**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 an reburned upland stand boreal Interior Alaska that contains a mosaic of burn perimeters from fires that occurred once, twice or three times in short-intervals (>30 years). We quantified understory community composition and compare estimates of species richness abundance of nitrogen-fixers and cover across plots distributed in a gradient of fire and reburn histories. We used linear regression to determine whether canopy structure and light availability mediate or accelerate the impact of repeat reburning on regenerating plant communities. [results] 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). Multiple short-interval fires in the boreal can drive shifts in regeneration of overstory composition from conifer to deciduous species (Hayes and Buma 2021). In this context of emerging novel overstory assemblages after continued reburning, 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). Fire as a disturbance drives initial X TREND in species richness of understory communities [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 and composition 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 stands with different fire histories.

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. 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. 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.

## Methods

#### Study design

To examine the effects of short-interval disturbances on plant communities, we established a network of 26 plots in Interior Alaska within a mosaic of unburned, burned and reburned stands that were dominated by mature black spruce prior to the first burn. Fire perimeters, severities and years were determined using a combination of aerial photography, remote sensing, and ground truthing. Each fire burned at high enough severity to produce full canopy mortality and fires occurred within 14-38 years of one another, well within the regional definition of a short-interval (50 years, cite).

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 and identified species 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.

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

To evaluate how plant communities in reburned stands differ according to reburn history, we used presence and cover data of individual species to calculate a Bray Curtis dissimilarity value for each plot (Beals 1984) using the ‘vegan’ package (CITE). To test our hypotheses about the mechanisms driving understory community richness, we used generalized linear regression to model changes in Bray Curtis dissimilarity values and cover against fire history, light availability and stand density. We performed all data analysis in R version ## (R Core Team ##).

## Results

### Species composition

111 unique species and 41 genera of understory and overstory plants (including moss and lichen) were present across plots (n = 26) (Table 1, Table 2). Moss made up 22.5% of the unique species observed (n = 25), followed by lichen (13%, n = 15), evergreen shrubs (9.%, n = 10), forbs (8%, n = 9), graminoids (4.5%, n = 5) and finally seedless vascular species (2.7%, n = 3).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Table 1. Lichen and moss species present across plots. | | | | | |
| Genus | Species | n in 0x burn | n in 1x burn | n in 2x burn | n in 3x burn |
| *Cladonia* | *clorophaeau* | 0 |  |  |  |
| *rangiferina* |  |  |  |  |
| *borealis* |  |  |  |  |
| *belliflora* |  |  |  |  |
| *squarosa* |  |  |  |  |
| *Multivclavula* | *mucida* |  |  |  |  |
| Pelitigera | neopolydacta |  |  |  |  |
|  | apthosa |  |  |  |  |
| Nephoma | resputinatum |  |  |  |  |
|  | espalidum |  |  |  |  |
|  |  |  |  |  |  |

### Species cover

Across

### Species richness

### Nitrogen fixers

### Canopy structure / light availability

## Discussion

## Data Availability

All code used in the analyses of this paper are publicly available as a repository on github () and datasets are available on Zenodo (doi).

## 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.