

## **The Effect of Fuel Manipulation Treatments on Giant Sequoia Growth Rate in Whitaker Forest**

Bradley Kerr

### **ABSTRACT**

Fire exclusion practices have dramatically affected mixed conifer forests in the Eastern Sierra Nevada. The Giant Sequoia, *Sequoiadendron giganteum*, of Whittaker forest experienced a mean fire return interval of approximately 8 to 12 years, with a fire free interval rarely larger than 15 years. The removal of regular fire events from this fire-adapted ecosystem has changed the stand level structure of these forests. This study examined the growth rate response of *S. giganteum* to a series of fuel manipulation treatments, comparing the resulting ring widths between the control and fuel manipulation treatments. Two paired-sites were used to account for site variability. Increment tree cores were taken from 70 individual *S. giganteum*, and then prepared and analyzed using a tree ring table; ring width per annum (mm/year) was used as a proxy for growth rate. Ring width data between 1950 and 2008 was interpreted for all samples, so an understanding of average growth rate before the treatments in 1964 could be determined for all sites. After comparing the mean ring width between treatments at each site per annum, I found that the fuel manipulation treatment resulted in significantly larger ring widths within 4 years after the fire when compared to the control treatment. However, there was a lapse interval of approximately 10 years, after which there was no significant difference in growth between the two treatment groups. There was no significant correlation between the increased growth observed in the fuel manipulation group and nearest distance to water.

### **KEYWORDS**

Fire Surrogate Treatment, Prescribed Fire, Fire Exclusion, Tree Ring, Fire Return Interval

## INTRODUCTION

The Sierra Nevada historically experienced frequent, low to moderate intensity fires as part of a regular fire regime (Stephens and Collins 2004). However, the European-American practice of fire exclusion over the past century has resulted in dramatic changes in tree growth, fuel loads, soil structure, and fire hazard (Moghaddas and Stephens 2007). Wildland fire provides many ecosystem services in mixed conifer ecosystems, such as the regulation of disease, stand density, and fuel loads (Busse et al 2009). The absence of wildfire from these fire-dependant systems threatens ecosystem stability due to the risk of increased fire severity, which is further amplified by the overall increasing risk of wildfire in the Sierra Nevada due to global climate change (Notaro 2008). While it is difficult to describe the reference conditions for pre-settlement forests, studies have shown that mechanical and fire based treatments are effective at restoring certain species, such as giant sequoia, to their historical stand parameters (Stephenson 1999). Understanding how sensitive habitat such as old growth giant sequoia forests will react to the reintroduction of fire is necessary if these relic ecosystems are to be maintained. Preparing these fire-excluded regions for the reintroduction of fire is critical to mitigating potentially damaging fire effects, as well as overall wildland fire risk.

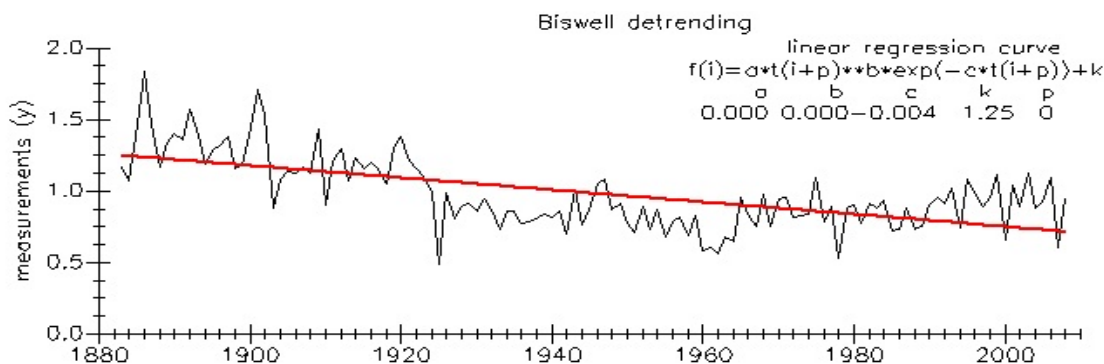
A fire event can alter many characteristics of an ecosystem, including growing space and biogeochemical pathways. Nearest neighbor distance (NDD), a component of growing space, is a critical factor in determine giant sequoia growth rate (Stohlgren 1993a). Roy and Vankat (199) showed that burned plots in Sequoia National Park had a 39% decrease in density compared to unburned plots, which leads to a decrease in NDD and a corresponding increase in growth rate (Peracca and O'Hara 2008). Fire also creates heterogeneity with respect to spatial distribution patterns, which has been shown to increase overall long-term resistance (Stohlgren 1993b). With respect to biogeochemical processes, fire has been shown to affect immediate and long-term availability of many nutrients key to plant growth (Chromanska and DeLuca 2001, Giovannini et al 1987). Soil respiration following a burn event can increase immediate availability of carbon, but decrease soil stocks (Campbell et al 2009); however, this loss of soil carbon is often counteracted by carbon storage in the form of charcoal (MacKenzie et al 2008). In addition, fire has been shown to increase post-burn nitrogen levels (Lezberg et al 2008), as well as altering the structure of fungi communities in the soil (Stendell et al 1999); fungi play an important role in regulating nutrient levels.

To address changes in forest dynamics caused by fire exclusion, forest management practices focus on the use of Fire Surrogate Treatments (FST), anthropogenic activities that seek to restore fire-excluded regions to their historic stand parameters in lieu of natural fire regimes (Stephens et al 2009). FST are very adaptive and can be used to achieve a wide variety of objectives, from reducing surface fuels and fire risk to improving game habitat (Biswell 1999). There are many types of FST that are commonly used. Mechanical thinning and mastication is often used to reduce stand density through the use of large equipment. Prescribed burning, another FST, is a general term used to describe the wide variety of fire applications, such as pile and broadcast burning. When used alone or in combination, FST have been shown to effectively restore habitats to their pre-settlement conditions, improving overall resilience, health, and diversity (Stephens et al 2009, Collins et al 2007).

Experimental forests in the Sierra Nevada, such as the Blodgett Forest Research Station and Whitaker Forest, are used to evaluate the effectiveness of different combinations of FST, with the definition of effectiveness varying with the intent of each treatment. In 1964, Harold Biswell, a forestry professor at UC Berkeley, performed a series of FST at Whitaker Forest, collectively call a Fuel Manipulation Treatment (FM treatment), with the intent of reducing potential fire intensity and overall fire hazard in a stand of giant sequoia, *Sequoiadendron giganteum*. This was one of the first FM treatments that had been performed on an old growth *S. giganteum* grove; consequently, it is important to understand how the giant sequoia responded to the treatment. As per the objective of the treatment, the majority of underbrush was removed, but the large diameter trees, those with a diameter greater than 1 m, remained. The reduced competition also increases water and light availability, which can increase the growth rate of the remaining trees (York et al 2003). Encouraging the continued growth and survival of large diameter trees is paramount to maintaining increased fire resistance (Stephens et al 2009).

My study focuses on how the giant sequoia's growth rate responded to Biswell's FM treatment in Whitaker Forest; the remnant *S. giganteum* had experienced reduced growth rates due to a number of factors, such as crowding, as a result of fire exclusion (See Figure 1). I chose to use increment cores to analyze how the difference in ring widths between control and FM treatments corresponded to *S. giganteum* growth rate response. This will develop further understanding of how to use FST in old growth ecosystems, as well as build fire resistance in mixed-conifer forests. Due to the stresses the FM treatment imposed on the trees, I hypothesize

that there will be a 2 year lag period, before which the difference in growth rates will not be noticeable. After this period, however, I think that there will be about 10 years of significantly increased growth; I will refer to this period as the lapse interval. The FST likely had many ecosystem consequences, but, due to the scope of this project, I focused specifically on the growth rate response of the giant sequoia.



**Figure 1. Average tree ring widths from *S. giganteum* in Whitaker Forest.** Note how the average ring width steadily decreased as a result of fire exclusion.

### Study Site

The Whitaker Forest (36°42'N; 118°57'W), located on Redwood Mountain near Kings Canyon National Park, is a mixed-conifer forest containing species such as white fir, ponderosa pine, incense cedar, and giant sequoia (Agee et al 1978). Whitaker Forest came under the management of research groups in 1915, and is currently managed as an experimental forest under the Center of Forestry at UC Berkeley. The region rarely experienced a fire free interval of more than 13 years before European-American settlers began practicing fire exclusion (Swetnam, 1993). Whitaker's soil is primarily granitic in origin. The region receives approximately 1092 mm precipitation annually with moderate temperatures, ranging from 80 degrees Fahrenheit in the summer to 20 degrees Fahrenheit in the winter.

### Study Design

In 1964, Harold Biswell, a former UC Berkeley forestry professor, combined several FST to create an overall fuel manipulation (FM) treatment for portions of Whitaker Forest. There are two paired sites, each with a FM and control treatment. The reason for pairing the sites is to assume that slope, aspect, precipitation, and other topographical/climate variables will have a null effect. All of the individuals belonging to a particular treatment group were clustered into

one category, assuming that any variation between the sites within treatment would be the same for each group.

### Data Collection

Rob York, the Research Stations Manager for the UC Berkeley Center for Forestry, collected tree cores from 70 individual Giant Sequoia in the summer of 2009. Two cores were taken from each tree at breast height; the primary core was used for analysis, while the backup core provided security against an illegible core. The tree cores were mounted on standard core mounts using Gorilla Glue® and then sanded down with fine-grit sandpaper. I used a ring table to determine the width, in millimeters, of the annual growth rings; ring width is used as a proxy for overall tree growth in this experiment. Measurements will be taken for up to 84 years of growth or the end of the core, whichever comes first. In addition, further detail about the individual trees was incorporated in to the database, including diameter at breast height, dbh, treatment group, and nearest distance to a water source, NDW. This information was provided by 1999 GIS survey of Whitaker Forest.

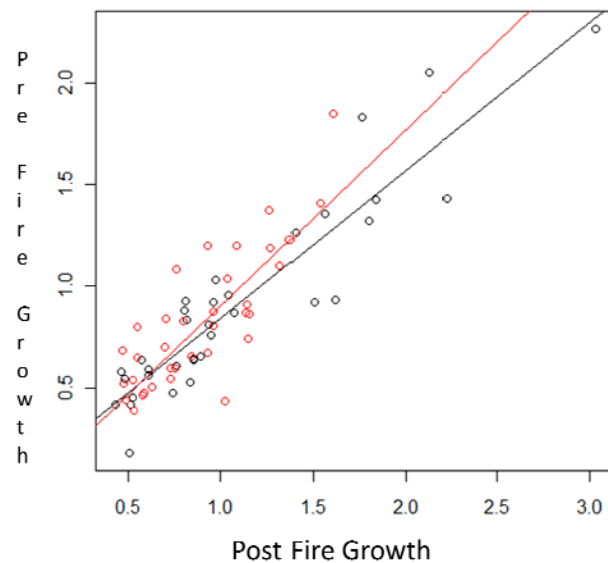
### Data Analysis

In order to confirm equivalent background growth rates between the treatment groups, I compared mean pre-treatment growth for each tree from 1950 until 1963,  $\overline{g_{pre,trt}} = \sum_{n=1950}^{1963} x_n / 13$ , as well as the average chronology for each treatment,  $g_{n,pre,trt} = \overline{x_{n,t}}$  using a t-test of significance. To build the mean chronology, I took the growth for each tree and created an average for each individual year; this set of averages is called the mean chronology. The term mean (pre/post-treatment) growth signifies that I took all corresponding growths, 1964 being the barrier year, and averaged the value for each individual tree; these values were treated as the set called mean growth. I then repeated the tests for the post fire data, using 1964 and 2008 as my boundary years (2009 was excluded from this analysis since the growing season had not finished when the cores were taken). In order to compensate for differences in dbh between trees, I created a standardized unit of measure for all growth by dividing the annual growth by dbh,  $x_{std} = x_{n,i} / dbh_x$ ; in my results, I report all values from tests done using the standardized growth. All tests of significance were one-sided, using a 95% confidence interval with  $df = 69$ .

I tested for the effect of two covariates in my study: dbh and NDW. I used standardized metric for ring width to account for differences in dbh and chose to test for the effect of NDW. I did not directly test for the effect of dbh on tree growth post-treatment, but used the standardized measurements for all tests of significance. I believe that this method accounted for any potential impact dbh would have had on growth rate. I used a 1999 GIS survey of Whitaker to input what data was available. However, the database only provided measurements for distances less than 200 feet; to compensate for this, I input values of 200 feet for any tree in the database that did not have a NDW measurement. I then used R (2009) to run a linear model comparing post-treatment growth to treatment group and NDW to test for any significant effect of NDW on growth rate, as well as confirm my t-test results on any significance of the FM treatment.

## RESULTS

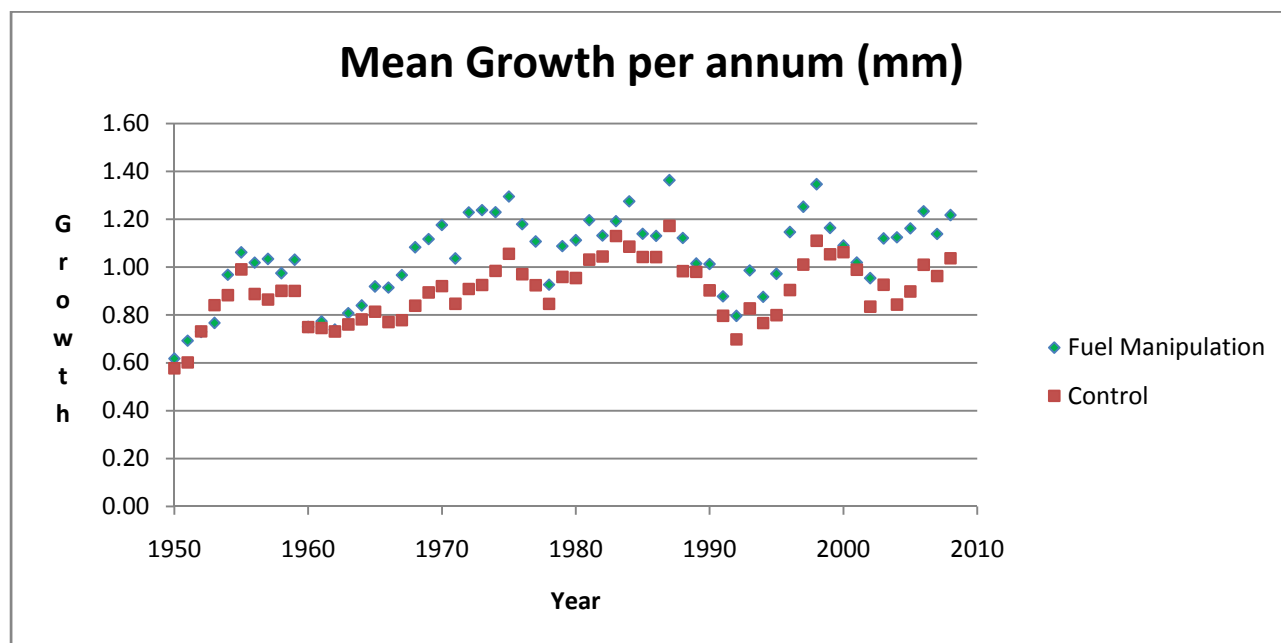
I found that there was no significant difference in pre-treatment growth rates between the control and FM treatments;  $p = 0.279$  for mean chronology,  $p = 0.500$  for mean pre-treatment growth. However, I found that post-treatment growth was significantly higher in the FM treatment group for both mean growth,  $p = 0.048$ , and mean chronology,  $p = 1.15e-18$  (see Figure 3). When I tested for significant increases in growth between each individual year following the burn, I found that there was a 4 year lag period; that is, it took only 1 year for there to be a noticeable difference in growth rates between the two treatment groups, but the difference was not significant until 4 years after the treatment. I noticed that the pattern of increased growth



**Figure 2. Pre-treatment growth vs. post-treatment growth (black = FM; red = control).** The reduced slope of the FM treatment indicates that post-treatment growth was greater than pre-treatment growth when compared to control.

rate in the FM treatment was still visible after the 10 year lapse interval, though the difference was no longer significant.

I found that there was no significant relationship between NDW and the increase in growth rate observed in the FM group ( $p = 0.46$ ,  $df = 67$ ). When I plotted pre-treatment growth and post-treatment growth for both treatments in R, I found that the FM treatment had a lower value for slope, confirming that the growth rate for the FM was indeed elevated compared to the control group (see Figure 2).



**Figure 3. Mean Chronology of growth per annum for FM and control treatments.** Note how the FM treatment begins to exhibit increased growth approximately 1 to 2 years following treatment.

### Discussion

The exclusion of fire from fire-dependant ecosystems has dramatically affected stand and landscape level dynamics, especially in mixed-conifer forests. The use of fire surrogate treatments could provide a way to ease these systems' transition back to their regular fire regime by restoring several habitat characteristics to their pre-settlement status. York and Heald (2006) demonstrated that small diameter *S. giganteum* exhibit a release potential following shrub removal, in which they underwent a period of elevated growth rates. It is possible that large individuals, such as those in this study, exhibit a similar release potential that relates to the increase in nearest neighbor distance, as well as increased resource availability. Reducing total

understory cover could allow these trees more room to grow. It is important to note that while a release is expected in small diameter trees, to see a significant response from large, relic trees is important. Busse et al (2009) observed no significant growth rate response to FST, though the maximum stand age and species of interest were different; I was studying giant sequoia who are aged in terms of millennia, whereas his study focused on ponderosa pine under the age of 60 years. While some studies may not have had similar results to mine, I believe that fire is necessary to maintain ecosystem health in giant sequoia groves. Lambert and Stohlgren (1988) showed that low to moderate intensity surface fires did not affect tree mortality for giant sequoia, so a low to moderate intensity burn results in increased growth rate with little impact on mortality. My study supports further study of FST on long fire-excluded habitats as a means of restoring ecosystem health and encouraging growth of large tree species.

I determined that there was a lag period in the growth response of the trees, before which the FM group did not exhibit significantly increased growth. Testing for when the difference was noticeable is more difficult due to natural fluctuations in growth patterns, so I was only able to test for when the differences were significant or not. I predicted that there would be a lag period of 2 years due to stresses imposed on the trees by the fire. Regardless of the positive benefits associated with fire, it does act as an immediate stressor on the affected landscape (Piirto et al 1991). For example, some of the trees might suffer some amount of damage from the flaming front or suffer critical heating in the cambium tissue as a result of long term heat exposure. This explains why the trees did not demonstrate an immediate response to the FM treatments. It's likely that they were recovering from injuries that they may have endured and were acclimating to the new resource levels. I determined the lag period to be about 4 years before the FM treatment exhibited significantly increased growth over the control. While this figure is longer than I had originally anticipated, this is the period before the difference in growth rates was significant, not observable.

There was also a 10 year lapse interval, after which the difference between growth rates was no longer significant. Piirto (1999) stated that giant sequoia need regular burn events to maintain ecosystem health, which is supported in a study by Swetnam (1993), in which he determined that there was rarely a period of 15 years or longer in which giant sequoia groves didn't experience a low to moderate intensity fire. After a 10 year period, surfaces fuels would have accumulated enough to maintain a constant surface fire, but not enough to cause significant



crown damage to large trees; the potential for high-intensity crown fires typically required about 35 years of fuel accumulation, in order to accumulate sufficient surface and ladder fuels to carry the flame into the canopy (Shellhammer and Shellhammer, 2006). Kilgore and Taylor (1979) noticed that fire scars found on individual giant sequoia were often found in 8 to 11 year intervals. Fire scars are made when a fire is intense enough to cause some damage to the tree, but not kill it entirely; this type of behavior is indicative of low to moderate intensity surface fires with a low torching index. While there may not be the potential for high-intensity fires, 10 years is a long enough period that there would be increased competition for resources from shrubs and saplings in the understory, which could reduce growth rate for some of the larger trees. The 10 year lapse interval supports Skinner and Chang's (1996) argument that frequent, low to moderate intensity fires were prevalent in the Eastern Sierra Nevada; this short fire-free interval was necessary to maintain ecosystem health and promote the continual growth and reseedling of conifer species.

When constructing my methods, I felt that the majority of confounding factors were accounted for with the paired-site design, with the exception of two major factors: dbh and NDW. In a future study, I would like to restructure my data so that I could run a separate test for any relationship between dbh and the increased growth rate so I could definitively say that there is no significant association, but I did not include this study in this experiment. I found that there was no significant correlation between the increased growth in the FM plots and NDW ( $p = 0.46$ ,  $df = 67$ ), indicating that treatment type was the only significant factor that I tested for that accounted for the difference in post-treatment growth rates. Since the GIS survey only had data for distances under 200 ft, I had to input values for some of the samples. Even though the gaps were evenly distributed between the two treatment groups, I would like to go back and take specific NDW measurements for the remainder of the samples to solidify this finding.

### **Limitations**

It's important to remember that my study focused on one aspect of the FST series which likely had many effects on the ecosystem. I did not look at post-fire erosion, though Guerrant et al (1991) showed that soils of granitic origin, like those in Whitaker, tend to be naturally resistant to the elevated erosion rates that are often characteristic in post fire soils. Also, I do not have a photographic chronology of my study site. While I can make inferences into what the forest

looked like before and after treatment based upon previous experience, unless I have photographs, it is hard to say how understory vegetation was affected.

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