Modified Group Selection Silvicultural Regimes: Supplanting Herbicide Application on Establishing Coniferous Seedlings in the Mixed Conifer Forest of Sierra Nevada

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ABSTRACT

Management of mixed conifer forests in California's Sierra Nevada often uses rotations that require the use of herbicides and patch sizes of up to 8 hectares to ensure successful regeneration of mixed conifer species. Yet, concerns over the toxicity of herbicides presents an opportunity to explore alternative methods of controlling competing shrub species. Our study created 20 random openings of 0.08 hectares in size at Blodget Forest Research Station, California and planted 4 rows of mixed conifer species with openings randomly treated with herbicide or not; to examine whether the use of herbicides significantly affected growth. Using data on groups 0.1 to 1.0 hectares in size from a similar study, we also analyzed whether the variance in patch size would significantly impact growth rates. The results demonstrated that herbicide application did not significantly impact the growth of any of the 4 mixed conifer species regenerated in 0.08 hectares patches. We also found that annual growth did not significantly differ with patch size when comparing the grouped 0.08 ha patches with openings of 0.1/0.3 hectares in size. Yet, there was a significant difference in growth at the plot level when comparing the 0.08 ha patches to groups of 0.6/1.0 hectares for all species and individually except for ponderosa pine and sugar pine. The results of this present interesting findings for management of mixed conifer forests; chiefly that small groups provide opportunities to regenerate coniferous seedlings without the use of herbicide without a substantial loss in annual growth rates.

KEYWORDS

Gap dynamics, Edge effects, Shrub competition, Silviculture, Forest disturbance patches

INTRODUCTION

Yellow pine and mixed conifer forests are some of the most widely distributed forest types in the California Sierra Nevada mountain range. They are primarily mid-elevation montane forests of canopy dominants that generally include combinations of 6 different species of conifers and one species of oak (Safford & Stevens, 2017). Distributed broadly across the west, from the Colorado Rocky Mountains to Oregon montane ranges and the California Sierra Nevada, they occupy some 1.8 to 3.2 million ha of land from southern Oregon to California (Allen, 2005). Given the extent of the land coverage, management styles, whether that be in working forest for timber or national and state reserves, have a huge effect on their subsequent structure, species composition, habitat provisions, and resilience. Of the forested land in California, 24 percent are covered by the mixed conifer forest type (7.8 million acres) and in those forests private and public landowners use a variety of harvest regimes to achieve an amalgamation of objectives (Brodie & Palmer, 2020; *California Forest Practice Rules*, 2020). Historical approach to management has primarily emphasized even aged regeneration styles for mixed conifer and ponderosa pine forests in California (Helms & Lotan, 1988; Youngblood, 2005). Yet more recently those recommendations have begun to include selection systems for forests found in eastside and westside California, primarily group selection over single tree (Graham & Jain, 2005). As a result, forestry practices in California have come under scrutiny as of late from the "plantation" style forestry pattern, common to much of the Sierra Nevada, used after the high grading of the early 20th century, mostly due to socio-political pressures (O'Hara, 2001). The perceived "unnaturalness" of clear felling styles of silviculture pressured land managers to invest in uneven aged and heterogenous methods of growing timber (O'Hara, 2001, p. 7; Powers, 2005; York et al., 2003). Group selections or gap based silvicultural methods both provide ample opportunities for silvicultural systems that are adept at facilitating timber growth and also meet the more nuanced attributes of resilient forests, like heterogeneity, species diversity, structural diversity, and habitat components (Baker et al., 2013; Bradshaw, 1992; Powers, 2005; York et al., 2003). These alternative styles are becoming more widely used as restorative measures for transitioning formerly even aged stands to a more diverse and heterogenous steady state (Kern et al., 2017; O'Hara, 2001; York et al., 2003).

Herbicide Application

The smaller opening sizes used often in un-evened aged methods like group selections or modified shelterwoods, defined as patches between 1 and 2.5 acres in size in the California Forest Practice Rules, require more intensive care for conifer seedlings to ensure successful establishment of seedlings battling light constraints and competition from shrubs (Bradshaw, 1992; *California Forest Practice Rules*, 2020; Walters et al., 2016; Zachary E. Kayler et al., 2005). Given these constraints, broad applications of herbicides are used to control the growth of early successional shrubs and forbs like deer brush (*Ceanothus)*, manzanita (*Arctostaphylos)*, Rushes *(Juncus)*, and tanoak (*Notholithocarpos*), often in the first year post site treatment and at another interval during the first 7 years of seedling growth (Allen, 2005; Dovčiak & Brown, 2014; Kern et al., 2017). A 25-year study examining vegetation management methods in mixed conifer forests found herbicide application to be the most effective treatment for controlling competing species, when compared with mulching, grazing, mechanical and manual release (P. M. McDonald & Fiddler, 2010).

Herbicide usage is not without its drawbacks as well and its usage faces heavy public criticism (Bradberry et al., 2004; Portier et al., 2016). Common herbicides used in forestry include Accord and Roundup, both of which use the product Glyphosate as their chief active ingredient, a chemical that is considered "probably carcinogenic to humans" according to the International Agency for Research on Cancer and the World Health Organization (Portier et al., 2016; Van Bruggen et al., 2018). Furthermore, a 2019 meta-analysis by Zhang et al. found that exposure to glyphosate based herbicides (GBHs) was related to a 41% increased risk of developing cancers like non-Hodgkin lymphoma (Zhang et al., 2019). More studies have called for greater examination of GBHs considering the drastic increase in their application in our agriculture and forestry industries (Myers et al., 2016; Portier et al., 2016; Zhang et al., 2019). On the other hand, multiple chemical regulatory agencies from nations including the U.S, Japan, Canada, The United Kingdom, and those in the European Union have found glyphosate to be non-carcinogenic to humans and a meta-analysis by conducted in 2016 found inconclusive results on the causal links between GHBs and certain types of lymphohematopoietic cancers (Chang & Delzell, 2016; *Glyphosate: Herbicide Information Profile*, 1997).

Another nuance to the debate over its toxicity is the consideration that a surfactant, polyoxyethyleneamine (POEA), used in many commercial herbicides like Roundup, was found to have higher toxicity than glyphosate itself (Bradberry et al., 2004; Portier et al., 2016). Furthermore, a 2002 study commissioned by the California Environmental Protection Agency on herbicide residues and movement in forested land adjacent to Tribal lands and browsing ranges found long lasting residues of traditional herbicides in plant material, soil, and watersheds (Ando et al., 2002). Studies examining alternative methods of vegetation control generally have not been attempted in great volume; with the exception of one study, McDonald and Abbott 1994, there is a large gap in research on the subject. Even the most comprehensive 25-year study on vegetation control, which concluded with its support for herbicide application, acknowledged that "indirect vegetation management by using shade and organic material to reduce growth and density of competition vegetation has promise but needs more study" implying the potential for progress in this realm (P. McDonald & Abbott, 1994; P. M. McDonald & Fiddler, 2010).Given the uncertainties surrounding herbicide use and the cautionary principle applied to most environmental management decisions, despite benefits in cost effectiveness and vegetation control, it is important to explore alternative methods of control in transitions to multi-cohort silvicultural systems.

Edge Effects

The edge effects created by the forest matrix are instrumental in affecting microclimate conditions in recently harvested sites and could provide new insights into alternative methods for controlling competing understory species (Zachary E. Kayler et al., 2005). Edge effects in the context of mixed conifer forests are simply the effects that the denser and impact forest matrix has on the environment of the species regenerating in a patch, represented by an area of recently disturbed forest. Those effects can include shade creation, wind protection, habitat creation for edge preferring species, and even alteration of fire conditions. Edge effects are increasingly important when considering the successful establishment of post-harvest regeneration, especially with commercial consideration, and can influence any number of important growth drivers, like light, water, nutrient availability, and browsing interactions (Baker et al., 2013; Kern et al., 2017; Walters et al., 2016; Zachary E. Kayler et al., 2005). Successful establishment of post planted conifer seedlings is heavily affected by light restrictions either by the surrounding matrix or by competing vegetation in the patch. That is why clear felling is often the method of choice for commercial forestry (Baker et al., 2013). McDonald and Abbot (1994) examined the interactions of smaller group selections less than an acre in size, 0.60 acres, 0.25 acres, and .05 acres (0.24, 0.1, and 0.02 hectares respectively), which would have conifers regenerated in high numbers but with slower rates (P. McDonald & Abbott, 1994). The study hypothesized that these group selections would prevent the "normally aggressive shrub species, negatively affected by the shady environment, [from affecting] the survival and growth of conifer and hardwood seedlings" (P. McDonald & Abbott, 1994). While this study included patch sizes as small as 0.02 hectares, the associated light restrictions with openings of that size might be too strong for adequate growth rates, this is why our study included opening sizes on the larger end of the spectrum presented by McDonald and Abbot (1994) Hypothesizing that with openings of 0.08 hectares in size our plots could capture the benefits of shading out of competing vegetation while not inhibiting the growth of desired conifer species.

Furthermore, York et al. 2003 and the follow-up report in the Forest Service General Technical Report from 2007 studied the effects of a modified group selection regime on a gradient on the growth of several mixed conifer species (Powers, 2005; York et al., 2003). Their analysis found that species demonstrated growth responses to changing gap size up until about 0.6 of a hectares in patch size, suggesting that further increases in opening size don't create worthwhile changes in growth rates (York et al., 2003). Coates 2000 similarly examined growth rates of 5 coniferous species in gaps located in British Columbia ranging from single tree size to 0.5 hectares in size and concluded that absolute height and annual growth rate increased until about 0.1 hectare in size but then showed little to no change across species type (Coates, 2000). This is notable because even light exclusionary species used in the study, like lodgepole pine *Pinus contorta*, showed similar trends, implying that large gaps may not be necessary to maximize growth rates (Coates, 2000). Cautiously, Coates 2000 was performed in forest types found in B.C, different in annual precipitation, temperature, and relative humidity, its use of gap size and light exclusionary species maybe applicable to mixed conifer forests and species like ponderosa pine. While these studies touched upon performance results from a variation patch size, neither studied examined the intersection between patch size and herbicide application. This intersection is extremely important both as the extent of herbicide damage to human and natural ecosystems remains in question and when considering the importance of introducing more patch size variation into California's mixed conifer forests, which are often regenerated, in private timberland, with clear-cuts of standard 1.0 hectare opening sizes (*California Forest Practice Rules*, 2020).

METHODS

Study Site

The Blodgett Forest Research Station (BFRS) occupies land on the western slope of the Sierra Nevada in California. Its climate is Mediterranean with dry, warm summers (14 – 27° C) and mild to cool, wet winters (0 – 9° C) while sitting at an elevation ranging from 1200 to 1500 meters. On an average year annual precipitation comes in at 166 cm with a range of 580 – 2740 mm and by the winter season (December to March) annual snowfall averages about 2540 mm. The soil comes from either a granodiorite or andesitic parent material and can support trees reaching heights of 27 to 34 meters in 50 - 60 years (*Blodgett Forest Research Station*, 2020; York et al., 2003).

The study site is located in the mixed conifer forest that covers the entirety of BRFS, conglomerated of 5 coniferous trees and one hardwood species. The 20 plots are located in compartment 70 and 100 of BRFS each measuring 0.08 hectare. The forest was high graded in the early 1900s and with much of the removable timber coming in the form of ponderosa pine and sugar pine (*Blodgett Forest Research Station*, 2020; Powers, 2005). The study sites were logged throughout the 20th century and now are mostly second growth forest. The forest hosts some of the most productive mixed conifer soils in California including Cohasset, Holland, Piliken-variant and Musick. Plots were located on a range of aspects, N, E, and SE, averaging gentle slopes of 10 to 20%.

The six tree species native to BRFS include white fir (*Abies concolor*), coast Douglas-fir (*Pseutotsuga menziesii var menziesii*), sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), incense-cedar (*Calocedrus decurrens*) and California black oak (*Quercus kelloggii*). For the purpose of the study 4 species were planted: Douglas-fir, ponderosa pine, incense-cedar, and sugar pine in the 0.08 hectacre gaps across the compartments. On the other hand, York et al. 2003, the dataset used as a range of more conventional sized gaps found in group selection regimes, planted 6 species: ponderosa pine, white fir, incense cedar, Douglas-fir, sugar pine, and giant sequoia (*Sequoiadendrom giganteun)*. Blodgett Forest research station plants species of Giant sequoia because although not currently native, their historical range included parts of BRFS.

Experimental Design

In the fall of 2014 twenty openings of 0.08 hectare in size were created in compartment 70 and 100 in BRFS. These openings were chosen in compartments that had an overabundance of incense cedar in the 10 to 16 inch dbh (diameter-at-breast-height) range. With the chosen compartments, the plots were then randomly allocated and randomly assigned a treatment value, either treated with vegetation control or not. In each plot (See figure 1) the 4 mixed conifer species were planted in rows oriented north to south, with trees labeled starting at the northern edge. The northern edge is bordered by PVC pipes and the 1-year container seedlings are planted in rows following this arrangement: The westernmost species is Douglas-fir, followed by incense cedar, then ponderosa pine, and sugar pine along the eastern edge of the opening. Each plot was planted with around 14 individuals per species, sometimes varying based on plot spacing, 56 individuals total, with each individual planted 8 feet from the next individual and rows spread 8 feet apart. During site preparation all plots were pre-commercially thinned, a method that removes trees less than 10 inch dbh in size to open up growing space for desired species without making any commercial gains, and then harvested. No other site preparation besides that necessary for the experimental design in the treated plots was undertaken.

Beginning in the fall of 2016, the treatment plots, those treated with a combination of herbicide application and vegetation control, were treated with common vegetation control methods. The site preparation was to have all woody shrubs cut using brush cutters or loppers at the base, while avoiding disturbing the soil. Shrubs that were less than 1.5 feet tall were left. This was done in tandem with the treatment of herbicide, often as a way to site prep before herbicide application, which began in the spring of 2017. In spring of 2017 the treatment plots (Plots B, D, H,II, M, O, T, Y, and Z) were treated with 4% glyphosate on all woody shrubs, avoiding forbs and black oak. Then in the spring of 2018 3% glyphosate was sprayed on woody shrubs while avoiding forbs and black oak, including species like sierra gooseberry (*Ribes Roezlii*), deer brush (*Ceanothus integerrimus*), creeping snowberry (*Symphoricarpos mollis*), mountain misery (*Chamaebatia foliosa*), and tanoak (*Notholithocarpos densiflorus*). The goal of these treatments was to ensure coniferous seedlings would have ample light, water, and growing space resources to ensure they would successfully establish, by removing competing vegetation. On the other hand, the non-treated plots (Plots CC, DD, E, EE, FF, G, I, L, N, P, U) were harvested and planted with each of the species, but not site prepped nor sprayed.

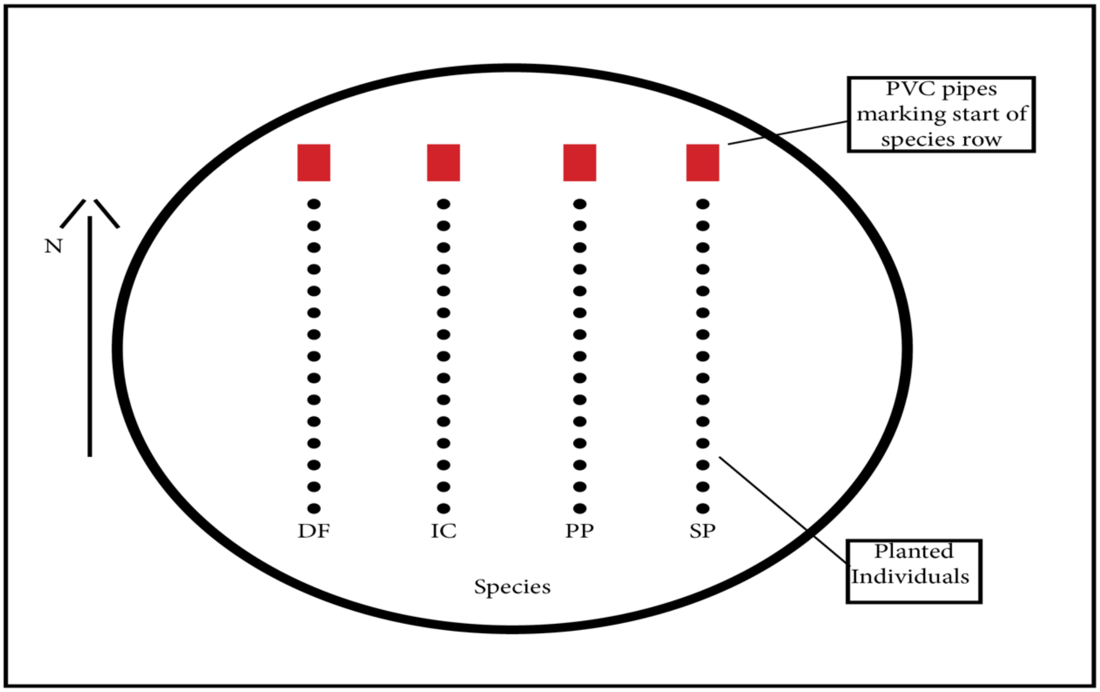

Figure 1. Plot Layout. Overhead view of planting layout of plots created in Blodgett Forest Research Station, California. Each row of dots representing one of the species and their row of individuals: Douglas-fir (DF), incense cedar (IC), ponderosa pine (PP), and sugar pine (SP), with pvc pipes marking the plot edges.

Study Tree Measurements

Beginning in 2016 study tree measurements were taken for both treatment types measuring height and basal diameter. For height, using a height pole, measurements were taken from the uphill side of the individual and were measured to the closest centimeter. Delineations for height were taken at the last apical bud from the most vertical shoot of the stem. For basal diameter, calipers were used to measure the diameter of the stem at 4 inches above the ground surface in the closest millimeter. Measurement protocol was repeated in 2018, then again in 2019 and 2020, giving our data a high precision analysis of 6 years of growth.

Furthermore, in each plot shrub data was collected in the fall of 2019. In order to establish the effect of the herbicide treatment and the contributing effect of the edge effects generated by the surrounding forest matrix. Shrub coverage was collected by using a transect intercept method. In each plot a transect tape was affixed to either ends of the plots, bordered by PVC pipes on both the north and south end. Using chaining pins to make the transect tape taut, measurements were collected with the zero starting on the south end. On the right side of the tape, every shrub that intercepted the tape was recorded in its species, height (to the nearest centimeter), and location along the transect. This was then repeated for every plot in the study set to give information on shrub percent coverage.

Finally, we also used the dataset from York et al. 2003 a similar study started in BRFS in 1996 that measured the effects of a varied opening sizes on mixed conifer species growth. Using the same species we used for this study, we will compare the two datasets to see if there is a significant difference in growth rates when you substantially reduce the opening size, thereby increasing the effect the matrix forest has on the establishing conifers.

Data Analysis

Our data analysis at 3 main objectives, (1) analyze the effect that herbicide and site preparation had on shrub coverage in tandem with enhanced edge effects, (2) compare the effect of enhanced edge effects on the height growth and basal diameter growth of conifers with and without herbicide treatments and (3) compare the effects of smaller patch sizes on conifer height growth rates in context with larger group selection sizes.

Much of the data analysis is strict hypothesis testing, using two sample independent t-tests to determine the relationship between the tested variables and the varying treatment types; with the first two objectives working to establish whether or not there is a statistically significant difference in the percent shrub coverage and the growth rates between the two treatment types. The mean annual height growth in centimeters and mean annual basal diameter growth in millimeters were calculated at the plot level. An average was taken for all species together and sampled individually by species to return a value of mean annual growth rate, height or basal diameter, for each plot. Plot level values were then averaged together to get our sample means.

The 3rd objective acts as a way to compare the results from objective 2, to real world application of opening sizes, and better contextualize the growth rates found in small groups. York et al. 2003 used a wide range of opening sizes, anywhere from 0.1 to 1 hectare, this is the range of patch sizes allowed under the California Forest Practice rules in order for that management style to be considered a group selection (*California Forest Practice Rules*, 2020; York et al., 2003). Thus, determining whether there is a statistical difference in growth rates between the small patch plots and the range of opening sizes in York et al. 2003, we can hope to isolate opening size as the main driver either in the growth rate variance or in its commonality. York et al used a range of group selections sizes, 0.1, 0.3, 0.6, and 1.0 hectares, to capture the effects of changing patch size on species growth and mortality. This study was a set of replicated plots of varying opening sizes ranging from 0.1 of a hectare to 1 hectare (0.25 acre, 0.75 acre, 1.5 acres, 2.5 acres), that had 6 different species of conifers (Incense-cedar, ponderosa pine, white fir (*Abies Concolor*), sugar pine, giant sequoia (*sequoiadendron giganteum*), Douglas-fir) planted in them in cardinal direction oriented rows, and measured the effect of resource gradients, represented by the North-South row, on 3 of the species: Douglas-fir, giant sequoia, and ponderosa pine. These plots were also treated with conventional vegetation control methods. For our analysis we grouped the opening sizes to allow for more effective comparisons of growth rates. Opening sizes 0.1 and 0.3 hectares were sampled together and a mean annual height growth value was obtained from the weighted average of both plot sizes, 3 from each opening size and six total. For our large group, 0.6 and 1.0 hectare plots were sampled together and returned plot level means. The patch sizes were grouped like this to better reflect the potential range of opening size in California commercial and private forestry. 0.1 and 0.3 hectares plots were representing the smaller side of group selection opening sizes and 0.6 and 1.0 hectare plots would represent opening sizes on the larger end of the spectrum. For this analysis we treated the smallest group (0.08 ha) data collected since 2014 as one dataset, in order to isolate the effect of opening size, rather than herbicide and site preparation, on coniferous seedlings growth rates. That is the plot level means were averaged together regardless of treatment type for 0.08 ha plots. For York et al. 2003 we had access to the absolute heights of the species in question from 2003. We isolated the species desired, pulling ponderosa pine, incense cedar, Douglas-fir, and sugar pine from the dataset and again using plot level means to estimate sample means. We then used an independent sample two tailed t-test to return our values on significance between the small group openings and the various categories from York et al. 2003, comparing the smallest groups of 0.08 hectares to both the 0.1/0.3 ha group and the 0.6/1.0 group.

RESULTS

Shrub Coverage in Small Group Openings

Overall, the site treatments had the desired effect on shrub coverage, reducing shrub coverage of plots by 44%. Treated plots averaged 76% of the plot with no vegetation coverage whatsoever vs. 32% no vegetation on the untreated plots. This difference was significant, (p = 0.0001) as would be expected since two treatments of Glyphosate, 4% in the spring of 2017 and 3% in the spring of 2018, were applied. Furthermore, there was no significant difference in coverage by forb or grass species, with untreated and treated plots showing similar levels of coverage (p = 0.6137), 15.3% for treated plots and 18% for untreated plots. This supports the design for the herbicide to target the woody shrubs but not necessarily the forb and grass species. Similarly, there was a significant difference in percentage of the plots that were covered by shrubs across treatment types(p = 0.0036). The untreated plots averaged about 30% coverage while the treated plots averaged about 2%, The remainder of the plot area in both treatment types was covered by planted study trees and some natural regeneration. Overall, much of the results of the herbicide data analysis, collected in 2019, showed that the treatments effectively removed the competing vegetation in the plot area. This leads me to reject the null hypothesis that under smaller group selection opening sizes (0.08 hectare) herbicide treatment has no effect on the percent of the plot dominated by shrubs and non-conifer forb and grass species. Beyond that, this result allows us to isolate the effects on seedling performance in our further analysis, by showing that the plot sizes and herbicide application effectively resulted in significant differences in shrub coverage.

Figure 2: Untreated plot displaying ponderosa pine in competition with individual of Ceanothus.

Figure 3: Treated plot displaying ponderosa pine without competition from shrub species.

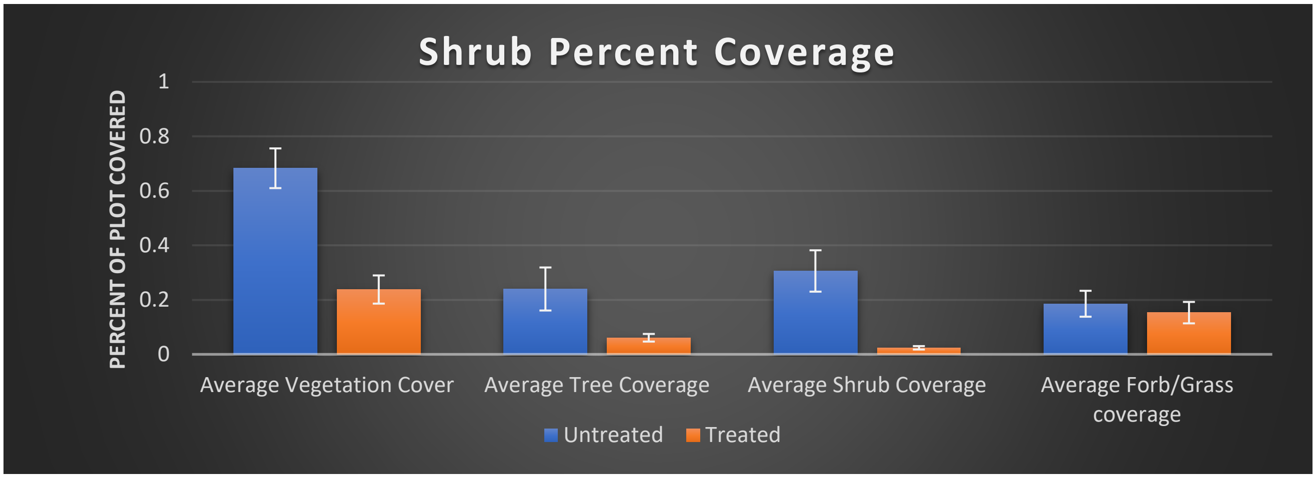

Figure 4. Comparison of Shrub percent coverage by category and by treatment type. Average vegetative cover was significantly different between treatment types (p=0.0001). Mean forb and grass cover was nonsignificant (p=0.6137). Average shrub coverage was significantly different, higher, in the untreated plots (p= 0.0036).

Height and Basal Diameter Growth Rates

The results of the height and basal diameter measurements over the course of 6 growing seasons found no significant difference in mean annual growth rates between the two treatment types, when all 4 species were sampled together. This leads us to accept our null hypothesis that under a modified group selection opening system the use of herbicide application does not significantly affect the mean annual height ($p = 0.9692$) and basal diameter ($p = 0.6087$) growth rates of 4 mixed conifer species regenerated together. When sampled together all 4 mixed conifer species averaged 15.18 centimeters per year in height growth in treated plots and 15.26 centimeters per year in untreated plots which was a nonsignificant difference in average annual height growth. For mean annual height growth (centimeters year^{-1}), when broken down by species the differences were still not significant at the 95% confidence level (Figure 2). Ponderosa pine and sugar pine were not significant at the 95% confidence level. Treated ponderosa pine had an average annual height growth rate of 23.04 centimeters per year while untreated had 23.74 centimeters per year average over the 6 growing seasons ($p = 0.8327$). Sugar pine had average annual height increases of 11.40 centimeters for treated plots and 13.79 centimeters for untreated plots ($p = 0.2182$). Incense cedar and Douglas-fir, similarly, had a no significant difference in average annual height growth at the 95% confidence level. The treated plots of Douglas-fire averaged 14.3 centimeters per year, while the untreated plots averaged 12.2 centimeters per year, a nonsignificant difference ($p = 0.3679$). Treated plots of incense cedar averaged 11.99 centimeters per year of height growth, while the untreated individual averaged 11.26, again a nonsignificant difference in height growth over the 6 growing seasons at the 95% confidence level ($p = 0.7463$).

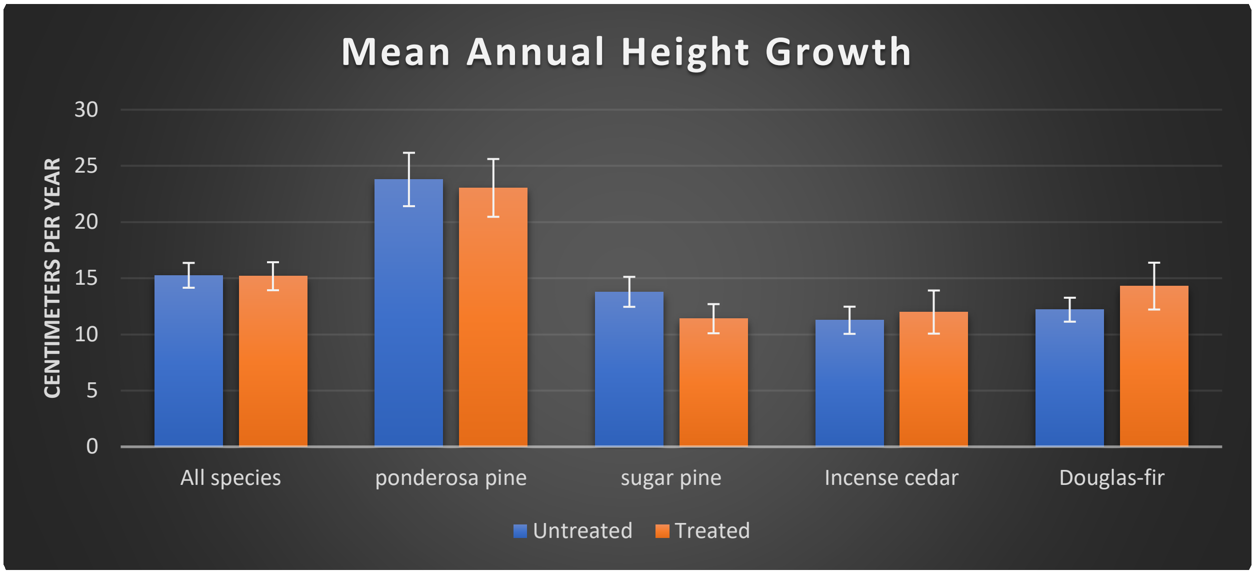

Figure 2: Comparison of mean annual height growth (cm) by species and by treatment type. All species were found to have a nonsignificant difference in mean annual height growth across treatment types. (p = 0.9692). Ponderosa pine non-significant at the 95% confidence level (p = 0.8327). Sugar pine had a nonsignificant difference in mean annual height growth for both treatments (p=0.2182). Douglas-fir individuals also had a nonsignificant difference in mean annual height growth across treatment types (p = 0.3679). Finally, incense cedar had a nonsignificant difference in mean annual height growth (p = 0.7463).

Changes in basal diameter reflected when all species were sampled together found that there was no significant difference in diameter growth between treatment types at the 95% confidence level (p = 0.6087). When broken down by species type the trend holds up, with all species not showing a significant difference in basal diameter annual growth rates, in millimeters. Treated ponderosa pine individuals averaged 6.74 millimeters of annual radial growth, while untreated plots averaged 6.25 millimeters annually (p = 0.6786). Treated sugar pine individuals averaged 3.32 millimeters of basal diameter growth annually, while untreated individuals averaged 3.43 millimeters per year (p = 0.8381). Similarly, Douglas-fir found no significant difference in basal diameter growth, with untreated individuals averaging 3.42 millimeters a year and treated individuals averaging 3.75 millimeters a year (p = 0.6188). Incense cedar individuals also had no significant difference in a basal diameter across treatment types, untreated individuals averaged 3.35 millimeters a year and treated individuals averaged 3.95 millimeters (p = 0.4432).

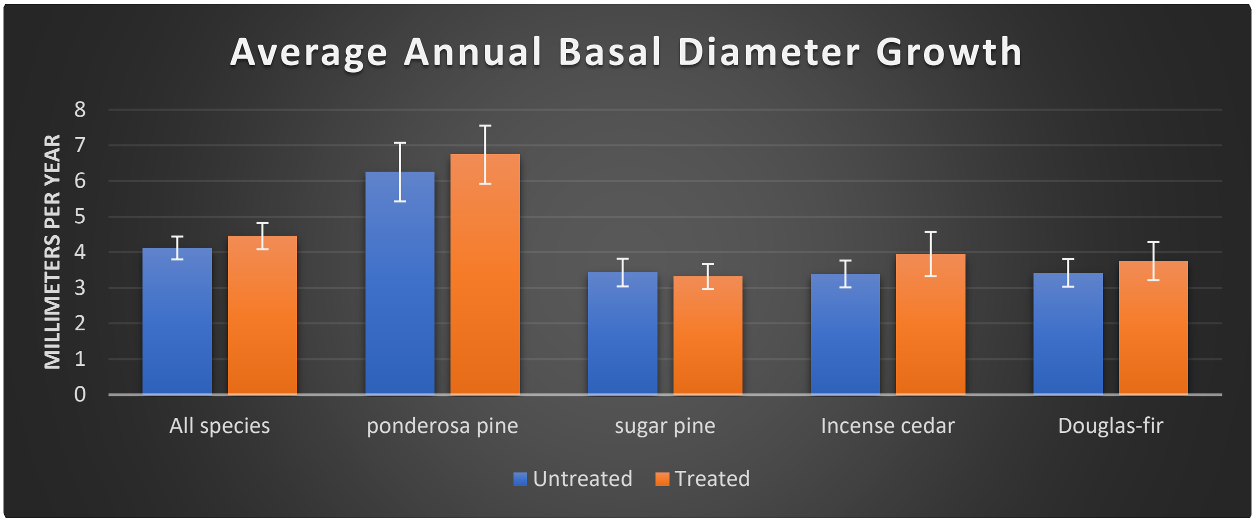

Figure 3: Comparison of mean annual basal diameter growth (mm) by species and by treatment type. All species were found to have a nonsignificant difference in mean annual basal diameter growth across treatment types. (p = 0.6087). Ponderosa pine non-significant at the 95% confidence level (p =0.6786). Sugar pine had no significant difference in mean annual basal diameter growth for both treatments (p = 0.8381). Douglas-fir individuals also had no significant difference in mean annual basal diameter growth across treatment types (p = 0.6188). Finally, incense cedar had no significant difference in mean annual basal diameter growth (p = 0.4432).

Contextualizing Growth of Seedlings with Data from York et al. 2003

While the findings presented above present some clear information on the extent to which herbicides are needed for increasing annual growth rates in small patch openings, the extent to which those growth rates compare to more commonly used group selection sizes, anywhere up to 1.0 hectare in the California Forest Practice Rules, is still up for consideration. To examine that comparison, we looked at the mean annual growth rates with a similar study that analyzed edge effects brought upon by adjusting patch size on different species, York et al. 2003. Our findings from a simple comparison of the datasets were of mixed results. Overall, our analysis which followed 19 plots of 0.08 hectare in size, grouping both treated and nontreated plots together (to isolate for patch size), compared the mean annual height growth rates of 4 mixed conifer species to two different patch size groupings from York et al. 2003. The smaller grouping (1) from York et al. 2003 was the mean annual height growth of 6 plots of 4 mixed conifer species found in patches sized 0.1 hectares or 0.3 hectares. The larger grouping (2) was the mean annual height growth of 6 plots of 4 mixed conifer species found in patches sized 0.6 hectares or 1.0 hectares.

These groups were separated to demonstrate the range of legally allotted opening sizes found in group selection silvicultural operations in California (*California Forest Practice Rules*, 2020). Because of this, the mean annual height growth for group (1), the small gaps, was averaged from all the trees in both patch sizes, 0.1 and 0.3 hectares. Similarly, the group (2) values, the larger gaps, were mean annual height growth increments averaged from patches sized 0.6 and 1.0 hectares. This comparison should generally capture the range of potential opening sizes allotted within the California Forest Practice Rules.

The results of our analysis found that using a 2 sample independent t test, the mean annual height growth of all 4 mixed conifer species was not significantly different in small patches of 0.08 hectares when compared with mean annual height growth rates of species in small patches from York et al. 2003 of 0.1 to 0.3 hectares ($p = 0.3356$). Species in smallest patches of 0.08 hectares averaged 15.22 centimeters year^{-1}, whereas species in group (1) patches of 0.1 to 0.3 hectares averaged 27.48 centimeters year^{-1}, a nonsignificant difference with respect to the pooled variation. On the other hand, when comparing the smallest patch openings of 0.08 hectares to the height growth rates found in larger patch openings of 0.6 to 1.0 hectare, our analysis found there was a statistically significant difference in mean annual height growth for all species together ($p = 0.0469$) (See Figure 5). Species in the large patch openings averaged 38.32 centimeters year^{-1} in mean annual height growth, a 253% difference in mean annual height growth when compared with the 15.22 centimeters year^{-1} found in small patches of 0.08 hectares.

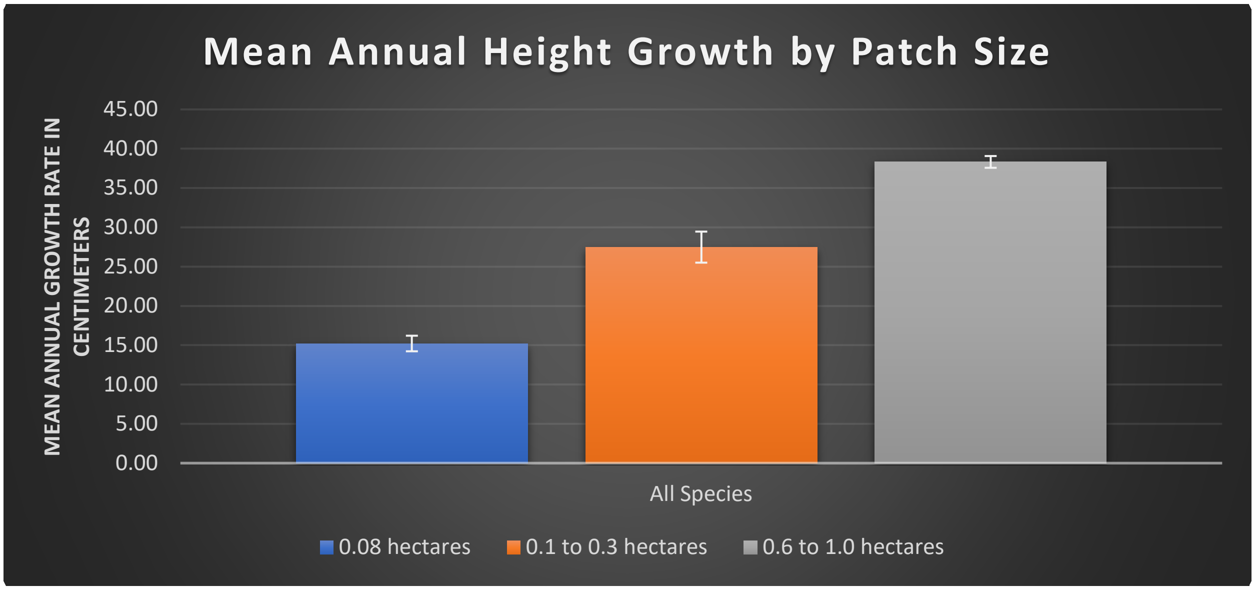

Figure 5: Comparison of mean annual height growth (cm yr^-1) of all species grouping and patch size. All species nonsignificant difference in mean annual height growth between 0.08 ha patches and 0.1/0.3 ha patches (p = 0.3356). There is a significant difference in mean annual height growth in the all species group between 0.08 ha patches and 0.6/1.0 patches (p = 0.0469).

Similarly, when applying the same test to the mean absolute heights of the 4 mixed conifer species after 6 growing seasons, we received the same results. There was a nonsignificant difference in the mean heights (centimeters) of species in small patches of 0.08 hectares when compared with mean heights of species in slightly larger patches of 0.1 to 0.3 hectares (p = 0.2848). Species in small patches of 0.08 hectares averaged 95.15 centimeters, whereas species in slightly larger patches of 0.1 to 0.3 hectares averaged 164.91 centimeters, a nonsignificant difference with respect to the pooled variation. Reflecting the results found when comparing mean annual height growth rates, the difference in mean heights found in species in small patches of 0.08 ha and larger patches of 0.6/1.0 hectares was significant (See Figure 6) . All species in larger patches averaged 229.97 centimeters after 6 growing seasons, a 241.69% increase in height from the 95.15 centimeters mean height found in small patches (p = 0.0183).

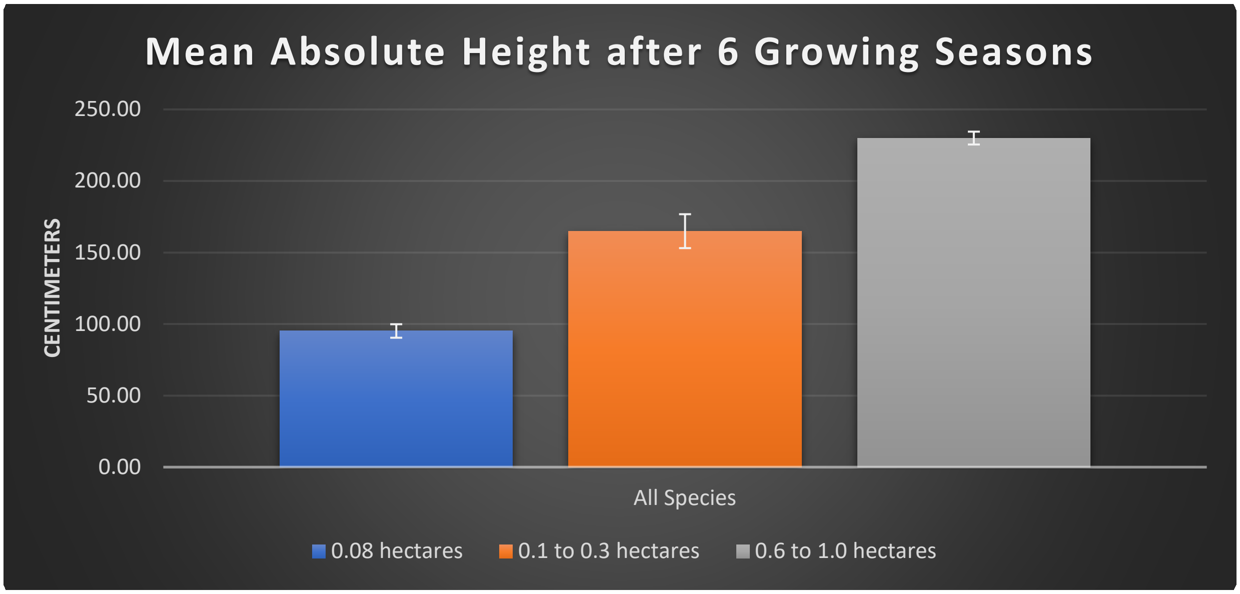

Figure 6: Comparison of mean height after 6 growing seasons (cm) of all species grouping and patch size. All species nonsignificant difference in mean annual height growth between 0.08 ha patches and 0.1/0.3 ha patches (p = 0.2848). There is a significant difference in mean heights after 6 years in the all species group between 0.08 ha patches and 0.6/1.0 patches (p = 0.0183).

Our analysis also examined the difference in mean annual height growth rates when sampled individually by species. We found similar mixed results across species and patch size gradients. Ponderosa pine had nonsignificant differences in growth rates when comparing the 0.08 ha patches to both the small grouping of 0.1/0.3 ha (p = 0.7052) and larger patches of 0.6/1.0 hectares (p = 0.3165). Sugar pine also had a nonsignificant difference in mean annual height growth rates both in comparison to the small grouping of 0.1/0.3 ha(p = 0.4486) and the larger patches of 0.6 to 1.0 hectares (p = 0.1397). Both Douglas-fir and incense cedar had a nonsignificant difference in mean annual height growth when comparing the rates of species in patches of 0.08 ha to the small groups of 0.1/0.3 ha (Douglas-fir p = 0.2328) (incense cedar, p = 0.3500). On the other hand, when comparing individuals of Douglas fir in patch sizes of 0.6/1.0 hectares to the 0.08 ha patch size growth rates there was a significant difference in mean annual growth, with individuals in the large group averaging 37.70 centimeters year^{-1}, a 325% increase from a mean annual growth rate of 11.63 found in 0.08 ha patches (p = 0.0491). Following Douglas-fir, incense cedar also showed similar results, with a significant difference in mean annual height growth when comparing 0.08 ha patches to the 0.6/1.0 ha group. Individuals in the larger group averaged 44.20

centimeters year^{-1} while the mean annual growth rate of individuals in 0.08 ha patches was 13.25 centimeters year^{-1}, a 331% increase in growth (p = 0.0212).

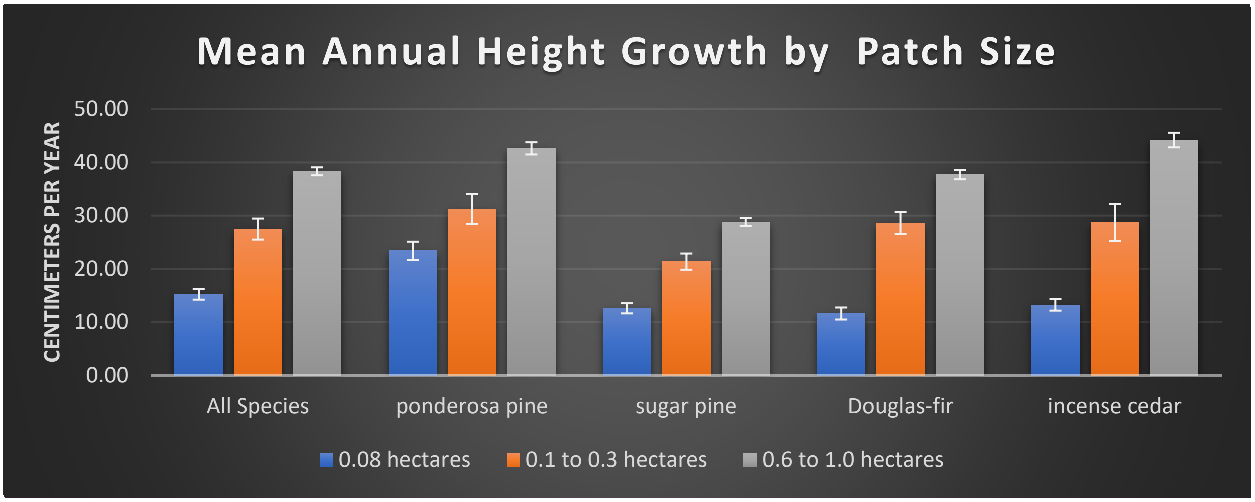

Figure 7: Comparison of mean annual height growth centimeters year^{-1}after 6 growing seasons of species and patch size. Mixed significance in results. All species nonsignificant when comparing 0.08 ha patches to 0.1/0.3 ha patches (p = 0.3356), yet significant when comparing 0.08 ha patches to 0.6/1.0 ha patches (p = 0.0469). Ponderosa pine nonsignificant difference for both 0.1/0.3 ha (p = 0.7052) and 0.6/1.0 ha groups (p = 0.3165) compared to 0.08 ha openings. Sugar pine nonsignificant difference for both 0.1/0.3 ha (p = 0.4486) and 0.6/1.0 ha (p = 0.1397) groups compared to 0.08 ha openings. Douglas-fir nonsignificant difference when comparing 0.08 ha groups to 0.1/0.3 ha patches (p = 0.2328) yet found a significant difference in mean annual height growth when comparing rates of 0.08 ha groups to 0.6/1.0 ha patches (p = 0.0491). Similar results for incense cedar groups, nonsignificant difference in growth rates between 0.08 ha patches and 0.1/03 ha groups (p = 0.3500) and found a significant difference in growth rates between 0.08 ha groups and patches of 0.6/1.0 ha (p = 0.0212).

DISCUSSION

Several studies on modified group selection regime have been used to explore performance variations in seedlings (de Montigny & Smith, 2017; Walters et al., 2016).Yet there exists a gap in the current literature on the ability to regenerate mixed conifer species in a Sierra Nevadan group selection system without herbicide. This paper's central research question was to analyze whether the use of herbicides on competing shrubs significantly impacted the mean annual growth rates of 4 planted mixed conifer species being regenerated in small groups of 0.08 hectares in size. This study also analyzed the difference in shrub percent cover between plots treated with herbicides and those without. Finally, this analysis compared resulting mean height and basal diameter growth rates to a 2003 study which examined the range of allowable group selection sizes under the California Forest Practice Rules. The results of our analysis demonstrated that mean annual height and basal diameter growth rates did not significantly differ for all species sampled together whether herbicide was applied or not in small group selections. Furthermore, it found that the herbicide treatment applied did have a significant impact on percent shrub coverage, with plots treated with herbicide averaging 2% shrub coverage whereas untreated plots averaged 30% coverage. The resulting comparison to the 2003 study York et al. 2003, presented some mixed results but interesting implications for management regimes similar to those employed here.

The conditions present when regenerating mixed conifer species in group selection systems are often less conducive to rapid growth than those found in even aged systems, with patches up to 20 acres in size, mostly due to light constraints (Bradshaw, 1992; Zachary E. Kayler et al., 2005). Because of this, group selection systems, as with even aged systems, rely on herbicide application to ensure successful establishment and early age growth of conifer seedlings by preventing competition from surrounding shrubs. Group selections present more challenges to management styles that prioritizes fast growth rates and high levels of seedling mortality because of the greater light restrictions present in smaller patch sizes (Bradshaw, 1992; Brodie & Palmer, 2020; Kern et al., 2017; Zachary E. Kayler et al., 2005). The results of our study suggest that when using patches of drastically smaller opening size, such as 0.08 ha, herbicide application need not be used to ensure adequate mean annual growth rates and high levels of successful seedling establishment. This is of particular importance for land managers who want to regenerate mixed conifer species in groups, while planning for multiple species, without the application of herbicide. My analysis further reflects that group selection size can be more variable than is typically found and gaps of smaller size can be of use for those hoping to achieve different goals like increasing forest patch diversity. Furthermore, should managers have an interest in regenerating certain species, as is common under even aged plantation style regeneration regimes, the trend in mean annual height and basal diameter growth holds up. Each species individually had no difference in mean annual height and basal diameter growth whether herbicide was applied or not after 6 years of growth. While the application of herbicide significantly limited shrub coverage of plots, the competitive effect from shrubs seemed to have no noticeable effect on mixed conifer growth rates, which is often the concern when regenerating mixed conifer species in smaller patch openings. At some level the resulting interference from the surrounding forest matrix may have allowed mixed conifer species to regenerate just as effectively, since competitive species were inhibited by shade like conditions created by the edge effects of 0.08 hectare openings.

Mean annual basal diameter growth also displayed no noticeable significant difference in mean annual growth; both when all species were sample together and individually by species type. Basal diameter is often more discretely affected by variations, specifically increases, in competition and edge effects like shading. This is in part because of the nature of coniferous seedlings aim to prioritize height growth over diameter growth when competition is high in the early stages of their development and so will sacrifice basal diameter growth while spending more energy and resources for apical growth (P. M. McDonald & Fiddler, 1989). Similarly, the early stages for coniferous seedlings are the most essential for their establishment and successful growth. McDonald and Fiddler 1989 demonstrated how ponderosa pine seedlings suffer from more extreme competition from shrubs in the first few years, up to 5, before they can fully establish on a site. Despite this both treatments showed no difference in mean basal area annual increment despite the untreated group having to contend with a significantly higher percentage of competition shrubbery. Again this, reflecting my original hypothesis, seems to support the notion that the resulting increase in edge effects on small group opening nullifies the competitive effect of shrubbery and other non-timber species.

Numerous studies have documented the impact of competitive shrubbery and coniferous seedling mortality rates and growth (Bannister et al., 2020; Erickson & Harrington, 2006; Jaramillo et al., 1985; White et al., 1990; Zavitkovski et al., 1969). Zavitkovski et al. 1969 examined the impact of native snowbrush (*Ceanothus velutinus*) dominated sites in Oregon and found that the growth rates of conifer species were reduced by up to one half in plots heavily covered with snowbrush. Similar studies also demonstrated how herbaceous vegetation or shrubbery species limit coniferous growth rates via impacting microsite dynamics like light penetration, soil moisture, and precipitation (Jaramillo et al., 1985).

On the other hand, there is a growing body of literature that recognizes the beneficial effects of competing shrubs on conifer establishment and growth in patches (Bannister et al., 2020; Erickson & Harrington, 2006). Erickson & Harrington 2006 found that individuals of 6 conifer species with leader shoots above *Ceanothus* exhibited 18-70% taller heights than individuals grown in open conditions. Likewise, Bannister et al., 2020 examined how herbaceous vegetation provided important microsite functions, like increasing available moisture, to slow growing conifer seedlings of *Pilgerodendron uviferum* in Chile, that aided their establishment and growth. This growing body of research presents further support for understanding the beneficial dynamics between shrub species and establishing conifer individuals grown for timber. As was evident in the small group opening, neither treatment had a significant difference in annual height growth rates, yet there was a significant reduction in shrub coverage in the plots treated with Glyphosate applications. The difference in height growth, 15.26 centimeters year^{-1} in untreated plots and 15.18 centimeters year^{-1} in treated plots may provide some further support for the notion that added competition from shrub species induces a faster apical growth response in coniferous seedlings that can overtop them. This is supported by Erikson et al. 2005, which found a significant increase in heights of conifer species that had overtopped *Ceanothus* compared with open grown individuals, but also found a significant decrease in the heights of individuals without leader shoots above *Ceanothus* when compared with their open grown counter parts (Erickson & Harrington, 2006).

This notion maybe further supported by the fact that small group openings were able to limit shrubbery establishment even without herbicide application as percent coverage of shrub species was lower than the values found in a nearby clear-cut plot at Blodgett Research Forest. Plots that were untreated in the small group openings of 0.08 hectares averaged 30% shrub coverage which was significantly higher coverage than the 2% coverage found in plots treated with herbicides. Yet, neighboring clear-cuts of 8 hectares in size, measured in 2019, displayed mean shrub percent coverage of at 60%, a value double the coverage that was found in untreated small group openings. This holds many implications for management, chief among them is that the smaller opening size significantly limited shrub coverage in the recently cleared patches. A decline by half percent coverage presents significant opportunities for conifer seedlings to survive and retain high annual growth rates. Despite neither opening being treated with herbicide, the smaller group opening retained much less competition from shrubbery and therefore allowed the mixed conifer species a much better chance at securing resources and growing space. This difference in present coverage may also imply that the increased edge effects presenting in smaller patches provides some benefits to establishing seedlings in inhibiting shrub coverage, which poses the largest threat to seedling survival.

Considering the nonsignificant difference in both mean annual height growth and mean annual basal diameter increment across treatment types, our results were better contextualized by a comparison to the study undergone at Blodget Forest Research Station in 2003. While our study produced 20, 0.08 hectare patches replicated in the forest matrix, York et al. 2003 used 12 plots replicated in threes across a range of gap sizes 0.1 to 1.0 hectares. Our results support our initial hypothesis that small patches regenerated within a forest matrix with or without herbicides would produce growth rates with enough similarity to those found in larger openings. By mean annual height increment there was no statistically significant difference for all species when comparing the 0.08 ha plots to the 0.1/0.3 ha grouping of plots. There was, on the other hand, a statistically significant difference in growth rates when comparing the 0.08 ha plots to the 0.6/1.0 ha group, which was presumably due to the march larger light allotments given in opening sizes on the larger end of the spectrum. These findings may offer no surprise; even York et al. 2007, an analysis of the initial study set after 7 years of growth, finds that "height growth responses to gap size consistently diminished as gap size increased, typically leveling off or decreasing in rate beyond a size range from 0.3 to 0.5 ha" (Powers, 2005).

Where the result of our analysis gets more complicated is in the interspecies comparison. Both ponderosa pine and sugar pine had no significant difference in mean annual height growth when comparing the 0.08 ha openings to either the 01/03 ha or 0.6/1.0 ha group, despite them being considered shade intolerants. Likewise, Douglas-fir and incense cedar, both considerably more shade tolerant, showed no difference in mean annual height growth at the 0.1/0.3 ha group, but a significant difference in mean annual height growth when comparing to 0.6/1.0 ha. These findings in the data present some new questions about the response of different species to patch gradients. In the case of our study, they suggest no noticeably statistically significant difference in mean annual growth rates for both ponderosa pine and sugar pine regardless of gap size. This could be due to a variety of factors including the faster growth rates found in sugar pine and ponderosa pine that may not be as minutely affected by opening size. Further, study is needed on this aspect especially since gap size is often seen as a large predictor of both successful establishment and ample growth rates for shade intolerant species like ponderosa pine and sugar pine.

Limitations

When considering the comparison to a similar study undergone at Blodgett Forest Research Station in 2003, we examined at the plot level how the mean annual height growth rates of the four chosen mixed conifer species compared. While York et al. 2003 used similar species types and site location, its experimental design differed in that it used a wagon wheel planting layout to examine the effect of gap size and inter gap spacing on seedling performance. While our study employed 4 parallel rows of seedlings, variance in seedling spacing and closes to an edge could affect their performance during growth years. Furthermore, York et al. 2003 used paired seedlings for the first 2 years protected with vexar before the lesser seedling was removed, a variable that may affect the results differently from our study. Their analysis was also planted in 1997, a full 17 years before our planting regime and while sharing a common planting site may have been impacted by regional climatic trends, including drought and temperature changes that may have affected the dataset differently. Other considerations for our study, include acknowledging that we used plot level estimates for mean annual growth rates, rather than individual mean calculations. This implies that the means were weighed at the plot as an average of the number of individual species in each plot rather than an average of all individuals in the population. This might have diluted the variance found in individual plots and effected our annual growth rate calculations. Furthermore, plot N was dropped during our data analysis because of data loss over the years due to variations in data collection methodologies. Overall, we feel as if this analysis does an effective job in understanding the comparison in growth rates both for the small patch openings of 0.08 hectare and for the comparison to the dataset from the 2003 study.

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REFERENCES

Allen, B. (2005). *Sierran Mixed Conifer* [California Wildlife Habitat Relationships System]. California Department of Fish and Game.

Ando, C., Li, L., Walters, J., Gana, C., Segawa, R., Sava, R., Barry, T., Lee, P., Tran, S., White, J., Hsu, J., & Goh, K. (2002). *RESIDUES OF FORESTRY HERBICIDES IN PLANTS OF INTEREST TO NATIVE AMERICANS IN CALIFORNIA NATIONAL FORESTS* (EH-02-08). California Environmental Protection Agency.

Baker, S. C., Spies, T. A., Wardlaw, T. J., Balmer, J., Franklin, J. F., & Jordan, G. J. (2013). The harvested side of edges: Effect of retained forests on the re-establishment of biodiversity in adjacent harvested areas. *Forest Ecology and Management*, *302*, 107–121. https://doi.org/10.1016/j.foreco.2013.03.024

Bannister, J. R., Travieso, G., Galindo, N., Acevedo, M., Puettmann, K., & Salas-Eljatib, C. (2020). Shrub influences on seedling performance when restoring the slow-growing conifer Pilgerodendron uviferum in southern bog forests. *Restoration Ecology*, *28*(2), 396–407. https://doi.org/10.1111/rec.13090

Blodgett Forest Research Station. (2020). Berkeley Forests, University of California, Berkeley.

Bradberry, S. M., Proudfoot, A. T., & Vale, J. A. (2004). Gyphosate Poisening. *PubMed Toxicology Review*, *23*(3), 159–167.

Bradshaw, F. J. (1992). Quantifying edge effect and patch size for multiple-use silviculture—A discussion paper. *Forest Ecology and Management*, *48*(3), 249–264. https://doi.org/10.1016/0378-1127(92)90148-3

Brodie, L. C., & Palmer, M. (2020). *California's forest resources, 2006–2015: Ten-Year Forest Inventory and Analysis report* (General Technical Report PNW-GTR-983; GTR, p. 60). U.S Department of Agriculture.

California Forest Practice Rules. (2020). Natural Resources Agency State of California.

Chang, E. T., & Delzell, E. (2016). Systematic review and meta-analysis of glyphosate exposure and risk of lymphohematopoietic cancers. *Journal of Environmental Science and Health, Part B*, *51*(6), 402–434. https://doi.org/10.1080/03601234.2016.1142748

Coates, K. D. (2000). Conifer seedling response to northern temperate forest gaps. *Forest Ecology and Management*, *127*(1), 249–269. https://doi.org/10.1016/S0378-1127(99)00135-8

de Montigny, L. E., & Smith, N. J. (2017). The effects of gap size in a group selection silvicultural system on the growth response of young, planted Douglas-fir: A sector plot analysis. *Forestry: An International Journal of Forest Research*, *90*(3), 426–435. https://doi.org/10.1093/forestry/cpw068

Dovčiak, M., & Brown, J. (2014). Secondary edge effects in regenerating forest landscapes: Vegetation and microclimate patterns and their implications for management and conservation. *New Forests*, *45*(5), 733–744. https://doi.org/10.1007/s11056-014-9419-7

Erickson, H. E., & Harrington, C. A. (2006). Conifer–Ceanothus interactions influence tree growth before and after shrub removal in a forest plantation in the western Cascade Mountains, USA. *Forest Ecology and Management*, *229*(1), 183–194. https://doi.org/10.1016/j.foreco.2006.03.029

Glyphosate: Herbicide Information Profile. (1997). U.S Department of Agriculture.

Graham, R. T., & Jain, T. B. (2005). Application of free selection in mixed forests of the inland northwestern United States. *Forestry*, *209*, 131–145.

Helms, J. A., & Lotan, J. E. (1988). *Selecting silvicultural systems for timber* (pp. 221–225). Washington State University.

Jaramillo, A. E., Cromack, K., & Rose, S. (1985). The role of the genus Ceanofhus in western forest ecosystems. In *Gen. Tech. Rep. PNW-GTR-182. Portland, OR: U.S. Department of*

Agriculture, Forest Service, Pacific Northwest Research Station. 72 p (Vol. 182). https://doi.org/10.2737/PNW-GTR-182

Kern, C. C., Burton, J. I., Raymond, P., D'Amato, A. W., Keeton, W. S., Royo, A. A., Walters, M. B., Webster, C. R., & Willis, J. L. (2017). Challenges facing gap-based silviculture and possible solutions for mesic northern forests in North America. *Forestry*, *90*, 4–17.

McDonald, P., & Abbott, C. S. (1994). *Seedfall, regeneration, and seedling development in group-selection openings. Forest Service research paper (Final)* (psw-rp-220). United States Department of Agriculture.

McDonald, P. M., & Fiddler, G. O. (1989). *Competing vegetation in ponderosa pine plantations: Ecology and control.* (General Technical Report PSW-113; GTR, p. 26). Forest Service, U.S Department of Agriculture.

McDonald, P. M., & Fiddler, G. O. (2010). *Twenty-five years of managing vegetation in conifer plantations in northern and central California: Results, application, principles, and challenges.* (General Technical Report PSW-GTR-231; GTR, p. 87). U.S Department of Agriculture.

Myers, J. P., Antoniou, M. N., Blumberg, B., Carroll, L., Colborn, T., Everett, L. G., Hansen, M., Landrigan, P. J., Lanphear, B. P., Mesnage, R., Vandenberg, L. N., vom Saal, F. S., Welshons, W. V., & Benbrook, C. M. (2016). Concerns over use of glyphosate-based herbicides and risks associated with exposures: A consensus statement. *Environmental Health*, *15*(1), 19. https://doi.org/10.1186/s12940-016-0117-0

O'Hara, K. (2001). The silviculture of transformation—A commentary. *Forest Ecology and Management*, *151*, 81–86. https://doi.org/10.1016/S0378-1127(00)00698-8

Portier, C., Armstrong, B., Baguley, B., Baur, X., Belyaev, I., Bellé, R., Belpoggi, F., Biggeri, A., Bosland, M., Bruzzi, P., Budnik, Lygia, Bugge, M., Burns, K., Calaf, G., Carpenter, D., Carpenter, H., López-Carrillo, L., Clapp, R., Cocco, P., & Zhou, S.-F. (2016). Differences in the carcinogenic evaluation of glyphosate between the International Agency for Research on Cancer (IARC) and the European Food Safety Authority (EFSA). *Journal of Epidemiology and Community Health*, *70*, 741–745.

Powers, R. F. (2005). *Restoring fire-adapted ecosystems: Proceedings of the 2005 national silviculture workshop* (General Technical Report PSW-GTR-203; GTR, pp. 181–191). U.S Department of Agriculture.

Safford, H. D., & Stevens, J. T. (2017). *Natural range of variation for yellow pine and mixed-conifer forests in the Sierra Nevada, southern Cascades, and Modoc and Inyo National Forests, California, USA* (General Technical Report GTR-PSW-256). U.S Department of Agriculture.

Van Bruggen, A. H. C., He, M. M., Shin, K., Mai, V., Jeong, K. C., Finckh, M. R., & Morris, J. G. (2018). Environmental and health effects of the herbicide glyphosate. *Science of The Total Environment*, *616–617*, 255–268. https://doi.org/10.1016/j.scitotenv.2017.10.309

Walters, M. B., Farinosi, E. J., Willis, J. L., & Gottschalk, K. W. (2016). Managing for diversity: Harvest gap size drives complex light, vegetation, and deer herbivory impacts on tree seedlings. *Ecosphere*, *7*(8), e01397. https://doi.org/10.1002/ecs2.1397

White, D. E., Witherspoon-Joos, L., & Newton, M. (1990). Herbaceous weed control in conifer plantations with hexazinone and nitrogen formulations. *New Forests*, *4*(2), 97–105. https://doi.org/10.1007/BF00119003

York, R. A., Battles, J. J., & Heald, R. C. (2003). Edge effects in mixed conifer group selection openings: Tree height response to resource gradients. *Forest Ecology and Management*, *179*(1), 107–121. https://doi.org/10.1016/S0378-1127(02)00487-5

Youngblood, A. (2005). *Silvicultural systems for managing ponderosa pine.* (General Technical Report PSW-GTR-198; pp. 49–58). Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture.

Zachary E. Kayler, Lucas B. Fortini, & John J. Battles. (2005). GROUP SELECTION EDGE EFFECTS ON THE VASCULAR PLANT COMMUNITY OF A SIERRA NEVADA OLD-GROWTH FOREST. *Madroño*, *52*(4), 262–266. https://doi.org/10.3120/0024-9637(2005)52[262:GSEEOT]2.0.CO;2

Zavitkovski, J., Newton, M., & El-Hassan, B. (1969). Effects of Snowbrush on Growth of Some Conifers. *Journal of Forestry*, *67*(4), 242–246. https://doi.org/10.1093/jof/67.4.242

Zhang, L., Rana, L., Shaffer, R. M., Taioli, E., & Sheppard, L. (2019). Exposure to glyphosate-based herbicides and risk for non-Hodgkin lymphoma: A meta-analysis and supporting evidence. *PubMed*, *781*, 186–206.