DeVlieg Undergraduate Research Report

Exploring Altitudinal and Climatic Effects on Coniferous Seedling Regeneration in Burned Areas in Central Idaho

Pseudotsuga menziesii seedling and cones found within one of my plots.

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Executive Summary

Higher temperatures and the redistribution of precipitation have influenced the northern Rockies in recent years. These climatic changes could alter the distribution and abundance of important tree species. Frequently burned landscapes offer the best chance to monitor and analyze the regeneration dynamics of tree seedlings through time. The Frank Church-River of No Return Wilderness (FC-RNRW) possess some of the most suitable environments for observing natural changes in the distribution of conifer stands through time. The scope of this project is to infer possible conifer redistributions the climate is causing across a vast spatial landscape in the semi-arid mountains of central Idaho.

For this study, vegetation plots were established along altitudinal gradients in burned areas in the wilderness. Quantifying levels of regeneration allows us to examine the success of conifer re-establishment at different elevations. Regeneration was present in 43% of plots sampled, but only 21% of the total plots had 5 or more established individuals. Douglas-fir (*Psuedotsuga menseizii*) accounted for 99% of the regeneration observed. Current regeneration levels are highest at the 1800m elevation class, with 1263 +/- 2142 conifer stems present per hectare, while the 1400m elevation class represents the lowest level of regeneration with just over 139 +/-357 stems per hectare. Current regeneration levels at the various elevations show a high correlation with historical basal area observed on that landscape. Monitoring three experimentally watered plots sowed with seedlings resulted in 39 seedlings surviving until August 1st, representing around 18% of the total emergents that established in the plots. Plots receiving additional water throughout the summer had higher rates of survival showing evidence that water is a limiting resource in the dry climate of central Idaho.

The observed shifts of forested area will result in changes in the ability of vegetation to sequester carbon dioxide. The succession of forests to grasslands at lower elevations could also be induced, signifying a change in forest biomass arrangement. Additionally, as tree distributions migrate up slopes, other plants and animals that interact with these species could be either positively or negatively affected. As discovered in this research, plant available water is a prevalent limiting resource for some conifers, especially vulnerable seedlings, occupying dry environments.

I. Abstract

Higher temperatures and the redistribution of precipitation have influenced the northern Rockies in recent years. These climatic changes could alter the distribution and abundance of important tree species. The wilderness areas of central Idaho possess some of the most suitable environments for observing natural changes in the distribution of conifer stands through time. For this study, vegetation plots were established along altitudinal gradients in burned areas in the wilderness. Quantifying levels of regeneration allows us to examine the success of conifer re-establishment at different elevations. Regeneration was present in 43% of plots sampled, but only 21% of the total plots had 5 or more established individuals. Current regeneration levels are highest at the 1800m elevation class (1263+/-2142 stems/ha), while the 1400m elevation class represents the lowest level of regeneration (139+/-357 stems/ha). The observed shifts of forested area will result in changes in the ability of vegetation to sequester carbon dioxide. The succession of forests to grasslands at lower elevations could also be induced signifying a change in vegetative biomass.

Key Terms: climatic changes, distribution, altitudinal gradients, regeneration, sequestration

II. Introduction and Background

The current trend of increasing concentrations of greenhouse gases leads to higher atmospheric temperatures (IPCC 2007). Increasing annual temperatures are evident at Taylor Wilderness Research Station (TWRS) from 1976-2006 (Figure 1). In spite of high annual variability there is a trend of increasing annual temperature over this 30 year time period. Warmer than average temperatures not only have direct heat related effects on trees, such as causing heat lesions and desssication (Kolb and Robberecht (1996) , but also indirect effects such as decreasing the amount and duration of the snowpack leading to low soil water availability in the growing season (Mote et al. 2005). This is especially true of the climate in Central Idaho, where precipitation is limited during the summer months. Compounding the effect of warmer temperatures, a trend of decreasing precipitation in these critical summer months has been recorded at TWRS (Figure 2). Again, there is high variability in the data, but with the exception of 1993 and 1998, there has been a decline in the mean precipitation in the summer months.

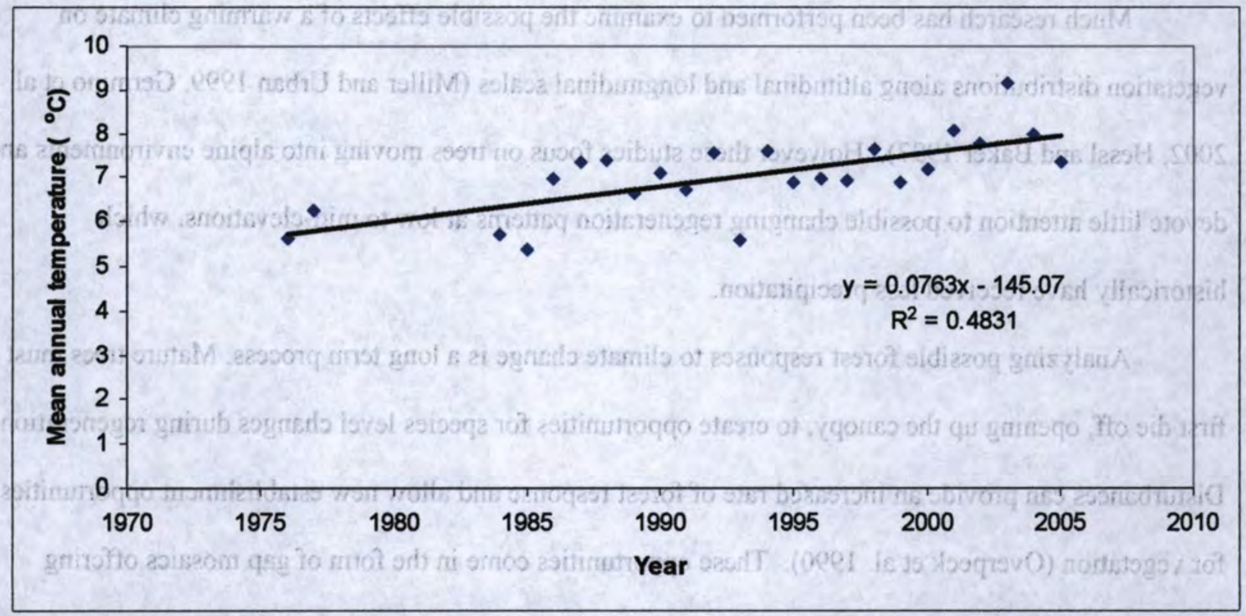

Figure 1. Average annual temperature at TWRS, Frank Church River of No Return Wilderness. (Katy Kavanagh 2008).

Emerging seedlings in which transpiration is limited by soil water have a reduced capacity for stem cooling, therefore increasing heat stress and mortality (Kolb and Robbrecht 1996). Thus, the compounding effects of drought, high temperatures, and evaporative demand can cause high rates of seedling mortality (Kolb and Robbrecht 1996).

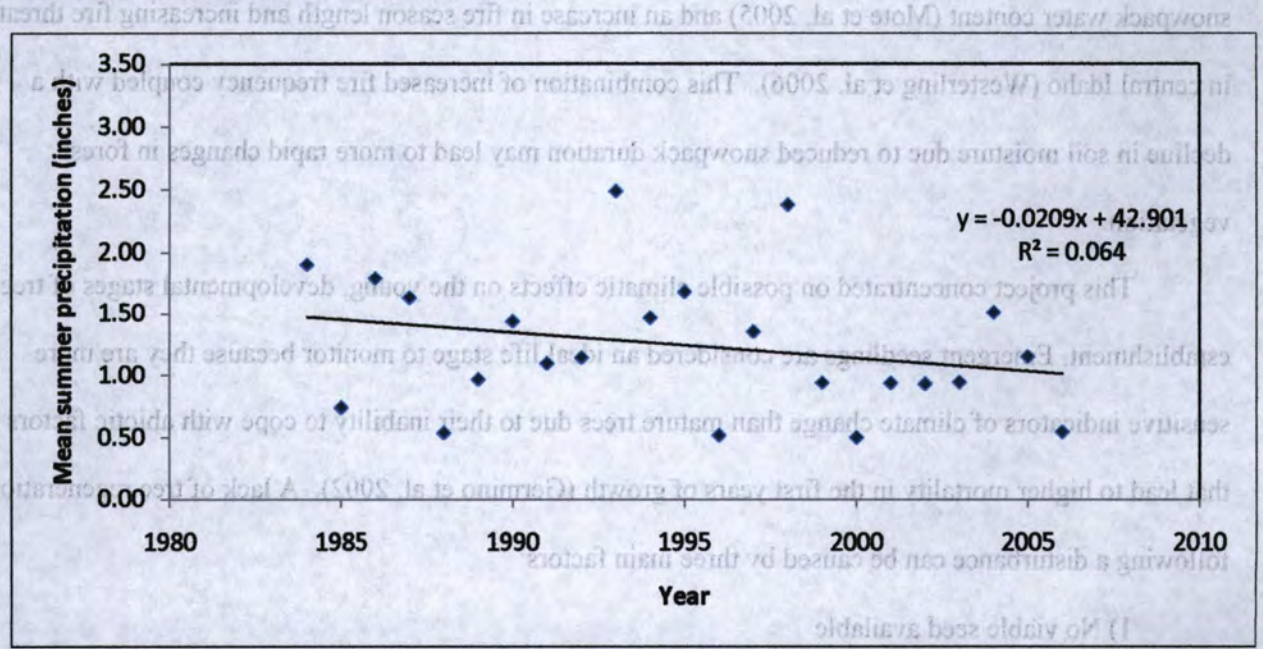

Figure 2. Average summer precipitation at TWRS, Frank Church-River of No Return Wilderness. The mean summer precipitation was calculated using the average amounts of precipitation over the course of June, July and August.

Much research has been performed to examine the possible effects of a warming climate on vegetation distributions along altitudinal and longitudinal scales (Miller and Urban 1999, Germino et al. 2002, Hessl and Baker 1997). However these studies focus on trees moving into alpine environments and devote little attention to possible changing regeneration patterns at low to mid-elevations, which historically have received less precipitation.

Analyzing possible forest responses to climate change is a long term process. Mature trees must first die off, opening up the canopy, to create opportunities for species level changes during regeneration. Disturbances can provide an increased rate of forest response and allow new establishment opportunities for vegetation (Overpeck et al. 1990). These opportunities come in the form of gap mosaics offering more available light and resources for regeneration (Reader et al. 1995). By examining regeneration patterns following disturbance it may be possible to detect changes due to climate that are not yet evident in older established forests.

Wildfires, both natural and human caused, are a common form of disturbance in the coniferous forests of Idaho. The accelerated arrival of spring (Cayan et al. 2001) has resulted in a 30% decline in the snowpack water content (Mote et al. 2005) and an increase in fire season length and increasing fire threat in central Idaho (Westerling et al. 2006). This combination of increased fire frequency coupled with a decline in soil moisture due to reduced snowpack duration may lead to more rapid changes in forest vegetation.

This project concentrated on possible climatic effects on the young, developmental stages of tree establishment. Emergent seedlings are considered an ideal life stage to monitor because they are more sensitive indicators of climate change than mature trees due to their inability to cope with abiotic factors that lead to higher mortality in the first years of growth (Germino et.al. 2002). A lack of tree regeneration following a disturbance can be caused by three main factors:

1) No viable seed available
2) Conditions are not favorable for germination
3) Seedlings are unable to survive once germination occurs.

This study attempted to eliminate the first two issues and focus on the third factor.

III. Research Objectives

There are two objectives for this research:

1) Quantify the difference in post-fire seedling establishment as a function of elevation.

2) Monitor success of emergent seedlings that are given supplementary water over the course of a growing season.

Hypothesis

I hypothesize that higher elevation sites will have higher rates of regeneration than the low to mid-elevation sites. To test the prediction, I gathered information to reject the following null hypotheses:

H_o: Regeneration of coniferous seedlings in recent burns is not significantly different along an altitudinal gradient.

IV. Study Area

The research was based out of the University of Idaho's Taylor Wilderness Research Station (TWRS) in the Frank Church-River of No Return Wilderness (FC-RNRW) in rugged central Idaho. FC-RNRW encompasses over 2.3 million acres and provides some of the least human-tainted habitat for monitoring forest dynamics. The most common species of trees in low to mid-elevations in the wilderness are Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa),* grand fir (*Abies grandis*) and lodgepole pine (*Pinus contorta).* Common shrubs and forbs in these environments include spiraea (*Spiraea betulifolia*), ninebark (*Physocarpus malvaceus*), heartleaf arnica (*Arnica cordifolia*), yarrow (*Achillea millefolium*), arrowleaf balsamroot (*Balsamorhiza sagittata*), serviceberry (*Amelanchier alnifolia*), creeping oregon grape (*Berberis repens*), and snowberry (*Symphoricarpos albus*).

Elevations in the wilderness range from around 600 m (2,000 ft), on the Main Salmon River, to over 3000 m (10,000 ft) in the Bighorn Crags. Sampling was carried out within the Big Creek drainage in the wilderness. Big Creek is the largest tributary of the Middle Fork of the Salmon River. TWRS is located in a deep valley alongside Big Creek, which results in relatively hot, dry and barren landscapes in the vicinity of the research station. Seasonally, summers around TWRS are characterized by warm temperatures and little precipitation with frequent clear skies in the mornings giving way to intermittent afternoon cloud cover. The winters are mild and relatively dry as well with little snow accumulation in the lower elevations. The research station has maintained a small weather station on the property that dates back to the mid 1970s. The mean annual temperature at TWRS is 45° F (WRCC 2005). The mean annual amount of precipitation at TRWRS is 14.2 inches per year (WRCC 2005), with a majority of the precipitation occurring in the winter and spring.

In 2000, over 1.3 million acres of forests burned in Idaho, the most ever scorched in one fire season (USFA 2001). Naturally-caused fires in the FC-RNRW are allowed to burn to reduce the impact of human management on the natural ecosystems. The severity of the fires in 2000 varied highly on the landscape due to a multitude of factors such as fuel availability and topography. High variation in fire severity allows for a mosaic of burnt patches and helps to determine how quickly an ecosystem can recover from the disturbance. Following the fires, no efforts were made to re-seed or alter any landscapes, as the wilderness was allowed, and is still being allowed, to recover naturally.

Currently, little is known about current landscape level tree assemblages in the wilderness and how they might be affected by climatic changes. With historic habitat suitable for conifer stands and a rich fire history, the landscapes around Taylor Ranch will provide ample opportunities for this research (Figure 3 and Appendix E).

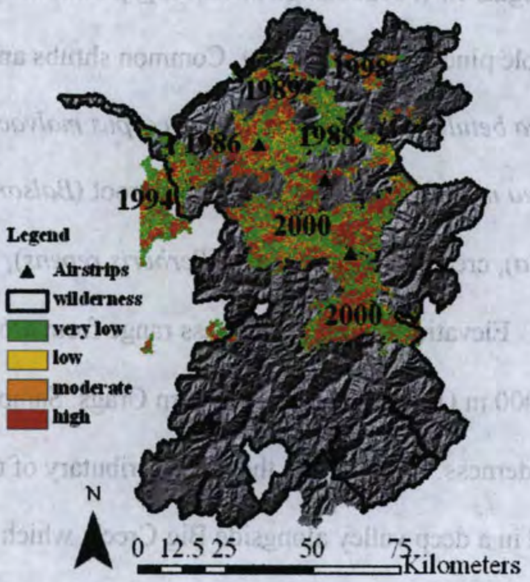

Figure 3. Burned area and severity within the northern half of the Frank Church Wilderness. Date represents year of the fire. (Zach Holden 2008)

V. Methods

The research plots established for this study were all located within the FC-RNRW, in central Idaho. Since elevation is a pertinent factor of the study, plots were established at elevations ranging from 1100-2100 m (3600-6900 ft). This altitudinal range primarily supports ponderosa pine and Douglas-fir in the vicinity of the Big Creek drainage with some lodgepole pine and subalpine fir forests at the higher elevations.

In order to focus on climate effects, sites that were historically ecologically suitable habitat for conifer regeneration were selected. Suitable sited were indicated by the presence of fire-killed and occasional live trees. Post-fire seedling density is greatest after moderate to low severity fires with significantly fewer seedlings present in high severity burns (Chappell et al. 1996). In order to eliminate seed source as a possible limiting factor, we selected sites that had moderate intensity fires to ensure that some seed-bearing trees are still available. Historical fire maps that include year of fire and fire severity layered onto geographic information systems software (GIS) were used to choose tentative regions to sample from (Figure 3). Potential seedbed was also taken into account. Rocky, thin soils will inhibit regeneration so plots were only positioned on sites with adequate soil for seedling establishment. The locations sampled were also restricted to northeast to northwest aspects in landscapes where there were trees before the fire and there is currently a local seed source. These requirements were met by visually assessing the landscape (Figure 4). Actual transect locations were randomly chosen once the site was visited.

We utilized a stratified-random sampling scheme. Once a site was deemed suitable, an elevational transect was initiated (See Appendix A). Starting from the lowest altitude, the nearest live, mature tree was chosen as plot center. All sampling and measurements originated from this anchor tree.

Figure 4. Effects of hill slope on burn severity and sampling suitability. The right slope, with visible live trees, represents a potential sample site, while, in contrast, the left slope is deemed unsuitable to sample due to the lack of surviving seed source. (Eric Clippinger)

Ten meter transects were established that radiated upslope, down slope, and to both side slopes of the anchor tree for a total of 4, 10m transects (See Appendix B for sampling schematic). Sampling was then conducted in 1m^2 circular quadrats situated every 3m within plot transects for a total of 12 subplots in each plot. The next sample site was then determined by moving approximately 100m in elevational relief to a suitable habitat and assigning the closest live, mature tree as plot center. This sampling was then repeated along the landscape as long as suitable burned area and regenerative conditions persisted.

In order to infer differences in post-fire seedling regeneration, the species and abundance of emergents, seedlings, and saplings was recorded in each plot. Guidelines similar to those established by Germino et al. (2002) were followed to differentiate among age classes. Emergents are newly germinated shoots in their first year of growth; seedlings are older than one year, but less than 5 years and less than 6 cm in height while saplings are older, but less than 8 years, and larger individuals. Each plot was assigned a number and the latitude and longitude was recorded through a hand-held G.P.S. (Global Positioning System) unit. The percent of each subplot that was covered by duff, litter, rocks/exposed soil or other plants was recorded. Also, the height and species of each seedling was recorded. The historic basal area of timber around each plot was measured by documenting both live trees and snags in the vicinity of the anchor tree. Historical basal area is an estimate of standing timber on a site which is a representation of the amount of trees pre-fire. Basal area is usually recorded in square feet per acre. Mature trees that fell in the plots were also recorded. The anchor tree was then measured and cored to determine the age. Additionally, a detailed description of each site was recorded, as well as the percentage of ground cover and vegetative cover within the quadrat. (See Appendix C for Data Sheet).

An experiment was also set up on the edge of TWRS property in order to quantify summer survival, and observe the condition of seedlings to examine the effects of spatial variability on establishment. Ponderosa pine and Douglas-fir seed and seedlings obtained from the University of Idaho nursery were sowed in three plots with different environmental conditions. The seed and seedlings were obtained from the University of Idaho Experimental Forest and the Clearwater National Forest, and originated at elevations and climates similar to those at TWRS. Both seed and seedlings were planted to infer any differences in establishment and survival between the groups. Seed was soaked in cold water 36 hours before planting while seedlings underwent the germination process back at the nursery. Each plot was systematically set up consisting of 10 linear groupings of ponderosa pine seedlings and Douglas-fir seedlings, as well as 5 groupings of ponderosa pine seed and Douglas-fir seed for a total of 30 groupings in each plot. In each plot, approximately 4 germinated emergents were planted in the seedling groupings or subplots while around 6 seeds were planted in each seed subplot. For both the seed and germinants, litter was removed and the potential trees were sowed around ½ - ¾" deep into the substrate.


Figure 5. Monitoring condition of ponderosa pine emergents sowed in Plot 1. Photo was taken in mid-July. (Eric Clippinger)

Plot 1 was located at 1200m and characterized by an eastern aspect and rocky, dry soil. Plant species within the vicinity include bluebunch wheatgrass (*Elytrigia spicata*), arrowleaf balsamroot (*Balsamorhiza sagittata*), and to lesser extent big sagebrush (*Artemisia tridentata*). Plot 2 was also located ay 1200m, but with a northern aspect and considerable more organic, less dry soil. This plot had extensive vegetative cover including bluebunch wheatgrass and arrowleaf balsamroot. Both plot 1 and 2 received supplemental water throughout the summer growing season. This regiment consisted of around 5 oz. water per grouping/subplot each watering. Watering took place once, twice, or three times a week depending on local precipitation amounts. Plot 3 was located at 1190m and distinguished by an eastern aspect and rocky, dry soil. Plant species on the site included bluebunch wheatgrass and arrowleaf balsamroot. Plot 3 acted as our control and received no supplementary water over the course of the summer. Relevant observations and field notes on seedling condition was periodically recorded while the number of surviving seedlings was documented every other week (Figure 5).

VI. Results

The occurrence and number of naturally established seedlings was recorded in 75 plots situated at various altitudes on the landscape (Appendix D). Regeneration (emergents, seedlings, or saplings younger than 8 years) was present in 43% of plots sampled, while only 21% of the total plots had 5 or more established individuals (n=75). Of the total regeneration discovered in 75 plots, 58% was classified as saplings, 25% was seedlings, and 16% was emergents in their first year of growth. Seedling will be used as an encompassing term and includes all three classifications to represent regeneration on the data presented below. Regeneration classified as saplings, accounted for a majority of the regeneration, and had the highest numbers in the 1200m and 2000m elevations (Figure 6). Emergents and seedlings were most prevalent in the 1800m elevation class with an average of 1 emergent per plot and 2 seedlings per plot.

Although approximately 10% of sites sampled had mature ponderosa pine present, ponderosa pine regeneration accounted for less than 1% of total regeneration recorded. The more successful conifer species that made up the other 99% of regeneration was Douglas-fir.

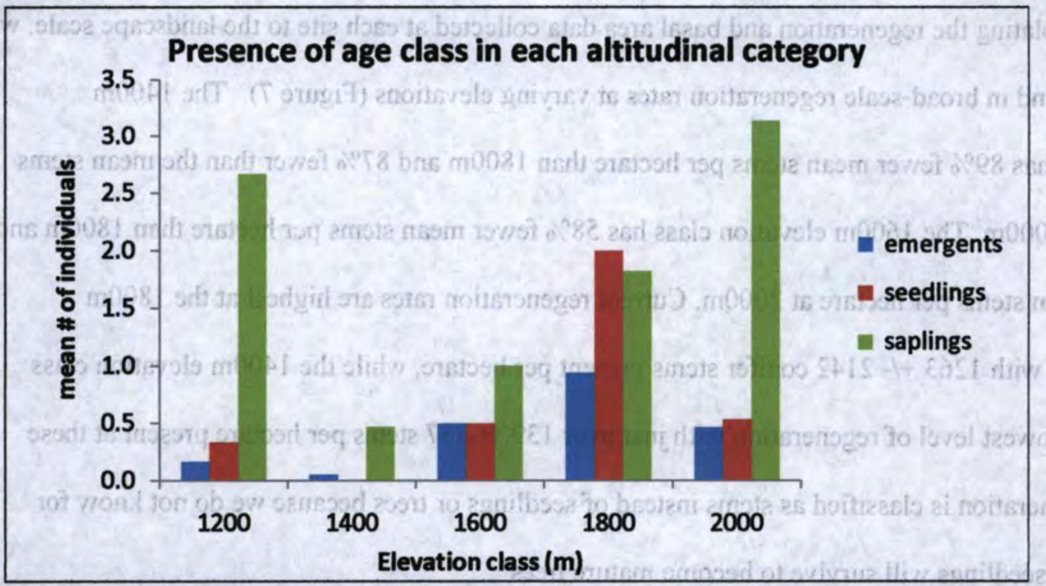

Figure 6. Bar graph showing the distributions of different categories of regeneration across an elavational gradient. Data collected in the summer of 2008, in FC-RNRW around Taylor Wilderness Research Station by Eric Clippinger.

Altitudinal Effects

Since a major focus of this research was analyzing possible differences in regeneration along altitudinal gradients, elevation classes were stratified into five categories: 1200m, 1400m, 1600m, 1800m, and 2000m. Comparing all areas that were sampled, the percentage of plots with regeneration is larger at the higher altitude classes and the average number of individuals discovered is also higher at these higher elevations, although an anomaly exists in the 1200m category (Table 1). Mean historical basal was also highest in the high altitude classes (1800m and 2000m). This anomaly is most likely attributed to plot locations near bottomlands compounded by a small sample size of elevations around 1200m (n=6).

Table 1. Effects of elevation on number of plots with regeneration, mean amount of regeneration, and mean historical basal area. Data collected in the summer of 2008, in FC-RNRW around Taylor Wilderness Research Station by Eric Clippinger.

Elevation Class (m)	Number of Plots	Plots with Regeneration (%)	Mean Amount of Regeneration Per Plot (Individuals)	Mean Historical Basal Area (ft^2/acre)
1200	6	50	3 +/- 5.4	93 +/- 45
1400	19	16	0.5 +/- 1.3	75 +/- 35
1600	18	33	2 +/- 3.5	87 +/- 42
1800	17	65	5 +/- 7.5	124 +/- 60
2000	15	60	4 +/- 4	113 +/- 41

Extrapolating the regeneration and basal area data collected at each site to the landscape scale, we see a similar trend in broad-scale regeneration rates at varying elevations (Figure 7). The 1400m elevation class has 89% fewer mean stems per hectare than 1800m and 87% fewer than the mean stems per hectare at 2000m. The 1600m elevation class has 58% fewer mean stems per hectare than 1800m and 52% fewer mean stems per hectare at 2000m. Current regeneration rates are highest at the 1800m elevation class, with 1263 +/- 2142 conifer stems present per hectare, while the 1400m elevation class represents the lowest level of regeneration with just over 139 +/-357 stems per hectare present at these altitudes. Regeneration is classified as stems instead of seedlings or trees because we do not know for certain that the seedlings will survive to become mature trees.

Another way to compare the data is to look at what percentage of the mean the basal area and current regeneration account for at the various altitudinal classes. The 1800m and 2000m elevations account for 163% and 142%, respectively, of the mean total regeneration at all elevations, whereas the amount of regeneration at the 1400m elevation is only 18% of the mean total regeneration (Figure 8).

Due to my data violating several assumptions involved in running a one-way ANOVA, using this test to compare the differences between the means of my data was not feasible. This is because several outliers are present in my data and overall it is not normally distributed. Also the high variability of the data makes it hard to interpret significant differences with a relatively small sample size of 75. Running several transformations on the data resulted in similarly skewed data sets. This means that either a larger sample size is required or a non-parametric statistical test could be attempted. Most non-parametric tests utilize a ranking system in order to alter the data (Wheater and Cook 2000). This ranking clumps actual values into groups and is not always reliable when applied to highly variable data (Wheater and Cook 2000). Probably the most effective way to determine if there are significant differences between the elevations is to establish more sample sites in a similar fashion to increase the number of values in each category.

Consequently, I can not refute the null hypothesis and prove there is a significant difference between the different elevations. As the descriptive statistics point out, this does not mean that there is no difference between the amounts of regeneration at the altitudinal categories. Through continuing to monitor regeneration in the FC-RNRW, future studies can add to this work, accumulating even more available data to analyze.

Regeneration Compared to Basal Area

As of 2008, 8 years post-fire, current seedling establishment levels are considerably lower than the total amount of regeneration seen following previous fires in all elevation classes except 1200m (Figure 7). Current regeneration levels at the various elevations show a high correlation with historical basal area found on that landscape.

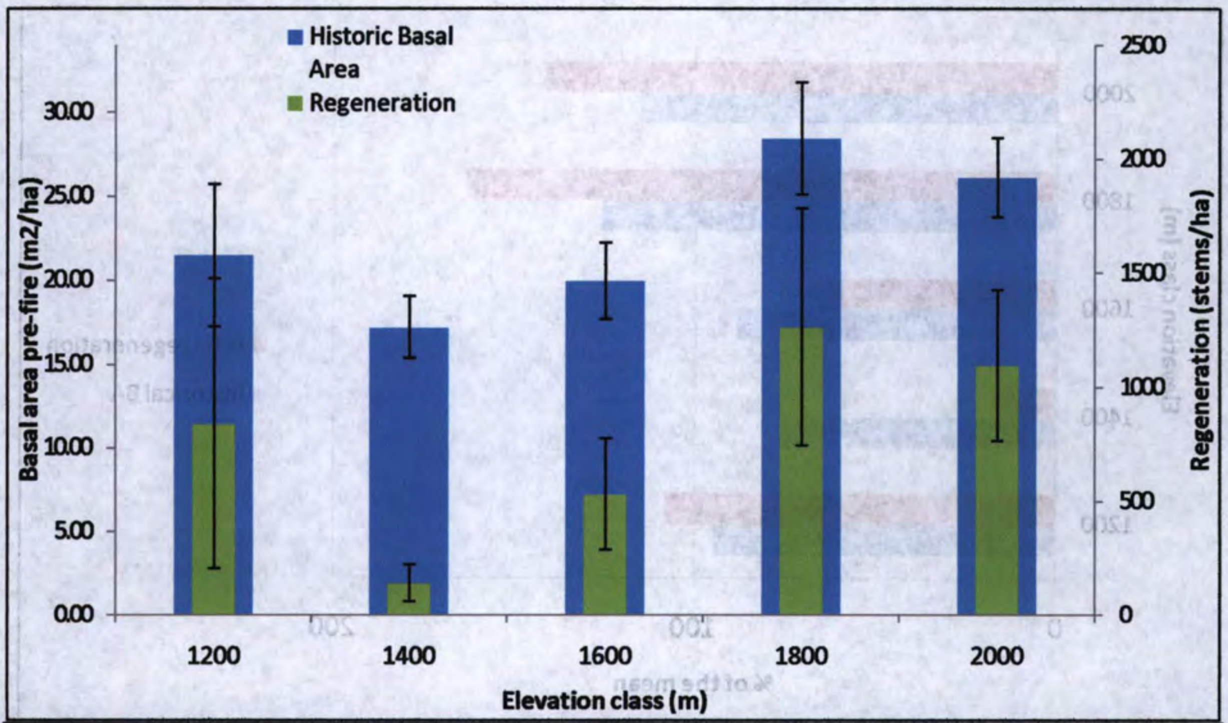

Figure 7. Historic (pre-fire) basal area and current regeneration compared across different altitudinal strata. Data collected in the summer of 2008, in FC-RNRW around Taylor Wilderness Research Station by Eric Clippinger.

As with total regeneration, low to mid-elevations display this trend most obviously. The level of regeneration at the 1400m elevation class would have to increase ten-fold to reach the historical amount of mature trees on the site. Regeneration at elevations around 1200m, 1800m, and 2000m is over half of the historical basal area at these elevations. Previous forests, represented by the pre-fire or historical basal area, in the wilderness also established more successfully at the higher elevations. Sites around 1800m and 2000m contain a mean historical basal area of 27 +/-11.5 m^2 per hectare, while sites in the 1400 to 1600m category have a mean historical basal area of 19 +/-8.8 m^2 per hectare.

In contrast to the amount of regeneration at the different elevations, pre-fire basal area at the different elevation classes is more clustered around the mean total basal area of all the plots (Figure 8). The 1200m, 1400m, and 1600m categories account for 95%, 76%, and 88%, respectively, of the mean total basal area, while the basal area at 1800m and 2000m is higher than the overall mean representing 126% and 115%, respectively.

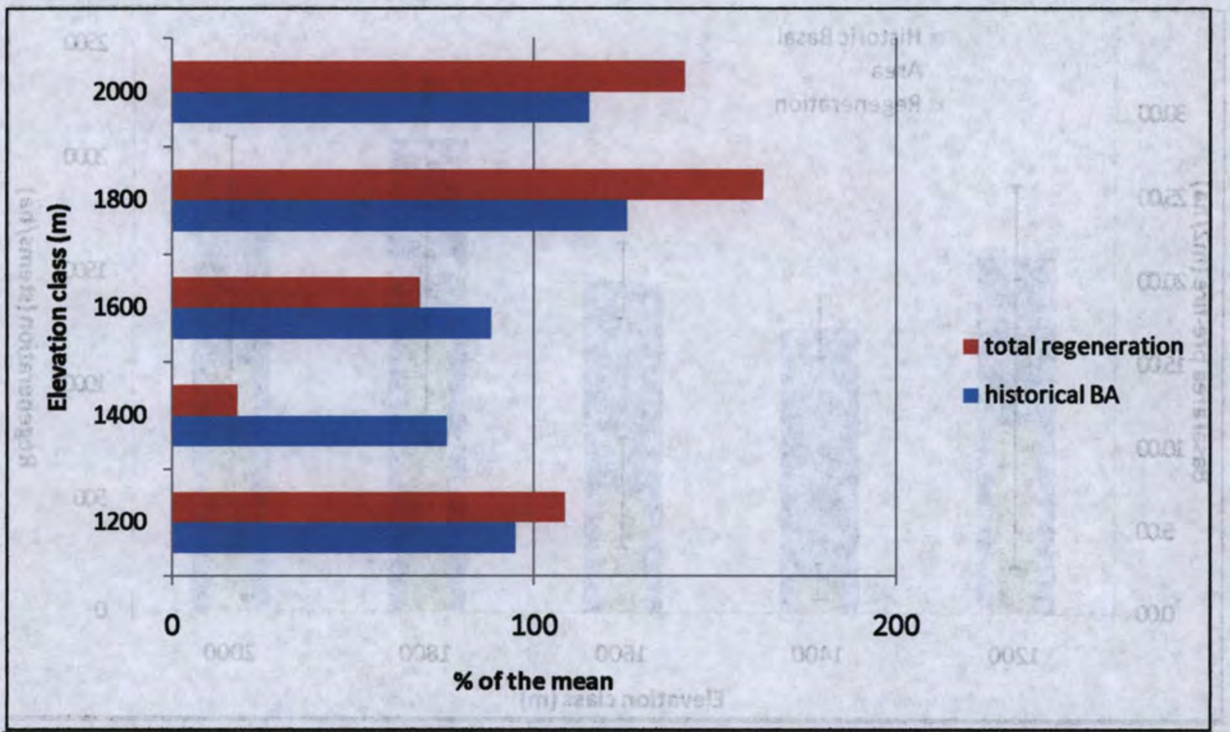

Figure 8. Total regeneration and historical basal area as a percentage of the combined mean of each variable across an elevational gradient. Data collected in the summer of 2008, in FC-RNRW around Taylor Wilderness Research Station by Eric Clippinger.

Survival of Monitored Emergents

Plots 1 and 2 had relatively low rates of seedling survival, but they were still considerably higher than the survival in the control plot (Plot 3). Plots 1 and 2 both received additional water to supplement the sparse amounts of precipitation that fall in the summer in the Big Creek drainage. Although unrealistic, if all planted seedlings/seeds germinated and survived there would be a total of 80 seedlings from emergents and 60 seedlings from seed in each plot for a grand total of 140 seedlings per plot. For this study, survival was determined by using the number of seedlings that successful establish and then comparing that to the individuals that go on to live through the summer. Combining the results from all three plots, 39 seedlings survived through August 1st, representing around 18% of the total emergents that established in the plots.

Plot 1 had a total of 48 seedlings colonize the plot, and 10 seedlings went on to survive the summer until early August (Figure 9). This means that 21% of the emergents that successfully germinated and established in Plot 1survived until August. All 10 surviving emergents were ponderosa pine. While 6 survivors were planted as germinated shoots, the remaining 4 were sowed as seeds. The germination rate of ponderosa pine seed sowed in this plot was 10% while the germination rate of Douglas-fir seed sowed was only 2%.

Plot 2 contained 29 emergents that survived until August. This plot faired only slightly better than Plot 1 with almost a quarter (24%) of the total established emergents surviving. Once again, ponderosa pine was able to persist more successfully than Douglas-fir on this landscape (Figure 10). Of the surviving seedlings, 25 were ponderosa pine and 4 were Douglas-fir. Nearly half of the ponderosa pine seed sowed in this plot germinated (47%) while the germination rate of Douglas-fir seed was 23%.

Plot 3 received no supplemental water and was at the mercy of the climate and local weather patterns. By mid- June, 47 individuals, nearly the same number of seedlings that inhabited Plot 1 at the same time, had germinated and established in the plot. In early July, approximately 23 emergents were still alive, but by August there were none surviving. This resulted in 0% survival in the plot (Figure 11). Not surprisingly, 18 of these were ponderosa pine. The germination rate of ponderosa pine seed planted was 10% with 7% of Douglas-fir seed successfully germinating.

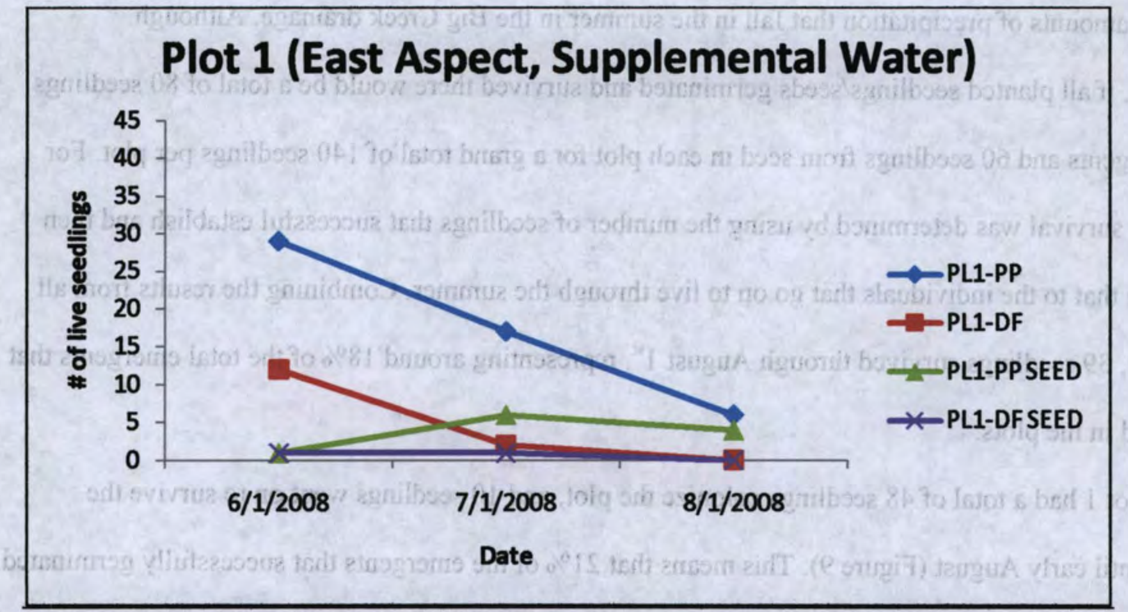

Figure 9. Survival of seedlings and seed positioned on an eastern aspect and given supplemental water over the course of a summer. Data collected in the summer of 2008 around Taylor Wilderness Research Station by Eric Clippinger.

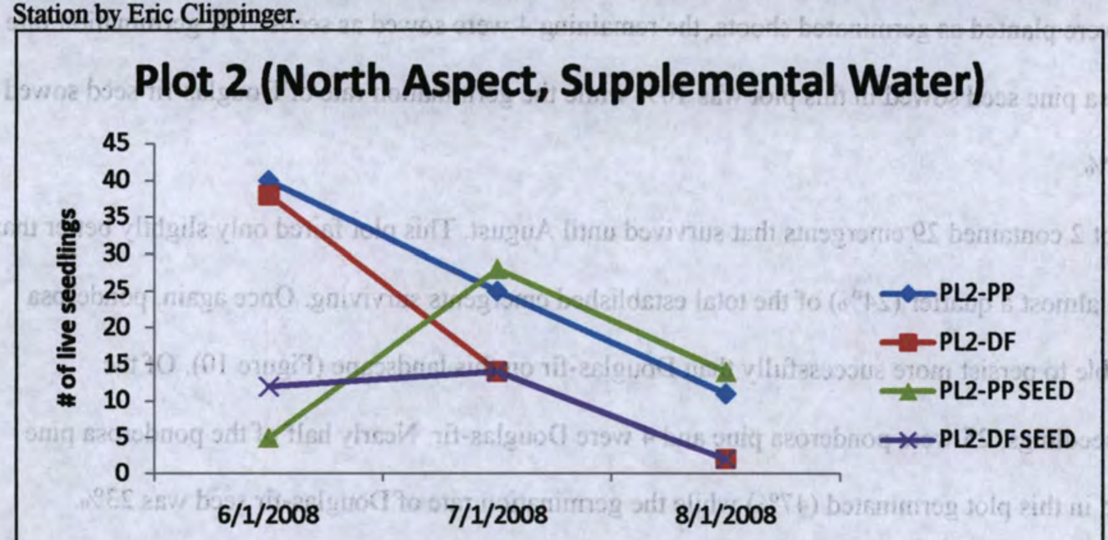

Figure 10. Survival of seedlings and seed positioned on a northern aspect and given supplemental water over the course of a summer. Data collected in the summer of 2008 around Taylor Wilderness Research Station by Eric Clippinger.

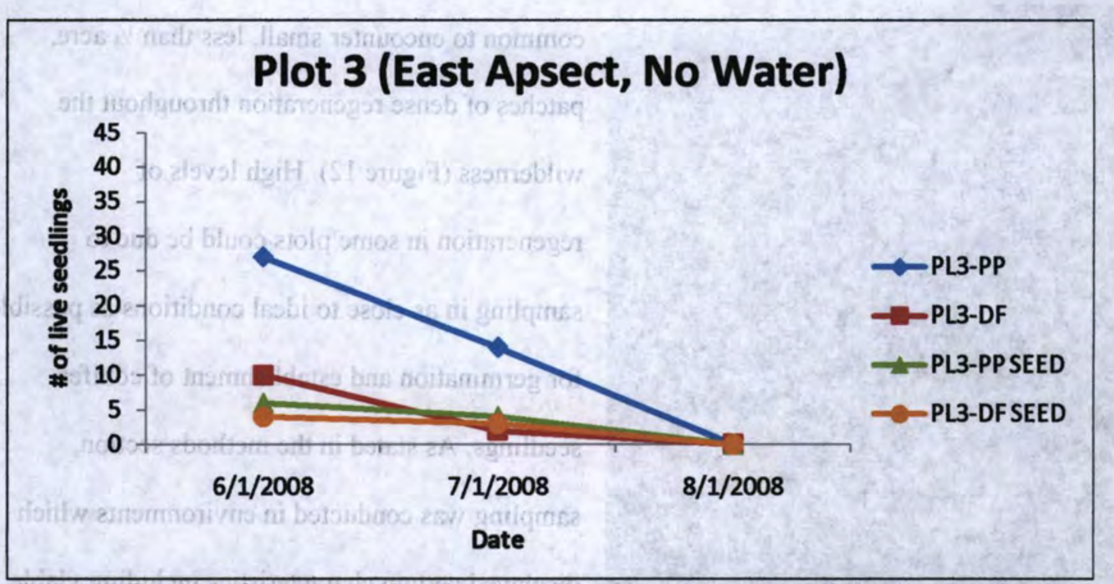

Figure 11. Survival of seedlings and seed positioned on an eastern aspect and not given supplemental water over the course of a summer. Data collected in the summer of 2008 around Taylor Wilderness Research Station by Eric Clippinger.

VII. Discussion

Of 75 plots laid out and sampled, 32 contained regeneration of at least one conifer seedling and only 16 plots had 5 or more seedlings present. A relatively low percentage of plots with regeneration present (43%) might be explained by the ecology of the inland sub-species of Douglas-fir, Rocky Mountain or (*var. glauca*). Low availability of water and high temperatures encountered during the inland growing season can constrain the growth and overall recruitment of a given stand of these false firs (Rehfeldt 1989). In contrast to our observations, a similar study by Larson and Franklin (2005) examining Coastal Douglas-fir (*var. menziesii*) regeneration following a wildfire in the Cascade Range of Oregon, resulted in 95% of plots sampled with seedlings present. That research was conducted 11 years post-fire.

Extrapolating the mean amounts of regeneration in each elevation class to a coarse, landscape scale resulted in hundreds of stems within one hectare in the three lower elevation classes, and over one thousand stems per hectare in the 1800m and 2000m elevation classes. This potential exaggeration of recruitment levels is due to a fraction of plots that had very high amounts of regeneration. In fact, 6 plots had levels of 12 or more seedlings and 2 had over 24 individuals in around 300m^2 of area sampled. It was

Figure 12. Example of regeneration occurring in distinct patches on the landscape. (Eric Clippinger)

common to encounter small, less than ¼ acre, patches of dense regeneration throughout the wilderness (Figure 12). High levels of regeneration in some plots could be due to sampling in as close to ideal conditions as possible for germination and establishment of conifer seedlings. As stated in the methods section, sampling was conducted in environments which displayed certain characteristics including viable local seed source and adequate substrate for germination. Since all of the plots established were directly under a live tree, this also increases the likelihood of seedlings being found in the vicinity. This also affects the amount of regeneration seen at the landscape level.

A majority of the regeneration observed was classified as a sapling which are trees >7cm in height and less than 8 years old. This is a good sign that some saplings have established and are surviving at all elevation classes. A fair amount of emergents were observed (n=35) and represent a 2008 spring in which precipitation levels were relatively average. In fact, in 2008 the month of May received around the mean total precipitation recorded for May for the past 30 years (WRCC 2005).

A repercussion of limiting sampling to northern aspects and relatively fertile soil is that ponderosa pine accounted for a very small proportion of the trees recorded. Ponderosa pine was designated as an anchor tree less than 1% of the time and was found in only 1% of the plots sampled. Douglas-fir was the dominant conifer species encountered throughout the study area. As hot and dry conditions continue to escalate at lower elevations ponderosa pine does not seem to be successfully moving into higher elevations where more water is available longer into the growing season. Yet the species struggles to regenerate contiguous or even scattered stands at lower altitudes. The species is known to be drought tolerant (Kolb and Robberecht 1996), but could be facing increased water stress in their current habitat from a changing climate.

Altitudinal Effects

Analyzing regeneration at different elevations reveals that the two highest elevation categories, 1800m and 2000m, also had the highest amounts of regeneration. Altitudes around 1400m, representing the category with the least regeneration, averaged only 139 stems per hectare and the mean value of seedlings in this category was only 18% of the total mean regeneration of all the plots. Conversely, the 1800m elevation class had a mean of over 1200 stems present in one hectare and a mean amount of regeneration over 120% of the total plot mean. Regeneration density at higher elevations, above 2400m, is usually lowest for fire resistant species, namely ponderosa pine and Douglas-fir, following a mild severity fire (Fule and Laughlin 2007). This data supports my hypothesis that more conifer seedlings are establishing at higher altitudes relative to lower altitudes.

The 1200m elevation category has higher rates of regeneration than the 1400m and 1600m categories, but less than the 1800m and 2000m classes. The 1400m through 2000m altitudinal categories represent sampling carried out on hill slopes rising from valley floors. I expected the 1200m class to possess the fewest amount of regeneration in these low-elevation, usually dry and hot environments. If sampling at these elevations was conducted on hill slopes consistent with the other elevation, I believe the results would be far different. The results from the 1200m class have been discounted because some of the sampling in this stratification took place in the bottomlands of valleys. In these environments groundwater becomes more readily available and dynamic cold/hot air pools move moisture throughout the valleys.

I was not able to fully answer my research questions. More data needs to be collected in order to interpret the results clearly or a long, advanced statistical approach might provide some additional information as well.

Although, all indications show that seedlings are having more success germinating and establishing at the higher elevations of their range. For example, the mean number of seedlings present per plot was highest in the 1800m and 2000 elevation class, and the mean historical basal area was also highest in these two classes allowing us to infer the success of establishment of previous forests. This points out that the previous forest also established more successfully at higher elevations resulting in more patches or stands of mature conifers, ultimately meaning a higher recorded basal area in the 1800m and 2000m elevation classes. Although the pre-fire basal area of elevation classes displays a similar trend to the current regeneration levels, the range of current regeneration amounts has increased markedly from the range of historic basal area.

Regeneration Compared to Basal Area

Because it has only been 8 years since the fire, and the establishment of conifer seedlings following a fire can go on for several decades (Larson and Franklin 2005), it is not surprising that current regeneration levels are not equivalent to the pre-fire basal area of the sites. But the magnitude to which regeneration is lagging behind at some elevations is pertinent. The 1400m elevation category in particular is currently showing reduced amounts of seedlings compared to the levels that the previous forest has attained. The highest historic basal areas were located in plots around elevations of 1800 and 2000m. Thus, even now there are more mature trees inhabiting higher elevation environments. Although historically, low to mid-elevations have had less basal area or amounts of forests on the landscape, current regeneration levels indicate that even more pronounced losses of forests at these elevations is occurring.

Yearly regeneration success can vary greatly year to year and is controlled by a variety of climatic, topographical, and ecological processes. This means that seeds can fail to germinate for many years, but when the conditions are just right for germination they can simultaneously respond quickly resulting in noticeable pulses of regeneration. From our data the only elevation classes that are seeing pulses of regeneration somewhat comparable to what is needed to keep track with previous biomass in the forest is the two highest altitude classes, while the lower elevations, particularly sites around 1400m, are struggling to adequately support several seedlings on a couple hundred square meters.

Survival of Monitored Emergents

Examining the results from our supplemental water experiment, water appears to be a limiting resource in the dry climate around TWRS, especially during the summer months. The results also indicate that the relative location of seedlings on the landscape, and the species of tree present affect the survival of emergents in their first year of growth. A low survival rate of sowed conifer seedlings in their first year of growth has been documented at the alpine-treeline ecotone as well (Germino et al. 2002). This research, although focused on a different landscape, offers insight into climatic variables that constrain emergents. Germino et al. (2002) suggested that patterns of seedling survival are affected by low temperatures and water stress and that high light conditions might intensify this effect. Replace low temperatures with high temperatures, which might make the situation bleaker, and you have some of the rough conditions emergent conifers face during the summer months in the Big Creek drainage

. The experimental plot that had the highest survival rate was Plot 2, although the survival in Plot 1 was only slightly less. Scattered vegetative cover in Plot 2 could be responsible for fabricating microsites and subsequent climates that facilitated seedling survival (Germino et al. 2002). Both of these plots received additional water throughout the summer. Plot 3, which received no supplementary water through the summer, suffered 0% survival. By species, ponderosa pine enjoyed a higher rate of survival than Douglas-fir. In fact, only 4 Douglas-fir emergents survived until August, which does not even encompass survival over the entire summer. Taking the biological and ecological characteristics of the trees into account, it was fairly obvious that drought tolerant ponderosa pine could establish and survive more readily on the exposed sites than the Douglas-fir.

The increased detrimental effects of the summer climate can be observed as we monitor survival through the latter summer months. Even in the plots that received supplemental water, by August, the substrate was dry and crumbly and many seedlings showed signs of dessication. The dramatic effects that prolonged exposure to high light and high temperatures coupled with low available water can have on young seedlings are no more obvious than in Plot 3. While 23 individuals occupied the site in early-July, none survived until August. Decreased amounts of precipitation in July and August can exacerbate insufficient supplies of ground water, especially in xeric environments, leading to increased water stress and mortality of seedling in their first year of growth (Kolb and Robberecht 1996).

Seed that was sowed did not immediately germinate and establish, but waited several weeks until conditions were right and then finally emerged from the dirt (See Figure 8 and 9). This was interesting because I thought that seeds might wait to emerge from the substrate to reduce exposure to high sunlight which can increase transpiration and reduce available water. By residing underground, other potentially harmful or even fatal environmental conditions are avoided. But immediately after emerging through the topsoil, the number of emergents present from seed source was nearly the same as the amount of live seedlings sowed and, moreover, seedlings from seed stock exhibited the same decline in survival that seedlings exposed for 3-4 more weeks experienced. In the end, for seeds, this strategy did not help facilitate survival as seed sown suffered nearly the same mortality of emergents that were planted.

VIII. Implications/Conclusion

The broad, landscape level changes in total biomass and composition of forests in Idaho are very relevant to not only natural resource managers and scientists, but also to a general public who appreciate the variety of ecological processes our forests carry out everyday. Modeling the biotic responses to future climate projections, it has become widely accepted that distributions of trees will move to higher latitudes as well as to higher altitudes (Fagre et al. 2003).

Forests are one of the largest sequesters of atmospheric carbon dioxide, helping to limit the harmful effects of high concentrations of greenhouse gases. A decrease in forested area or shifting of forests distributions will result in changes in the net primary productivity (NPP) of these ecosystems, and thus the ability of the stand to sequester atmospheric carbon will also change. Although trees readily use CO_2 for photosynthesis, indirect effects of increased atmospheric CO_2 (e.g. changes in current climate regimes) will most likely override short-term gains in productivity and express control over the extent and distribution of forests. Already, leaf area index (LAI), an indicator of forest productivity, in central Idaho is increasing at mid- to high elevations while it decreases at lower elevations (Kavanagh, unpublished). This trend has become particularly apparent during the regeneration of vegetation following the fires of 2000, as sharp changes began around 2003.

The coniferous forests of central Idaho are also incredibly important to the ecology of the environment around them. In FC-RNRW conifer stands provide many valuable benefits to the ecosystem including habitat for animals, stabilization of hillsides, and precipitation interception and retention. As tree distributions move up slopes, other plants and animals that interact with these species could be either positively or negatively affected. Landscapes where forests are locally extirpated will leave ecosystems without a critically important component of the environment. Other biota in the ecosystem will have to live without conifer trees or migrate to areas with forested cover. Long-term effects of losing tree biomass on a site could mean alterations of physical and chemical processes taking place resulting in drastic changes to the soil, topography, and vegetation within the site. Conifer stands moving into higher elevations have started to succeed into alpine meadow environments where trees have historically been absent, effectively regulated by low temperatures and a very short growing season. Again forests establishing in these foreign environments will alter the ecology of the landscape, mostly by replacing low growth meadows with environments with high forest cover (Fagre et al. 2003).

For several tree species, such as ponderosa pine, the survival of seedlings on hot, dry sites is dependent on their ability to dissipate heat through transpiration (Kolb and Robberecht 1996). High levels of transpiration require seedlings to utilize all the water that is available to them. This makes plant available water a potential limiting resource for some conifers, especially vulnerable seedlings, occupying dry environments. Forest structure is most sensitive to climate change in these water-limiting landscapes (Miller and Urban 1999). In the dry environments of central Idaho and the FC-RNRW, Douglas-fir and ponderosa pine regeneration is decreasing at lower elevations and the ponderosa pine in particular appears to be struggling to effectively migrate to favorable habitat.

Specifically, here are some questions related to this project that should be continually monitored to describe conifer tree species shifts in Idaho: Are landscapes that burned so severely that almost no live

trees remained experiencing the same pattern of regeneration at the higher elevations, or is propagation even occurring without a seed source present? Might we see a large-scale loss in ponderosa pine biomass because it is unable to adapt and evolve to compete in the same environment as Douglas-fir? By continuing to examine seedling recruitment and success, researchers may be able to draw critically important conclusions about vegetation redistributions that our changing climate is affecting across a dynamic spatial and temporal landscape.

IX. Acknowledgements

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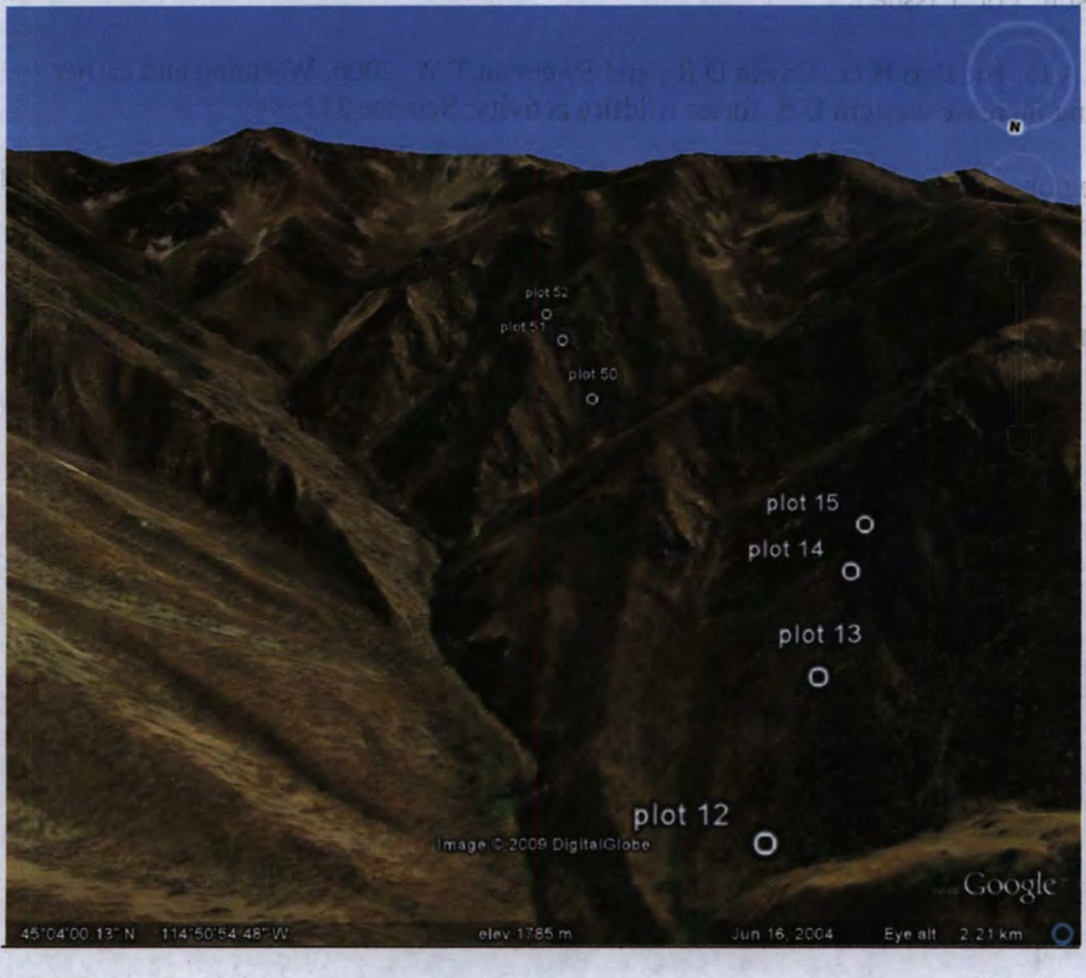
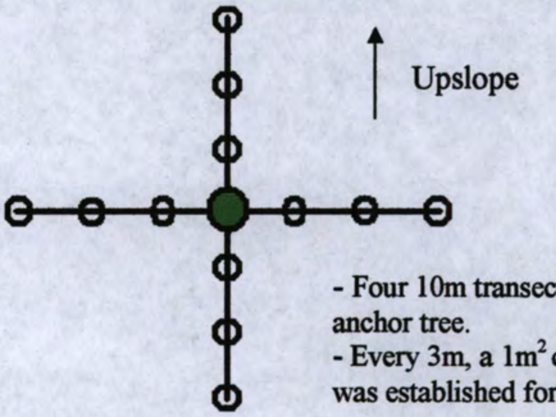
XI.
Appendix A.

- Landscape view of sampling showing plots located on transects ascending the hill slopes. Google Earth 2009



Appendix B.

- Schematic of plot sampling; green circle represents anchor tree.



- Four 10m transects radiating from anchor tree.
- Every 3m, a $1m^2$ circular quadrat was established for a total of 12.

Appendix C.

- Field collection data sheet

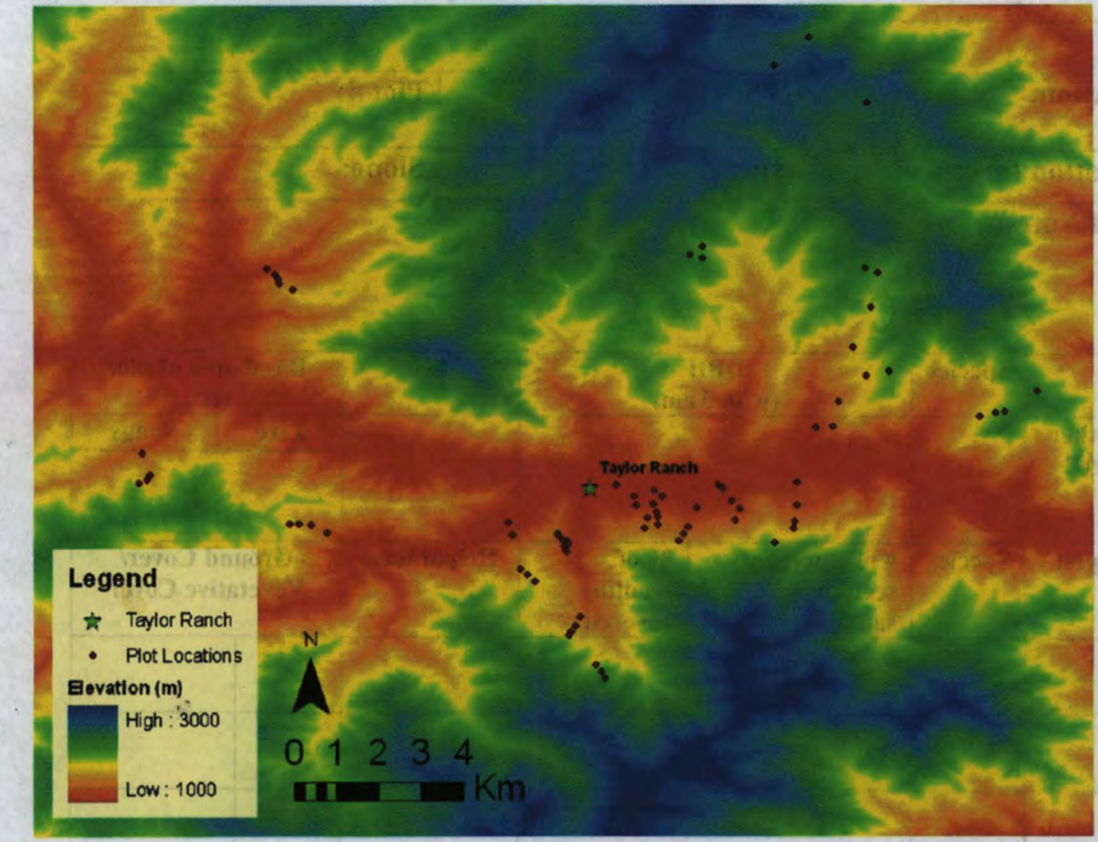
ID:		
Location:	**GPS:**	**Plot #:**
Elevation (m):	**Aspect:**	**Slope:**
Field Notes:		

	Species	**DBH (w/in 5 cm)**	**Age**	**Basal area of plot (ft^2)**	
				Live	**Snags**
"Mother Tree"					

Subplot	**Species**	**# of emergents, seedlings, saplings**	**% of seedling covered**	**Height (cm)**	**Ground Cover/ Vegetative Cover**	
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

Appendix D.

- GIS derived digital elevation model (DEM) showing locations of plots in Big Creek drainage



Appendix E.

- Fire year, number of fires that occurred each year, and area burned within the northern half of Frank Church Wilderness.

Year	# of Fires	Hectares Burned
1986	2	7,684
1988	6	51,230
1989	2	1,280
1990	3	3,204
1991	2	3,800
1994	2	44,900
1998	3	65,610
1999	4	4,300
2000	5	161,600