An Analysis of Tree Regeneration following the Hayman Fire in the Upper-Montane Zone of the Colorado Front Range

By:

Jeremy Arkin

University of Colorado at Boulder

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Thesis Advisors:

Dr. Thomas Veblen, Geography, Committee Chair

Dr. William Travis, Geography

Dr. Timothy Seastedt, Evolutionary Biology and Ecology

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Abstract

Studies of tree regeneration following forest fires along the Colorado Front Range offer valuable insights into how climate change could be influencing conifer seedling establishment statewide. While the relatively hotter and drier conditions observed along the Front Range may not be enough to lethally damage mature trees, there is a strong potential that these novel conditions could prevent the successful establishment of new trees. This study explores variables that influence the establishment of tree species found growing within the 2002 Hayman Fire perimeter. This exploration was carried out through the collection of ~90 fifty-meter transects in the upper montane zone of the burn. Over 30 variables were recorded for each transect, but special attention was given to counts of juvenile and mature trees. The data analysis was carried out through the comparison of species-specific seedling counts with all other variables. Species-specific seedling growth was found to be associated with elevation, distance to seed source, fire severity, slope aspect, and a variety of ground cover variables. For the most part ponderosa pine seedlings were found in higher numbers in quadrats located on south facing slopes that burned at a low severity. Douglas fir seedlings were found in higher numbers in quadrats located on north facing slopes that burned at either low or moderate severities. Aspen seedlings were also found in much higher numbers on north facing slopes, but unlike any other species the aspen seedlings thrived in quadrats that burned at high severities.

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Introduction

Fire History and Species Composition

The objective of the current study is to examine patterns of post-fire tree establishment following the large Hayman fire in 2002. The large extent and severity of the 2002 Hayman fire raised concerns that the event was unprecedented (Graham et al. 2003) but recent research has shown that the severity of the Hayman 2002 fire did not differ from the reconstructed severity of 19th century fires in the same area (Sherriff et al. 2014). However, the large extent and severity of the 2002 Hayman fire raises legitimate questions about post-fire forest recovery. For example, the trend of a warming climate in Colorado raises concerns over the success of post-fire tree regeneration, and questions over how topographic and elevation variation affects the success of post-fire tree regeneration.

The area burned by the Hayman fire spans the lower (1,981-2,590 meters above sea level) and upper (2,590-2,895 meters above sea level) montane zones of the Colorado Front Range characterized by ponderosa pine and mixed conifer forest types (Kaufmann et al. 2006). Along the elevation gradient of the montane zone, the historic fire regime is characterized as a "mixed-severity" regime in which relatively frequent surface fires are more common at low elevations and there is an increasingly important role played by high severity fires towards higher elevation (Sherriff et al. 2014). The occurrence of high severity fires (i.e. killing > 70% of the canopy trees over large areas of 100s to 1000s of hectares) in the Hayman area during the 19th century and earlier has been documented by studies using tree-ring reconstruction of past fires (Brown, et al. 199; Kaufmann et al. 2000).

Ponderosa pine is the most common tree species throughout the montane zone (1,981-2,895 meters above sea level) (Kaufmann et al. 2006). The lower montane zone is characterized primarily by pure stands of ponderosa pine and the upper montane zone by ponderosa pine as well as Douglas fir, lodgepole pine, and aspen. The vegetation of the upper montane zone is sometimes classified as "mixed conifer". While recovery of conifer-dominated forests following 19th century fires in montane zone of the Front Range shows that they are inherently resilient to fire, it is not known if under the warmer climate conditions of the early 21st century whether more extreme fire severity effects or unsuitable post-fire climate may slow or impede the post-fire recovery of these forests.

Changing Climate

The Rocky Mountains have seen an increase in annual mean temperatures over the last thirty years, and reduced precipitation in the last fifteen years (Lukas et al 2014). Warmer temperatures increase potential evapotranspiration rates and decrease water availability for many terrestrial ecosystems in Colorado, creating hotter and drier conditions at higher latitudes that historically were seen in areas lower in latitude. The distributions of many terrestrial plants are expected to move up in latitude to areas that exhibit a climate similar to that of their historic range (Jump et al 2009).

A similar phenomenon can be observed along an elevational gradient. A 10-kilometer latitudinal range shift for a given plant species translates to a 10-meter elevational range shift for that same plant species (Jump *et al* 2009). Accordingly, one might hypothesize that ponderosa pine forests are shifting upwards in elevation as a result of warming. One way this response will occur is through tree regeneration, or lack thereof following fire.

Ecosystem Shift?

I hypothesize that post-fire ponderosa pine forests are undergoing a quicker than expected shift in elevational range as a result of novel climate factors that are compromising ecosystem resilience (Hobbs et al 2009). The warmer and drier conditions may not be enough to kill mature trees, but there is potential that these novel conditions may prevent the establishment of trees following fires of varying severity.

The distinction between something that is novel rather than historic is crucial here. Historically, the montane zone was slightly cooler and wetter than the foothills/grassland zones found downslope, which gave the lower montane zone the needed conditions to facilitate an ecosystem dominated by ponderosa pines and Douglas fir. But the novel climate makes the montane zone slightly warmer and drier, which facilitates the success of shrubs and grasses, as they both have adaptations that give them advantages over young ponderosa pines during hot and dry conditions. Therefore, shrubs and grasses have the potential to compete strongly with young ponderosa pines following forest fire.

While novel factors have the potential to cause extreme change in species composition, the diversity of a system can help maintain species composition even under novel conditions. Since fires burn heterogeneously with regard to severity, burned areas are usually left with varying amounts of plant survivorship, which can leave intact patches of mature trees. These patches of mature trees represent valuable seed sources, which can provide a type of insurance against novel disturbances, helping the ecosystem to return to its pre-disturbance composition. For example, if a section of ponderosa pine forest is completely wiped out as a result of a crown fire, then it must rely on the surrounding forest to help reestablish the burned area. Enough intact, mature forest in the surrounding area provides a chance of the system returning to its former state. However, if only small amounts of intact, mature forest remain following a fire, then the burned area has a much lower chance of returning to its former state. Thus, following a disturbance, an ecosystem could either return to its former state or transform into a different ecosystem type (Holling 2001).

Research Question

Monica Rother of the CU-Geography Department is currently researching ponderosa pine and Douglas fir regeneration in the lower montane following mixed-severity forest fires. Her preliminary analysis suggests that ponderosa pine and Douglas fir regeneration is very limited in lower montane zones. My research project also examines ponderosa pine regeneration following forest fires, but in the upper montane zone. I want to find out if ponderosa pine regeneration is significantly different in the upper montane zone compared to the lower montane zone. This is an important research question because it will provide insight into the future evolution of Colorado's forests.

I expect one of two outcomes from this study:

Hypothesis

> Ponderosa pines and Douglas fir will exhibit more successful regeneration in the upper montane, which would suggest a shift in ecosystem type along an elevational gradient based upon the premise that conditions in the lower montane may now be too hot and dry to support conifer regeneration. This shift would cause the dominant vegetation type to transition from ponderosa pines and Douglas fir to one dominated by either shrubs or grasses. This potential outcome would necessitate further research to isolate what microhabitat

conditions (e.g. slope, aspect, etc.) along the elevational gradient ponderosa pines will be able to successfully regenerate.

Null Hypothesis

Ponderosa pines will have similar low levels of regeneration in the upper montane as observed in lower elevations, which suggests that there is a regional factor that is causing high rates of seedling mortality.

Methods

Study Area

Southwest of Denver, Colorado, the Hayman Fire burned from June 8th to June 28th during the summer of 2002, eventually burning over 138,000 acres of forest (Map 1). The burn spanned from lower montane zones to upper montane zones, a feature that is not common in most fires in the Colorado Front Range. The lower montane zone was almost entirely composed of ponderosa pine and Douglas-fir, while the upper montane was composed of a more diverse mix of ponderosa pine, Douglas-fir, blue spruce, lodgepole pine, and aspen, even though ponderosa pine and Douglas-fir tended to dominate the canopy. The fire was of mixed severity, including portions of low, moderate, and high severity fire (Map 2). For the most part, both zones had low crowns that encouraged the spread of fire into the canopy (Graham et al 2003).

Study Site Selection

ArcGIS was used to help me to identify potential sampling sites. Data was sourced from the Landfire Dataset and various other USGS sources (Table 1). After starting a new blank map in ArcGIS I loaded geospatial data, including: burn severity and a digital elevation model (DEM). I then identified the burn area and used the "clip" tool to take a subset of the burn severity data to generate a shapefile depicting the extent of the burn. This shapefile was then symbolized to give it a very bold outline to clearly show the burn extent. To make this shapefile more useful I then gave it a hollow fill so I could analyze the interior of the burn using other data.

I then identified which parts of the burn area were in the upper montane zone. To do this I used the “extract by attribute” tool to clip a DEM to only include areas that were considered upper montane (2590-2895 meters above sea level). Once I had this file I used the “raster to polygon” tool to convert the clipped DEM from a raster into a shapefile, which makes data processing much easier since shapefiles are not as large as raster files.

To narrow down my sample areas even further, I next identified north and south facing slopes. I used the “aspect” tool to generate an aspect map from the digital elevation model, which assigned each pixel within the raster to the exact degree of its aspect. I then used the “reclassify” tool to assign areas with a south facing aspect (135°-225°) to one class and areas with a north facing aspect (315°-45°) to another class. To make this aspect map visually intuitive I also changed the symbology so the south facing slopes were displayed as red and the north facing slopes were displayed as blue.

The last step in identifying potential sampling sites was to identify which slopes burned at which severity by combining the burn severity data with the slope aspect data. To do this I used the “draw” tool to outline particular burn severities on each north and south facing slope in the upper montane zone. Once I had these polygons drawn out, I changed the symbology to show burn severity and slope aspect, with darker red/blue representing higher burn severity.

The last applications I used ArcGIS for was to identify potential camping areas since most of the trips necessitated at least a 4 day backpacking trip. To do this I loaded complete watershed information and forest service roads into my Arcmap and used the “clip” tool to subset these files to the burn extent. Furthermore, I changed the symbology of the watershed information to highlight creeks and rivers that had water all year long, as well as the symbology of the forest service roads to insure that we could get my 2 W/D vehicle within 5-7 miles of potential campsites.

Field Methods

My field methods had the goal of comparing north and south facing slopes that burned at low, moderate, or high severities within the upper montane zone of the Hayman Fire burn extent. Low severity referred to areas where tree mortality was less than 20%, moderate severity referred to areas where tree mortality was between 20% and 80%, and high severity referred to areas where tree mortality was higher than 80%. Six different settings were sampled: north facing low severity, north facing moderate severity, north facing low severity, south facing high severity, south facing moderate severity, and south facing low severity. At each of these settings we randomly situated a fifty meter transect and analyzed it within 5-meter intervals, for a total of 10 quadrats in each transect (Figure 1). All of the sampled transects were located between 2,580 and 2,828 meters above sea level.

Nine ground cover variables were recorded in each quadrat: shrubs, forbs, graminoids, coarse woody debris, bare soil, litter, rock, snag/stumps, and crown cover (Table 2). To analyze the impact of ground cover variables on seedling regrowth, two groups of data were compared: the quadrats that did not have any seedling regrowth and the quadrats that did have seedling regrowth. This analysis was completed separately for ponderosa pine seedlings, Douglas fir seedlings, and aspen seedlings. P-values were calculated using the Wilcoxon Rank-Sum test since none of the data fit the parameters of normality.

Results

Elevation

Transects were taken at elevations between 2,580 and 2,828 meters above sea level, so the sampled transects spanned nearly the entire upper montane zone. Across this range of elevation seedling regeneration varied to some degree for all tree species found. Ponderosa pine seedlings were found in high concentrations around both 2,640 m and 2,700 m, while Douglas fir seedlings were only found in high concentrations around 2,750 m. Aspen seedlings on the other hand were found in high concentrations across the entire range of sampled elevations (Figure 2).

Distance to Seed Source

A strong relationship was found between distance to seed source and the number of seedlings found in each quadrat was observed (Figure 3). While the same general relationship was present for both ponderosa pine and Douglas fir seedlings, the Douglas fir exhibited a much stronger relationship. Of the nearly 700 quadrats recorded, only the ones that were within ~50 meters of a seed source had any Douglas fir seedlings present. Furthermore, both Douglas fir and ponderosa pine had drastically higher regeneration rates in quadrats that were less than 20 meters away from a seed source (Figure 3).

Fire Severity

Three categories of fire severity were recorded at each transect: low, moderate, and high. The average number of each tree species found within each of the severity classes varied between each species (Figure 4). Ponderosa pine had over three times as much regrowth in areas that burned at a low severity when compared to areas that burned at a high severity. Douglas fir showed almost no regrowth in areas that burned at high severities, but did show regrowth in areas that burned at both low and moderate severities. Aspen on the other hand showed its highest regrowth in areas that burned at a high severity (Figure 4).

Slope Aspect

Transects were only recorded on north and south-facing slopes so the two extremes of water availability could be compared. Both Douglas fir and aspen seedlings were found growing in much higher numbers on north-facing slopes compared to south-facing slopes (Figure 5). In contrast, ponderosa pine seedlings were found at concentrations three times higher on south-facing slopes compared to north-facing slopes (Figure 5).

Slope Steepness

Slope steepness was recorded at the center of each transect on a scale of 1 to 5, with 1 representing the least steep slope and 5 representing the most steep slope. Both the presence of ponderosa pine and Douglas fir seedlings had a significant relationship with slope steepness (Table 3). Slope steepness was found to be higher on plots without ponderosa pine seedlings compared to plots with ponderosa pine seedlings. On the contrary, slope steepness was found to be lower on plots without Douglas fir seedlings compared to plots with Douglas fir seedlings (Figure 6).

Ground Cover

Ponderosa pine seedling regrowth was found to have significant relationships with: shrub, forb, litter, and rock cover (Table 3). Slightly higher averages of forb and litter cover were found within quadrats that had ponderosa pine seedlings present, while a slightly higher average of shrub and rock cover was found within quadrats that lacked the presence of ponderosa pine seedlings (Table 3). Douglas fir seedling regrowth had significant relationships with: forb, graminoid, litter, rock, snag/stump, and crown cover. A higher average cover of forb, graminoid, and litter was associated with plots that lacked Douglas fir seedlings, while a higher average cover of rock, snag/stump, and crown were associated with plots that had Douglas fir seedlings (Table 4). Aspen seedling regrowth had significant relationships with: graminoid, coarse woody debris, bare soil, rock, snag/stump, and crown cover. A higher average cover of graminoid, bare soil, and rock were associated with plots that did not have aspen seedlings, while a higher average cover of coarse woody debris, snag/stump, and crown cover were associated with plots that did have aspen seedlings (Table 5).

Discussion

The present study has made the first detailed assessment of tree regrowth in the upper regions of an area destroyed by fire in 2002. The work demonstrates a number of findings relevant to what we should expect to see in the regrowth forests of this elevation type in the coming years.

Preliminary results by PhD candidate Rother from work in the lower montane zone indicate that densities of juvenile conifers (both ponderosa pine and Douglas fir) are relatively low in the lower montane zone (mean = 1.4 total seedlings per quadrat). In contrast, my thesis research demonstrates notably higher densities of both ponderosa pine and Douglas fir (mean = 2.7 total seedlings per quadrat). This finding is consistent with the idea that conditions in the upper montane zone are still suitable for conifer regeneration by ponderosa pine and Douglas fir, and that conditions may now be too hot and dry in the lower montane zone.

Elevation

In general species-specific seedling densities matched the general habitats of ponderosa pine and Douglas fir in that the ponderosa pine seedlings were found at higher densities at elevations lower than where Douglas fir seedlings were at their highest densities. The aspen seedlings were able to grow at high densities throughout a range of elevations sampled.

Distance to Seed Source

The relationships between species-specific seedling densities and distance to seed source also correspond to general characteristics of the species in question. More specifically these relationships reinforce the idea that patches of mature trees left standing after forest fires strongly favors the establishment of juvenile trees down the line.

Fire Severity

Ponderosa pine seedling density showed the most linear relationship to fire severity, with the average number of seedlings found per quadrat decreasing as severity increases. Douglas fir seedlings were also sparse in areas that burned at a high severity, suggesting that they have not yet been able to reestablish themselves in these areas. For both species, these results are consistent with their capacity to resist low severity fires due to their thick bark and therefore provide seed sources where fire severity is lower. Given that the measure of fire severity covaries with presence of seed sources, these results cannot be easily interpreted in terms of potential inhibitory influences of the microsite effects of higher fire severity (i.e. higher soil surface temperatures, reduced soil moisture availability, and other edaphic factors) on the success of post-fire tree regeneration.

Aspen seedlings were the only seedlings that showed a high average density in areas that burned at a high severity. This is almost entirely due to the fact that aspen are able to regrow themselves from existing root networks, which allows them to reestablish themselves very quickly following fires.

Slope Aspect

The relationships between species-specific seedling regrowth and slope aspect followed the general characteristics of each species. Douglas fir and aspen are relatively shade tolerant, so they were found in higher concentrations on north-facing slopes, while ponderosa pines do better in sunny environments, so they were found in higher concentrations on south facing slopes.

Slope Steepness

The relationship between slope steepness and species-specific seedling growth makes intuitive sense if you consider the relationship that less steep slopes generally receive more sunlight than steeper slopes. This results in a difference in relative moisture availability that explains why ponderosa pine seedlings were associated with less steep slopes, since ponderosa pine seedlings will tend to do better in these hotter and drier areas.

Ground Cover

The relationships between seedling counts and each of the ground cover variables offer interesting perspectives at what kind of microhabitats favor or disfavor the growth of seedlings post fire. The cover of rock was negatively associated with seedlings of all tree species (ponderosa pine, Douglas fir, and aspen), which makes intuitive sense, as seedlings cannot possibly establish within dense rock cover. The cover of litter was positively associated with both ponderosa pine and Douglas fir seedling counts. Given that the measure of litter cover is associated with distance to seed source, these relationships are difficult to interpret.

Conclusion

In conclusion, this study indicates that forest composition throughout the montane zone in the Colorado Front Range is undergoing a transition due to warmer, drier climate conditions. This general trend is made evident by comparison of densities of post-fire conifer regeneration in the lower vs. upper montane zones of areas burned by the 2002 Hayman Fire. The relatively low densities of conifer regeneration in the lower montane zone (preliminary results from Monica Rother's dissertation) compared to higher densities in the upper montane zone (this study) suggests that lower elevations may be more vulnerable to reduced resiliency to fire under warming climate conditions. Although stand densities are typically higher in the upper montane vs. the lower montane, the differences with elevation are exceptionally large and appear to be inconsistent with historic patterns.

Furthermore, this study indicates that a number of site factors can help explain spatial variability in tree regeneration in the Colorado Front Range following fire. Distance to seed source is positively associated with juvenile conifer densities, which supports the idea that remnant conifers are important in establishing conifer seedlings post fire. Higher elevations and more northerly slope aspects are also both associated with higher conifer densities, likely due to higher water availability.

Acknowledgements

This project was made possible with funding and guidance from the Undergraduate Research Opportunity Program (UROP) and the Biogeography Lab directed by Thomas Veblen through the University of Colorado Geography Department. Further guidance was provided by Monica Rother, who is currently pursing her PhD through Dr. Veblen's Biogeography lab. I also received assistance with data collection from two field assistants: David Anderson and Drew Meyer. Last but not least, I would like to acknowledge the work put in by Darla Shatto who assisted with the administrative tasks needed to complete this project.

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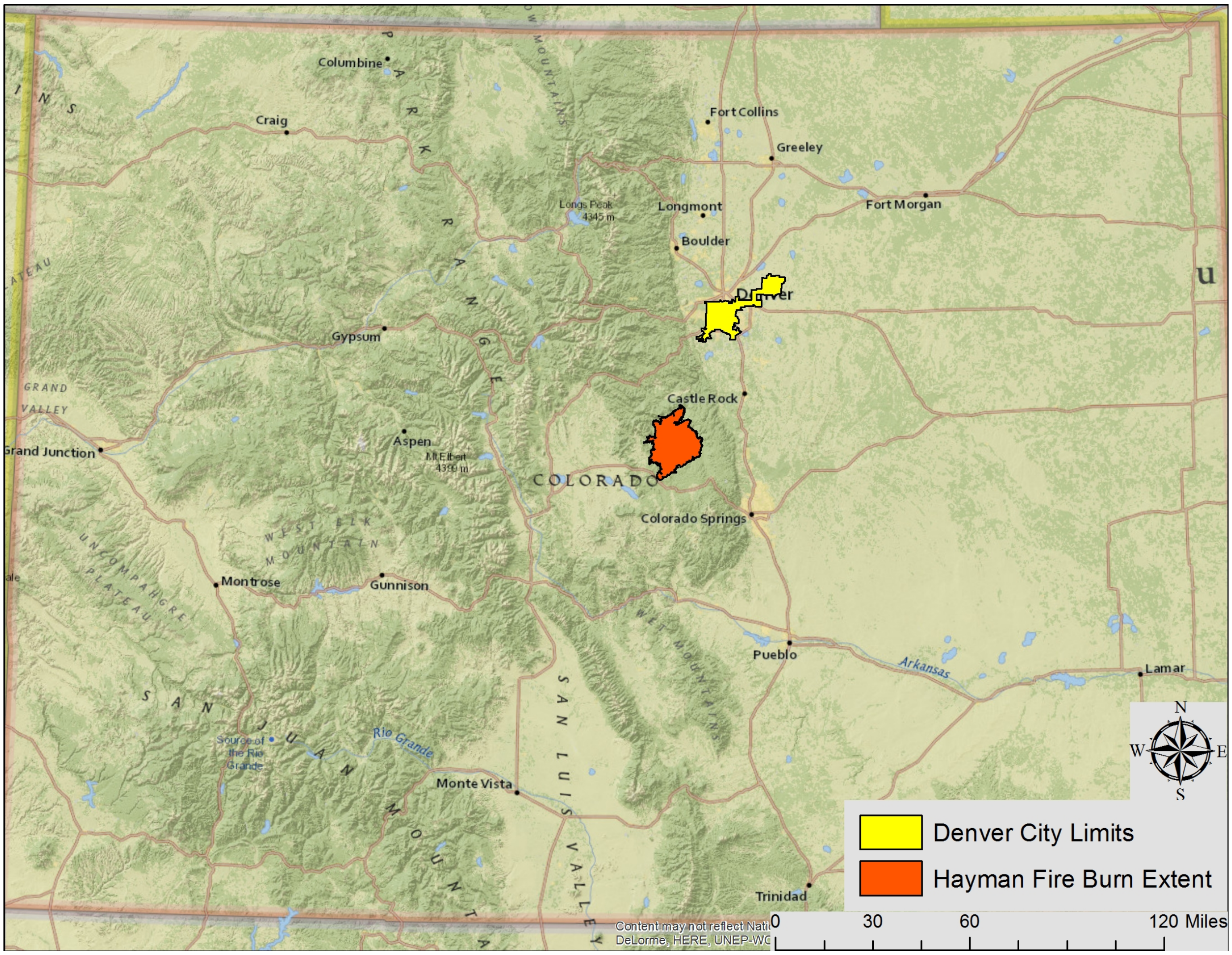
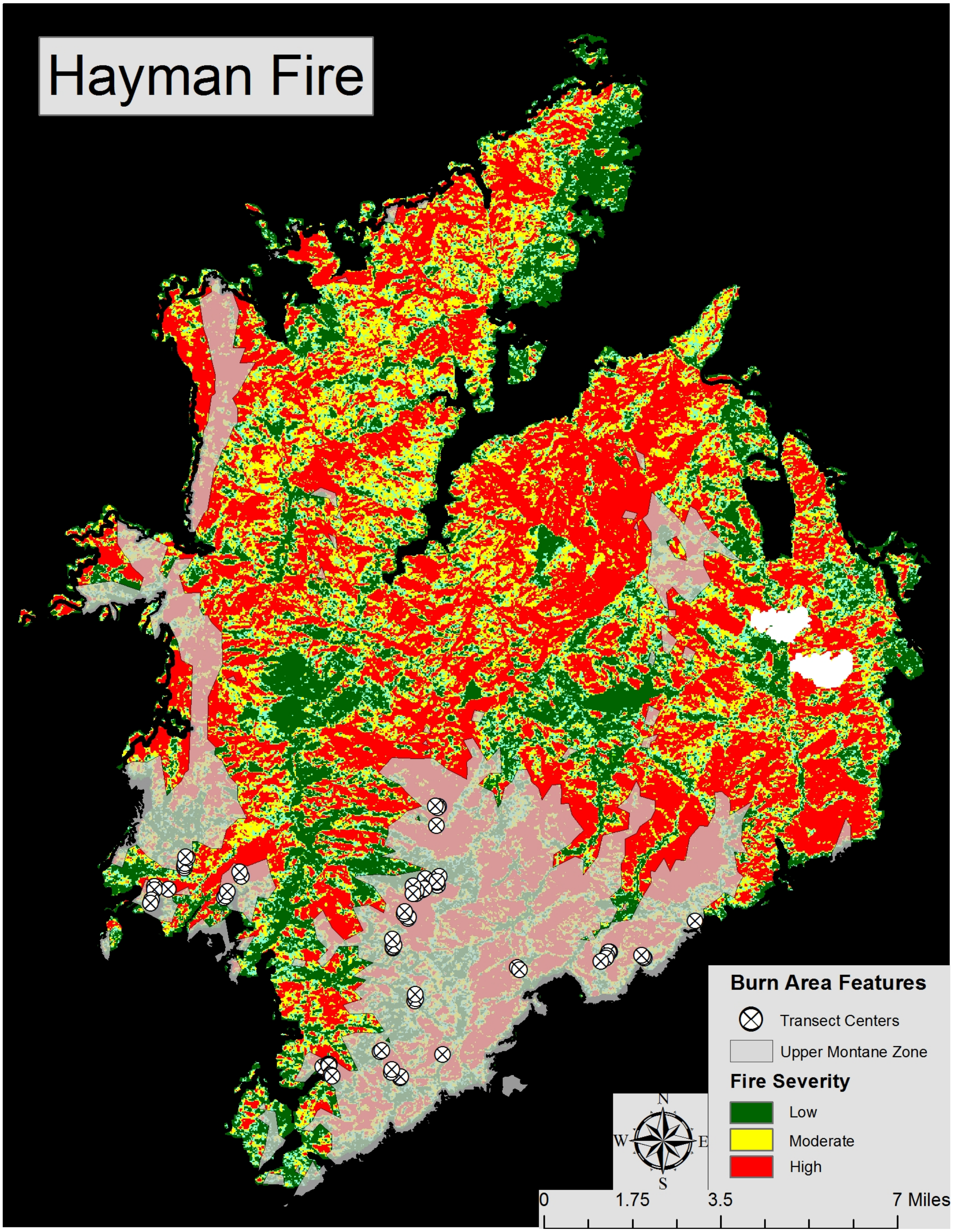
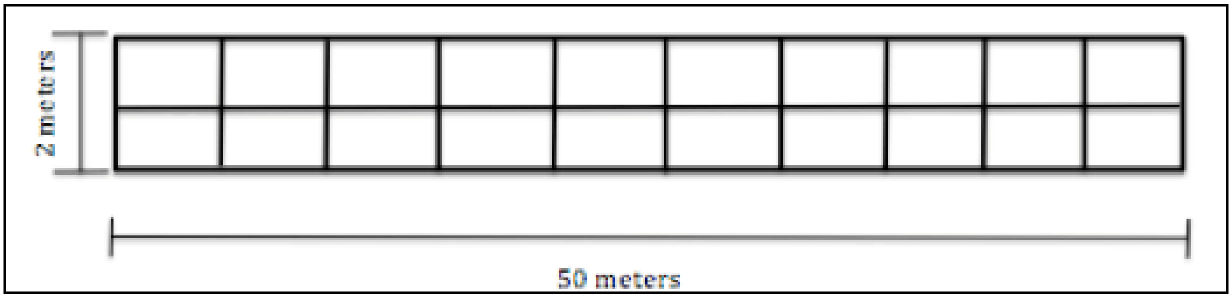
Appendix



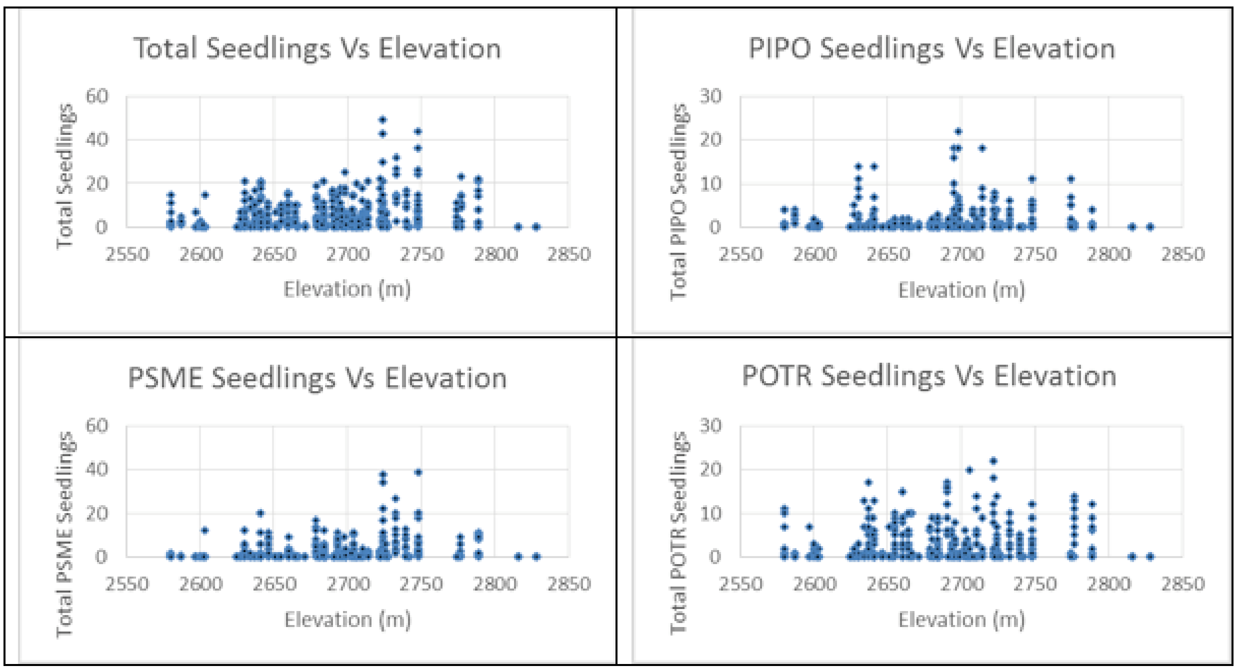
(Map 1) Reference map of the Hayman Fire burn extent in respect to the state of Colorado and the Denver city limits. (Fire extent sourced from (http://www.landfire.gov/).



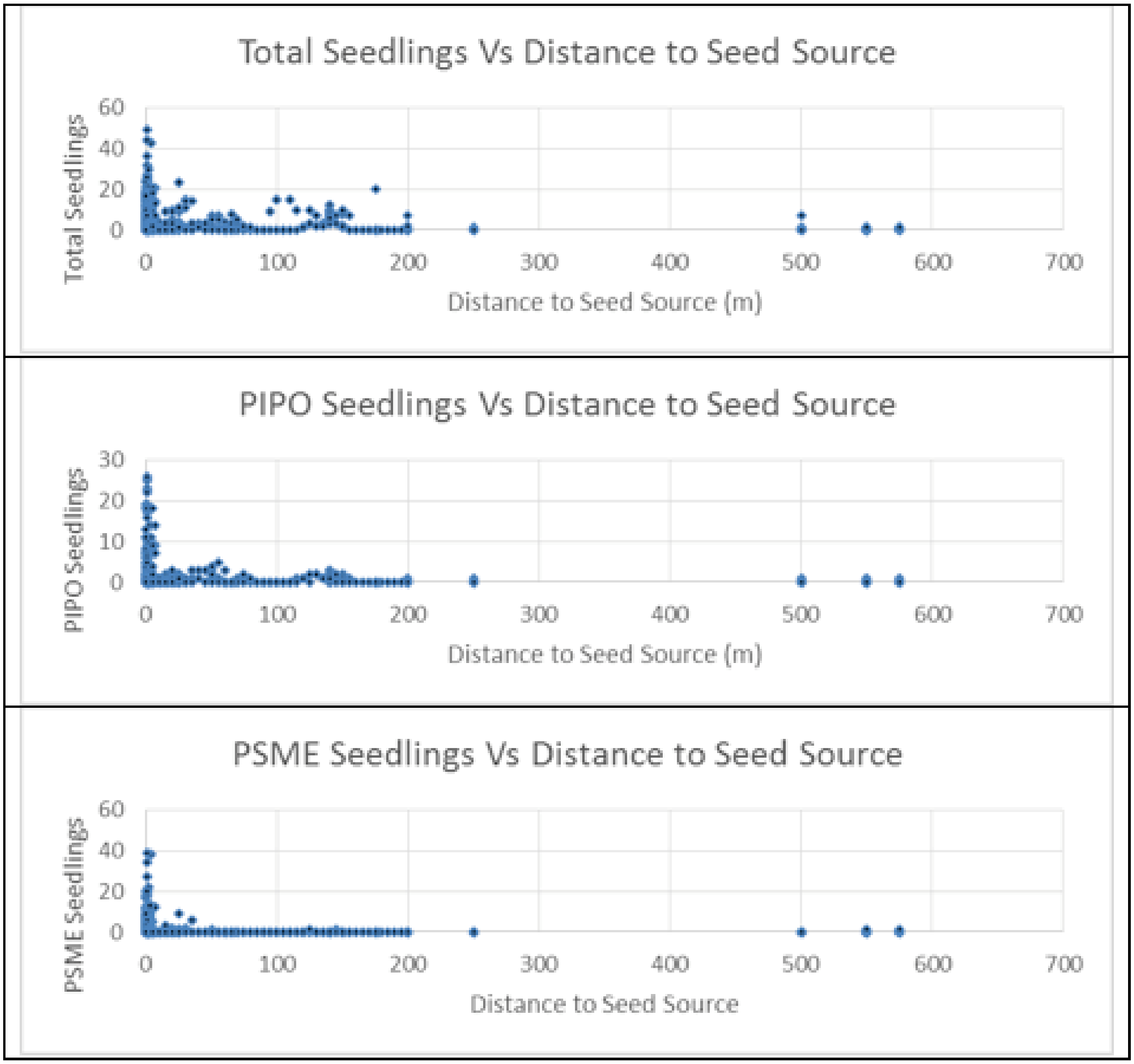
(Map 2) Close-up map of the Hayman Fire depicting: transect centers, the upper montane zone, and the relative burn severities. Fire severity data sourced from (http://www.landfire.gov/).



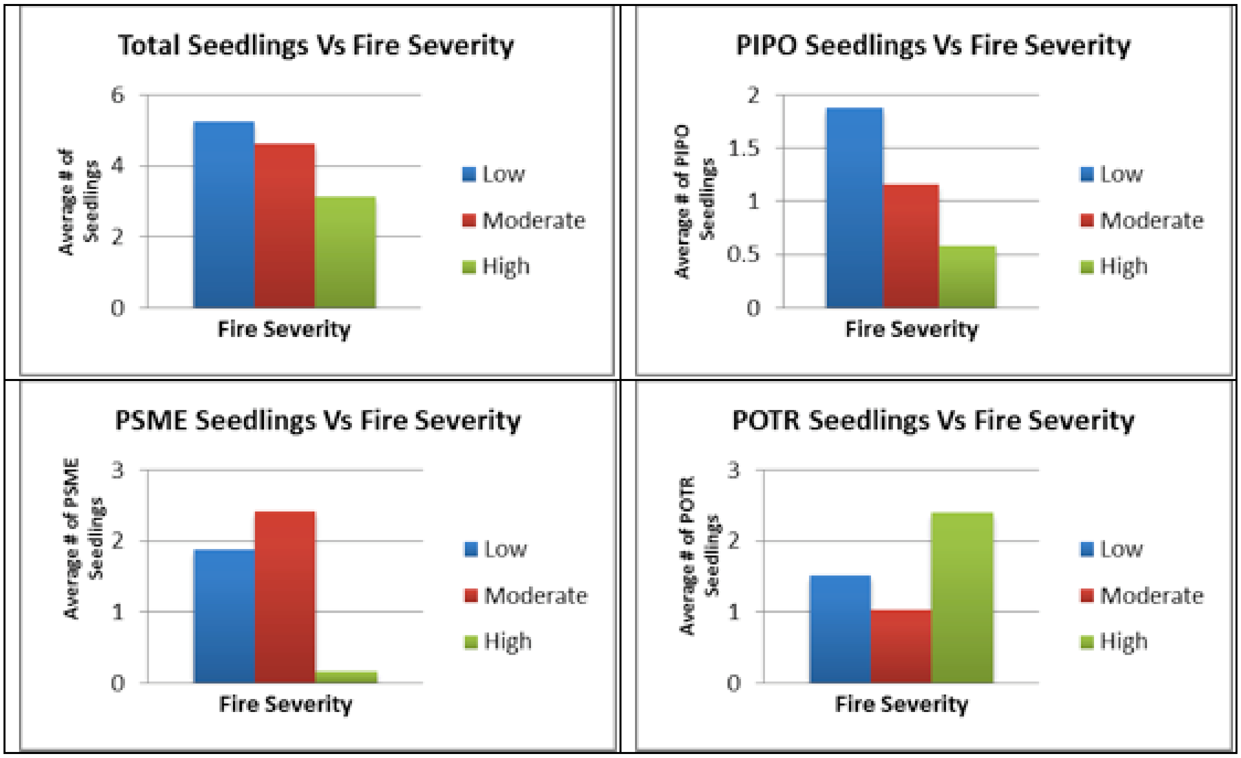
(Figure 1) Typical transect layout



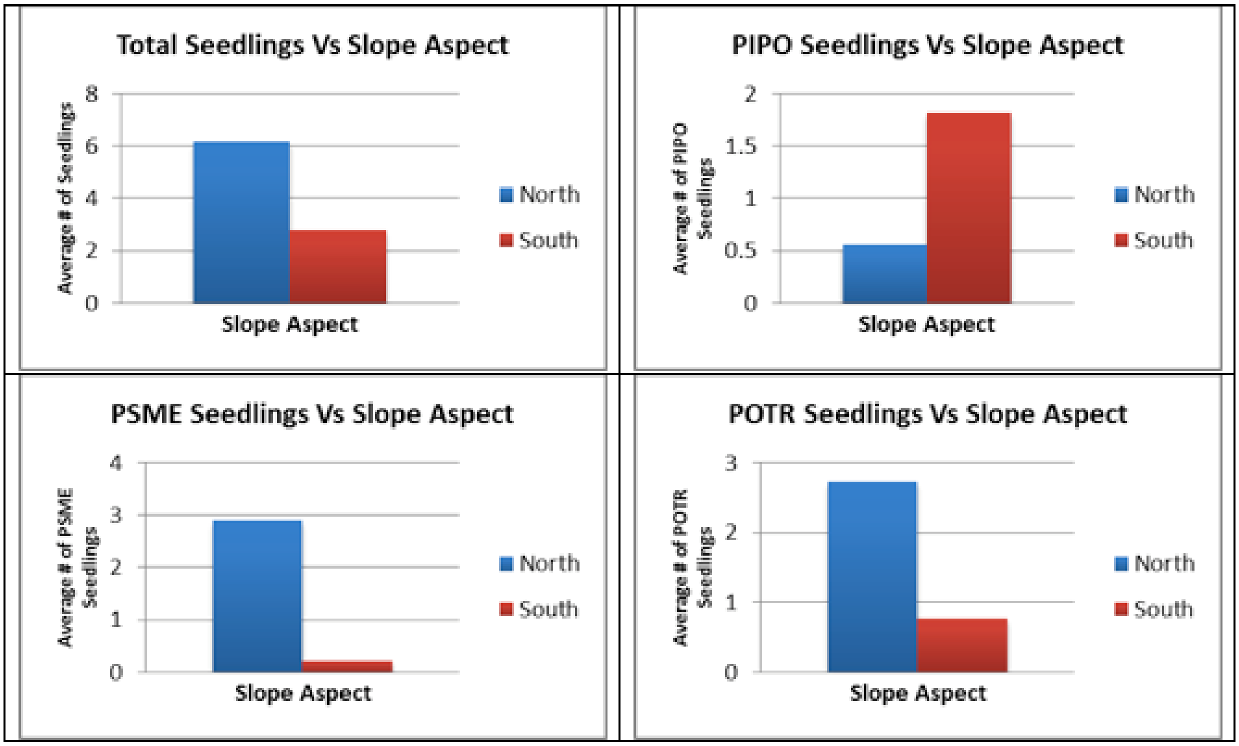
(Figure 2) Relationship between seedling counts per quadrat and elevation for: ponderosa pine seedlings (PIPO), Douglas fir seedlings (PSME), and aspen seedlings (POTR).



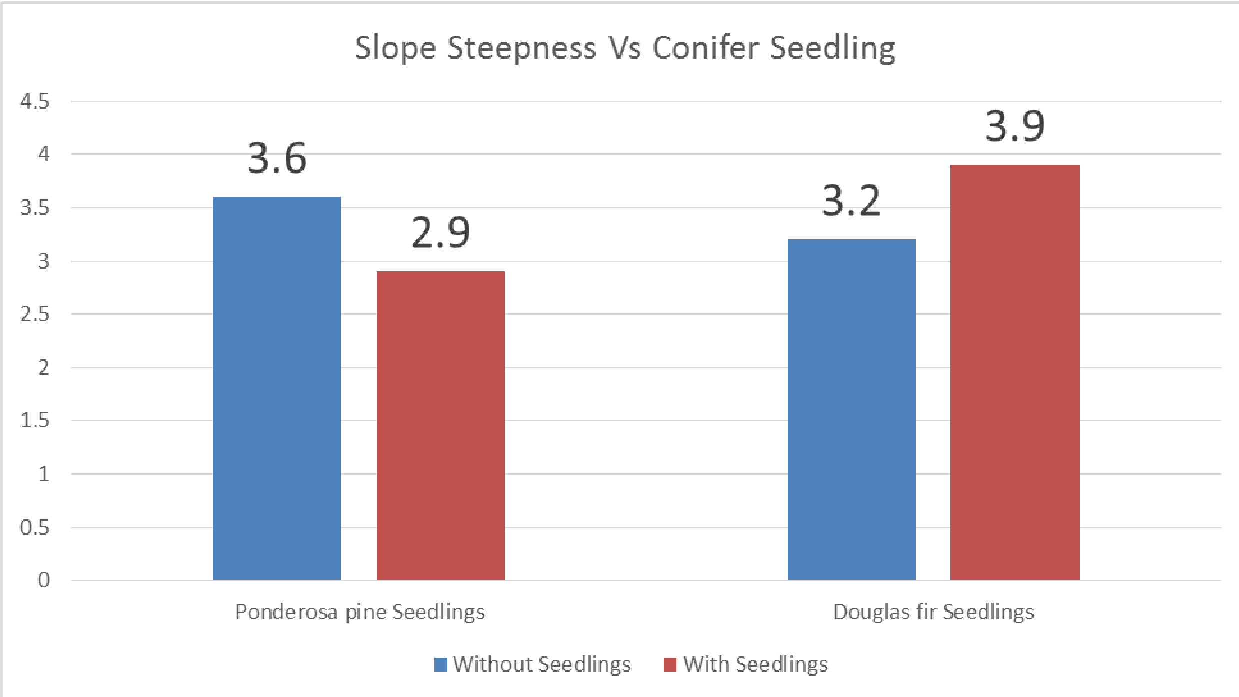
(Figure 3) Relationship between seedling counts per quadrat and distance to nearest seed source for: ponderosa pine seedlings (PIPO) and Douglas fir seedlings (PSME) (aspen seedlings not included due to their general lack of propagation from seed).



(Figure 4) Relationship between the average seedling count per quadrat and relative fire severity for: ponderosa pine seedlings (PIPO), Douglas fir seedlings (PSME), and aspen seedlings (POTR). Fire severity was defined as: Low < 20% stand mortality, Moderate 20-80% stand mortality, and High >80% stand mortality.



(Figure 5) Relationship between the average seedling count per quadrat and slope aspect for: ponderosa pine seedlings (PIPO), Douglas fir seedlings (PSME), and aspen seedlings (POTR). North-facing aspects were defined as being between 315 and 45 degrees and south-facing aspects were defined as being between 135 and 225 degrees.



(Figure 6) Relationship between the average slope steepness for quadrats with and without species-specific seedlings present. Slope steepness was qualitatively recorded as being between 1 (flat) and 5(very steep).

(Table 1) Data sources for obtaining needed geospatial datasets.

Data	Source
Burn extent/severity	Landfire Dataset (http://www.landfire.gov/)
DEM	USGS National Elevation Dataset (http://ned.usgs.gov/)
Watershed Information	USGS National Hydrography Dataset (http://nhd.usgs.gov/)
Forest Service Roads	USDA Forest Service (http://data.fs.usda.gov/geodata/)

(Table 2) Measurements of 12 different variables in each 5m x 2m quadrats. General information about the sample area in the center of each 50m transect.

Measured Variables	
General	Slope Position
Taken at center of transect	Slope Shape
	Slope Steepness
	Elevation
	Aspect Bearing
Tree Measurements	Diameter at Base Height (DBH) of Mature Trees
Taken in each quadrat	Diameter at Base Height (DBH) of Juvenile Trees
	Height of Juvenile Trees
	Distance to Nearest Seed Source
Understory Measurements (% cover)	Shrubs
Taken in each quadrat	Forbs
	Grasses
	Coarse Woody Debris
	Bare Soil
	Litter
	Rock
	Snags/stumps

(Table 3) Values comparing quadrats without ponderosa pine seedlings present (top) to quadrats with ponderosa seedlings present (bottom).

	% Mortality	Elevation	Aspect	Slope Steepness	Shrubs	Forbs	Graminoid	Coarse Woody Debris	Bare Soil	Litter	Rocky	Snags/Stumps	Crown Cover	Distance to Seed Source
Mean	48.4	2686.9	91.7	3.6	1.8	1.7	2.2	0.8	1.7	2.7	2.6	0.3	1.7	68.8
Median	35	2685	140	3	2	2	2	0	2	3	3	0	2	2
UQ	100	2710	160	5	3	2	3	2	2	3	3	0.75	3	47.5
LQ	12.5	2651	15	3	1	1	1	0	1	2	2	0	0	0
Range	95	248	175	4	5	4	5	5	4	5	5	3	5	575
P-value	0.08	0.31	0.09	1.10E-08	0.001	0.04	0.18	0.23	0.21	0.004	0.05	0.4	0.32	0.35
Mean	45.9	2681.4	96.7	2.9	1.6	1.8	2.2	0.9	1.6	2.9	2.5	0.3	1.6	31
Median	35	2690	140	3	2	2	2	0	2	3	3	0	2	2
UQ	95	2714	165	3	2	2	3	2	2	4	3	1	3	20
LQ	10	2641	20	1	0.5	1	2	0	1	2	2	0	0	1
Range	95	209	175	4	4	4	5	4	4	4	4	2	5	575

(Table 4) Values comparing quadrats without Douglas fir seedlings present (top) to quadrats with Douglas fir seedlings present (bottom).

	% Mortality	Elevation	Aspect	Slope Steepness	Shrubs	Forbs	Graminoid	Coarse Woody Debris	Bare Soil	Litter	Rocky	Snags/Stumps	Crown Cover	Distance to Seed Source
Mean	54.4	2679.3	112.8	3.2	1.7	1.8	2.4	0.9	1.7	2.6	2.7	0.3	1.5	75.4
Median	40	2684	150	3	2	2	2	0	2	2	3	0	0	4
UQ	100	2705	165	5	3	2	3	2	2	3	3	0	3	70
LQ	10	2641	25	3	1	1	2	0	1	2	2	0	0	1
Range	95	248	175	4	5	4	5	5	4	5	5	3	5	575
P-value	1.25E-08	4.57E-09	1.50E-26	1.46E-08	0.1	0.0004	9.87E-13	0.38	0.14	1.36E-11	1.57E-11	0.00008	2.26E-08	2.53E-17
Mean	30.3	2700.6	43.4	3.9	1.9	1.6	1.7	0.8	1.6	3.1	2.2	0.5	2.2	10
Median	25	2699	20	4	2	2	2	0	2	3	2	0	2	1
UQ	40	2733	30	5	3	2	2	2	2	4	3	1	3	2
LQ	15	2679	10	3	1	1	1	0	1	3	2	0	1	0
Range	95	209	175	4	5	3	3.5	3	4	3	5	2	5	575

(Table 5) Values comparing quadrats without aspen seedlings present (top) to quadrats with aspen seedlings present (bottom).

	% Mortality	Elevation	Aspect	Slope Steepness	Shrubs	Forbs	Graminoid	Coarse Woody Debris	Bare Soil	Litter	Rocky	Snags/Stumps	Crown Cover	Distance to Seed Source
Mean	45.6	2683.3	111.6	3.4	1.8	1.7	2.2	0.8	1.7	2.8	2.7	0.3	1.5	67.4
Median	35	2684	150	3	2	2	2	0	2	3	3	0	0	2
UQ	97.5	2708	165	5	3	2	3	2	2	3	3	0	3	40
LQ	10	2641	25	3	1	1	2	0	1	2	2	0	0	1
Range	95	248	175	4	5	4	5	5	4	5	5	3	5	575
P-value	0.04	0.04	1.58E-17	0.24	0.33	0.26	0.03	0.01	0.0007	0.29	0.002	0.0004	0.0003	0.37
Mean	51.8	2689.5	53.8	3.4	1.7	1.7	2.1	1	1.5	2.8	2.4	0.5	2	34.8
Median	40	2690	20	3	2	2	2	0	2	3	3	0	2	2
UQ	100	2723.5	140	5	3	2	3	2	2	3	3	1	3	25
LQ	15	2656.25	10	3	1	1	1	0	1	2	2	0	0	0.5
Range	95	209	175	4	4	3	5	3	4	4	4	2	5	575