Project Title: Impacts of changing fire regimes in the alpine treeline ecotone

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I. Abstract

We studied the effects of a shift in the fire regime of an ecosystem that is very sensitive to climate change: the ecotone from closed forest to open alpine tundra, hereafter the alpine treeline ecotone (ATE). Results suggest that ATEs will become more complex spatially in a warming climate, rather than moving up or down *en masse*. Management of these areas, many of which are in protected areas (wilderness and national parks), will continue to be adaptive, anticipating landscapes of the future that will change in complex ways and differently in different ecoregions.

II. Background and Purpose

Across the western U.S., climate change presents perhaps the biggest challenge to both the idea and the conservation of protected areas, particularly in the context of dynamic and rapidly changing disturbance regimes. This project addresses the JFSP topic of climate change and fire, by examining the effects of a shift in the fire regime of an ecosystem that is very sensitive to climate change: the ecotone from closed forest to open alpine tundra, hereafter the alpine treeline ecotone (ATE).

The influences of climate and local feedbacks on tree establishment and growth in the ATE are well studied. Increased tree establishment in subalpine parkland and an upward movement of treeline are expected in a warming climate, and these changes are already occurring in some treelines, but not all (Harsch et al. 2009). Other factors that may limit altitudinal treeline, such as disturbance, have received more attention globally than in North America. The same climate warming has been linked to increased area burned by wildfires across the West (Littell et al. 2009); indeed the same factors associated with increased tree establishment in some areas—decreased snowpack and longer growing seasons—will encourage wildfire in alpine treeline ecotones. It is presently unclear how the subalpine ecotone will respond to the combination of the direct effects of climate and the indirect effects of changing fire regimes. This research examined burn severity and post-fire regeneration in the alpine treeline ecotone (the zone extending from closed forest, through a mosaic of forest and non-forest, to treeless alpine tundra) to identify the relative influences of climate, fire, and endogenous factors (local topography, soils, and biological legacies), thereby enabling inferences about the future of the subalpine parkland in fire-prone ecosystems. Key research questions included:

a. Are regional increases in area burned also correlated with increased area burned in the ATE?
b. How does fire change the location, composition, and spatial pattern of the ATE?
c. How does the probability of fire occurrence and severity vary based on pre-fire vegetation cover within ATE?

III. Study Description and Location

In order to determine if recent regional climate-driven increases in area burned are affecting ATEs, we conducted a geospatial analysis of wildfires in ATEs in eight mountainous ecoregions of the Pacific Northwest and Northern Rocky Mountains, USA, over 29 years (1984-2012). We calculated area burned and fire rotations across 795,210 ha of subalpine parkland, and 1,028,909 ha of alpine vegetation, and tested whether subalpine parkland and alpine vegetation were less likely or as likely to burn as the overall landscape, at the scale of the study area and within each ecoregion. To calculate the area burned, we used geospatial burn-severity data from all fires >400 ha, and bracketed uncertainty by using two estimates of area burned: all area within fire perimeters, and excluding the "unburned to low" severity class.

We also evaluated the use of aerial photography to classify different pre-fire canopy-cover structural classes—closed forest (>40% tree cover), tree clumps, and unforested areas—at three field sites, in order to detect change from pre-fire to post-fire at resolutions that matched the spatial grain of the forest-non-forest mosaic in the ATE. We assessed object and reflectance-based classification methods, with the goal of identifying individual tree clumps and unforested areas.

At a local scale, we examined variability in fire severity and changes in plant structure, using data from >500 plots within four alpine treeline ecotones sites in the Cascade Range and Northern Rocky Mountains, which had burned 19-28 years prior. Sites extended from *Abies lasiocarpa/Picea engelmannii* forests at lower elevations to a mosaic of *Pinus albicaulis/Larix lyallii* parklands, meadows, and alpine tundra at higher elevations. We assessed the likelihood of different pre-fire canopy-cover structural classes—closed forest (>40% tree cover), open forest (10%-40%), parkland (<10%), and unforested areas (alpine, meadow, and Krummholz)—to burn and to change to a different structural class after fire. Lastly, within field sites we measured changes in forest structure—specifically the abundance of live trees within five diameter at breast height (DBH) classes—using non-metric multidimensional scaling (NMDS) to visualize differences, and Permutational Multivariate Analysis of Variance (PERMANOVA) to test statistically for differences from pre-fire to post-fire, and between unburned and three higher-severity classes.

IV. Key Findings

a. Regional trends in area burn in alpine treeline ecotones

Our results support past research demonstrating that fires are infrequent in alpine ecosystems: in all but one ecoregion, fire rotations were long (>400 yrs) and little of alpine area (<7%) burned during the 29 year study period, despite recent climatic warming. In contrast, in the Blue Mountains 19%-25% of the alpine zone burned during the study period. In four of eight ecoregions—three in Rocky Mountains and the Cascades—the proportion of subalpine parkland burned was either statistically no different, or exceeded the proportion of the entire ecoregion that burned. In subalpine parkland, fire rotations were within the wide historical range (100-350 years) identified in dendrochronological studies, implying that the relatively high percentage of subalpine parkland burned during the last 29 years is not outside the range of historical variability.

Table 1. *[following page] Total area burned over the 29-year study period within vegetation groups in each ecoregion, and the proportion of each vegetation type that burned. Ranges are based on (1) including only areas that burned with severity other than "unburned to low" and (2) all area within fire perimeters. Subscripts note whether the total proportion, over 29 years, of area burned in subalpine parkland and alpine vegetation were less than or greater than the proportion of area burned across the landscape. The fire rotation was calculated as 1/(mean annual proportion of area burned), and represents the number of years it would take to burn an area equal to the area of landcover for a given vegetation type.*

Ecoregion	Area burned (ha)	Proportion burned	Fire rotation
	Subalpine parkland		
All Eight Level III Ecoregions [a]	55 137-78 621	0.07-0.10	289-412
Blue Mountains [a]	3722-5467	0.09-0.13	228-334
Canadian Rockies [b]	8863-11 524	0.08-0.11	276-359
Cascades [b]	3268-4160	0.04-0.05	592-754
Columbia Mountains [b]	695-865	0.03-0.04	742-923
Eastern Cascades Slopes and Foothills [a]	211-322	0.03-0.04	748-1138
Idaho Batholith [a]	17 013-24 686	0.22-0.32	91-132
Middle Rockies [b]	7162-9307	0.08-0.10	280-363
North Cascades [a]	14 201-22 291	0.04-0.06	454-713
	Alpine vegetation		
All Eight Level III Ecoregions [a]	27 510-66 565	0.03-0.07	448-1083
Blue Mountains [b]	942-1255	0.19-0.25	118-157
Canadian Rockies [a]	531-1156	0.01-0.03	1050-2288
Cascades [a]	381-512	0.02-0.02	1208-1626
Columbia Mountains [c]			
Eastern Cascades Slopes and Foothills [c]			
Idaho Batholith [a]	1525-2681	0.04-0.06	468-823
Middle Rockies [a]	23 469-58 644	0.03-0.07	416-1041
North Cascades [a]	638-2275	0.01-0.03	919-3278
	All vegetation types		
All Eight Level III Ecoregions	5 015 686-6 965 218	0.08-0.11	262-364
Blue Mountains	769 493-1 120 291	0.11-0.16	184-267
Canadian Rockies	317 990-385 028	0.06-0.07	429-519

Cascades	140 947-184 418	0.03-0.04	730-955
Columbia Mountains	240 568-313 346	0.02-0.02	1272-1657
Eastern Cascades Slopes and Foothills	303 403-403 307	0.05-0.07	404-537
Idaho Batholith	1 757 879-2 496 174	0.29-0.41	70-99
Middle Rockies	1 191 033-1 691 822	0.07-0.10	282-400
North Cascades	294 374-370 832	0.08-0.10	288-363

[a] The total proportion of subalpine parkland or alpine vegetation burned was less than the mean of the annual proportion all vegetation types burned in these ecoregions.
[b] The total proportion of subalpine parkland or alpine vegetation burned was greater than the mean of the annual proportion all vegetation types burned in these ecoregions.
[c] Alpine vegetation classes in the Columbia Mountains and Eastern Cascades Slopes and Foothills Ecoregions were not evaluated because there was little alpine vegetation in those ecoregions

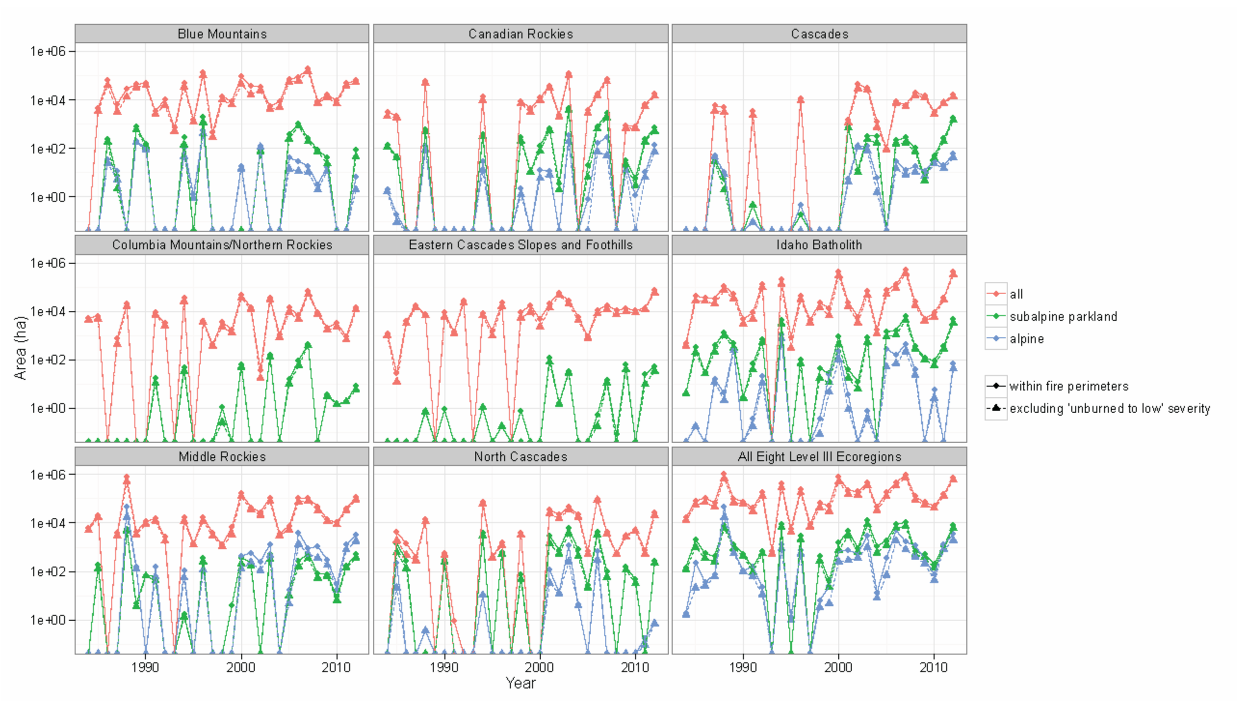

Figure 1. *Time series of the of total area burned, subalpine parkland area burned, and alpine vegetation area burned for each CEC Level III Ecoregion, and across the study area (the eight Level III ecoregions included in this analysis; bottom right panel).*

b. Aerial photograph assessment

We obtained panchromatic images and LANDSAT images from the USGS (USGS 2012) covering the extent of the sampled alpine treeline ecotone in each fire. Fires occurred in 1994, and images were from 1990 and 1998. Image segmentation methods were evaluated on three focal fires, including methods using only reflectance and a combination of reflectance and image texture analysis (e.g. “object-based classification”). For each fire, field-plot data (Table 2) were used to assess accuracy of the classification following standard remote-sensing accuracy assessment methods (Lillesand et al. 2007).

Table 2: Fires used to validate the classification of aerial photography.

Fire	Year	Location	Number of plots
Butte Creek	1994	Okanogan Wenatchee National Forest, WA	162
Tyee Creek	1994	Okanogan Wenatchee National Forest, WA	25
Helen Creek	1994	Flathead National Forest, MT	187

Overall, classification accuracy was very low, and with only two classes—forest and non-forest—the observed accuracy was < 50% (i.e. no better than random). In summary, despite trying a number of methods of image classification, images did not meet a level of accuracy that is considered acceptable for classified remote-sensing products (Lillesand et al. 2007). A major issue involved shadows being misclassified as forest. This particularly affected the comparison of images from pre-fire to post-fire, in that the two dates of image were taken at two different times of day, so shadows were in different directions, obscuring vegetation structure in different parts of the images. Therefore, our pairs of images were showing changes from unforested to forested, which were actually driven by classification errors. Because our field data provided more detailed and accurate information regarding the spatial variability of vegetation structure and fire severity, we focused on using those data to answer our two research questions regarding how fire changes the spatial pattern of the ATE, and how the probability of fire occurrence and severity varies based on pre-fire vegetation. We discuss other remote-sensing data that could be used to classify vegetation with fine resolution in the “future work needed” section, below.

c. Site-level probability of burning and plant structural changes

To quantify the probability of burning at a given severity and the effects of fire on vegetation structure we used data from 531 field plots within four alpine treeline ecotones sites extending from *Abies lasiocarpa/Picea engelmannii* forests at lower elevations to a mosaic of *Pinus albicaulis, Larix lyallii* parklands and meadows and alpine tundra at higher elevations. Two fires, Hubbard Creek (1985.) and Butte Creek (1994), were in the northern Cascade Range, and two fires were in the northern Rockies, Upper Bear (1988) and Helen Creek (1994).

Unforested areas were less likely to burn than the landscape as a whole, and across each ecotone, fire increased the proportion of area that was unforested. Fire severity and fire effects were mixed: previously forested stands had a similar probability of retaining some forest cover as they had of becoming unforested due to fire. Of the plots that burned, the unforested class became more frequent after fire, and the open forest and closed forest classes became less frequent after fire.

Table 3. The probability of burning and of burning at high severity decrease along the gradient from closed forest to alpine vegetation. The χ2 statistic and P-values are for Pearson's chi-squared of the null hypothesis that pre-fire structural classes burned with the same distribution of severities as the landscape as a whole (α=0.01).

Burn severity probabilities for all fires	**χ2 =54.53**		***P*=<0.001**	
Pre-fire structural class	**Unburned**	**Low**	**Moderate**	**High**
Unforested	0.71	0.07	0.05	0.17
Parkland	0.22	0.15	0.20	0.43
Open forest	0.15	0.19	0.18	0.48
Closed forest	0.20	0.27	0.20	0.33

Unlike what one might expect for lower-elevation forests, tree mortality was highest in the largest tree size classes. Ordination and PERMANOVA results showed that greater fire severity was associated with an increase in the relative abundance of smaller tree size classes (<10 cm). In summary, the mixed effects of the fire created patchiness at the scale of the study sites, and selected for smaller tress at the scale of plots. Our results contrast with those of previous studies in continuous subalpine forests, which are typified by high-severity stand-replacing fire. In the alpine treeline ecotone, fire severity is mixed, likely reflecting discontinuous fuels and higher fuel moisture, and survival of smaller trees through the fire will play an important role in setting the post-fire successional trajectory. Isolated trees and Krummholz high within the ecotone rarely burn, and may provide important fire refugia if fires become more prevalent in the alpine treeline ecotone with climate change.

V. Management implications

Research has projected that climate change will cause continued increases in area burned in western North America. Strong significant correlations between the overall annual area burned across all vegetation types and the area burned in subalpine parkland and alpine vegetation indicate that fire may become more prevalent in both subalpine parkland and alpine vegetation if the overall area burned increases due to climate change. Nevertheless, fire return intervals over the last 29 years are still within historical ranges, and therefore the current level of burning should not be causing changes in ATEs at regional scales.

Within burned ATEs fire effects are moderate, and highly heterogeneous. Climate change may cause treelines to expand upward and trees to infill previously snow-dominated sites, and increased wildfire is most likely to cause mortality at sites with older trees and lower fuel moistures. In other words, at a fine scale, it will not directly counteract climate-driven changes in ATEs, but at regional scales, it will likely become a more prevalent process that maintains non-forest areas within ATEs.

VI. Relationship to other recent findings and ongoing work

Post-fire dynamics in ATEs are complex and may respond differently among ecoregions in a warming (non-stationary) climate. For example, high-elevation ecosystems in drier ecoregions such as the Sierra Nevada or American Southwest may be drought-sensitive to the point that increased fire will depress treeline because of the increased constraints post-fire establishment (water limitation). Similar work is needed in these drier ecosystems, along with the many ongoing studies of the direct responses of treelines to climate.

VII. Future work needed

- High-resolution satellite imagery or LIDAR data would be needed to detect changes in plant structure at fine resolutions (1-2 m), using infrared bands and a procedure to circumvent shadows. This would be a major project.

VIII. Deliverables

Table 5. *Deliverables cross walk*

Deliverable Type	**Description**	**Product**
Oral presentations or posters	(1) Climatic and topographical controls of fire severity in the alpine treeline ecotone (2) How will climate change and fire affect succession in the alpine treeline ecotone?	Cansler, C.A., D. McKenzie. 2015. Fire occurrence, severity, and influence on plant structure in alpine treeline ecotones. Perth III: Mountains of Our Future Earth. 10/4-8/2015, Perth, Scotland. Cansler, C.A., D. McKenzie. 2015. Influence of fire and post-fire succession in alpine treeline ecotones. 2015 IALE World Congress. 7/5-10/2015, Portland, OR. Cansler, C.A., D. McKenzie. 2014. Are recent increases in area burned in the Pacific Northwest reflected in increased area burned in alpine treeline ecotones? MTNCLIM Conference. 9/15-18/2014, Midway, UT. Cansler, C.A., D. McKenzie. 2014. Tree regeneration after fire in *Abies lasiocarpa-Larix lyallii-Pinus albicaulis* subalpine parkland in the North Cascades, Washington. Northwest Scientific Association Annual Meeting. 3/26-29/2014, Missoula, MT.
Report to JFSP	Full documentation of the data, analysis, and outcomes	Present document plus expected publications.
Peer-reviewed manuscript(s)	Focuses on ecological inferences for understanding ecotone response to climate change	Cansler, C.A., D. McKenzie. Recent trends in area burned in alpine treeline ecotones. To be submitted to International Journal of Wildland Fire. Cansler, C.A., D. McKenzie. Fire influences forest structure in alpine treeline ecotones. To be submitted to Landscape Ecology. Cansler, C.A., D. McKenzie. Post-fire succession in alpine treeline ecotones. To be submitted to Ecology.

Archival Data	Georeferenced ArcGIS shape files containing pre-fire classification of subalpine parkland components, and post-fire classification of fire occurrence and severity.	Field data from this study will be archived and available after the initial papers are published.

IX. Literature cited

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