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Keck Geology Consortium: Projects 2014-2015
Short Contributions— Fire and Catastrophic Flooding, CO Project

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BURN SEVERITY EFFECTS ON HILL-SLOPE SOIL CHARACTERISTICS AND LOCAL VARIATION FOUR YEARS AFTER THE FOURMILE FIRE, BOULDER COUNTY, CO

OMAR KAUFMAN,Carleton College
Research Advisor: Mary Savina

INTRODUCTION

Fourmile Creek is located in the Colorado Front Range and flows into Middle Boulder Creek four miles outside historic Boulder. The study area is primarily underlain by granitic and high-grade metamorphics of sillimanite grade (Dethier et al., 2014). The Fourmile creek eroded into uplifted bedrock following the Laramide orogeny (Anderson et al., 2006). Bedrock is exposed on canyon slopes and locally along Fourmile Creek. The area has been heavily altered with mine tailings, waste rock, and construction remnants scattered through the watershed (Graham et al., 2012; Writer et al., 2012).

From September 6-10 2010, the Fourmile Canyon burned. According to the USGS, 23 percent of the 2,600 hectare watershed was burned by a mixed severity fire (Graham et al., 2012; Writer et al., 2012). This fire burned through the lower portions of the watershed, leaving the soils and vegetation of the upper watershed unaltered by the fire. The impacts of fires can vary dramatically, with burn severity quantitatively and qualitatively measuring these effects (Bento-Goncalves et al., 2012; Keeley, 2009; Parsons, 2010). Burn severity is characterized by unburned, low burn, moderate burn, or high burn for each location. Burn severity was measured by satellite using the “difference Normalized Burn Ratio” (dNBR) at a resolution of 30 $^{\text{m2pixels}}$ (Ebel et al., 2012; Keeley, 2009; Key and Benson, 2006). This burn severity assessment was ultimately utilized to determine erosion remediation strategies and areas of interest after the burn (Graham et al., 2012). The Black Tiger Fire of 1989, also considered in this paper, burned mostly in adjacent watersheds (NFPA, 1992). These two fires were major burns that have dramatically altered the vegetation and soil of Fourmile Canyon (Calkin et al., 2014; Dickinson, 2014).

When a landscape burns, the soil and associated systems can be dramatically altered. Fires remove organic material from the landscape, which leaves the soil bare and unprotected from raindrop impact (Robichaud, 2000; Shakesby et al., 2003; Shakesby and Doerr, 2006). Moreover, hydrophobic substances are vaporized during a fire and are driven down into the soil, where they reform a lower, hydrophobic layer (DeBano, 2000). These characteristics ultimately lead to the destabilization of hillslope soils and increased erosion following fires (Cerda and Doerr, 2008; Stoof et al., 2015). As material is transported over the landscape, soils and their characteristics can easily change.

Understanding how fires affect soils on greater time scales is important for understanding how landscapes change. The recovery of moderately burned areas is not identical with that of highly burned soils. Four years after a fire burned a ponderosa pine forest in Arizona, moderately burned areas had dropped down to normal levels of runoff, the same study showed runoff on highly burned soils increased over three orders of magnitude relative to the control immediate after the fire and remained an order of magnitude higher four years after the burn (Campbell et al., 1977; Shakesby and Doerr, 2006). Another study found that runoff on the catchment scale remained elevated for the first three years following a fire and then began approaching control levels after five years (Mayor et al., 2007). In an 11-year study of revegetated, Mediterranean soils after fire, all soils lost their hydrophobic surface soil to erosion within six to twelve months (Cerda and Doerr, 2005).

METHODS

Samples were collected from lower Fourmile Canyon, Colorado in July 2014. Soils from the area of both the 2010 Fourmile fire and 1989 Black Tiger were sampled, as well as unburned areas (Fig. 1). Samples were acquired in groups of ten as either a transect or a “type” site. For transects, samples were collected every 5 m across boundaries between burn severity zones, perpendicular or parallel to the slope. “Type” site were used to broadly characterize different burn severity zones. These samples were taken in matrices of 2 by 5 meters with spacing every two m and the long axis of the grid perpendicular to the slope.

Samples were acquired using a tulip bulb sampler of diameter 7.5 cm and approximate length of 15 cm. Due to the rockiness of many of these soils, samples were taken within 0.5 m of the marked location. Samples represent areas where boulders or larger vegetation did not impede sampling. Maximum sample depth was 15 cm (length of bulb sampler); some samples were thinner because of impedance from rocks. Due to a general looseness of soil, samples were dug out from the downslope side and captured with a spade at the lower side of the tulip bulber.

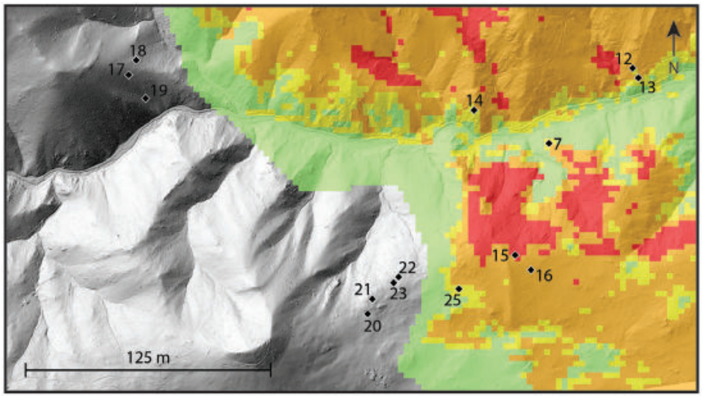

Figure 1. Map of Lower Fourmile Canyon. Burn Severity satellite data from Graham et al. (2012) is overlain on high-resolution digital elevation model. Red maps for high burn severity; orange for moderate burn severity; yellow for low burn severity; and, green for unburned. Areas beyond the extent of the satellite data were unburned in the Fourmile Fire. Sites 20 and 21 are within the extent of the Black Tiger 1989 fire.

Samples were dried and sieved using the Wentworth Phi system with 1ϕ (2 mm), 0 ϕ (1 mm), -1 ϕ (.5 mm), -2 ϕ (250 µm), and -3 ϕ (125 µm) sieves. Due to the absence of a -1ϕ sieve, an .589 mm sieve was used in its place. LOI was measured on the <125 µm fraction at ~550° C. For increased accuracy on LOI >10 g was used for each sample of at least that size in the <125 µm fraction. The diameters of the thickest roots were measured from those in the > 2 mm fraction. Fallout radionuclides were measured from the <125 micron fraction of five samples each from sites 21 and 22. For a more detailed description of methods see Abrahams contribution to this volume.

Site	Burn Severity	Aspect	Vegetation	Litter	Bioturbation	Burn Markings	Comments
15	High	NF	Shrubs, Grasses	None	None	Singed Regolith	Some Ash at surface
16	Moderate	SF	Grasses	Lichen	Gopher	Singed Regolith	
25	Low	SF	Trees, Grasses	Vegetation	Gopher	Burned Trees	Fire scars only on some trees
20	25-year Burn	SF	Trees, Shrubs, Grasses	Vegetation	Gopher	None	Buried organic at one sample
21	25-year Burn	NF	Trees, Shrubs, Grasses	None	Gophers, Ants	None	
17	Unburned	SF	Shrubs	Lichen, Needles	None	None	Downed tree crossed site
18	Unburned	NF	Trees	Lichen, Moss, Needles	Ants	None	
19	Unburned	SF	Trees, Shrubs	Needles	None	None	
22	Unburned	NF	Trees	Needles	None	None	Some samples with bleached horizons
23	Unburned	NF	Trees/Grasses	Needles	None	None	Directly downslope of extent of Black Tiger Fire

Table 1. “Type” site descriptions and observation characteristics (See Figure 1 for site locations).

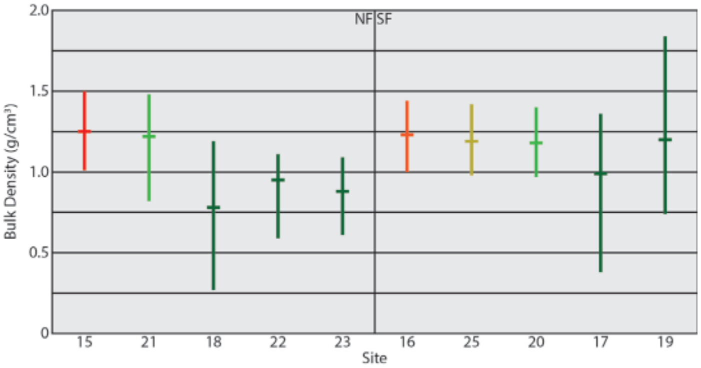

Figure 2. Bulk density graph of “type” sites. Each bar shows the range of results and the mean. North-facing sites are on the left, south-facing sites are on the right. See Table 1 for burn severity.

RESULTS

Ten type sites were sampled and observed covering a broad range of slopes and burn severities (Table 1). Grain size analysis showed no correlation between site and burn severity. Dry, bulk density of the soil was relatively elevated at sites both on north- and south-facing slopes (Fig. 2). South-facing slopes appear to have a higher concentration of larger particles compared to all burned sites (Black Tiger and Fourmile). Otherwise, grain size distribution shows no significant difference across sites. LOI records significant differences on north-facing slopes (Fig. 3). The average LOI for the high burn site is 6.70%, with a range of 5.61% to 8.06%. Both the Black Tiger site and the three unburned sites record averages significantly higher LOI (11.65%, 20.68%, 10.13%, 12.14%) with only one site having an overlapping range. While south-facing slopes have average LOI lower than unburned slopes, the ranges overlap. Average root thicknesses show similarly muted results. For north-facing sites, root thickness shows average values lower for high burn and Black Tiger burn sites (.5 mm, 1.4 mm) compared with unburned sites (1.7 mm, 1.9 mm, 2.3 mm). South-facing sites do not show any significant difference; the lowest average root thickness was at an unburned site. Radionuclide data were found for sites 21 and 22, a 25-year-burn, north-facing slope and an unburned, north-facing slope, respectively. Site 22 has remained unburned for at least 120 years, shown by Ponderosa pine cores showing 124 and 117 years of growth rings. Radionuclide data for sites 21 and 22 show no significant variation in concentrations of ^{226}Ra, ^{210}Pb, and ^{137}Cs (Fig. 4).

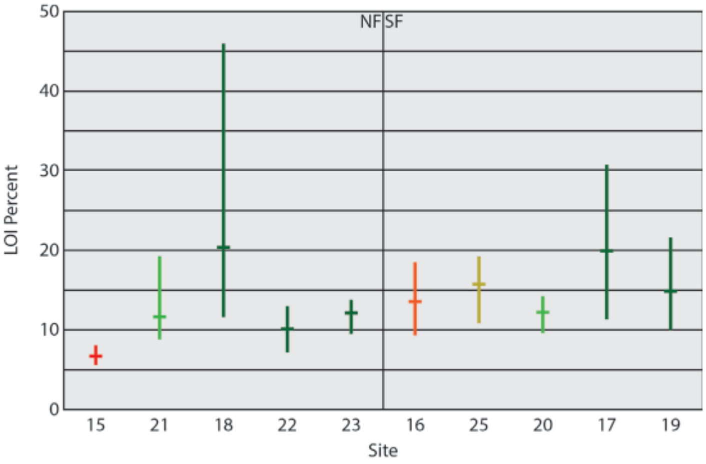

Figure 3. LOI by percent graph of "type" sites. Each bar shows the range of results and the mean. North-facing sites are on the left, South-facing sites are on the right. See Table 1 for burn severity.

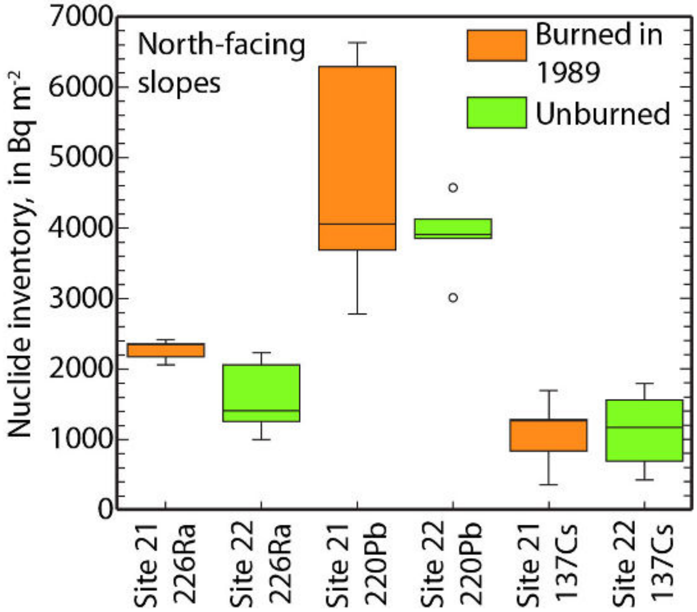

Figure 4. Box plot of radionuclide concentrations for Site 21 and 22. Concentrations of show median, quartiles, minimum, and maximum ranges for ^{226}Ra, ^{220}Pb, and ^{137}Cs. Outliers are marked with empty circles.

Transects recorded some variation in data across boundaries. Transects 12 and 14 were perpendicular to the slope and crossed boundaries between low and moderate burn sites. Transect 13 was the same except parallel to the slope. These sites recorded no significant differences across the transect for root thickness, grain size, LOI by percent, and organic/A horizon depth. Transect 7 crossed unburned and high-burned areas on the north-facing slope. LOI by percent, grain size, and root thickness did not vary significantly across the transect. However, organic/A horizon depth became thinner within the high burned area with distance from the boundary. This transect was also mapped as entirely within a low-burn severity pixel by satellite data.

DISCUSSION

Data from this study indicate that transects across burn severity zones correspond moderately well to on the ground differences four years post fire. While the accuracy of dNBR measurements recorded immediately after a fire have been questioned (Roy et al., 2006), the greatest inconsistencies have been shown to be across varying vegetation types (Allen and Sorbel, 2008). Given that many studies have focused on vegetation terrains consistent with our field area, its likelyetation (Cocke et al., 2005; Miller and Thode, 2007; Odion and Hanson, 2006). This data set is consistent with findings showing that the dNBR is relatively more accurate at high burn severity and that it's main weakness is along perimeters (Cocke et al., 2005; van Wagtendonk et al., 2004). These relationships hold up with time. Immediate post-fire dNBR has been shown to be relatively comparable to dNBR data 1-year-post burn (Lentile et al., 2009). While the comparison proved statistically significant, in the study by Lentile et al. (2009), the 1-year-post-fire burn severity data distinguished least well between low and moderate burn. Similarly, our data show that low and moderately burned sites can be relatively indistinguishable, while the highly burned site records the strongest differences in most tests (Fig. 2,3).

These samples also reveal that local variance can affect how burns influences the soil. For tests such as LOI and bulk dry density, the high burn site had noticeable differences from the controls. Because high burn was only sampled on the north-facing slopes, these differences may not hold up on the south-facing slopes, where there is less vegetation, litter cover, and organic matter for fires to remove. However, distinctions between sites were only observed in certain tests. The elevated bulk dry density of burned sites (Fig. 2) could be due to the removal of light-weight organic matter and/or the removal of lighter particle by erosion due to exposure post-burn. However, the broad and overlapping range of bulk density results from a single site could be accounted for by many different factors; soils could have been different pre-burn, the soils burned differently, and/or recovered differently over the following four years. Similar ranges in LOI results could be accounted for in these ways. Our samples are also confounded by dilution due to depth of sampling. The effects of fire on soils are often limited to the upper 5 cm of the soil (Stoof et al., 2013). Because samples were taken at varying depths, local variation in some tests could be accounted for by different levels of sample dilution due to depth.

For fallout radionuclides, the variance between samples was not significant. These were done for both site 21 and 22 (North-facing, Black Tiger burn and North-facing, unburned respectively). As these samples do not show significant variations in ^{226}Ra, ^{210}Pb, and ^{137}Cs for each site, we can draw the initial conclusion that fire and erosion do not greatly affect concentrations of fallout radionuclides on relatively low slopes. However, these initial results from only ten samples out of the entire study, must be confirmed by analysis of more sample sites.

CONCLUSIONS

1. Four years after the fire, burn severity inferred from satellite data is still most consistent with ground observations furthest from the boundaries. Differences between low and moderate burns are nearly negligible in the field after four years of recovery.

2. The average LOI and bulk dry density over a single site may reveal long-term differences between burned and unburned soils. However, significant local variation in many soil characteristics show that a single sample can look significantly different from the mean.

3. Preliminary radionuclide measurements suggest that there is no significant difference in the effect of fire and erosion across two sites, one burned and one unburned in recent history.

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