Pine Pub.

Magurran, A.E., 2013. *Measuring biological diversity*. John Wiley & Sons.

Oskanen, J., Blanchet, F., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P., O’Hara, R., Simpson, G. and Solymos, P., 2017. vegan: Community ecology package, Version 2.4-3.

Roland, C.A., Schmidt, J.H. and Nicklen, E.F., 2013. Landscape‐scale patterns in tree occupancy and abundance in subarctic Alaska. *Ecological Monographs*, *83*(1), pp.19-48.

Thom, D., Rammer, W., Dirnböck, T., Müller, J., Kobler, J., Katzensteiner, K., Helm, N. and Seidl, R., 2017. The impacts of climate change and disturbance on spatio‐temporal trajectories of biodiversity in a temperate forest landscape. *Journal of Applied Ecology*, *54*(1), pp.28-38.

Turetsky, M.R., Kane, E.S., Harden, J.W., Ottmar, R.D., Manies, K.L., Hoy, E. and Kasischke, E.S., 2011. Recent acceleration of biomass burning and carbon losses in Alaskan forests and peatlands. *Nature Geoscience*, *4*(1), pp.27-31.

Van Cleve, K., Dyrness, C.T., Viereck, L.A., Fox, J., Chapin III, F.S. and Oechel, W., 1983. Taiga ecosystems in interior Alaska. *Bioscience*, *33*(1), pp.39-44.

Viereck, L.A., 1973. Wildfire in the taiga of Alaska. *Quaternary Research*, *3*(3), pp.465-495.

Wirth, C., 2005. Fire regime and tree diversity in boreal forests: implications for the carbon cycle. In *Forest diversity and function* (pp. 309-344). Springer, Berlin, Heidelberg.

Whitman, E., Parisien, M.A., Thompson, D.K. and Flannigan, M.D., 2018. Topoedaphic and forest controls on post-fire vegetation assemblies are modified by fire history and burn severity in the northwestern Canadian boreal forest. *Forests*, *9*(3), p.151.

Whitman, E., Parisien, M.A., Thompson, D.K. and Flannigan, M.D., 2019. Short-interval wildfire and drought overwhelm boreal forest resilience. *Scientific Reports*, *9*(1), pp.1-12.