The Response of California Black Oak *(Quercus kelloggii)* to Ashland Forest Resiliency Fuels Treatments

Arlo Todd & Ollie Bucolo
Southern Oregon University
Department of Environmental Science and Policy

Abstract

California black oak (*Quercus kelloggii*) is an ecological and cultural keystone species and an integral component of the mixed-conifer and mixed-evergreen forests that make up the Klamath-Siskiyou Ecoregion of southwestern Oregon and northwestern California. California black oak and its associated woodlands have been in decline throughout its natural range due to fire exclusion from the late 1800s to the present. The Ashland Forest Resiliency project in Ashland, OR aims to restore the watershed towards its historical range of variability (HRV), including the preservation of old-growth black oaks, by fuels reduction and stand density management. Gaps in the scientific literature as to the effects of various fuels treatments on the vigor of black oaks warrant the monitoring of this management project. The response of 28 black oaks, greater than 150 years old, to fuels treatments was quantified. Measurements of radial growth, vigor, epicormic branching, and crown dieback were taken before and 5 years after treatment implementation, in treated units and in controls. The response of sample oaks indicates that AFR treatments do not negatively affect oak growth within 5 years and may benefit oaks that are not in advanced states of decline. Our research suggests restoration may be best directed at oaks with greater than 30% of crown intact, while oaks with greater dieback may not respond to treatments intended to improve their vigor and longevity.

I. Introduction

California Black Oaks (*Quercus kelloggii*) are a deciduous hardwood component of the mixed conifer and mixed evergreen forests of the Klamath-Siskiyou ecoregion of Southwest Oregon and Northwest California. They provide important ecosystem functions and services, such as forage in the form of acorns, which are eaten by at least 14 species of birds, many species of small mammals, and larger animals such as black-tailed deer and black bear (McDonald 1990). The large, open crowns of old black oaks also provide critical habitat structure in the form of broad, open canopies and nesting cavities in the hollows of trunks and large limbs infected with the heart-rot fungi *Polyporus dryophilus* and *P. sulphureus* (McDonald 1969). In addition to bird nesting habitat, species such as acorn woodpeckers use these hollows as granaries for acorn storage, and pacific fishers have been known to use oak hollows as resting habitat (Zielinski et al. 2006). The importance of CA black oak acorns as wildlife forage may further increase as sudden oak death continues to decimate the tan oak (*Notholithocarpus densiflorus)* populations of the region (Cocking et al. 2014). Additionally, black oaks and their acorns are of cultural importance to many Native American tribes in both California and Oregon, namely the Takelma, Galice, and Applegate tribes in southwest Oregon and the Shasta and Karuk tribes in northern California in what is now roughly Siskiyou County. Acorns were used as a traditional food source and were also significant in many cultural rituals such as dances, festivals, and ceremonies, so much so that *Q. kelloggii* is qualified as a “cultural keystone” species (Long et al. 2016). This cultural significance played into the historical role of fire on the landscape, with tribes frequently introducing fire to control underbrush as well as to facilitate acorn and berry production. The positive externalities of this anthropogenic fire extended far past food production, to include insect and disease mitigation and control (Duren and Muir 2010; Long et al. 2017).

Along with the other tree species in the mixed-conifer forests, black oaks evolved in the mixed-severity fire regime of the Klamath-Siskiyou. Historic fire return intervals varied across the Klamath-Siskiyou and in some locations, fires were frequent and of low severity while in others they were mid to high severity (Cocking et al. 2012; Taylor and Skinner 2003). An average historic fire return interval of twelve years in the Ashland, OR watershed (Metlen, unpublished research) has been established with many sites experiencing fire at an 8-year fire return interval (Metlen et al. 2018). This relatively short fire return interval likely maintained the populations of black oaks in the watershed by killing conifer seedlings that would otherwise eventually out compete oaks for resources. Conifers that encroach under oak canopies are mostly shade-tolerant, grow faster than oaks, and are susceptible to fire when young (Cocking et al. 2012; Engber et al. 2011). Douglas-fir (*Pseudotsuga menziesii*), and white fir (*Abies concolor*) are most likely to over-top and have deleterious effects on oaks. In contrast, pines such as ponderosa pine (*Pinus ponderosa*) have sparse crowns and are more likely to co-exist with oaks in a mixed conifer forest (Taylor and Skinner 2003; Engber et al. 2011) Interestingly, black oaks on xeric sites appear to show no signs of decreased vigor while growing in mixed stands with pines (Schriver 2015; Skinner et al. 2006).

California black oaks likely persisted in this mixed severity fire regime by two means. Firstly, black oaks endure moderate to high-severity fire by sprouting vigorously from epicormic basal buds following crown top-kill (McDonald 1990; Cocking et al. 2012). In fact, re-sprouting in some sites is the main mode of regeneration (McDonald 1990). Secondly, black oaks are able to resist low-severity fire. The open crowns of black oaks are less likely to carry crown fires and black oak leaves are a highly flammable fine 1-hour fuel conducive to frequent flashy but low severity fires. Large old vigorous black oaks are able resist low-intensity fires without complete top kill, maintaining oak canopy dominance with subsequent fires that kill conifer saplings (Cocking et al. 2012; Skinner et al. 2006).

It is widely accepted that the era of fire suppression, beginning around 1900, has greatly altered the forests of the west (Hessburg 2003). CalFire records indicate that active suppression in the Klamath mountains began in the 1940s and fire rotations have increased by an order of magnitude, from 20 to 238 years, in the Klamath-Siskiyou (Schriver 2015; Taylor and Skinner 2003; Hessburg 2003). In the Ashland watershed, historical fire regimes were disrupted as early as 1852, corresponding with the Euro-American settlement and the forced displacement of the Native Americans (Metlen et al. 2018).

Cessation of the habitat-maintaining disturbance regime has led to a dramatic change in forest and fuels structure, as well as stand composition. Increases in stand density have greatly altered the forest composition in the Ashland watershed with a large recruitment of shade-tolerant species increasing trees per acre from 50 trees per acre to over 300 (Metlen unpublished data). In the absence of fire, conifers have encroached upon individual oaks and oak habitats causing the degradation of oak canopy and understory habitat structure. Relatively shade-tolerant and fast-growing conifers such as Douglas and white fir are able to grow in the understory of oaks, pierce the crowns, and eventually overtop them by through-growth (Hunter and Barber 2001). Foresters have long known of the dynamics between black oaks and firs, and black oaks were historically thought of as nurse trees to conifer seedlings (McDonald 1990). These conifer saplings that would have otherwise been suppressed by recurring fire every 3-12 years (Taylor and Skinner 2006; Hessburg et al. 2005, Metlen et al. 2018), pose three threats to oaks trees. They compete for soil nutrients and water, eventually dominate the canopy by intercepting available light, and serve as ladder fuel, carrying surface fires into the canopy of the oaks. These threats lead to reduced vigor, tree mortality, and eventually habitat conversion.

Land managers attempting to restore forest structure to historic reference conditions prioritize preserving old fire-resistant trees as important ecological legacies. The Ashland Forest Resiliency Stewardship Monitoring Plan has identified large old black oaks as important forest components for the habitat, resources, and structure they provide (Metlen & Borgias 2013). In conjunction with a prescription of fuels and stand density reduction, AFR's actions aim to preserve "legacy trees," which are defined as trees established pre-settlement (greater than 150 years old). In the watershed, a monitoring plan was enacted to evaluate how legacy ponderosa pine, pacific madrone (*Arbutus menziesii*), Douglas-fir, California black oak, and sugar pine (*Pinus lambertiana*) responded to treatment (Metlen et al. 2013).

By thinning out younger, adjacent trees that have encroached upon them, and in some instances clearing fine surface fuels away from the base of these trees, forest restoration treatments aim to avoid negatively affecting legacy trees as well as possibly elicit positive growth responses. The management objectives specific to black oaks are to release the legacy specimens from conifer encroachment so they may regain vigor with the newly accessible resources gained by removing such interspecific competition as mentioned above. With more light available for photosynthesis, it is hoped that black oaks respond by increasing crown fullness, epicormic branching, radial growth rate, and eventually increase acorn yields (Devine et al. 2007). Additionally, by reducing the surface and ladder fuel loads around the oaks, mortality from prescribed and low-intensity wildfire will be reduced, increasing the odds that they remain on the landscape (Cocking et al. 2014; Cocking et al. 2012).

The need for black oak restoration in the Ashland watershed is supported by the scientific literature. California black oaks with pierced crowns in the Klamath Mountains have been found to be older than the conifers growing up through and eventually overtopping them (Hunter 2001; Cocking et al. 2012; Schriver 2015). Oak establishment was generally pre-fire suppression, from around the early 1900s and before, while the encroaching conifers were established in the 1940s and 50s (Cocking et al. 2012; Schriver 2015). These findings further support assumptions of recent conifer encroachment in the absence of fire, rather than oak conifer co-dominance or oaks as an understory species. Based on the disruption in the fire regime, determined to be in the mid- to late 1800s for Ashland watershed (Metlen et al. 2018), these legacy oaks are at risk for mortality based on the timetable outlined by Cocking et al. (2012) that states oak mortality occurs after 60-80 years from conifer establishment and habitat conversion after 80-100 years. Furthermore, as black oak vigor declines in the understory of conifers, their ability to both resist and re-sprout following fire is reduced due to diminished root reserves (Cocking et al. 2012). This is of concern to restoration ecologists who aim to use prescribed fire but wish to maintain older black oaks in treatment areas. In light of this research, the large old black oaks' ability to remain in the Ashland watershed is unclear, and the risk of losing these trees is increasing. It does however support restoration actions aimed at preserving and releasing these oaks from conifer encroachment.

Research specifically aimed at investigating the effects of fuels treatments prescribed fire and oak release for California black oaks is missing from the body of restoration ecology literature. However, other studies not directly related to black oak release from conifers are often cited as possible evidence of black oak release efficacy. For instance, 60-year-old cohorts of black oaks in the Sierra Nevada Mountains have been shown to increase growth rates up to 133% when thinned on productive sites compared to control plots (McDonald 2007). While this study indicates black oak vigor can increase with reduced intra-specific competition, it does not indicate that encroached oaks may regain vigor from conifer release or inter-specific competition.

Other studies of conifer encroachment upon the related Oregon white oak (*Quercus garryana*) have shown dramatic positive response in vigor when the oaks were released. In a control-and-release oak restoration study, the response of oaks was measured at five and ten years post treatment with encouraging results. White oak that had been encroached upon by Douglas-fir significantly increased radial growth rates, epicormic branching, and acorn production when released from conifers (Devine and Harrington 2006, 2013). The released white oaks had growth rates 243% greater than non-released oaks (Devine and Harrington 2013), indicating interspecific competition was greatly hindering oak vigor. Although Oregon white oaks are a different species, this work is commonly cited in discussions of California black oak restoration. Whether black oaks will respond in a similar manner, however, remains to be seen.

The literature reviewed provides grounds for investigating the response of the California black oak to forest restoration treatments. From this review, two questions emerge: First, can older, decadent, and over-topped black oaks recover from declining vigor when released by thinning treatments such as those performed in AFR? Second and alternatively, will the AFR management practices have negative effects on oak vigor and cause direct or indirect harm or mortality?

The hypotheses presented here are as follows: First, overtopped California black oaks will have reduced growth rates and vigor. This reduced growth rate and vigor will correlate with the degree conifer encroachment. Secondly, AFR fuel treatments will not negatively affect growth rates or increase crown dieback. Lastly, older decadent California black oaks regain vigor and increase growth rates when released from conifer encroachment.

II. Methods

To investigate these hypotheses, the growth response of twenty-eight sample California black oaks were monitored 5 years post fuels reduction treatment. The oaks are a component of the Legacy Trees portion of the Ashland Forest Resiliency Stewardship Project Monitoring Plan. The sample oaks were determined to be pre-settlement "legacy" oaks greater than 150 years old by dendrochronological analysis of age to DBH ratio of black oaks in the watershed (Metlen et al. 2013). The oaks are located in plots treated in 2013 during AFR fuels reduction, stand density, and prescribed fire treatments. The stands are grouped by those that received no-treatment (NT), commercial density management (DM), and staged commercial density management (ST), ladder fuel reduction. Seven oaks within this sample population have not received treatment and so are used as a control sample (NT). ST plots consisted of 10 oaks and DM of 11. Both commercial density management treatments consisted of low-impact commercial thinning of merchantable timber from the watershed. Staged treatment was incremental, with the first phase of work occurring in 2005. Ladder fuel reduction entailed thinning and hand-piling slash, ground fuels, and understory vegetation and small trees. Staged treatment saw, on average, 612 trees per acre reduced to 142, and density management saw an average of 398 trees per acre reduced to 133. Plots with no treatment had an average of 470 trees per acre with none removed. See appendix 2 for boxplots of treatment metrics.

A cursory site analysis for all 28 of our black oak plots was completed to help establish a baseline of plot conditions. The primary data analyzed were slope (degrees and percent), elevation (meters), and aspect. The data used was from a variety of government geospatial resources that were found online, as well as the baseline monitoring data provided by The Nature Conservancy. The Digital Elevation Model (DEM) is Lidar data provided by the Oregon Department of Geology and Mineral Industries (DOGAMI). The road, trail, and legal (section) feature classes were provided by the Rogue River-Siskiyou National Forest's Geospatial database. Finally, the basemap for the *Oak Monitoring Location* map is a USGS topo map from ArcGIS online. For the DEM, we downloaded and clipped to a workable extent (zoomed to our QUKE layer), and from there colorized it and ran a hillshade function at 75% transparency. The aspect and slope were both ran using the DEM as the source raster data, and both were symbolized appropriately. We elected to run slope twice to figure both percent and degrees. When symbolized in ArcGIS, degrees made much more sense and so is included here. After the raster analysis was completed, the *value to points* tool was used for each new feature class so that discrete data could be assigned as attributes to each oak. That data was joined, field by field, to the master *QUKE* layer, where statistics were then run. Initial analysis of the data using the three primary factors show us that our sample population has a mean slope of 28.3 degrees, a max slope of 41.4 degrees, and minimum of 10 degrees, with a standard deviation of 7. For aspect, our mean was 185.9 degrees, or almost due south. For elevation, the mean was 1040.1 meters, the minimum was 882 meters, and the max was 1273 meters. See appendix 1 for legacy oak locations.

In accordance with the AFR multiparty monitoring plan the following variables were measured to assess tree vigor and treatment response: tree condition, radial growth, canopy position, vigor, crown dieback, and epicormic branching. In addition, photos were taken of the oaks and surrounding stand for visual qualitative documentation of tree health and stand structure. The data was collected following the metrics protocols outlined by the AFR monitoring plan and analyzed with the pretreatment 2013 data from these trees. To further the monitoring procedure and establish historic oak - conifer species dynamics, oaks were cored for future analysis of growth rates. The analysis of the oak growth rings may provide detailed insight into the effects of conifer encroachment and fuels treatments on black oaks with more precision by analyzing increases in growth rates from pretreatment rates of individual oaks. Finally, the mean growth rates, determined by DBH increase pre and post-treatment in both the control and treatment plots, was statistically tested for a significant difference between treatments.

Epicormic branching is another common response of hardwood trees when released from competition and can be used to assess the recovery and response to treatment of oaks (Devine and Harrington 2006). These branches arise from dormant buds on the bole that sprout when exposed to light or stress. They are an important mechanism used by oaks to recover from severe crown dieback caused by prolonged encroachment and overtopping by conifers. These branches aid in recovery by increasing the photosynthetic capabilities of the tree (McDonald and Ritchie 1994) and some will likely eventually bear acorns, becoming a significant portion of the crown (Harrington and Devine 2006). Epicormic branches were tallied and compared with pretreatment levels and tested for significant differences between plots. In addition, the canopy measurements of canopy dieback, canopy position and crown percent were collected and compared with pretreatment levels to assess treatment intensity and response.

Canopy position is used to describe the position of a tree's crown relative to surrounding and competing trees as an indirect classification of the amount of the sunlight available to the tree. This measurement for legacy oaks is not a direct measurement of treatment response but assesses the condition in which the oak inhabits.

The overall vigor of a tree is perhaps the best indication of long-term treatment response; however, the timeframe of this study may be too short for meaningful changes in this metric to be observed.

The percentage of crown that no longer produces leaves is a strong indicator of the health an oak and is correlated to the duration of conifer encroachment (Hunter and Barbour 2001; Devine and Harrington 2006; Cocking et al. 2012). Crown dieback will quantify previous oak decline, and changes in crown dieback can indicate possible negative or negligible effects of treatment. Increases in crown dieback may be an indication of possible negative effects when compared to the control.

Protocols for Field Metrics

Tree Condition**:**

The condition of the tree simply indicates whether tree is alive or dead, whether it died after treatment, or was accidentally cut or otherwise damaged during treatment. Although it is not a response variable to treatment but an assessment of treatment effectiveness, if significant mortality of legacy trees is observed compared to the control, treatments may be determined to negatively affect black oaks.

Radial Growth = DBH:

Diameter at breast height was measured with a logger's diameter tape 4.5 feet above ground on the uphill side of the bole. If multi-trunked, all stems were measured. Trees were cored using an increment borer at 4.5 feet above ground on the uphill and side of the tree and again at approximately 90 degrees from that first, uphill location. Since treatment occurred 5 years prior to this study, at least 10 years of growth was collected to obtain growth rates 5 years prior treatment. When possible, a full core was taken for further analysis of oak and conifer competition.

Epicormic Branching = EPBR:

Epicormic branches were simply tallied as new branches arising from the bole below live crown less than 5 years old as indicated by the number of nodes. Binoculars were used when necessary to aid in the tally. Values are integers of total number of branches and do not include the number of nodes on each branch.

Canopy Position = CNP:

Canopy position is classified based on the following definitions:
Open grown trees: full light from all sides with little competition. *Dominants*: light from above and partly from the sides. *Co-dominants*: light from above but little from the sides. Intermediates: little light from above or sides but are in the upper canopy. *Suppressed*: below main canopy. Values are integer classes: 0=Open Grown 1= Dominant, 2=Codominant, 3=Intermediate, 4=Suppressed.

Vigor = VGR:

The vigor of trees was assessed as a qualitative ranking of tree health based on the combined metrics of crown dieback, crown percent, and observer judgment. This is classified from best (A) to worst (D).

Crown Dieback = CNDB:

Crown dieback was assessed visually as the percent of crown missing, dead, or dying, excluding epicormic branches, and the value reported is the percentage of total crown.

III. Results and Discussion

For simplification, test results given below were run between oaks treated and not treated and not further grouped by treatment type (DM & ST). Crown measurements were also simplified for testing into two groups of less than or greater than 50% crown dieback. To assess the growth response of the sample oaks to AFR fuels treatments the variables of radial growth and EPBR where tested for differences of means between plots using ANOVA. All differences in growth rates between plots where based on 95% confidence levels with p values < 0.05 accepted as sufficient to reject the null hypothesis of equal growth rates of oaks between plots. Plot basal area (BA) and trees per acre (TPA) were used as correlation independent variables of the growth responses of EPBR and radial growth. Oak cores were tagged and stored for future analysis when funding becomes available. Other metrics collected were used for site analysis and monitoring are presented in the appendix.

Treatment Damage and Mortality

A single sample oak was found with one major broken limb that could possibly be the result of treatment from a conifer falling on it or an indirect effect of wind damage. This oak appeared to be in otherwise good health and no other negative effects of treatment such as miss-cuts, broken limbs, or knocked-over oaks were observed in our sample, indicating treatment was executed with caution and as intended. In fact, two conifers growing straight along the boles of two separate sample oaks and through their canopies were girdled in lieu of removal to reduce the chance of damage occurring to the oaks. One of these conifers was successfully killed, the other was not.

Mortality in the sample was limited to one individual in a treatment plot. The tree was in a DM treatment plot and was broken off 2 meters up the bole in what looked to be not directly related to treatment but instead a case of wind-throw, possibly an indirect effect of tree removal. Mortalities such as these are concerning as they represent 4.7% of our treated trees. This individual oak, however, was noted in the baseline data taken pretreatment as having a "profound scar" running up the bole of the tree indicating the oak was in advanced states of decline and/or being previously damaged.

Direct and indirect effects from prescribed fire are difficult to evaluate at this time due to the lack of acres treated through underburns in the watershed thus far. From the oaks we studied that did see fire, no mortality was observed. One fatal instance of a large, legacy-sized oak was observed. While not in our sample, it was in a treated unit that did undergo a pile burn. The tree appeared to have had fire from a nearby pile creep into an open catface and burn it out. That said, many of the oaks were observed to have old, healed burn scars on their boles, many on the uphill side, which indicates the historical presence of medium and low-intensity fire, and the CA black oaks' ability to resist it in the past.

Radial Growth

For all data analysis of growth response, the one dead oak was removed from the sample. Radial growth was derived from the increase in DBH of the oaks since the baseline data was collected in 2013. The increase in DBH was converted in to basal area increment as cm^2 per year with the following equation.

Basal Area increment (cm^2/year) = $(((\pi / 4) * (DBH_2)^2) - ((\pi / 4) * (DBH_1)^2))$ / years since treatment.
DBH is in cm.

The mean oak basal area increment in control plots was 7.07 cm^2 while oaks in treatment plots increased on average by 12.49 cm^2 per year (figure 1). The mean radial growth rate was tested for significance with an ANOVA and a Welch Test not assuming equal variance with a 95

% confidence level (Table 2). The increased radial growth in treatment plots was determined to be statistically insignificant (ANOVA: p-value = 0.26, Welch p-value = 0.097). We therefore fail to reject the null hypothesis that oaks radial growth rates in treated and un-treated plots are different.

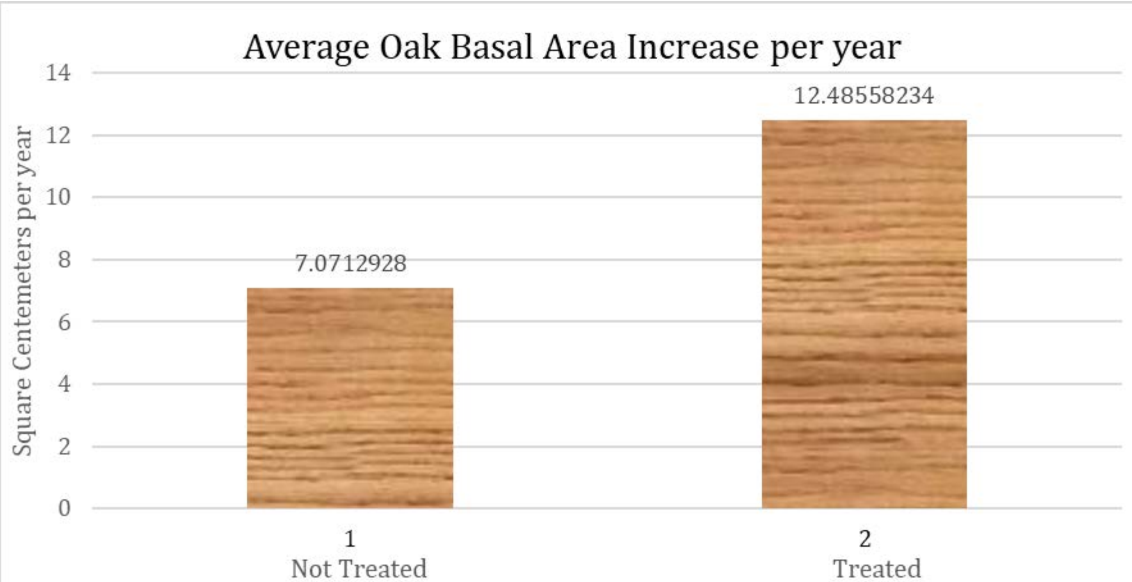

Figure 1. Mean basal area increase in treatment and control plots. The mean basal area increase of oaks was not statistically different (p=0.26).

Table 1. ANOVA results of means of radial growth as basal area increment per year. The radial growth in treated and not treated oaks was found to not be different (ANOVA: p=0.26, Welch not assuming equal variance p=0.0979).

ANOVA: Single Factor of Basal Area Increase Per Year						
SUMMARY						
Groups	Count	Sum	Average	Variance	Max	Min
No Treatment BA cm^2/year	7	49.49	7.07	18.36	14.02	3.81
Treatment BA cm^2/year	20	249.71	12.49	145.85	62.96	0
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	152.00	1	152.00	1.319	0.26	4.24
Within Groups	2881.44	25	115.26			
One-way analysis of means (not assuming equal variances) Welch Test						
F = 2.9564	num df = 1	denom df = 24.98	p-value = 0.09794			

The insignificance in the difference of means is not surprising given the variance in the response of oaks in treatment plots. While the range of growth responses of oaks in the control plots was small, the growth of oaks in treatment plots varied greatly (Figure 2). Some oaks did not respond with measurable radial growth at all, while others increased dramatically with a max growth rate of 47.9 cm^2 per year.

The difference in the variance is clear in the box plots of the sample oaks (figure 2) and this variance between plots is statistically significant, p=0.016, when tested with an F-test of variance (table 2). It is curious why oaks in treatment plots varied greatly in their treatment response while those in the control did not.

Table 2. F-Test of variance between trees that received no treatment and treated. This significant variance (p=0.016) indicates that there is a difference in growth variability between the groups.

Test of Variance	Treatment	No Treatment
Mean	12.49	7.07
Variance	145.85	18.36
Observations	20	7
df	19	6
P(F=f)	0.016	

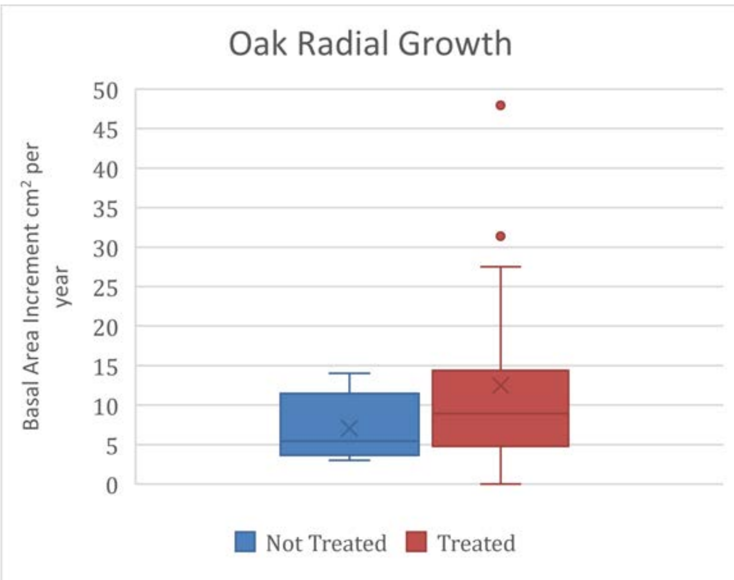

Figure 2. Box plot of basal area increase per year of treated and un-treated oaks. Oaks that were not treated had a much smaller range of response when compared to oaks the received treatment.

To further investigate the variance in oak response to treatment, the radial growth of oaks was plotted against post treatment plot basal area. Plot basal area can be equated with the remaining competition left around the oak after the fuels treatments. Although a strong correlation was not found (R^2=0.2763), the variance of oak growth is greater when plot basal area was lower (greater treatment) correlated to a greater range in oak response (Figure 3). When individual oak growth rates were analyzed, possible explanations for the variance and why some oaks that received high treatment did not respond much were found. Not only did treatments vary in the number of trees or basal area removed from plots but the plot photographs (appendix 4) revealed that some oaks in plots with heavy treatment are still in direct competition for light with conifers. In these circumstances the efficacy of the treatment is low even though the treatment was high. Not surprisingly oaks in these plots had lower growth rates. More precise metrics of plot conditions, such as canopy cover over oaks, could prove useful to factor out this confounding variable.

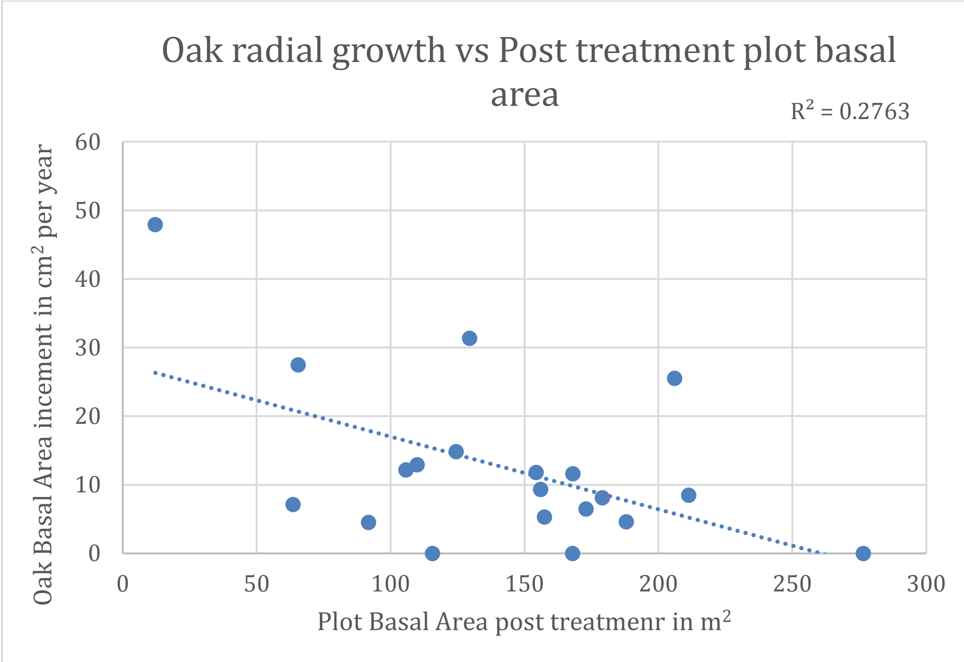

Figure 3. Radial growth of oaks in basal area increment plotted against the total basal area of the plot post treatment.

Furthermore, oak health may be the most influencing factor of response to treatment. Oaks that had experienced a high degree of crown die back not surprisingly had lower growth rates then oaks with more intact crowns that received similar levels of treatment (figure 10, appendix 4) The degree of crown die back was negatively correlated to the pretreatment plot basal area (Appendix 3), indicating, as others have suggested, that crown dieback is a function of the duration and intensity of conifer encroachment (Cocking 2012, Devine & Harington 2003). The metrics of oak vigor and crown dieback were used as additional factors when assessing oak response between treatments in a two-way ANOVA with oaks broken into two groups of less than and greater than 50% crown die back. Interestingly oaks that had received treatment but had lost more than 50% of their crown had mean growth rates very close to control oaks with more than 50% die back at 8.5cm^2 per year and 8.2cm^2 respectively while treated oaks with less than 50% crown dieback grew on average of 15.6 cm^2 while the control grew only 8.2 cm^2 and control oaks with greater than 50% die back only grew on average 4.2 cm^2 (Table 3). Although the differences in oak growth to crown dieback were insignificant (p=0.14) crown die back may be the best predictor of radial growth in response to treatment.

Table 3. Radial Growth by treatment and oak crown die back class

Radial Growth in cm^2 per year		
Crown Dieback class	No Treatment	Treated
1. Less than 50%	8.2	15.6
2. More than 50%	4.2	8.5

Epicormic Branching

Given the slow growth rate of black oaks and that only 5 years have passed since treatment, EPBR branching was expected to be the best indicator of treatment response. The number of new epicormic branches arising from the bole of the oaks revealed a similar pattern as the radial growth response to treatments. Trees that were treated put an average of 11 new epicormic branches compared to trees in the control plots averaged 7 (Figure 4). Although there was an increase in the treatment plots, this difference is statistically insignificant (p=.66) when tested with an ANOVA (Table 6). EPBR data was log transformed to obtain a normal distribution with the log (x=1) because of zero values as was done in other studies using EPBR as a growth response (Devine & Harrington 2003).

Similar to radial growth, when plotted as box plots in DM, ST and NT (control) plots groups, a pattern of increased variance can be seen with treatment (figure 5). Interestingly, not only did the range of the number of epicormic branches increase from the control, oaks in the ST (staged treatment) plots had the highest variance. Although the range of responses was much greater in treated oaks, this variance is not statistically significant (p-value = 0.1012) as it is in radial growth.

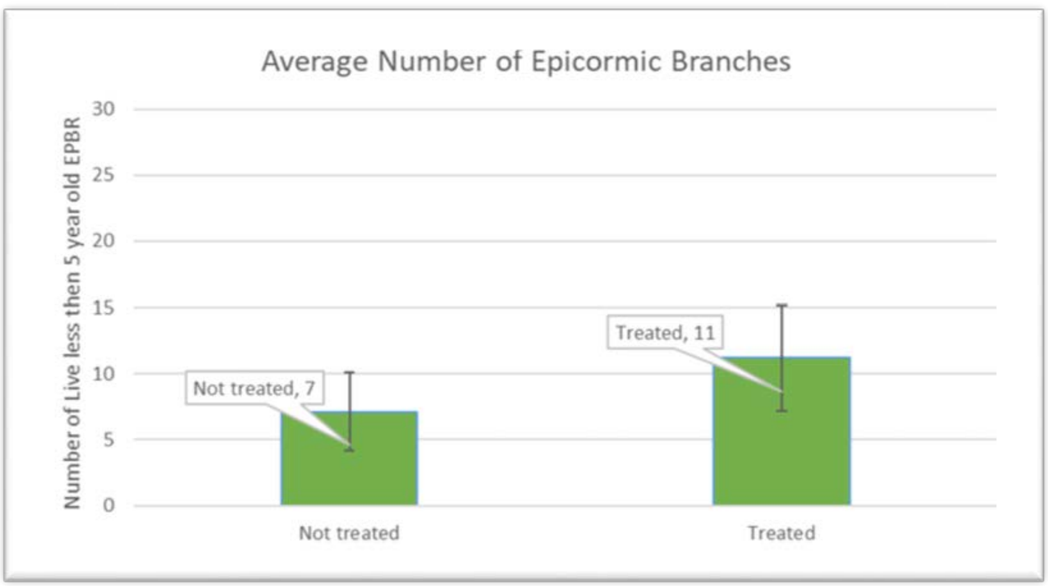

Figure 4. Average number of epicormic branches on oaks 5 years post treatment

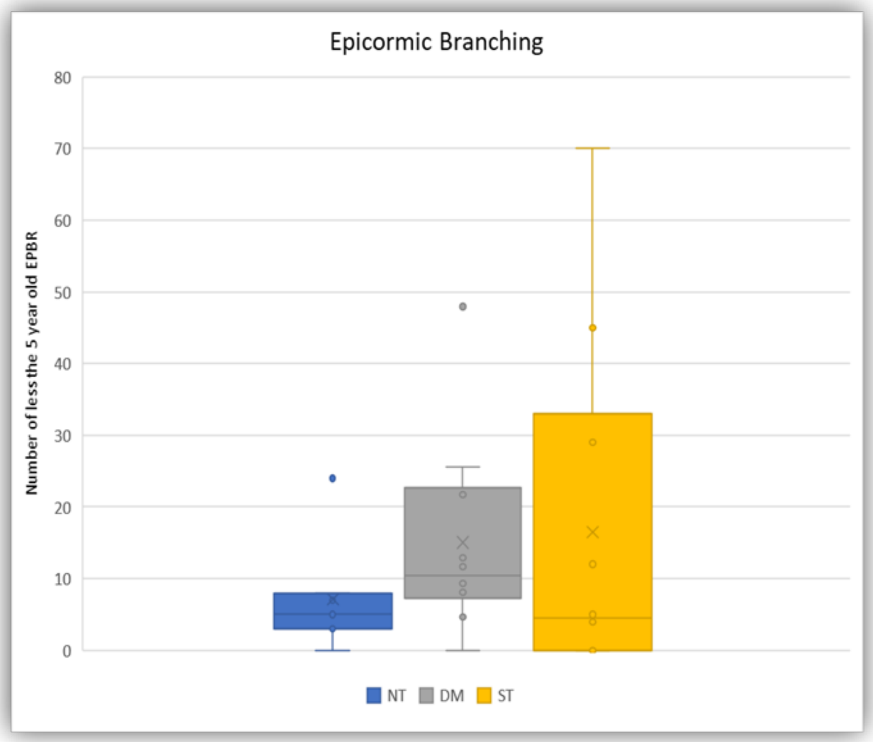

Figure 5. Box plot of EPBR by treatment group. EPBR varince is lower in control compared to both treatment groups.

Although epicormic branching in control oaks did not vary as much as oaks that received treatment, they did vary with many oaks producing no new EPBR and others over 20. This is not surprising, however, given epicormic branching can also be a response to crown dieback as oaks lose limbs to conifer shading. The number of epicormic branches of treated oaks was plotted against the number of trees removed in the plot (figure 6). Although the linear regression model was not a good fit (R^2=0.186) the response pattern echoes that of radial growth with increased variance with increased treatment and a weak positive trend of the number of EPBR with the number of trees removed around the oaks.

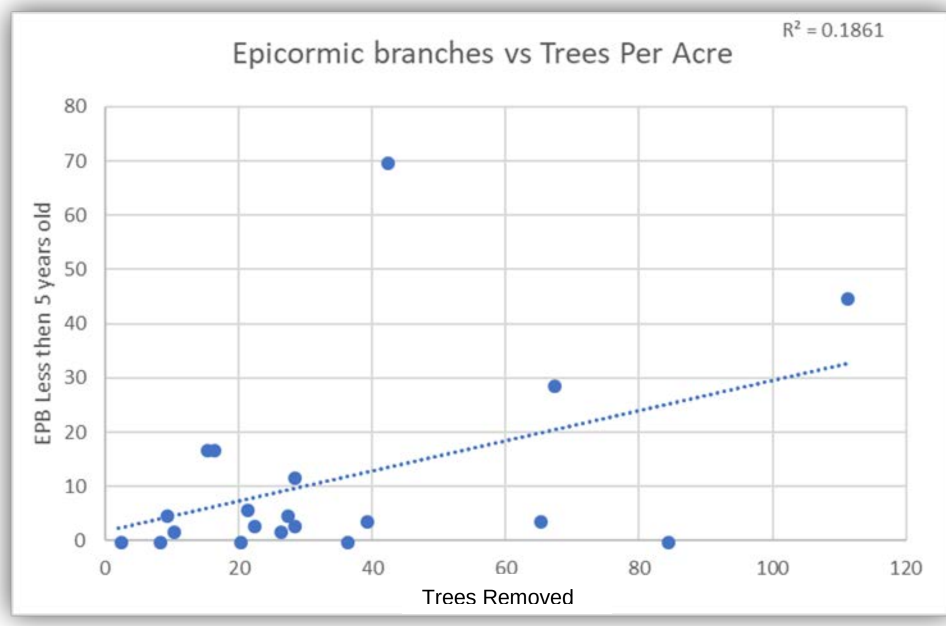

Figure 6. EPBR in treatment plots vs the number of trees removed.

Table 4. ANOVA of EPBR. EPBR was log transformed with to obtain a normal distribution of continuous data for the ANOVA. The log (x=1) was used because of zero values in the data for oaks with no new EPBR.

ANOVA: Single Factor EPBR log transformed						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Treated	18	11.467	0.637	0.267		
Not Treated	7	5.237	0.748	0.182		
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.062	1	0.062	0.254	0.62	4.28

The insignificance in the difference of EPBR comes as a surprise as it was expected be a variable that would have significant change in the 5 years since treatment. Larger sample sizes could prove to detect significant changes as they have in the other studies for this variable that is both a conifer suppression and release response.

Conclusion

In the era of fire exclusion conifers have encroached upon oaks, grown up through their crowns, and now overtop them (Cocking et al. 2012, Hunter and Barber 2001). Black oaks are shade intolerant and have begun to decline in the understory of conifers (Cocking et al. 2012, McDonald 1990). This is of concern to ecologists that fear this loss of a keystone species will disrupt the ecosystem function with the loss of the forage and habitat structure these oaks provide in the mixed conifer mixed evergreen forests of the Klamath Siskiyou region and beyond (Cocking et al 2012; Devine et al 2006). From the literature reviewed, the need for oak restoration, such as legacy tree restoration included in AFR plan, is clear, but the efficacy of California black oak release had to date remained unclear. Whether treatments including mechanical thinning, pile burning and under burns would positively or negatively affected oaks is necessary information for planning forest restoration efforts.

Our monitoring of the response of the California black oak to fuels and restoration treatments has shown us that trees that are already in an advanced state of decline may be more vulnerable to these treatments. This is evidenced by the tree that we found dead – possibly due to wind damage brought on by heavy thinning, as well as the tree we found with structural damage also possibly caused by post-treatment winds.

From the data collected and analyzed, the radial growth rates and epicormic branching of CA black oaks response to fuels treatment is not statistically different from those that were not treated. These findings indicate that AFR treatments are not negatively affecting oak radial growth or the ability of epicormic branching. However, oak response did vary significantly in treatment plots compared to oaks that did not receive treatment. Sample oaks that did not receive treatment had a small range of growth responses while oaks that did receive treatment varied greatly indicating that treatments did have some effects on oaks. The difference in the range of oak growth responses is likely due to variability in treatment intensity, treatment efficacy and oak health. Further analysis revealed that oaks that received effective treatment and had not experienced high levels of crown dieback were the oaks with the highest radial growth responses. These findings suggest that oaks in relatively good health may benefit from the fuels reduction treatments in the AFR. Oak heath is negatively correlated to the length of time under conifer encroachment (Cocking et al. 2012, Devine & Harrington 2003) and the duration and intensity of conifer suppression may be the best indicator of black oaks ability to benefit from conifer release, warranting future research.

The analysis of the tree cores that were collected from sample oaks will likely prove insightful for a number of reasons. Firstly, it would allow researchers to compare pre and post-treatment growth rings. Additionally, further research and monitoring with a *much* broader sample population of black oaks would be possible using dendrochronology because it would allow researchers to establish baseline data and collect monitoring data from one tree with one core, thereby negating much of the need that we had of staying with the original 28 oaks that TNC had previously observed and monitored.

The findings of this research help fulfill the effectiveness monitoring plan of the Ashland Forest Resiliency Stewardship Project and informs the adaptive management of legacy California black oaks. Specifically, the growth response of these trees indicates that treatments don't seem to be harming the oaks. However, the efficacy of AFR treatments in releasing legacy oaks so that they may regain vigor remains unclear. From the information collected and produced by this focused study, future treatments may be adapted and applied to best meet the management goals outlined in the AFR management plan regarding California black oak legacy tree retention and restoration. For example, efforts may be best directed at oaks with greater than 30% of crown intact, while oaks with greater dieback may have negligible response to treatment and therefore not a high priority.

Fuels thinning and prescribed burning will likely continue in perpetuity in the Ashland watershed and the monitoring of these treatments will serve as a long-term research opportunity of black oak and broader forest restoration. Black oaks are long-lived, slow growing species and the growth responses to fuels treatment may be delayed. It is important to remember that this study was only conducted 5 years post treatment. The continuation of this monitoring should be expanded into a study of the long-term responses of black oaks to conifer encroachment and forest restoration, and hopefully inform future restoration plans.

Acknowledgments

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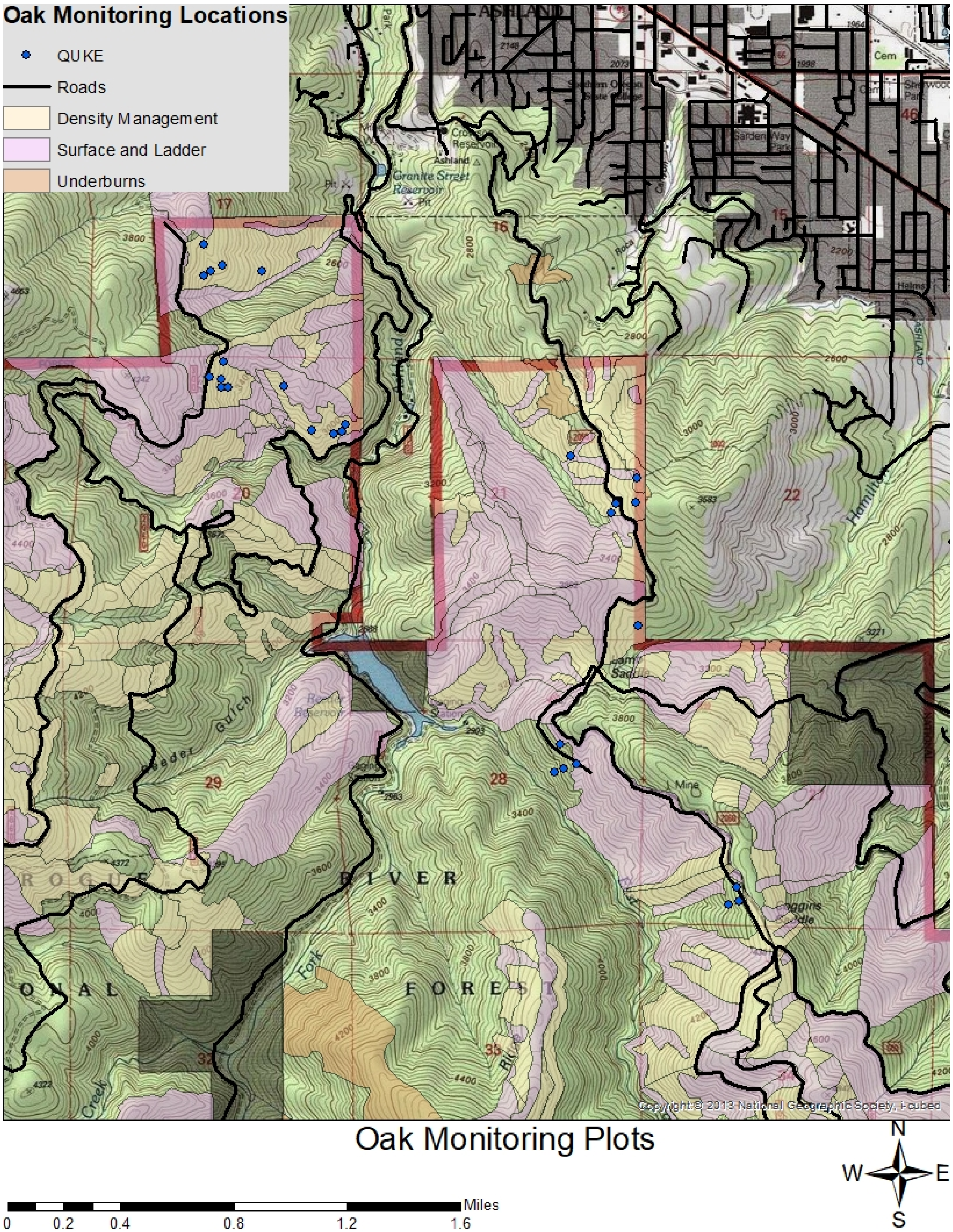
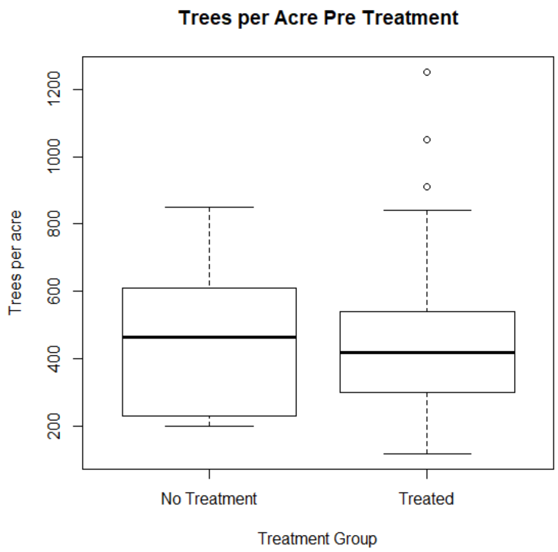
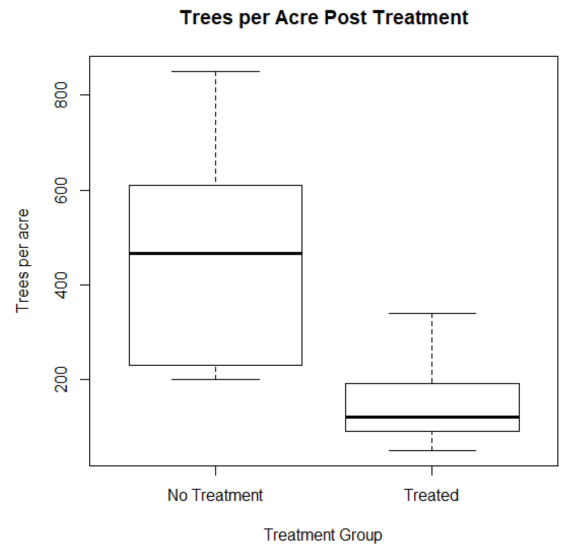
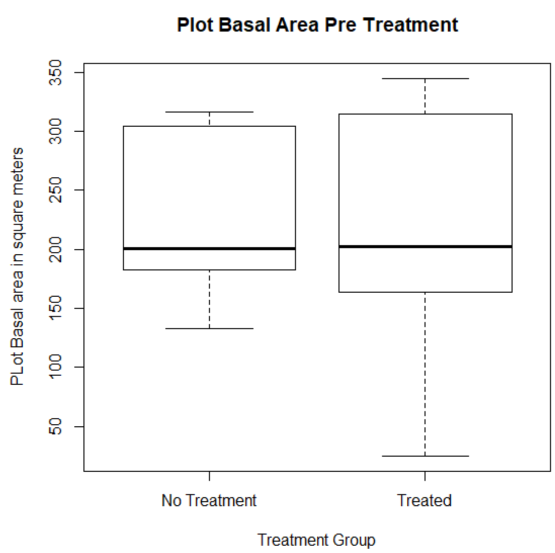
IV. Appendix 1

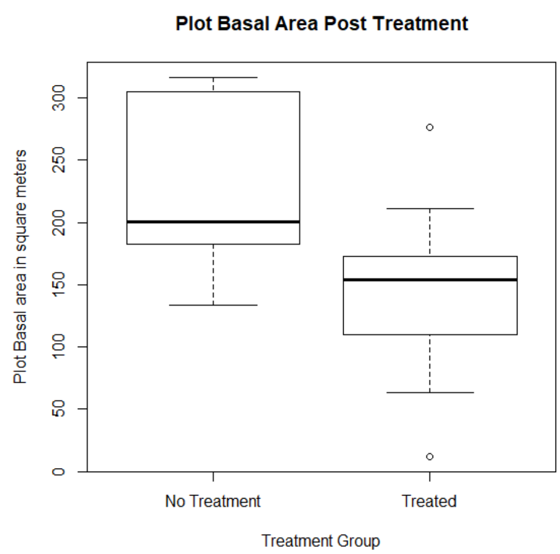


Appendix 2
Boxplots of stand conditions between plots pre and post treatment



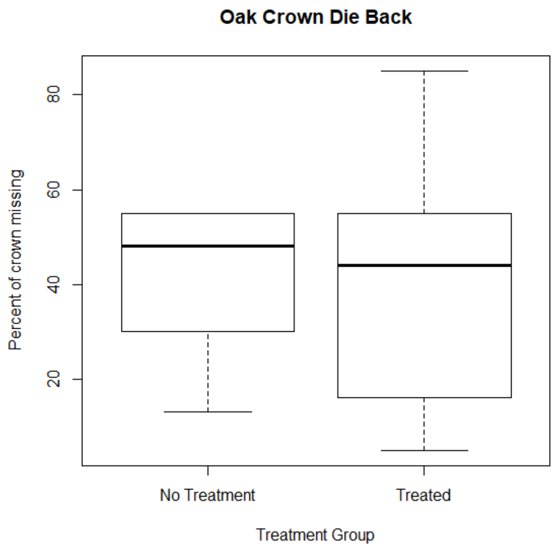


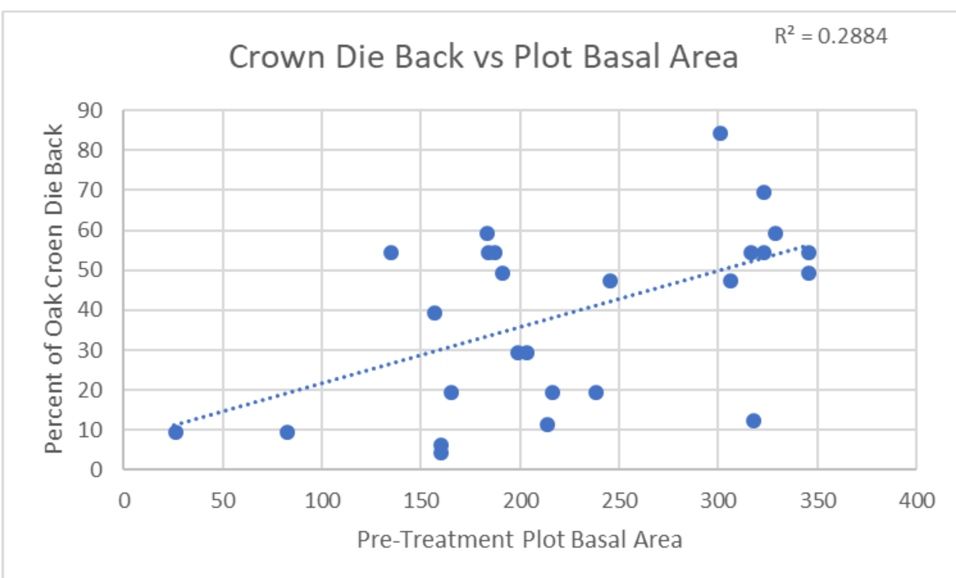




Appendix 3

Crown die back of oaks by treatment or no treatment and plotted over pretreatment plot basal area.





Appendix 4.

Photo points of legacy oaks

Sample oak pre and post treatment.

Example of effective high intensity treatment on a healthy oak

Figure 7. Oak pretreatment 2013 w/ fir piercing crown.

Figure 8. Same oak post-treatment with conifer dead from girdling. Oak responded well to treatment in radial growth in epicormic branching.

Example of sample oaks with low intensity and high intensity treatment

Figure 9 Two oaks that received lox intensity treatment on left and high intensity treatment on right. Trees in similar health grew more with high intensity treatment.

Example of sample oaks in effective high intensity treatment but in different stages of crown die back.

Figure 10. Oaks post treatment that received similar intensities of treatment but responded differently likely due to tree condition. Oak on the left has a higher degree of crown die back and had low response compared to healthier tree on the right.

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