THE IMPACTS OF SOIL PROPERTIES ON MIXED CONIFER SEEDLING RECRUITMENT IN THE POST-FIRE ENVIRONMENT OF EASTERN OREGON

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Abstract

Climate change is increasing the frequency and severity of fires, especially in the Western United States, making it pertinent that tree regeneration rates and causes are understood. The goal of this research is to assess the impacts of post-fire environments on seedling regeneration in dry conifer forest of eastern Oregon's Blue Mountain Ecoregion. Specifically, I seek to determine whether soil properties determine successful seedling recruitment. In the summer of 2016, sixty-eight soil samples from across four different fires in the Blue Mountain Ecoregion were collected to analyze for total carbon, total nitrogen, and pH. The soil variables were compared with additional independent variables of fire severity and slope aspect. Over 16 to 20 years after the fire, north-facing sites and low burn severity sites had more seedlings than south-facing and high burn severity sites. Significant differences were found between seedling counts and soil properties, though older seedlings were found more often in soils with lower pH. These findings will be useful to forest managers who seek to determine the microsite conditions that promote natural post-fire conifer regeneration.

KEY WORDS: seedling regeneration, soil properties, fire, aspect, fire severity, carbon, nitrogen, pH

Table of Contents

Figures and Tables

Preface

My underlying interest in forest ecology and conservation has always been with me – ever since my childhood in the great tree-covered state of Michigan. Then I moved to Colorado, and I had never realized the full impact that fire regimes have on Western forests until the summer of 2016, when I assisted in collecting field data for Angela Boag’s Ph.D. research. I had the privilege of both collecting my own samples and getting to know my study area of eastern Oregon very well, piquing my interest in the subject even more. Through this project I have gained a wide range of skills that will forever contribute to my career in environmental science.

Acknowledgements

This research and honors thesis would not have been possible without the knowledge and resources of my committee: Eve Hinckley, Joel Hartter, and Dale Miller, to whom I am grateful for providing support and encouragement I needed. A very special thank you goes to Angela Boag, who showed me the forests of Oregon and the world of environmental science, but most of all, shared a tent with me for three months. Wendy Roth and the Institute for Arctic and Alpine Research's (INSTAAR) Sedimentology Lab generously offered space, a breadth of knowledge, and assistant with soil analyses. Kathryn Snell's Stable Isotope Lab also provided assistance with my research and much needed materials. To others who assisted me in the lab, primarily Andrew Gentry and Lauren Zappaterrini, I could not have done it without you. I would like to acknowledge everyone in the Environmental Biogeochemistry Group for both helping me in the lab and with my analyses. My research was made possible with the support of the Undergraduate Research Opportunities Program (UROP) at the University of Colorado partially funding my research. This work is supported by the United States Department of Agriculture (USDA) National Institute of Food and Agriculture (NIFA) (2014-68002-21782). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author and do not necessarily represent the views of NIFA or USDA. Special thanks to Paul Oester at Oregon State University Extension Service, and Nils Christoffersen of Wallowa Resources, as well as the Communities and Forests in Oregon (CAFOR) project for their support and resources. Lastly, I thank my mother for the opportunity to go to college and for the inspiration to continually push myself.

Introduction

Soil is the blueprint of an ecosystem: when examined closely, it tells you information about the structure of the surrounding environment. It can reveal information on water retention, nutrient loads, and overall structural makeup, which in turn affects the vegetation that is able to thrive on the landscape. These complex systems are disturbed in the presence of wildfire, which not only affects the vegetation, but affects the soil as well. This is especially true in the Blue Mountain ecoregion of inland eastern Oregon, where high intensity fires ravish the landscape every summer as a result of a lifetime of human forest management that has altered the fire regimes of the area (DellaSala et al., 1995). As climate change intensifies, so do wildfires in both frequency and severity, potentially causing a forest regime shift in Western landscapes (Johnstone et al., 2016). A result of resilience declines, seedlings may experience recruitment failures due to the larger variability of climate and disturbance interactions (Johnstone et al., 2016). Worldwide, conifer seedlings are failing to regenerate in some areas as climate change impacts tree mortality through intensifying disturbance impacts (Dale et al., 2001).

Overall, post-fire seedling regeneration in conifer forests tends to occur in the short time frame immediately following the fire event (Turner et al., 1999). However, with disturbance regimes changing, drought is becoming more common: summer precipitation in the northwest US is expected to decrease as much as 30% by the end of the century (EPA, 2016). Disturbance interactions, like the combination of fire and drought, can be detrimental to seedling health. Drought, an abnormally low presence of precipitation for a season or more, when immediately following a fire event can significantly reduce the post-fire seedling regeneration densities (Harvey et al., 2016; Rother et al., 2015). This study looks beyond the broader scope of climate to determine if wildfires are having long-term impacts on soil, which in turn may have an impact on seedling recruitment.

The impacts of fire on forest recruitment have been shown across several studies; in Quebec, Canada, the highest severity fires show the lowest seedling regeneration counts (Jayen et al., 2006). In the Blue Mountain ecoregion specifically, only 10% old growth cover in the region is still intact, making seedling regeneration essential to preserve biodiversity of species and forest structure in the area (Henjum et al, 1994). This mixed-conifer forest transition is largely attributed to fire suppression, influencing the state change from a structure of *Pinus ponderosa* (Ponderosa pine) old growth forests with grassy understories, to high-density fir stands that burn more frequently and more severely (DellaSalla et al., 1995; Henjum et al., 1994). Few studies have investigated both disturbances and multiple biophysical characteristics like aspect and soil to determine whether soil properties are a contributing factor to reducing natural seedling regeneration following wildfires of varying severity.

The purpose of this project, in conjunction with the Communities and Forests in Oregon (CAFOR) project, is to understand how different soil properties contribute to seedling recruitment in post-fire environments of eastern Oregon. The goal of this research is to inform the CAFOR project by indicating whether or not soil properties like carbon (C), nitrogen (N), and pH, influence forest regeneration in study areas controlled for aspect and fire severity. These data will contribute to a larger project addressing the impact of environmental disturbances on ecological resilience (Boag, unpublished). This knowledge and connection of soil properties to seedling regeneration is important to study in order to develop a holistic understanding of factors affecting seedling regeneration, especially with evolving climate change effects, disturbance regimes, and changes in human use of the landscape.

To fill this knowledge gap, my research asks the questions:

1) How do various chemical and physical soil properties affect seedling recruitment and growth in wild fire affected areas? 2) What site characteristics, such as burn severity and topography, change soil properties to promote seedling recruitment and growth in fire prone landscapes? I hypothesize that if burn severity is classified as high in a site, it will have lower seedling regeneration due to lower soil C and N, but higher pH values. I also hypothesize that north facing sites will promote more seedling regeneration with higher C and N quantities and lower pH values.

Background

In 2015, two all-time global monthly temperature records were broken, including the first time that a record had been shattered by a 2-degree Celsius difference (NOAA, 2015). Global temperatures are on the rise and are drastically impacting climates like the Blue Mountain Ecoregion of Oregon. An impact of climate change, wildfires are projected to become more frequent and plants are expected to decrease growth due to higher temperatures (Enright et al., 2015). This trend has also affected soil microbial community composition, activity, and rates of biogeochemical processes (Knelman et al., 2015). Approaches to use integrated management techniques in western forests can benefit from information from wildfire-prone landscapes, in order to increase seedling regeneration rates and lower the impacts of fire disturbances across the West.

Along with more recurrent fires, fires are beginning to burn hotter and longer, strongly correlated with temperature change and earlier snowmelt (Westerling et al., 2006). As this trend continues, there are smaller and smaller fire free periods available for seedlings to establish themselves before the next one burns (Enright et al., 2015). This reality is paired with the fact that woody plants are not able to produce as many seeds in a hotter climate, resulting in fewer chances for seedling survival (Enright et al., 2015). There are limitations to how much heat the stored seeds in the ground can take, as seed banks often die out in high severity fire events (Malik, 2003). The correlation between low seedling regeneration and increases in wildfire presence demonstrates how climate change is actively impacting forests. It is essential to know the natural factors that cause seedling recruitment and where we can predict regeneration, in order for forestry management projects to be put into place to lessen the effects of climate change.

Soils supply essential components to sustain plant life, such as air, water, nutrients, and structural support, making them the backbone of ecosystem life (Neary et al., 2005). The soil can give us an idea of which species could inhabit a site naturally and the capacity of the soil to hold various states of succession. Mollisols are a common soil type of the Blue Mountains occurring in the transition zone between grassland and forest at moderate to high elevation ranges (Franklin & Dyrness, 1973). These high elevations were primarily covered in forest in the past, but with drought and fire occurring more frequently, the Mollisol order (typically a shallow soil) may be less able to hold seedlings as they grow (Meganck, 2017; Franklin & Dyrness, 1973; DellaSalla et al., 1995).

The most important layer of soil for establishing seedlings is the organic horizon at the surface – which is also the layer that is most exposed to wildfire. While wildfire can be beneficial to the recycling of nutrients in the soil and aiding in the decomposition of organic matter, this only has positive impacts up to a certain heat tolerance and severity. The trend of higher severity fires is a major key for evaluating how damaged the soil can be: the higher the severity, the hotter the soil becomes, leading to more volatized nutrients (Neary et al., 2005). Post-fire, trends show that the C and N loads typically increase due to the breakdown of nutrient rich materials in the organic material on the surface (Hough 1981; Neary et al., 2005). The increase in nutrient load is reflected in the site productivity of plant life. Although lower severity sites experience productivity increases, high severity and frequent fire sites may experience lower seedling regeneration as a result of lower quantities of C and N in the soil (Enright et al., 2015; Jayen et al., 2006; Neary et al., 2005).

Soil pH is linked with nutrient availability for plant use in the 6-7 range of pH (acidic), and pine dominated forests typically have acidic pH because of the needles that fall onto the ground (SUNY, 2017). After fire events, pH typically increases with high intensity (temperature) fires, and can overshoot the ideal pH range (Neary et al., 2005). In a study on coniferous trees in Wisconsin, soil pH had a significant negative correlation to tree growth, exemplifying the preference of many coniferous species for acidic soil conditions (Rawinski et al., 1992). Fire changes the elemental composition of nutrients in the soil and the positive effects of fire on plant life are shown to have a possibility of decreasing when the severity and frequency of fires increase (Enright et al., 2015; Jayen et al., 2006; Rawinski et al., 1992; Knelman et al., 2015; Neary et al., 2005).

In terms of slope aspect, north-facing slopes typically have up to 5 times more soil C and N than south-facing slopes (Kunkel et al., 2011). In dry environments like eastern Oregon, the south-facing slopes are generally water limited as southern aspects receive the most direct sunlight, therefore more vegetation grows on northern slopes, which is also reflected in higher C and N on north aspects (Kunkel et al., 2011). With lower pH associated with higher conifer tree densities on northern slopes, south aspects are likely to have higher pH measurements and lower seedling counts (Maren et al., 2015). Based on the fact that southern slopes are hotter and drier, one would predict that high severity fires happen more frequently across south aspects; however, less trees present means that there is less vegetation to burn to create higher severity fires.

There are abiotic factors that influence where particular species are found as well. Abiotic disturbances such as fire are one of the biggest determinants of seedling regeneration in forest landscapes (Baeza et al., 2007). Fire itself can even change the composition of species on a hillside, as more serotinous species, like *Pinus contorta* (Lodgepole pine), are typically fast-growing trees that can outcompete other species by growing in high density stands post-fire and can make a forest more homogenous, transitioning to a different forest structure (Romme et al., 2016). With changing precipitation regimes, it is important to note how water can be a limiting or propelling component of seedling recruitment, in an already dry region like the Blue Mountains, drought periods are more significant and influxes of precipitation can cause growth spurts (DellaSalla et al., 1995). Also, hotter temperatures are effecting higher elevations and creating harsher conditions for seedlings to grow, especially dependent on the slope aspect of a fire (Johnstone et al., 2016; Kunkel et al., 2011). Site characteristics such as elevation, aspect, temperature, and rainfall can determine whether a site would normally see more seedlings or not, which is important to note because this can determine vegetation locations and confound studies of soil effects on vegetation (Baeza et al., 2007).

Another impact of increased fire intensity and severity includes the potential for soil erosion, the “most immediate consequence of fire” (Moench & Fusaro, 2012, p. 1), which worsens with fire severity as roots and plant material holding the soil disappear (Moench & Fusaro, 2012; Dale et al., 2001). Other potentially detrimental effects of fire that can harm seedling regeneration are impacts like hydrophobicity, which makes the soil repel water from the surface level layer and can cause difficulty for surviving plants to obtain water as well as for seeds to regenerate (Moench & Fusaro, 2012).

Altered forest communities can be influenced heavily by fire and soil characteristics like C, N, and pH, often closely linked with burn severity. In this study, we test for relationships between conifer seedling abundance post-fire and pH, C, N, burn severity, and aspect. The biological processes that determine soil productivity have important repercussions on the seedling regeneration that we see in our forests (Harvey et al., 1994). The broader impact of my research is situated around the importance of soil properties for seedling recruitment in relation to forest management.

Methods

Sample Design

All data samples were collected in the Blue Mountain ecoregion in eastern Oregon. The elevation of the samples ranges from 876-m to 1,569-m, in what would generally be classified as once forested (if burned) or currently forested land.

Table 1: Site description by fire parameters.

Fire Name	Acres Burned	Cause of Fire	Year	National Forest	Drought Post-Fire
Hash Rock	18,000	Lightning	2000	Ochoco	Yes
Wheeler Point	21,980	Logging	1996	Umatilla	No
Bridge Creek	4,300	Camp fire	2000	Ochoco	Yes
Tower	50,650	Lightning	1996	Wallowa-Whitman	No

Sites were either north or south-facing with a focus on high or medium burn severity, as well as low severity sites as controls (in order to determine what regeneration would look like in a “normal” forest plot). Figure 1 displays the perimeters of the fires with each soil data sample point. Figure 2 shows pictures from each burn severity class in order to visualize what the terrain was like. These sites occurred across four fires, two from 1996 that had three normal precipitation years following the burn, and two from 2000, which saw a period of drought post-fire.

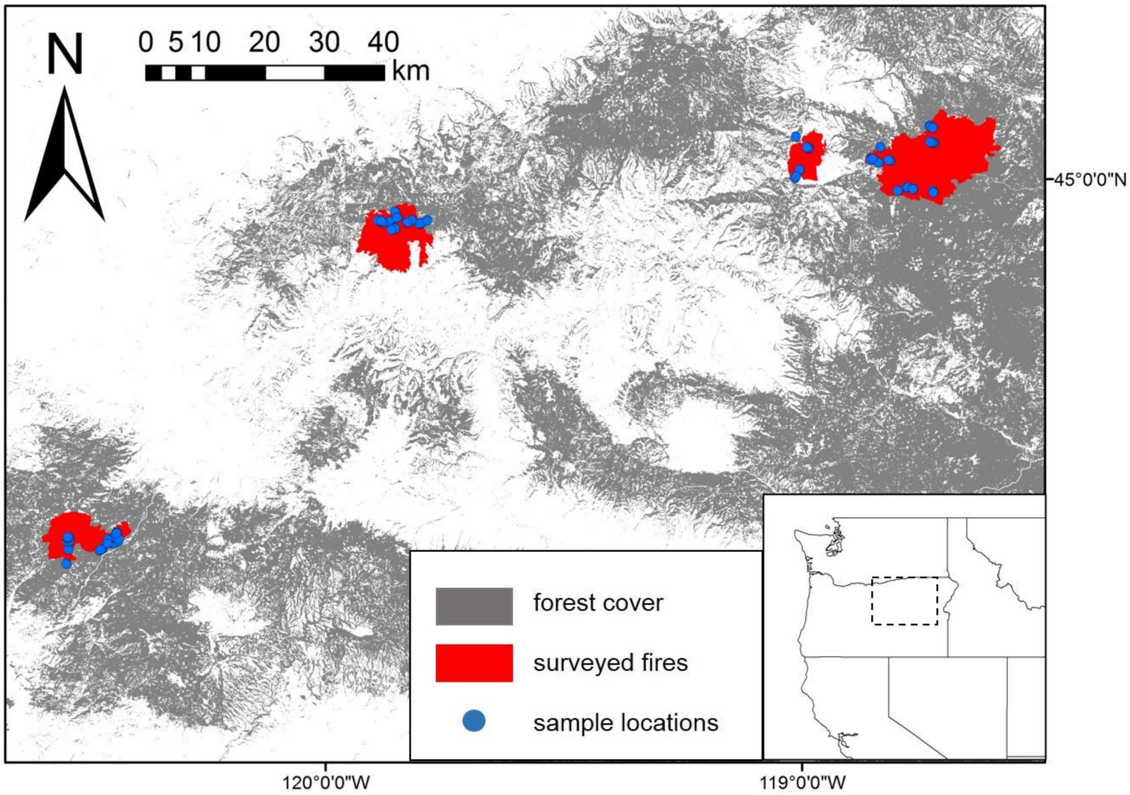

Figure 1: Site samples plotted within fire scar. From east to west the fires are as follows: Hash Rock, Wheeler Point, Bridge Creek, and Tower fire (Boag, unpublished).

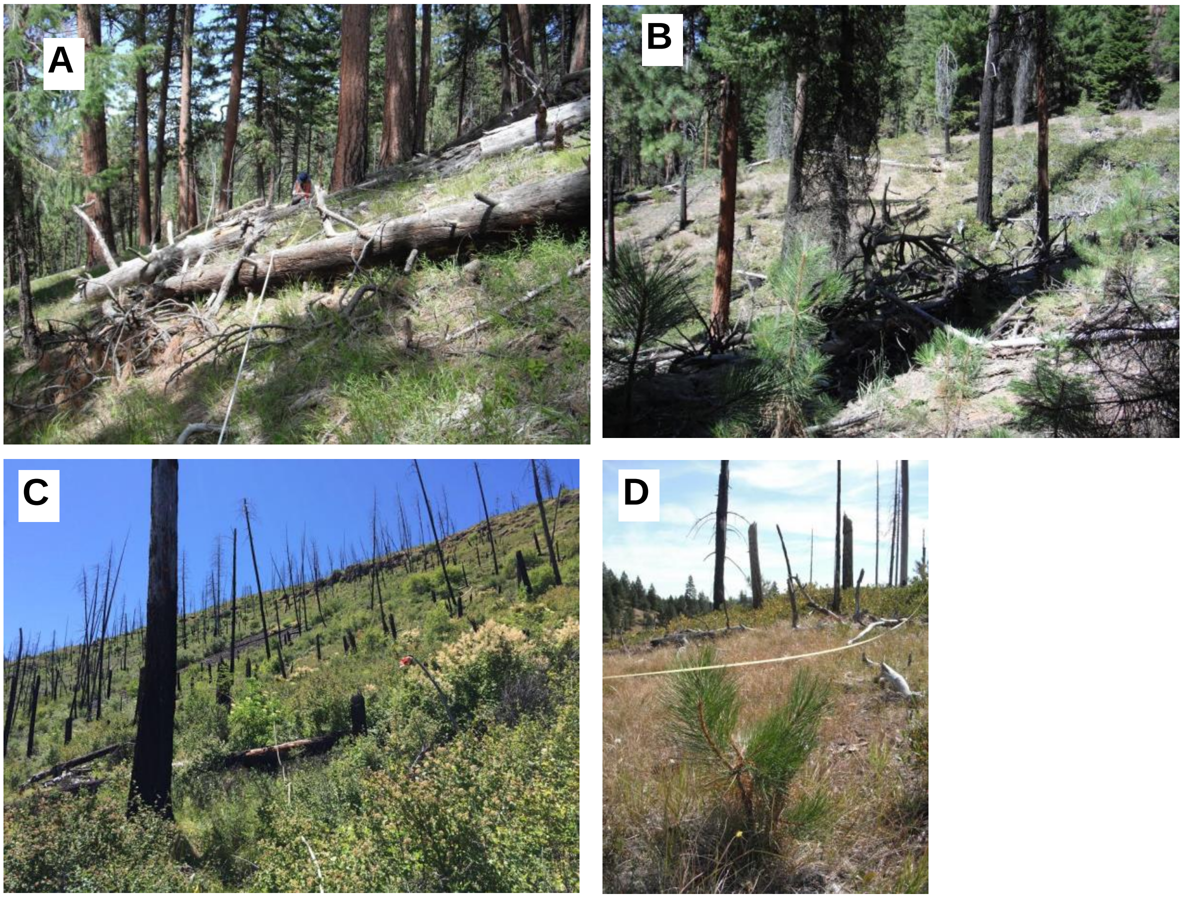

Figure 2: Photos showing example sites of: A. low burn severity, B. medium burn severity, C. high burn severity, and D. an example Ponderosa pine seedling. All photos are from 16 or 20 years after the fire event.

Site Selection

The state of Oregon still has an active timber industry despite declines in recent years (DellaSala et al., 1995). Sites were therefore heavily controlled for salvage logging, which limited our sites often to remote areas with steep gradients. An impact of the timber industry and erosion control, much of the forest is aggressively replanted post-fire, and we only sampled in unplanted sites.

Burn severity was assessed visually and by GIS of mapped severity (MTBS, 2016). All sites were categorized into three classes of severity: high (majority of trees in the stand are dead due to wildfire), medium (approximately half of the trees are dead due to wildfire), and low (almost no trees dead due to wildfire). Severity is typically assessed only using the tree data in the forest and not assessed by soil properties. All of the low severity sites are control sites to assess seedling regeneration in the absence of substantial over story mortality, while the study is intended to focus on the impacts of high and medium severity fires.

Sample Collection

Between June and August 2016, approximately 24 sites were measured per fire with a minimum of 120 meters in between them. Using a 2-m by 60-m belt transect we counted all seedlings (<1.5-m in height) by species and randomly sampled up to 25 seedlings (five closest to the center tape in each of six 10-m sections) for height and whorl count (indicator of seedling age) measurements. To gather the soil samples, I scraped away the surface litter and dug a minimum of 15-cm, picked out any large rocks and placed the remaining samples in brown paper bags to air dry. Due to limited access to coring tools, I used a gardening shovel and typically dug a diameter of 10 -12-cm. Each sample was collected within one meter of the center of the belt transect and the GPS point location was recorded for each. I collected a total of 78 soil samples from these sites that correspond with the seedling data; of these 10 were duplicate and mislabeled samples and could not be used, bringing the sample size down to 68. The soil data I collected corresponded with the forest inventory data by site ID.

Lab Sample Preparation

All soil samples were air dried for a minimum of a month and a half from the collection date until lab work began in October 2016. Soils were then sieved to </= 2mm in preparation for analysis. The soils that did not break down enough to fit through the 2mm sieve screen were soaked overnight in distilled water and then placed in the freezer around -18 degrees Celsius. From there they were freeze dried in the lab for a total of 36 hours at 100-mTorr or less in order to break up the larger clumps of aggregated, high clay content soil. The remaining soil was weighed and sieved again, and thoroughly mixed back into each sample. Each sample was divided into subsamples to run tests on the soil's total C and N, and pH. Standard lab procedures were followed for each test to uniformly assess each soil property (Davey, 2008; UCSC, 2008).

Carbon and Nitrogen Analysis

For an elemental C and N analysis, I used a flash elemental analyzer and Delta V mass spectrometer, which determine the concentrations of total C and N, as well as stable isotope information. With limited time, I was unable to use the isotope data and saved the information for future potential use. To prepare my soils, which have already been sieved, subsamples were weighed between 2 and 3 grams each and placed in small vials with metal balls and rods in order to pulverize the soil into a flour-like mixture.

The next step was to weigh and pack the samples to go into the elemental analyzer. The target weight for my samples was approximately 33-mg, as calculated with the percent of N present in a test sample of one of my soils run in the Arikaree Environmental Laboratory. The target weight per sample was weighed out and placed in little tin capsules that are folded down to sizes and placed in 96 well plates. Standard soil samples with known C and N values were ran every 4 samples, to ensure calculate instrument drift. Before each run, at least 5 samples of the standard were run at different weights to encapsulate the expected range of C and N values. These linearities create a slope equation that is applied to the rest of the run to calculate the total percent weight of C and N. Due to the high C content in the samples, the machine had to heavily dilute the C measurements in order to be able to compare the standard values to the sample values. This total weight percent data was cross-referenced with burn severity and seedling presence and counts near the sample site to determine any significant differences between variables.

pH Analysis

Lastly, I measured soil pH of each sample. A 10-g subsample of soil was soaked in 20 mL of distilled water for 5 minutes and continually then stirred 4 to 5 times over 30 minutes. Then, the soil settled for 30-60 minutes prior to the reading. Predicted to be acidic soil (due to the presence of pine trees), the electrode probe was calibrated between 4 and 7 pH with lab buffer solutions, and did not have to be recalibrated because no soils were above the neutral range.

Statistical Analysis

The data was all entered into an Excel document and analyzed in R to determine the trends in the data. I used non-parametric Kruskal-Wallis, Dunn and and Wilcoxon tests to test relationships among categorical variables and seedling counts due to the non-normal distribution of the seedling count data. Zero-inflated Poisson regression models were also used to analyze relationships between seedling count data and the continuous variables (Boag, unpublished).

Results

Variation in soil C, N, and pH does not appear to contribute to variations in total seedling counts. None of the soil characteristics varied between north and south aspects (pH, t test, $p > .05$; C, Wilcoxon test, $p > .05$; N, Wilcoxon test, $p > .05$). High burn severity sites had 31 seedlings present total, while medium severity had 616 total, and low severity had 505 seedlings total. There were some significant differences between specific burn severity classes and total seedling count (see below), but there were no significant relationships between seedling counts and soil properties. Of all the variables tested, only two relationships resulted in a significant difference between the variables: burn severity and seedling count, as well as whorl count and pH.

Initially, I used only seedling presence or absence (of any species) to test the effects of the soil and site variables because there was a large portion of sites that exhibited zero seedlings, which zero-inflates the data. Eighteen out of 68 sites sampled had no presence of any seedling at the site, and of those, 14 of the sites were in high severity burn areas. However, seedling presence and absence showed no significant differences in any test, so I also tested relationships between independent variables and total seedling count.

The total seedling count contained a maximum value of 235 seedlings in one transect, and a majority of sites exhibited either no presence or very low numbers of seedlings at all (Figure 3). The seedling species that appeared the most in our data and in the area of focus, was *P. ponderosa* and *Pseudotsuga menziesii* (Douglas fir), and both were tested against all the variables, but there was no significant difference in the chemical properties of the soil and the presence or absence of either species.

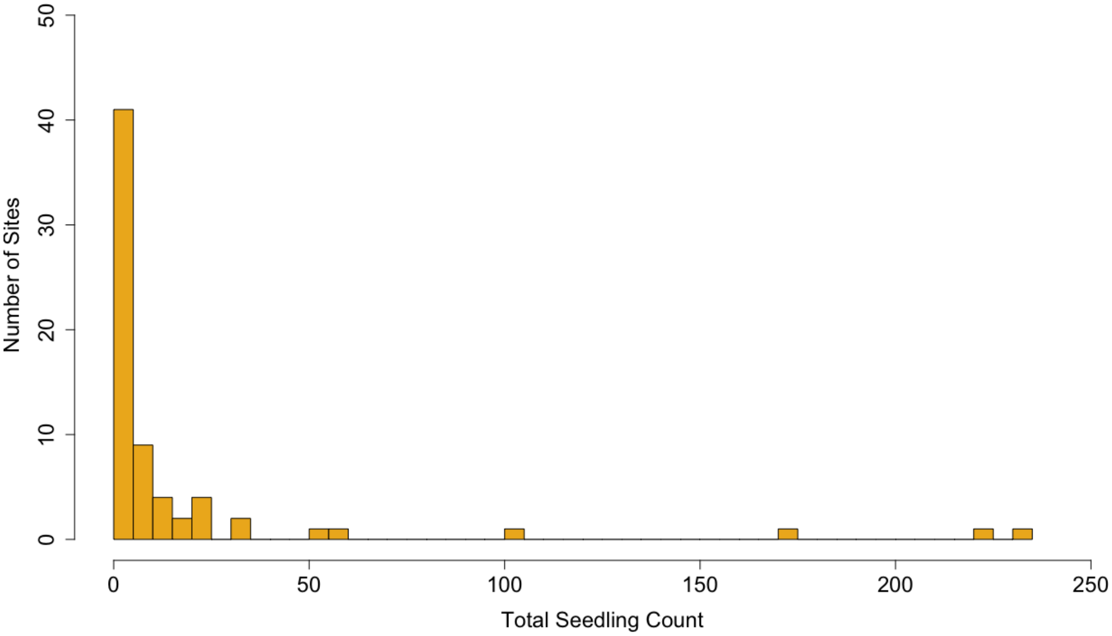

Figure 3: Site frequency of total seedling count.

Burn Severity and Aspect

I compared the total seedling counts against burn severity, with high severity fire sites experiencing lower seedling counts as predicted, and there was a significant difference in the amount of seedlings between high and low severity sites (Dunn test, Adjusted p value = .0003) with high severity fire sites experiencing lower seedling counts (see Figure 4). There was also a significant difference between high and medium severity sites and the seedling counts (Dunn test, Adjusted p value = .024). There were 31 high severity fire sites, resulting in an average of 2.8 seedlings at this severity, and medium severity sites had an average of 30.8 seedlings, with an average of 29 seedlings for low severity sites. There was an average of 36.59 seedlings counted on north-facing slopes, while south-facing slopes only saw an average of 3.77 seedlings (Figure

5). Total seedling count demonstrated significant differences between north and south-facing slopes (Kruskal-Wallis test, p = .0002). Each site was intentionally selected to be representative of equal amounts of north and slope aspect in this study, meaning any tests relating aspect and burn severity would not be valid analyses because the study was designed to show burn severity equally on both aspects, and was not randomly selected. Therefore we cannot statistically determine the relationship between burn severity and aspect through this research.

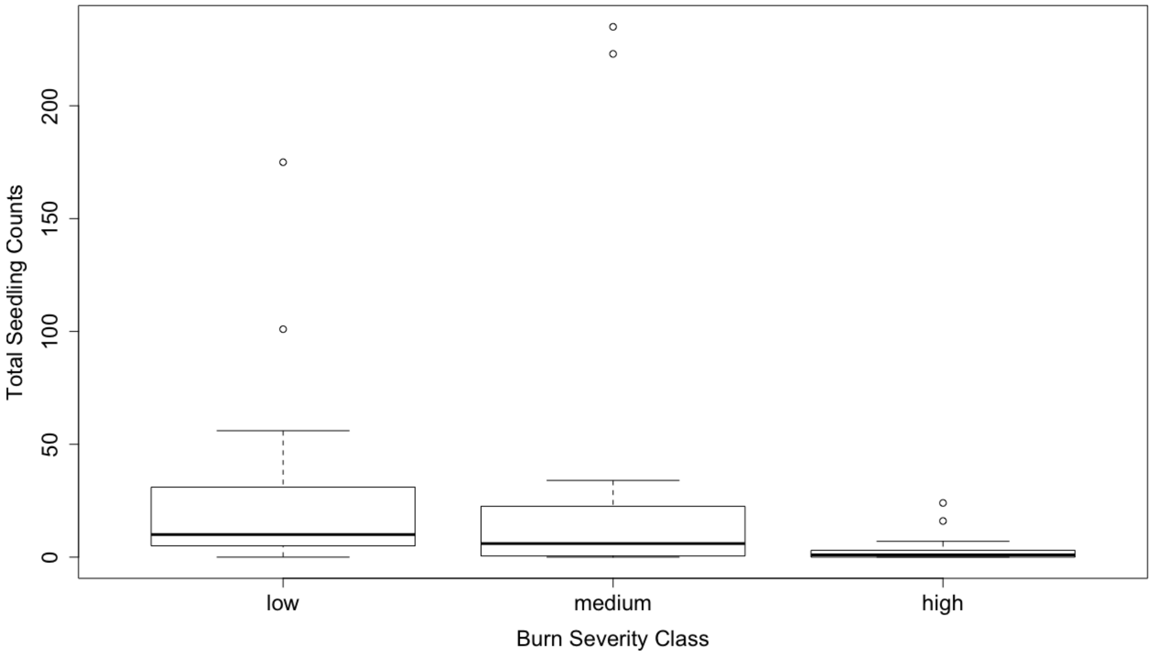

Figure 4: Burn severity and total seedling counts.

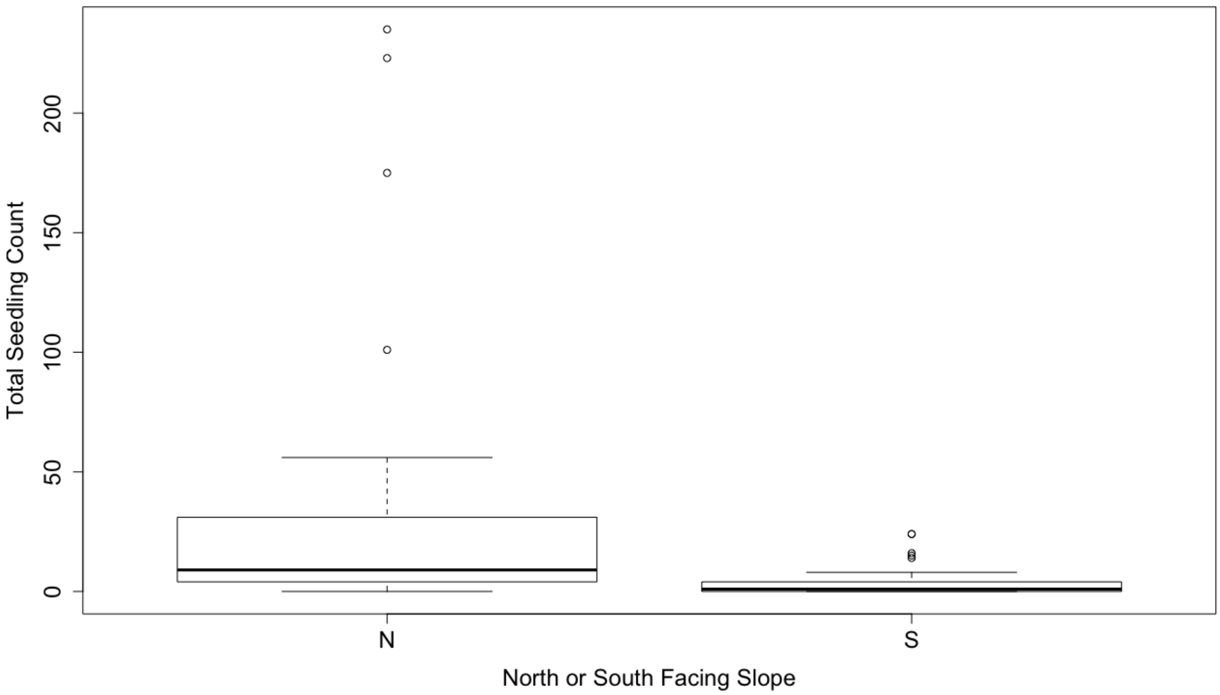

Figure 5: Seedling counts on North and South-facing slopes across.

pH

The measurements showed no statistically significant difference in pH between north and south-facing slopes (t test, $p > .05$). The average pH value across all fires was an acidic 6.52; the minimum pH value was 5.4 and the maximum was 7.89. The total seedling counts do not appear to show any correlation with pH (Figure 6).

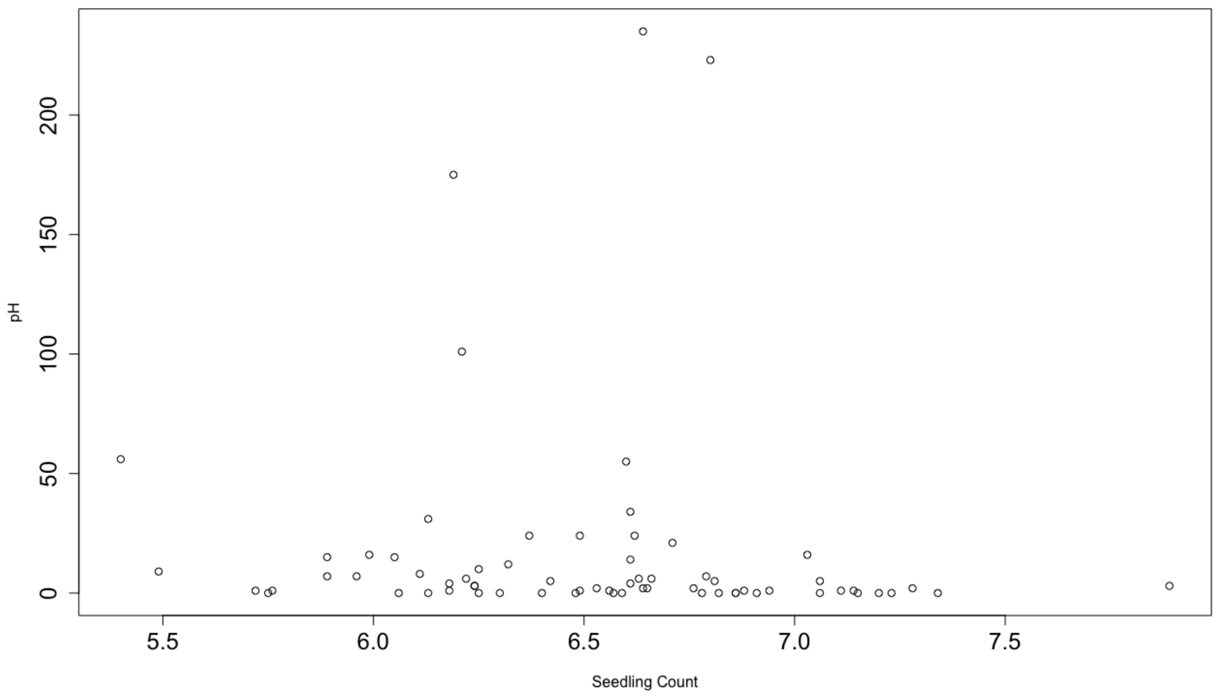

Figure 6: Seedling count vs. soil pH.

Carbon

Similar to the results of pH, the total seedling count is not related to C values when controlling for burn severity and aspect (zero-inflated Poisson model, $z = -0.279$, $p > 0.05$; Figure 7). Different categories of the other variables, such as aspect and burn severity, do not explain variation in the total weight percent of C in each sample. For example, seriously burned north slopes yield similar C values as the moderately burned south slopes (Wilcoxon test, $p > .05$).

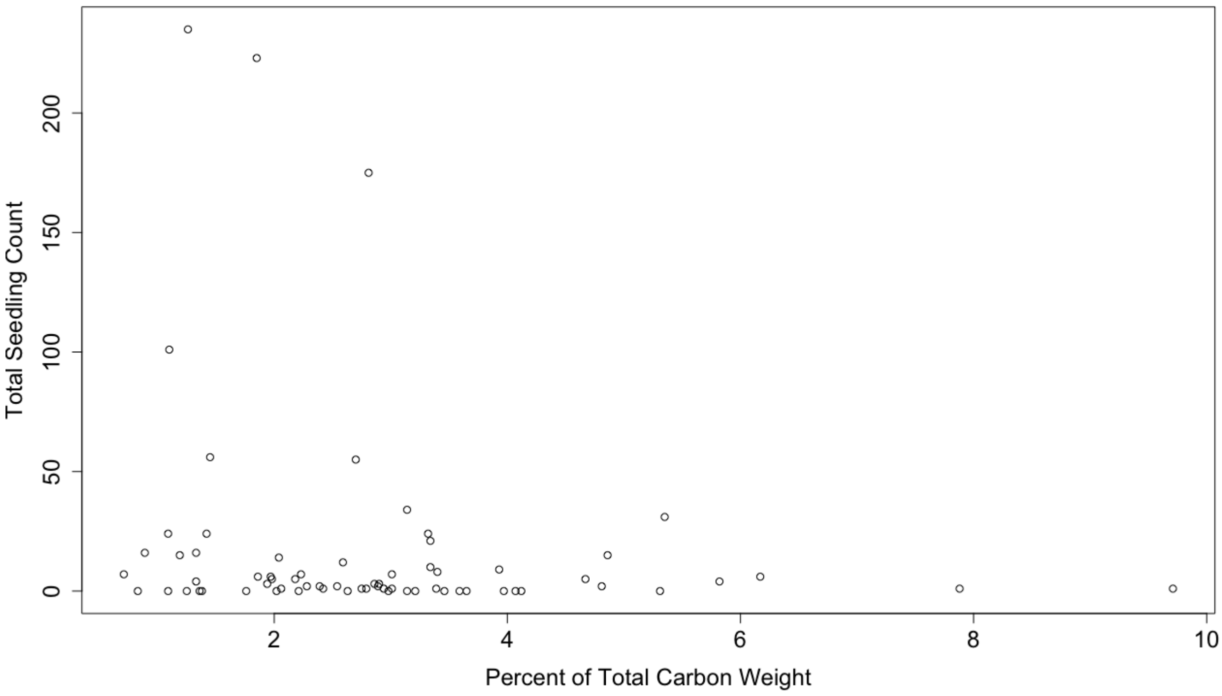

Figure 7: Total seedling count and percent total carbon weight.

Nitrogen

Along with C, N follows the same trend. No significant differences between the burn severity and the total percent weight of N were found (Kruskal-Wallis test, p value > .05). There was no relationship between total seedling count and soil N when controlling for aspect and severity (zero-inflated Poisson model, z = -0.175, p = 0.8613). However, there was a significant relationship between aspect and N weight, as northern aspects had more N (Wilcoxon test, p = .0494).

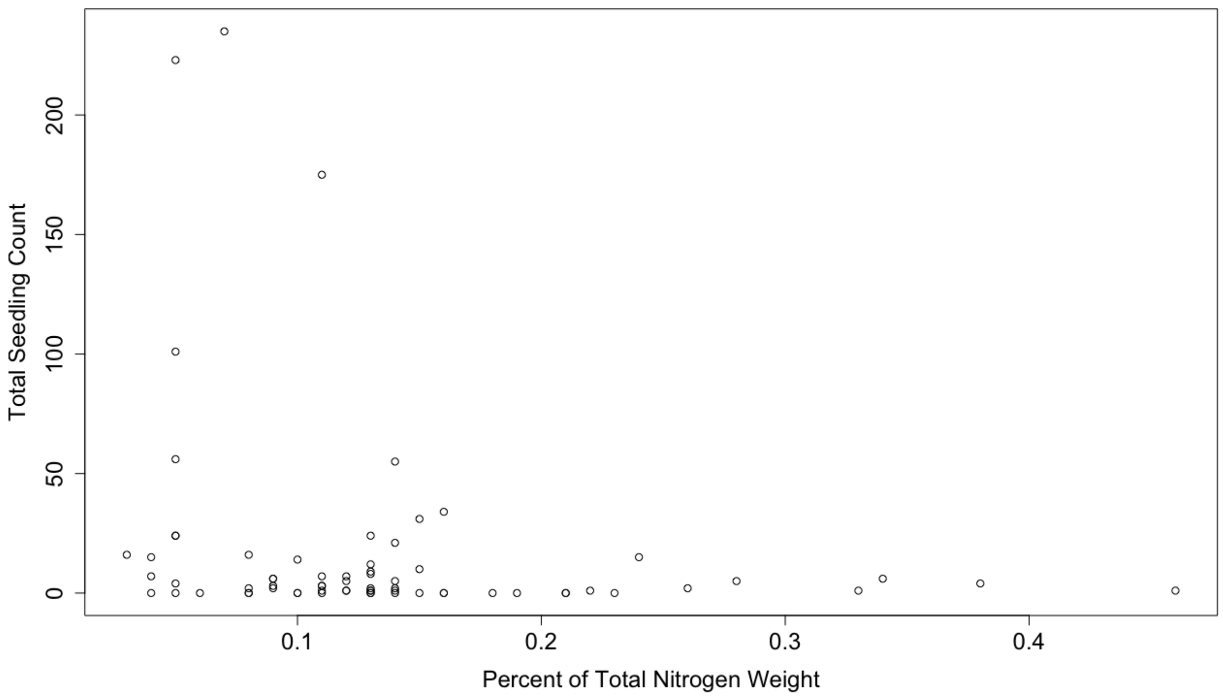

Figure 8: Total seedling count and percent total nitrogen weight.

Seedling Height and Whorl Count

Although not specifically mentioned in the background of the study, whorl count is an indicator of seedling age: seedlings of most conifer species add one branch whorl each year. There was no significant relationship between seedling height and soil pH, C or N; however, average seedling whorl count was negatively related to soil pH when controlling for burn severity and aspect (zero-inflated Poisson model, $z = -2.811$, $p = 0.00495$), meaning that sites with more acidic soils had older seedlings.

Texture

Although texture data was collected, due to set-backs in the collection and to software malfunction, the data are not analyzed at this time. The raw information on particle size is available for use for future analyses of this data, but was limited by the time schedule for preparation of this thesis.

Discussion

Site Description

The Blue Mountain ecoregion is a mixed conifer dry forest containing mostly *P. ponderosa* and *P. menziezii,* with other firs and spruces throughout the forest. At lower elevations, *Juniperus occidentalis* and grasslands are more likely to occur on southern-facing slopes, where forests give way to the shrub and grasslands (Boag, unpublished). These forested parts of Oregon used to be heavily logged, but recent decades have seen a large decrease in the presence of the timber industry (DellaSala et al., 1995). The soils of the region are typically Mollisols, which contain a rich organic layer and deep horizons (Franklin & Dyrness, 1973). With nutrient loaded surface layers, this soil type is likely be able to clearly demonstrate changes in the soil due to fire, if there are any.

Climate change is having a large impact on this region, as temperatures will increase overall, especially in the summer (Mauger & Mantua, 2011). The precipitation regimes will shift as well, more precipitation in winter months are projected, with as much as 17% decreases in precipitation in the winter, resulting in overall drier forests (Mauger & Mantua, 2011). Associated with the climate change of the region is a significant alteration of the fire regime of the area, which began in the mid-1980s (Hamilton et al., 2016). The larger, longer, and more frequent fires began relatively recently, and could potentially shift even more dramatically with the expected temperature shifts in the area.

Chemical Properties

As an impact of fire on soil, like the volatilization of nutrients in the soil or the burning of organic matter at the surface, we expect soil properties to change with variables of aspect or burn severity. Accordingly, the total number of seedlings at different classes of burn severity, and the total counts on north verse south slopes, ought to differ. However, the differences observed in this study are generally not being explained by the chemical components of soil. The only soil variable that corresponds with a seedling characteristic was a negative relationship between pH and whorl count. This may be because pH corresponds with the ability of plants to absorb nutrients in the soil and the pH value signifies a relationship between plant and nutrient uptake, which would allow seedlings to grow older (SUNY, 2017).

Soil samples were collected all across the Blue Mountains (Figure 1) from four areas that are far apart, where natural soil pH may be quite different even in the absence of fire, which may be why we saw no relationship between soil pH and burn severity. High fire temperatures and severities typically raise pH values after burning due to the fuel combustion in the soil and the ability of ash to cut the soil acidity (Neary et al., 2005). Perhaps there was no relationship between fire and severity due to the distance to seed sources, which was beyond the scope of this study. More seedling sources in the vicinity would drop pine needles and create an ideal soil pH, as well as offer a seed source to start the regeneration process. Also, there was the factor of time that could have allowed the soil to change in the long period since the fire event. Trees and woody vegetation tend to thrive in acidic soils (SUNY, 2017), similar to those in this study.

In some cases, C increases after fires and can stay in the soil for over 10 years after the disturbance, which is expected because nutrients are slowly released over time through decomposition (DeBano, 1990). However, when fires are high-intensity, all the nutrient stocks burn up in a fire, leading to regeneration limitations post-fire. We expected to see this dip reflected in burn severity, but results from this illustrated no difference in soil C between different burn severities. These fires occurred in either 1996 or 2000, so the benefits of C in the soil may have worn off for medium and low severity fires, and it is not known exactly how long the negative impacts of high severity fires last for (Turner, 1999).

Nitrogen can be a limiting nutrient for tree growth, and its depletion can be a cause of low seedling regeneration (DeBano, 1990). DeBano (1990) states that there is a high connection between C and N; so the rate of decomposition of organic matter can also affect the N in soil. This means that when N volatizes at a low combustion between 130 and 190°C, the carbon loads plummet with it (DeBano, 1990). The low temperature necessary for the volatizing of N makes the nutrient more susceptible to change in high severity fire situations, which in turn also impacts C availability. With the lower N in the soil, less regeneration will occur (Neary et al., 2005). For these reasons, it was important to determine significant correlations between N and fire severity. There was a significant relationship between fire severity and seedling regeneration, but this relationship cannot be attributed to the expected depletion of N in high severity fires. Again, this might be a result of the long period of time that passed between the fire event and soil sample collection. In addition, Nitrogen typically decreases immediately after the fire in the top layer of organic material due to the volatilization of the nutrient, but in lower severity fires, the pools of N in deeper layers are generally not impacted. This study only took surface level cores of soil, and it is unknown if the N availability was affected in deeper layers of soil.

None of the chemical properties of soil besides N differed significantly across north or south aspects. Nitrogen is more closely linked with water limitation and insolation, which could explain why N was the only variable to show a difference in aspect (Kunkel et al., 2011). Total seedling count also varied between aspects, and since this does not appear to be due to differences in soil, this could be a reflection of the water availability differences across aspect.

Study Limitations

Given a sample size of only 68 sites, more data may have to be collected to detect a significant difference between total seedling count and soil variables. In addition, many of the variables collected in the field that I used were visually accounted for, and human mistakes can introduce biases in the observations. Identifying tree seedlings in certain environments was challenging, especially if they were a small size or highly affected by herbivory – though we set a threshold of 10-cm to address this issue. All the lab tests were run with soil standards and duplicates to minimize sources of error, but samples have the possibility of getting contaminated or written down with mistakes. All numbers and data inputs were checked twice in the lab to reduce this potential problem.

I did not test for the impact of elevation on the seedlings. This study primarily focuses on the mixed conifer forests of *P. ponderosa* and *P. menziesii,* and these conifer species can have a habitat ranging from sea level to 10,700 feet (Encyclopedia of Biomes, 2008). Elevation and the changing climate should have a noticeable impact on seedling regeneration as it is very important for determining seedling regeneration; however, subsequent analysis was beyond the scope of this study.

Regeneration depends on many factors, including the seed bank in the soil that varies per species. Some species are serotinous and require fire for the seeds to germinate and start to grow; however, the fire severity can adversely impact the availability of the soil seed bank by completely charring the seed bank in the ground (Malik, 2003). The role of fire in affecting regeneration from the seed bank cannot be tested directly as I only have post-fire soil samples and the fire events happened 16 to 20 years ago. Severe fires could be a likely source of regeneration failure if they destroyed the seed bank. Distance to seed source is another factor that can help or hinder seedling recruitment post-fire; however, this was beyond the scope of the study. Herbivory information was collected in the seedling regeneration study, and could very well hinder the growth of healthy plants. Herbivory is likely not related to soil properties, and was left out of this analysis. Its role in regeneration as a whole remains to be determined in future studies. Erosion was also not possible to test as a variable in this study, but it is a factor that could have had impacts on seedling establishment when trees were starting to sprout.

In addition, there is a high amount of volcanic ash throughout the Blue Mountains, but due to the time constraint, it could not be tested. As a result of the history of volcanic activity in the region, we expect to see layers of ash in the soil, especially from Mount Mazama, present-day Crater Lake (Franklin & Dyrness, 1973). It is unlikely this ash layer overlapped with the study, as the presence of the ash at the surface is "almost completely restricted to broad ridge-tops and north-facing slopes" and is a noticeably hard mineral material, and I did not observe such deposits where I dug samples (Franklin & Dyrness, 1973, p. 28). However, this may be partially the reason for high percentages of C in the soil. Additionally, the soil contained high amounts of black carbon, which is considered to be an organic byproduct of fire (Poore, 2014). Poore (2014) did not find any correlation between black carbon and burn severity, but it still could have impacted soil C levels if close enough to the burn event.

Many soil papers and studies that have occurred after fire are becoming relatively old sources. It is pertinent that these same studies are retested in the age of shifting fire regimes in order to determine if there is an exponential impact on the soil properties with increase in fire severity and frequency. This study adds to the growing database of soil changes after fire in recent years.

Conclusion

In this study, soil characteristics in eastern Oregon were shown not to predict total seedling counts. The differences were expected to be more pronounced; however, a lot of time has passed since the fires occurred and this could explain why we are seeing differences in seedling counts across aspect and burn severity but not across the chemical properties of soil. It is likely that the properties have reverted or begun to revert back to the pre-fire soil conditions, as the changes were not permanent – multiple explanations for these results are described above. If samples were taken closer to the period of the fire, it is likely significant differences in the soil would have been prominent. In higher severity sites, less seedlings would have been observed and especially in the drought period, seedlings would not have been able to establish.

My study exemplifies how soil properties are not representing the impacts of fire 20 years after the event. This could mean that high severity fire sites, which are becoming more common, would benefit if they were replanted many years after the fire occurred – in order to allow soil properties to recuperate and be nutritious enough to hold a multitude of seedlings. This finding alters forest management tactics that often includes rushing to find funding and man power to replant large swatches of forest, when it might actually be beneficial in some areas to wait to replant. It seems that medium and low severity sites are not having as much trouble garnering large numbers of seedlings to regenerate, so these sites might only need management intervention in the case of drought because they were found to naturally regenerate with seedlings. Management efforts can be critical in preventing the state transitions of the forests of the region, and they need to know the best practices to do so.

The Blue Mountain ecoregion is at the forefront the of climate change and is in a critical stage: how we manage the forests will impact future generations. It is important to understand if these fires are having a lasting impact on soil, because it will be the source of nutrients and life for decades to come. Therefore, this research fills the gap of past, dated studies in quantifying soil properties and perhaps aiding in the provision of soil samples for longitudinal studies.

The results will be published and shared to help inform Oregon land owners and managers about where natural regeneration can be expected, which as I demonstrate, is primarily on north aspects and low fire severity affected areas. The ability to identify nutrient poor areas post-fire will allow forest owners and managers to replant trees effectively and attempt to reduce state transitions of vulnerable forest, and further studies on soil nutrients are necessary for this purpose. Not only will ecosystems benefit from research like this and allow forest managers to concentrate their efforts, but studies like this have the potential to decrease the impacts of wildfire on the region by influencing restoration responses.

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