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Effects of fire on geomorphic factors and seedling site conditions within the alpine treeline ecotone, Glacier National Park, MT

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ABSTRACT

This paper evaluates the geomorphic effects of fire on the alpine treeline ecotone and how those effects influence post-fire seedling establishment conditions. Forest fires are becoming more common in high elevations, and ecosystem responses in these areas are not well studied. Results indicated that burned areas experienced increased soil loss, complete loss of the duff layer, less compact soils, larger clast sizes, and increased rock spalling, and altered seedling site conditions. Seedlings showed distinct preferences for micro-sites with deeper, less compact soils, and a greater cover of rock. The effects of fire within the alpine treeline ecotone will affect treeline position and geomorphic processes within these higher elevations.

1. Introduction

The alpine treeline ecotone (treeline) is used as a proxy for changes in climate because the location of treeline is strongly influenced by climatic factors over the course of decades and centuries (Hofgaard, 1997; Camarero and Gutiérrez, 2007; Batllori and Gutiérrez, 2008). Within this zone of transition between the open tundra and the subalpine forest, trees, or krummholz (crooked, stunted trees), struggle to survive in these high elevation areas as they compete with tundra vegetation for resources (Malanson and Butler, 1994), and face limited precipitation, high solar radiation, strong winds, and frost action (Germino et al., 2002; Holtmeier, 2009). The position and movement of the alpine treeline ecotone are highly dependent upon the ability of trees to establish and survive, and disturbances can exert strong influences on seedling establishment and krummholz mortality (Butler and Walsh, 1994; Butler et al., 2007; Tomback and Resler, 2007). Therefore, it is important to consider disturbances when analyzing treeline position. This paper aims to evaluate the effects of fire on soil characteristics and how these effects influence seedling micro-site conditions after recent fires within the alpine treeline ecotone of Glacier National Park, Montana, U.S.A.

Research on this topic is particularly needed because in the United States and Canada, climate regimes and past management practices are increasing the occurrence of high intensity fires, especially in the Northern Rocky Mountains (Westerling et al., 2006). Warmer temperatures and decreased precipitation and snowpack duration are resulting in forests that contain less moisture and are drier for longer periods during the year. Westerling et al. (2006) found the fire season to have increased by 78 days since 1986 compared to the period between 1970 and 1986, based on the number of days fires were burning in the western United States. Years with early snowmelt resulted in an increase in fires five times that in years of late snowmelt. Snowpacks are now melting 1 to 4 weeks earlier than in the past, as spring and summer temperatures have increased about 0.9 °C (Mote et al., 2005; Stewart et al., 2005). These conditions have created an extended fire season, longer duration fires, and increased area burned by fires (Westerling et al., 2006). Westerling et al. (2006) found that fire activity particularly increased in the higher elevations during their period of study. It was uncommon in the past for high elevation forests to burn because of the long duration of the snowpack. However, with the earlier melting of the snowpack, these forests are now more vulnerable to fire.

Understanding the effects of fire in high elevation areas is particularly important because hillslopes and colder environments may respond differently to fire compared to other regions. Loss of vegetation on steep slopes may result in an increased risk of debris flows and snow avalanches (Butler et al., 1990). Fire may exert a significant impact on cryogenic processes, such as needle-ice formation and freeze–thaw patterns within colder, high elevation environments (Swanson, 1978). Loss of vegetation leads to a decrease in snow accumulation, and less snow results in decreased soil moisture, an important variable for vegetation,

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especially on thin soils found in alpine areas. However, research is limited on the effects of fire within the alpine treeline ecotone. Only a few studies have focused on fire within alpine treeline, and these primarily focus on static abiotic factors (e.g. elevation, slope aspect) (Germino et al., 2002; Stueve et al., 2009) in relation to vegetation or almost strictly geomorphic variables (e.g. erosion) (Sass et al., 2012). We fill a distinctive gap in the literature by bridging ecologic and geomorphic factors in response to fire within the alpine treeline.

2. Study area

Sites were selected based on the criteria of finding locations in protected areas of the northern Rocky Mountains of the United States that had experienced fire within the alpine treeline ecotone. We also selected sites based on time since fire. We were interested in recent fires in which the geomorphic factors influenced by fire were still evident, but allowing for enough time for vegetation and seedlings to begin establishing. We visited several burned areas at treeline in 2010, but only Divide Mountain and Swiftcurrent Mountain met our site objectives. Divide Mountain experienced a high intensity fire in 2006 and Swiftcurrent Mountain a high intensity fire in 2003. Field data were collected in 2011 and 2012. These sites and this time frame allowed us to evaluate both the soil conditions potentially affected by the fire as well as initial vegetation establishment patterns.

Our sites were located east of the Continental Divide in Glacier National Park, Montana (GNP) (Fig. 1). Two sites were located on Divide Mountain — Upper Divide and Lower Divide. Divide Mountain was treated as two sites because the two areas that burned at treeline differed in terms of the topography and the burned areas were separated by over 100 m of alpine tundra. The two sites were also the only areas on Divide Mountain that burned at treeline. The fire that affected Upper Divide appeared to have moved up from the western slope of the mountain, up the valley between Divide Mountain and Whitecalf Mountain; whereas the fire that reached treeline on Lower Divide appeared to have approached from the lower elevations on the northern slope of Divide Mountain. Upper Divide was located on a saddle (48° 39.5′ N, 113° 23.9′ W) at an elevation of 2200 m. The saddle is positioned with one slope facing east and the other facing west between Divide Mountain and the adjacent Whitecalf Mountain. Fine-scale topographic variations were also present on Upper Divide, and included a gully feature on the west-facing slope, steep slopes on both the west- and east-facing sides, and a more gentle sloping area near the top of the ridge. Sampling took place throughout the Upper Divide site. Lower Divide (48° 40.4′ N, 113° 23.6′ W) was located at a slightly lower elevation (2100 m) and was positioned on a north-facing slope. Most of Lower Divide was topographically uniform except for gradual change in elevation and a gully feature that extended up from the subalpine forest into treeline. Divide Mountain experienced a fire, the Red Eagle Fire, at treeline in 2006. The parent material is Altyn limestone (Resler, 2006). A third site was located on Swiftcurrent Mountain, where the Trapper Fire occurred in 2003. This site (48° 46.7′ N, 113° 46.1 W) was on a southward facing slope at elevations ranging from 2260 to 2340 m. The parent material is Grinnell argillite (Theodosis, 1955). Only one site was located on Swiftcurrent Mountain because fire only burned the sampled slope and the topography on that slope was uniform, except for change in elevation.

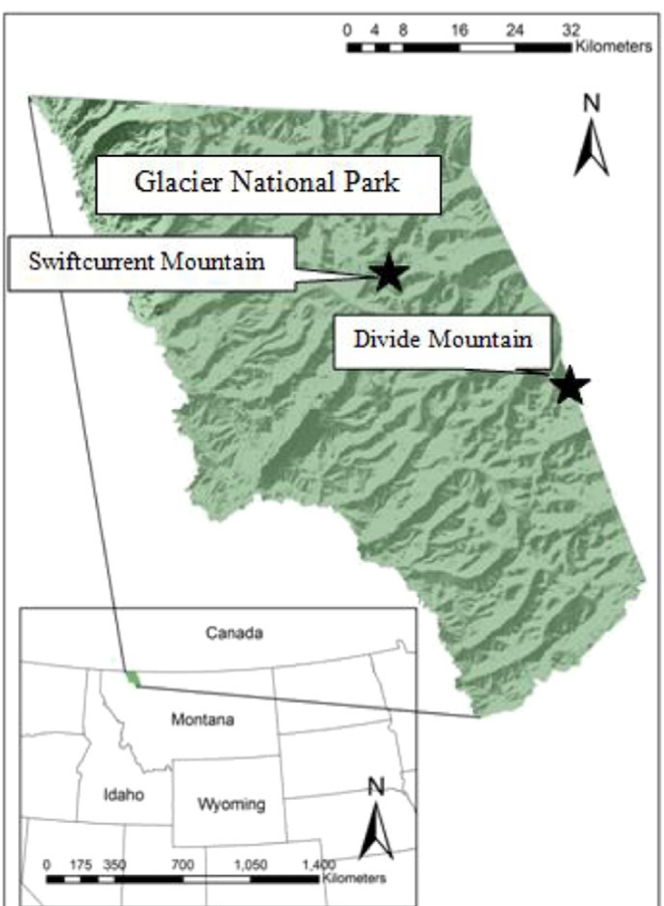

Fig. 1. Location of study sites.

Glacier National Park experienced extensive glaciation during the Pleistocene and Holocene, resulting in prominent peaks and U-shaped valleys. Steep-sloped valleys are generally positioned in a northeast–southwest orientation, and finger lakes occupy many of the valley bottoms. Soils are the product of periglacial processes operating on sedimentary bedrock and colluvial material. The treeline and alpine soils are characteristically slow to develop in the dry, sparsely vegetated areas. A soil fertility gradient was identified by Malanson and Butler (1994), and they found greatest soil fertility at lower elevations. The fire regime of Glacier National Park is strongly influenced by complex topography, fuel availability, and variations in moisture between north- and south-facing slopes and between areas on either side of the Continental Divide (Keane et al., 1999). Stand-replacing (most trees are killed); passive crown (patches of trees are killed); and non-lethal, ground-burning (most trees are not killed) fire regimes have been described for GNP (Barrett et al., 1991). Stand-replacing fires have a return interval of 120–150 years and are more common in moist areas where fuel loads are greater. Passive crown fires and low intensity, ground-burning fire regimes are common in the higher elevation areas where patchy fuel loads exist. Projections by Keane et al. (1999) indicate that future fires in Glacier National Park are likely to be more crown fires which cover greater spatial extents.

The research area is typical of many areas throughout the mountains of the North American west, where fire attempts from ca. 1910–1985 were absolute (Schoennagel et al., 2004). Fire suppression policies throughout the North American west resulted in a build-up of fuel loads in forests, even within treeline. This build-up of fuel combined with insect outbreaks and general climatic warming throughout the region has resulted in the increased occurrence and risk of fires within treeline (McCullough et al., 1998).

3. Methods

To evaluate the overall influence of fire on soil conditions, we placed quadrats measuring 5 × 20 m (Coop et al., 2010) and 5 × 5 m quadrats (where 5 × 20 m quadrats would not fit) in burned areas and adjacent unburned areas (as control quadrats) at the three sites within the treeline ecotone. Emphasis was placed on positioning quadrats in unburned areas that most closely resembled the sampled burned area (proximity, degree slope, slope aspect, vegetation type) (Table 1).