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Wildfire and topography impacts on snow accumulation and retention in montane forests

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ABSTRACT

Wildfires are increasing in frequency, severity, and size in many parts of the world. Forest fires can fundamentally affect snowpack and watershed hydrology by restructuring forest composition and structure. Topography is an important factor in snowpack accumulation and ablation as it influences exposure to solar radiation and atmospheric conditions. Few direct measurements of post-fire snowpack have been taken and none to this date that evaluate how topographical aspect influences the effect of forest fire on snowpack accumulation and ablation. We set up a two-year experiment on the Twitchell Canyon fire in south-central Utah on both north and south facing aspects and burned and unburned forest conditions across three replicated blocks. There was a significant interaction between burn condition and aspect for snow depth in which there was a reduction in snow depth in burned areas on south facing aspects but not on northern facing aspects. Snowpack disappeared earlier in burned areas than unburned areas, particularly on south facing slopes. Snow water equivalence (SWE) did not vary between burned and unburned forest. Year and topographical aspect were primary drivers of both snow depth and SWE. A review of five similar studies suggests that sites at southern latitudes and lower elevations could be more susceptible to reduction in snowpack after wildfire.

1. Introduction

More than 1 billion people depend primarily on snowmelt for fresh water (Barnett et al., 2005). Increasing temperatures (Brown and Mote, 2009) and disturbance such as wildfire affect snowpack characteristics, altering the timing and amount of snowmelt available for downstream communities and ecosystems (Kinoshita and Hogue, 2015; Wine and Cadol, 2016; Winkler, 2011). Because human activities are altering the frequency, severity, and size of wildfires globally (Bowman et al., 2009), there is a critical need to understand how changing fire regimes might alter snowpack characteristics that are vital to water security and ecosystem function (Adams, 2013; Miller et al., 2009; Westerling, 2016). Fire fundamentally affects watershed hydrology by restructuring vegetation, affecting the accumulation and loss of snow through interception, sublimation, and shading (Broxton et al., 2015; Musselman et al., 2008). In montane regions, where the majority of snowpack occurs, topographic position (i.e. slope, elevation, and aspect) also strongly influences snowpack dynamics (Geddes et al., 2005; Jost et al., 2007; Pomeroy et al., 1998) but little is known about how variation in topography in burned forest landscapes influences snowpack characteristics (Harpold et al., 2014).

Losses to snowpack from mid-winter fluxes such as sublimation and evaporation are mediated by surrounding vegetation (Biederman et al., 2014a; Molotch et al., 2007). Dense forest canopies intercept falling snow, facilitating losses that can exceed 60% of a total annual snowpack (Hedstrom and Pomeroy, 1998). Conversely, vegetation can protect snow from solar radiation both increasing snowpack quantity and decreasing the rate of melt (Musselman et al., 2008). Varhola et al. (2010) found in a review of 33 peer -reviewed articles spanning 65 sites across North America and Europe that forest cover could explain 57% of changes in snow accumulation and 72% in snow ablation. Topography also changes the intensity of solar radiation, temperature, and atmospheric conditions affecting peak snowpack or snow available for springtime melt; the deepest snowpacks normally occur on north-east facing aspects and shallowest snowpack on south-western facing aspects (Robert, 2004). Given the strong controls of both vegetation and topography on snowpack, it is critical for water management to better understand how wildfire impacts on forest structure interact with topography to affect snow-water resources.

The timing of spring snowmelt affects the amount of water available for both societal and ecological uses. Earlier snowmelt brought on by warming temperatures is a great concern for areas dependent on snowpack for water supply (Stewart et al., 2004). Faster snowmelt can create destructive pulses of abnormally high streamflow causing

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erosion, reservoir overfilling, and flooding (Lyon et al., 2008; Stewart et al., 2004). Several studies have shown most water storage facilities in the Northern Hemisphere to be insufficient to hold faster streamflow inputs due to global climate change (Barnett et al., 2005; Nijssen et al., 2001; Vorosmarty, 1997). Large disturbances such as wildfire in upstream watersheds could exacerbate these conditions causing essential water resources to be lost downstream to oceans, ecological degradation, dangerous flooding conditions in the springtime, and significant shortages of water supply in late summer.

While differences in snowpack characteristics are well understood in forested vs open meadows (Varhola et al., 2010) and disturbances such as logging clear-cuts (Woods et al., 2006) or insect infestations (Mikkelson et al., 2013), direct measurements of snowpack in post-fire landscapes have only been evaluated in a few studies which vary in results and do not consider interactions between burned forest and topography (Burles and Boon, 2011; Farnes, 1996; Gleason et al., 2013; Harpold et al., 2014; Skidmore, 1994; Winkler, 2011). Gleason et al. (2013) demonstrated that pyrogenic carbon particles and larger burned woody debris found in burned forest stands can drastically decrease snow spectral albedo and increase net shortwave radiation. These changes in albedo and shortwave radiation foster increased energy inputs into snowpack in burned forests more than in clear-cut or insect infested forests and will likely lead to different outcomes in the accumulation and ablation of snow-water resources (Gleason and Nolin, 2016; Harpold et al., 2014). Increased surface temperatures and wind speeds have also been documented in burned forests when compared with unburned forests (Burles and Boon, 2011; Winkler, 2011). While forest fires have shown to reduce soil infiltration rates (Granged et al., 2011; Versini et al., 2013), transpiration rates (Cardenas and Kanarek, 2014; Zhou et al., 2013), and alter other factors which may affect the hydrologic response of a watershed to fire, this study focuses on the peak accumulation and melt of snowpack or water available for springtime melt.

We investigated the effects of wildfire and topographic position on snowpack across three replicated blocks, in a two-year study in south-central Utah. Specifically, we asked: what is the role of wildfire, aspect, and their combination on peak snow depth, snow density, and snow-water equivalence (SWE) as well as snow ablation rates, and snow-free dates? We hypothesized that post-fire landscapes would have the greatest snow accumulation on burned north facing aspects due to reduced forest canopy and the least snow accumulation on burned south facing aspects due to more solar radiation reaching the forest floor (Harpold et al., 2014). We also hypothesized that increased solar radiation in post fire landscapes (Burles and Boon, 2011; Gleason and Nolin, 2016) would result in earlier snow free dates and faster ablation rates in both north and south facing burned forests.

2. Methods

2.1. Study site description

Study sites were located in the Shingle Creek watershed within the Twitchell Canyon fire complex east of Beaver, Utah (Lat: 38.49 Long: −112.49). The Twitchell Canyon fire burned over 18,500 ha in the summer of 2010, 67% of which was considered moderate-high burn severity (USDA-Forest_Service, 2010). The study area occurred in a subalpine zone between 2900 and 3100 m composed of Douglas fir (*Psuedotsuga menziesii*), subalpine fir (*Abies lasiocarpa*), ponderosa pine (*Pinus ponderosa*), limber pine (*Pinus flexilis*), and quaking aspen (*Populus tremuloides*). The median annual precipitation for the area from 1981 to 2010 was 83 cm, 47 cm coming as snow within the months of November through April (Table 1). Average annual temperature was 6.4 C, ranging from an average of −3.2 C in January to 16.3 C in August (NRCS-Kimberly_Mine_Snotel, 2017).

Table 1
Meteorological data taken from Kimberly Mine SNOWTEL site and separated into winter and spring months. Mean dew point was retrieved from Oregon State PRISM data.

	2015–16		2016–17	
	Dec–Feb	March–May	Dec–Feb	March–May
Temperature (°C)	−3.7	2.9	−3.2	3.7
Mean Dewpoint (°C)	−12.2	−6.9	−10.8	−7.5
Precip Accumulation (mm)	429.1	–	452	–
Max SWE (mm)	361.2	–	398.8	–
Day of Max SWE	Feb 24th	–	March 6th	–
Snow-Free Date	May 19th	–	May 21st	–

2.2. Experimental design

Using NAIP (National Agriculture Imagery Program) (USDA, 2010) satellite imagery and burn severity maps provided by MTBS (Monitoring Trends in Burn Severity) (MTBS, 2010) we identified three blocks containing paired burned and unburned sites on both north and south facing aspects (Figs. 1 and 2). Each of the four treatments in every block were separated by a maximum of 0.5 km, varied in elevation by less than 10 m , and were within 50–150 m from the unburned forest edge. The three blocks varied in elevation by less than 200 m (2900–3100 m), and were separated by a maximum of 3 km (Fig. 1). The average slope of transects on northern aspects was 18.5° and 13° on southern facing aspects. Dominant overstory vegetation, canopy height, and density were uniform between north and south facing aspects within blocks (Fig. 2).

2.3. Snowpack sampling

Snow depth, density, and snow-water equivalence (SWE) were collected the first week of March (estimated peak snowpack) in both the 2015–16 and 2016–17 winter seasons. Actual peak snowpack occurred Feb 24th in 2016 and March 6th in 2017 according to the Kimberly Mine SNOTEL station approximately 8 km away (Fig. 1).

Snow depth was taken along two parallel one-hundred meter transects which were thirty meters apart within each treatment plot (Figs. 1 and 2). Every five meters along each transect, depth measurements were taken in front, behind, to each side using a 2.5 m graduated depth pole (Veatch et al., 2009). Vegetation regeneration across the burned transects was limited to aspen and did not interfere with snow depth measurements; any portion of transect that fell within a tree well in either burned or unburned plots was measured and counted.

Density and SWE were measured using a standard US Federal snow sampler every 25 m on one of the two transects in each treatment totaling five measurements per plot. Standard protocol for measuring snow density and SWE found in the USDA snow survey sampling guide was used (USDA, 1984). When a density sampling point landed in a tree well or if regenerating vegetation was present beneath the snow surface, the sampling point was moved one meter to the side until the sample point was no longer touching regenerating vegetation or within one meter of a tree well. All samples were collected on clear days between 9:00 and 16:00 h and within 48 h of one another in each year.

2.4. Snow ablation

To capture continuous snow accumulation and ablation throughout the 2016–2017 winter season, time triggered cameras were placed in each of the four treatment plots within each of the three blocks for a total of 12 camera locations. While cameras were able to capture daily snow accumulation and ablation rates, they were unable to quantify sublimation or evaporation. Snow that is sublimated or evaporated