Pine and Oak Response to Fire in the Sierra Nevada Foothill Savanna

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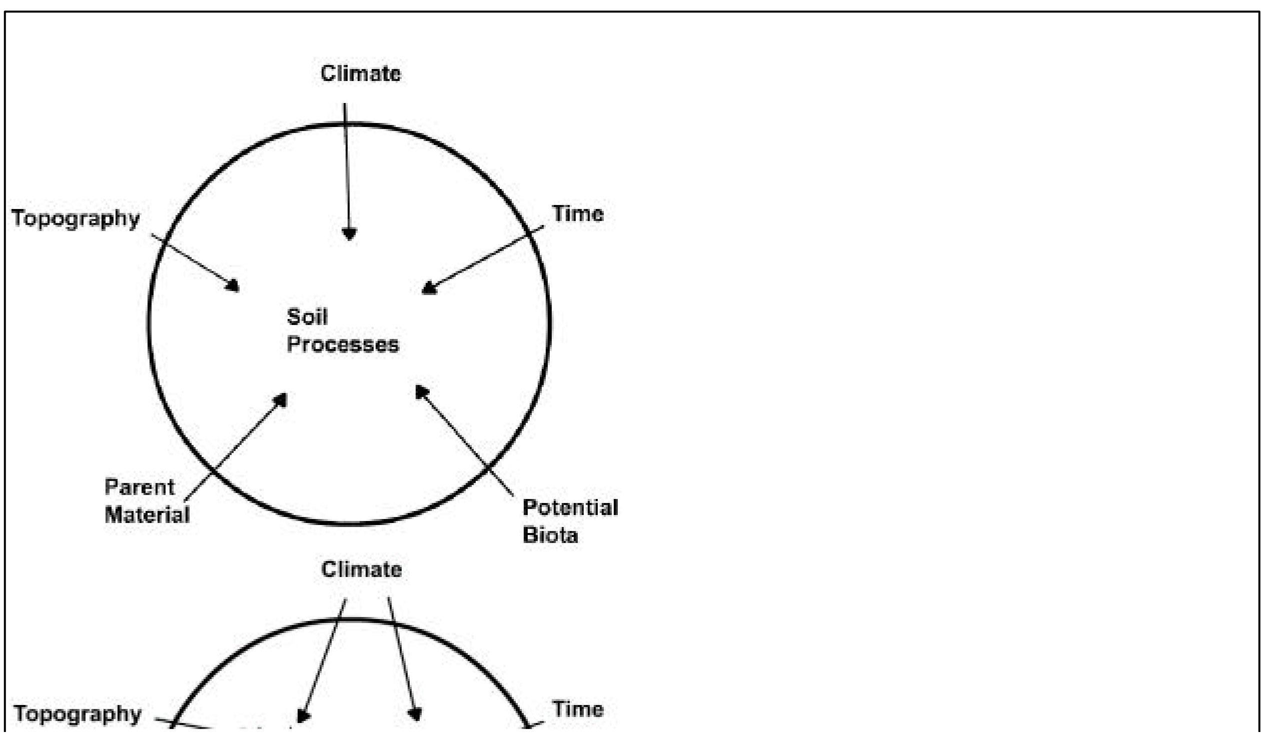
Abstract The pine-oak savanna of California's Sierra Nevada foothills has been greatly altered by the introduction of cattle grazing, exotic annual grasses and the suppression of fire. Fire is an important element of the disturbance regime of an ecosystem and is a common management tool for wildlands. Therefore it is important to understand the effects of fire on the growth rate of tree species native to this ecosystem. I used woody debris line-intercept sampling and Brown fuel transects to quantify fuels consumed by a controlled burn treatment at the University of California's Sierra Foothill Research and Extension Center (SFREC) in the northern Sierra Nevada mountains. I used the difference in ground fuels before and after the burn as a proxy for the fire intensity and compared the difference against tree diameter growth rates before and after treatment. *Quercus douglasii* and *Pinus sabiniana* both showed a significant negative difference in normalized rates of radial growth in the first year following the prescribed burn. I did not find a significant correlation between radial growth and fuels consumed on a sub-watershed scale. I developed a model to explain the relationship between woody debris and Brown fuel transects.
This pilot study suggests that a more in-depth study is needed to understand the relationship between fire and tree growth here. Longer term trends can only be determined future measurements of tree growth. Further work needs to be conducted on the specific parameters which best suit the implementation of woody debris and/or Brown fuel transects in the savanna ecosystem.

Introduction

California's Sierra Nevada foothills contain extensive blue oak savanna ecosystems, which have attracted attention as part of ongoing debates about the ecological role of fire and appropriate use of fire as a management tool. However, very few studies have been conducted on the blue oak savanna, and those studies which have examined these ecosystems have treated them as co-existing grassland and a woodland/forest ecosystems, not as a form in its own right. Approaching a savanna as a distinct ecosystem has the potential to more precisely describe and understand the unique dynamics of the system. Some past research has been conducted on similar pine-wiregrass systems in the southeastern US (Mitchell 1999), but conundrums outlined by House et al. (2003) limit and restrict the results of savanna study. They noticed that in order to better understand savanna dynamics, research must acknowledge three conundrums – which most studies of savanna systems fail to thoroughly address. House et al. pose the conundrums as three questions which most studies of savanna systems fail to thoroughly address. How is the woody and herbaceous plants ratio controlled? How do they interact? How does the net primary productivity (NPP) change with changes in the woody-herbaceous plant ratio? To address these questions, the savanna ecosystem must be viewed as a continuous ecosystem – not a mixture of grasslands and woodlands. Previous studies on blue oak savanna (e.g. Callaway 1991, Dahlgern 1997, Kay 1987) examined tree growth at the University of California's Sierra Field Research and Extension Center (SFREC), but none of these studies took a continuous ecosystem approach.

Ecosystem scientists recognize a model developed by Hans Jenny as one of the seminal works in the field. This model consists of five state factors which act upon ecosystem processes



introduced to the ecosystem. Interestingly enough, these ecosystems seem to be fairly stable. Battles (2005) has further suggested that grazing has taken the place of fire to keep r-selected species (herbaceous plants) in check while giving k-selected species (woody plants) a chance to thrive, but the effects of fire on growth have not been studied on a blue oak savanna as a continuum of woody and herbaceous plants.

My study examines how tree diameter growth correlates with fire intensity in a savanna dominated by blue oak (*Quercus douglasii)* and ghost pine (*Pinus sabiniana*) trees on plot and watershed scales. It also quantifies fire intensity by the difference in the amount of ground fuel before and after the fire using downed woody debris and Brown fuel transects (1974). In this study, I test the hypothesis that in areas of my study site with significantly less ground fuels after a prescribed burn than before the burn correlates with greater increase in tree diameter than would otherwise occur. I am also testing the hypothesis that trees in the watershed subjected to a prescribed burn will exhibit a more positive response in radial growth than occurs in the control watershed. In essence I am asking if fire is beneficial to the trees in a the blue oak savanna of the Sierra Nevada Foothills.

Methods

My study is a subset of a larger project conducted in the UC Berkeley department of Environmental Science Policy and Management which attempts to answer the NPP question in the blue oak systems at my site. Forest ecologist John Battles, and rangeland ecologists Barbara Allen-Diaz and James Bartolome focus on using a continuous ecosystem approach, which House et al. (2003) recommends for addressing the three conundrums of savanna ecosystems. By examining the response of trees to fire in this ecosystem, we can better understand how the woody and herbaceous plant ratio is controlled. The basic experimental design follows the small watershed approach (Likens 1985) using a before-after-control-impact (BACI) analytical framework. In two adjacent watersheds, we sampled both for downed woody debris in the year 2002 and we started sampling oaks for yearly radial growth. In 2004, we subjected one watershed to a prescribed burn, and the following year I returned to sample both watersheds for downed woody debris. I used the the difference in downed woody debris before and after the fire as a proxy for local fire intensity. Additionally, I cored pines to measure radial rates of growth, which I used to quantify the tree growth response (as opposed to using extension growth). The fuel load of the burned and unburned watersheds can be compared to give an understanding of the amount of fuels consumed by the fire instead of using coarse woody debris as a proxy.

The study site is located in two ~100 ha watersheds at the Sierra Foothill Research and Extension Center (SFREC) operated by the University of California. SFREC is located in the Sierra Foothills, with extensive savannas dominated by *Quercus douglasii* (blue oak) and *Pinus sabiniana* (ghost pine). The existing Battles NPP study established twelve 11 m radius plots in two watersheds on SFREC land. These plots were stratified across four different vegetation cover classes (as determined by aerial photography and the use of a spherical densiometer from a larger selection of test plots). In these plots a full inventory of all trees greater than 5 cm in diameter at breast height (dbh) was recorded in 2000, and a subset of trees has been measured every year using dendrometer bands. This sampling had been stratified by size across each watershed. Thirty-six trees in each watershed had dendrometer bands attached at breast height.

In June of 2004, we treated one watershed with a prescribed burn, as would be typically applied in such an area (burn prescription established by the SFREC staff). This study is the first re-entry into these watersheds, focusing on the growth response of trees.

In measuring downed woody debris, 11m transects were laid out from plot center 120 degrees apart. Any woody debris greater than or equal to 1 m in length and greater than or equal to 5 cm in diameter at the intersection with the transect was measured as coarse woody debris (CWD). If the debris ranged in diameter from greater than 5 cm to less than 5 cm then its length was measured from the large end to where the diameter equaled 5 cm. Branched debris had the shorter forks measured as separate tapered cylinders. Volume is determined by assuming the branch has a tapered cylinder shape. Fine woody debris (FWD) was selected as any debris greater than 1cm in diameter not included as CWD. Branching and measurements for FWD followed the same protocol. CWD was measured along 11 m of transect from plot center, while FWD was measured along the first 5 m of the transect. For the purposes of this study, any reference to CWD data includes the FWD measurements. This sampling protocol was the same one used for the initial 2002 and it is based on the sampling techniques described in Waddell (2002).

In 2005 I suplimented the CWD transects with a ground fuel load planar intersect sampling detailed in Brown (1974). This method is rapid, easy to use and a long established standard for sampling fuel loading for naturally fallen debris in conifer forests. I included this sampling technique in my study to compare it to the downed woody debris protocol. Specifically, I was interested in how well it could estimate ground fuels in a savanna. Three 9.14 m transects were run 120 degrees apart from plot center, along which four different timelag class fuels were counted. I tallied 1 hour timelag fuels (less than 0.6 cm in diameter) and 10 hour timelag fuels (0.6 cm to 2.5 cm in diameter) the first 1.83 m, 100 hour timelag fuels (2.5 cm to 7.6 cm in diameter) through the first 2.74 m and 1000 hour timelag fuels (greater than 7.6 cm in diameter) through the entire length of the transect. In addition, the diameter of 1000 hour timelag fuels were measured as well. The depth of litter (recognizable plant material) and duff (unrecognizable organic matter) were both measured at 1.83 m and 2.74 m. I analyzed this data in the Fire Program Solution's Fuels Management Analysis software package to produce an estimate of ground fuel load in Mg/ha.

Tree growth was measured using the dendrometer bands on oak trees within the plots. These were first placed on the Oaks in 2002. Oak growth data was not collected in 2004 because the bands were removed during the prescribed burn. In 2005, all pines within the 11 m plots were cored with increment borers and the dbh recorded. For plots with less than three pines, I cored the three closest pines to plot center. By measuring the recent growth in tree rings and the dbh, a very precise rate of growth of the pines can be established for the last 6 years.

In order to create a more robust and meaningful measurement of tree response, I normalized the annual growth rates for each tree against their mean growth rate for the entire measured time period data. I then calculated the mean normalized growth rate for each watershed by year. Using the standard BACI approach of comparing the differences in means for each year, I computed a 95% confidence interval for the difference in means between the two watersheds prior to the burn, then compared the post-burn difference. If the post-burn (2005) difference falls outside of this interval, the difference in rates of growth is significant. In analyzing the rate of growth as a function of fire intensity (using CWD as a proxy), I developed first and second degree models with which to fit the data. I chose to fit a quadratic model to the comparison between Brown fuel transects and CWD as this best shows each method's relative ability to detect differences in fuels across the range of quantities sampled in my study. A curve that bows towards the CWD axis indicates a greater resolution at low ground fuel loads than Brown fuel transects, but that resolution diminishes at higher fuel loads. All data was collected in the late fall of the year which it references.

Results

A plot of oak growth time series (Fig. 2) shows the growth rates of the treatment and control watersheds tracking in the same direction for the first two years of data collection but then

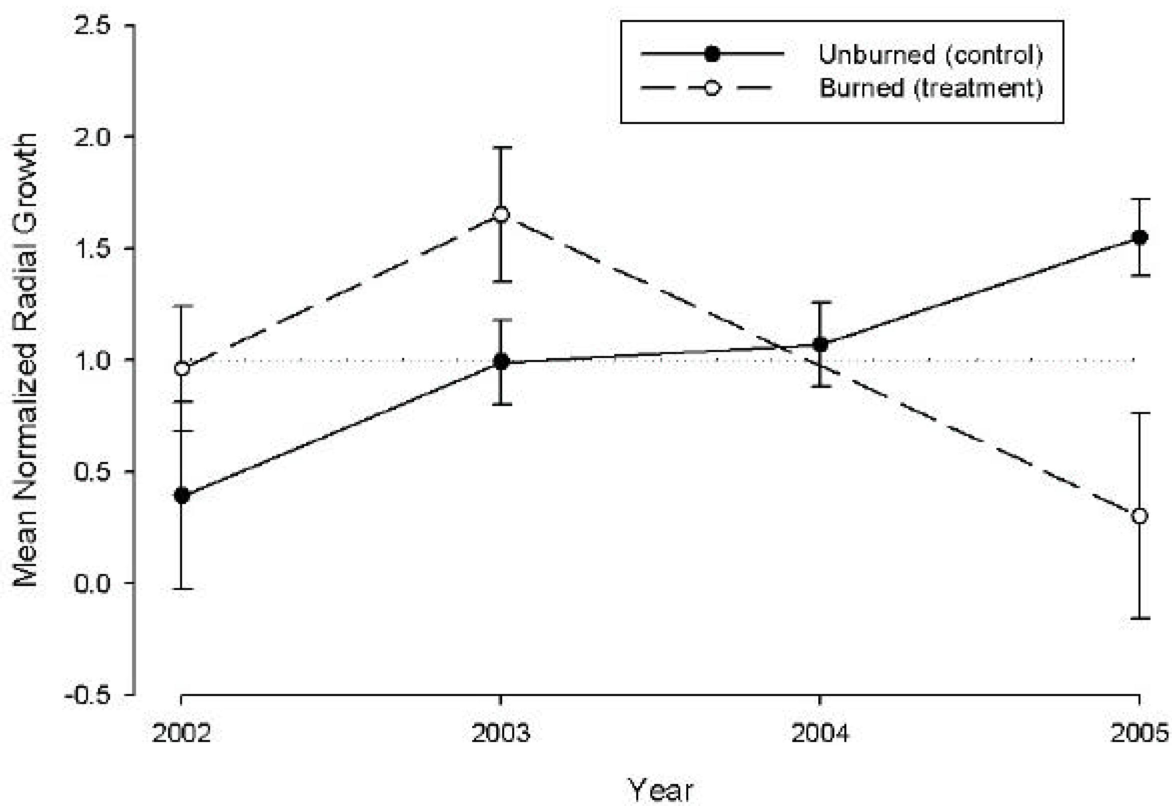


Figure 2. Time series showing the mean normalized growth rate of *Q. douglasii*, by watershed. Dashed vertical line indicates the time at which the treated watershed was burned. The only post-burn measurement (2005) shows a significantly large difference between the two means ($p > 0.05$). The error bars represent the standard error of the sample (n = 26, n = 22)

dramatically cross about the time of the prescribed burn. Also, the variation in growth increases in the treated watershed throughout the time series it declines or remains relatively constant in the control watershed (Fig. 3). The difference in mean normalized radial growth for 2005 (the single post-burn measurement) falls outside of the 95% confidence interval of pre-burn growth differences, suggesting that the fire negatively affected the growth rates of trees.

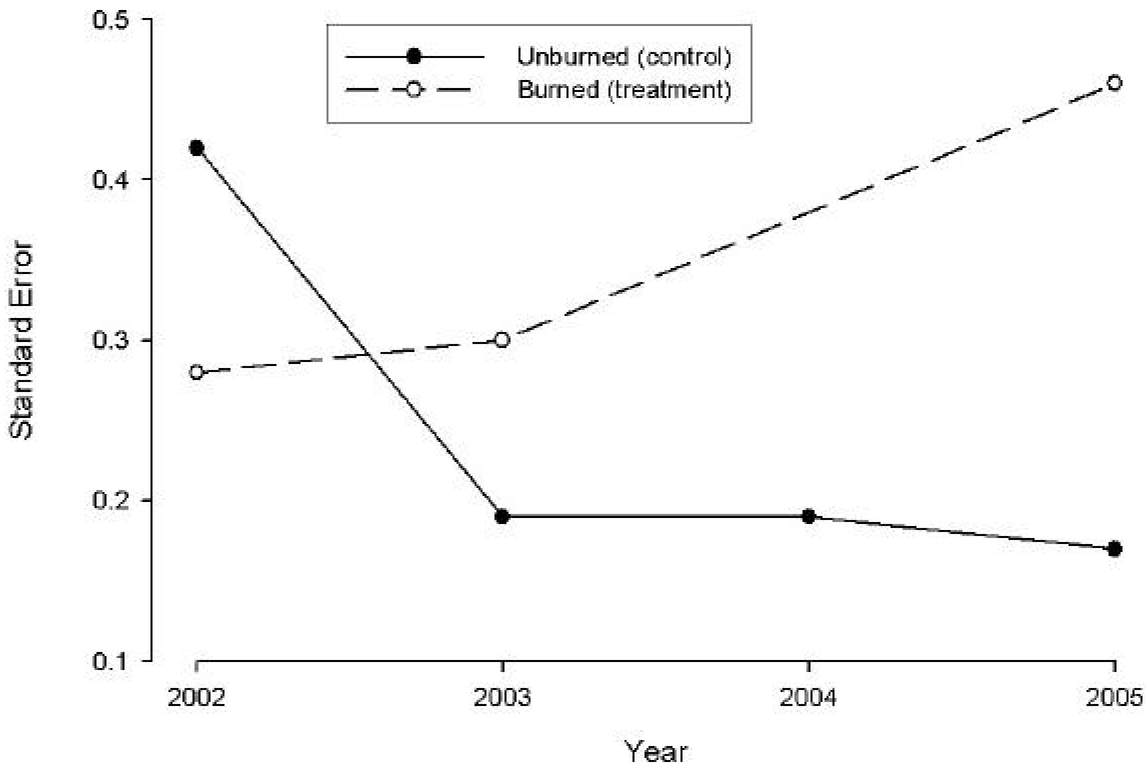


Figure 3. This plot shows the standard error of the mean normalized radial growth of oaks by watershed. The variability of the treatment watershed continuously increases and that of the control watershed decreases. The difference is most likely due to a large difference in sample sizes: $n_{control} = 36$, $n_{treatment} = 23$. Additionally, is difficult to confidently identify a trend in variability within a single watershed here due to a lack of data. The

The pine growth time series shows a similar trend (Fig. 4). In this case, the two watersheds track strongly but diverge sharply after the burn. In 2005, the burned watershed suffered its worse rate of growth in six years, while the control watershed experienced almost the mean rate of growth over the same six years. Again, the 2005 difference between the watersheds falls far outside the 95% confidence interval described by the pre-burn data. Although the variation for each watershed increases post-burn, the standard errors remains very similar (Fig. 5).

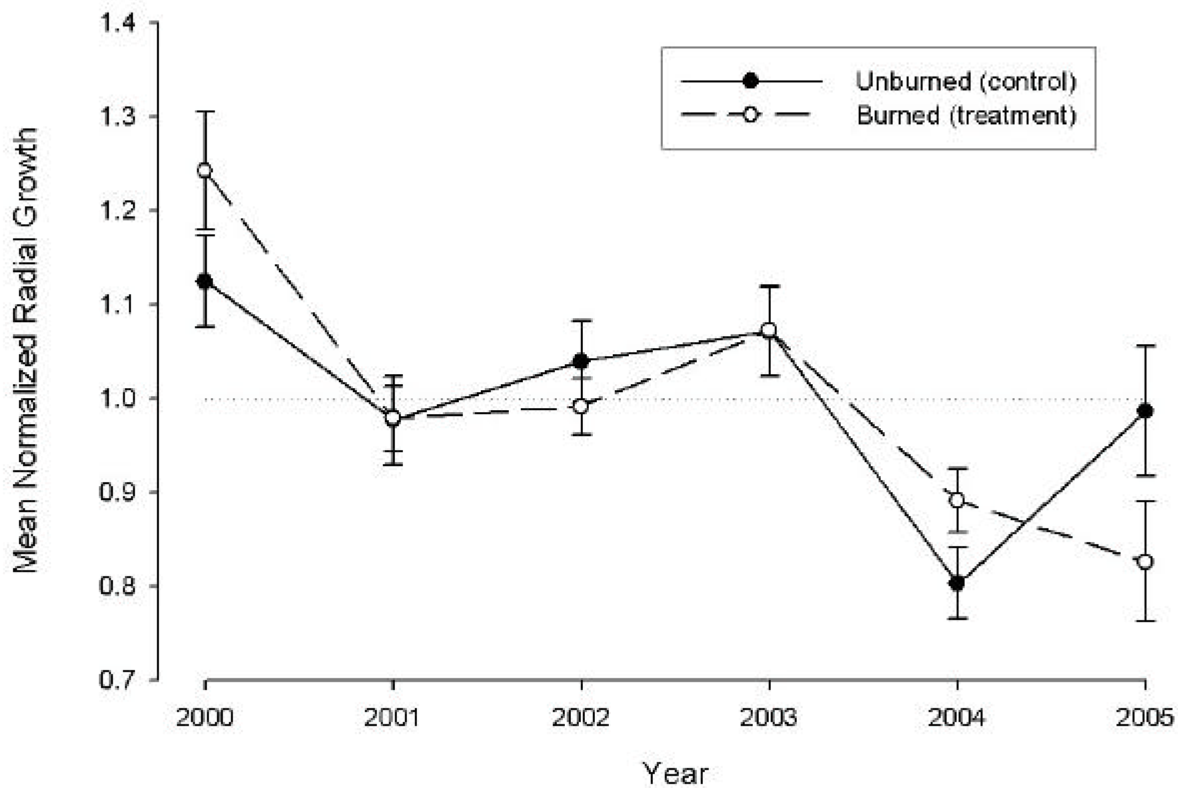


Figure 4. Time series showing the median growth rate of *P. sabiniana.* Dashed line indicates the time at which the treated watershed was burned. Rate the is diameter growth from winter to winter. Student's t-test strongly indicates that the burned watershed has a higher overall median rate of growth (p=0.0003). The error bars

I plotted the 2005 growth against the difference in fuels (2002 CWD – 2005 CWD, a higher difference would correspond to a more severe fire at that plot), which reveals a cloud of data points clustered around a fuel difference of 0 m^3/ha (Fig. 6). No trend is evidenced here, and any model has very poor fit. Of the few extreme fuel differences, their corresponding growth rates fall well withing the range of normalized growth of my sample. The treated watershed has the largest magnitude (both negative and positive) fuel differences.

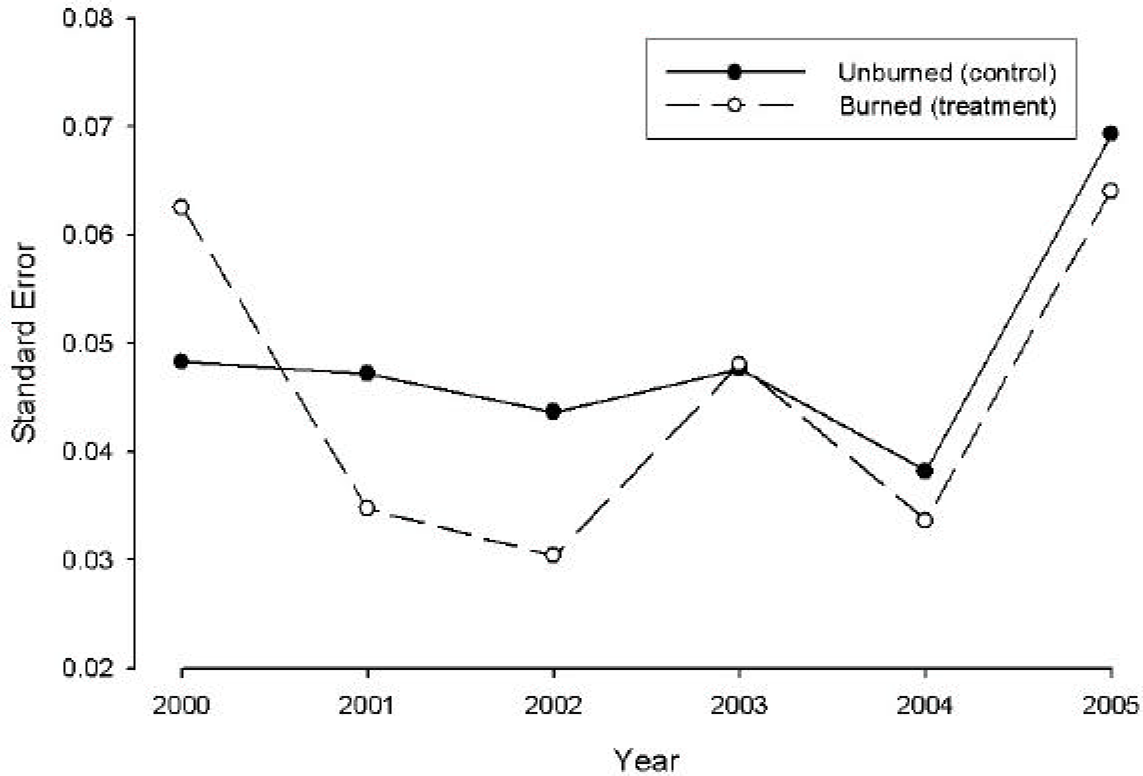


Figure 5. This plot shows the standard error of the mean normalized radial growth of pines by watershed. The variability become very similar in 2003, and remains so even after the prescribed burn. This indicates that the fire did not disproportionately affect the growth rates of trees in the treated watershed. The vertical dashed line marks

To examine how Brown fuel transects and woody debris transects are related, I plotted the Brown fuel estimates again the CWD estimates for each plot in the burned watershed (Fig. 7). The low levels of ground fuels in this savanna skews the data dramatically, but all of the large fuel estimates measured using the CWD protocol correspond to similarly large fuel estimates as measured by Brown fuel transects. A quadratic model fits the data well, with an R^2>0.975. Leverage analysis both with and without the most extreme data points suggest that a second-degree polynomial is the best fit.

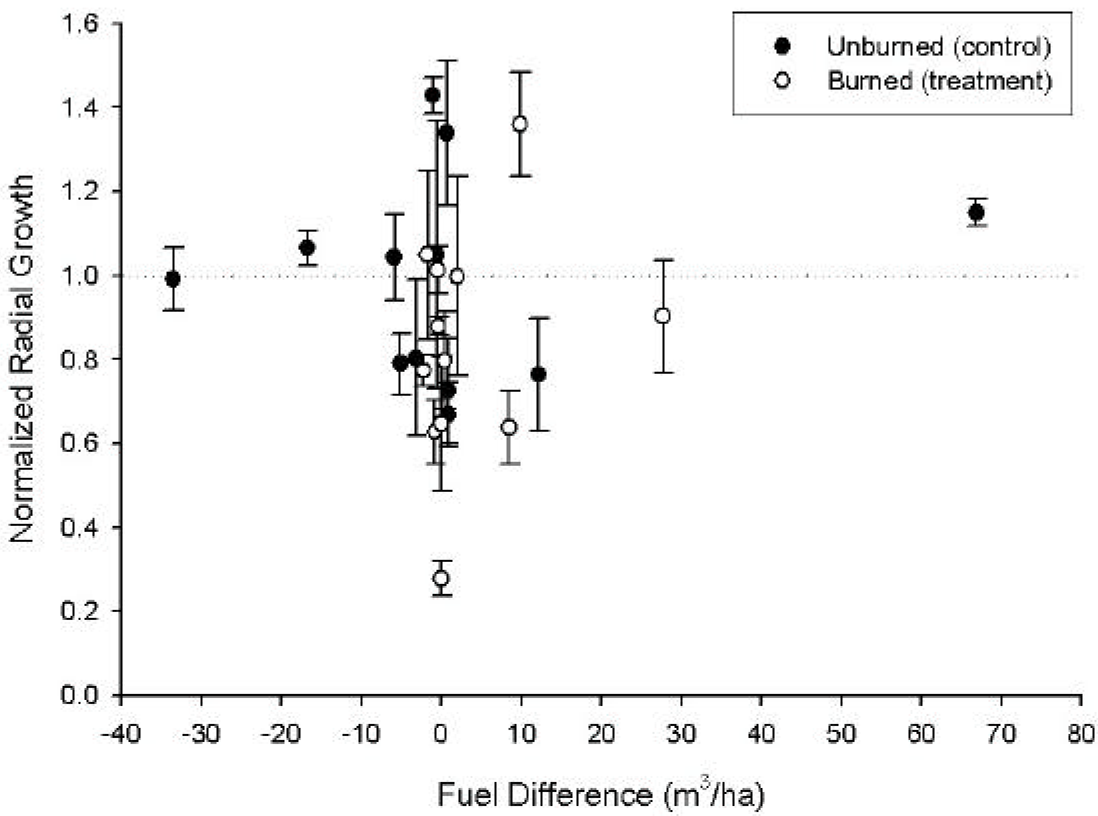


Figure 6. The mean of 2005 normalized radial growth of *P. sabiniana* by plot is graphed as a response of difference between woody debris sampled in 2002 and 2005. A large positive fuel difference suggests that the area was subject to a more intense fire. The cloud of data points indicates no real trend, and the number of negative fuel differences indicate the inability of woody debris to be used as a proxy for fire intensity. The vertical dashed band indicates a difference of zero, or no change in fuels between 2002 and 2005. The error bars represent the standard error of the sample (n = 3 for most points)

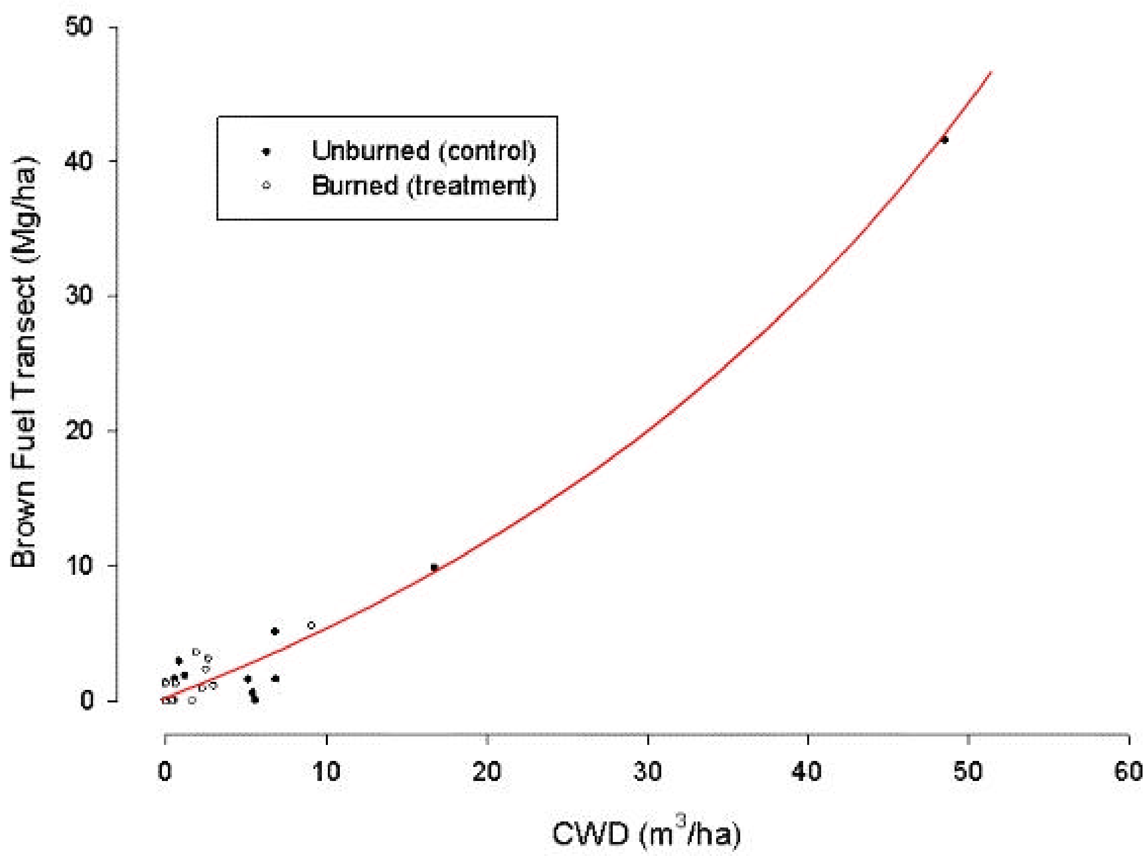


Figure 7. For each plot, the Woody Debris is plotted against the same plot's Brown Fuel measurement. The plotted quadratic function is $y = 0.426 + 0.406\,x + 0.011\,(x - 5.13)^2$ R2 = 0.976. Even in excluding the largest outlier, a quadratic function provides the best fit. There is no significant reason to suspect that the right most point is due to error, with this small of a sample size.

Discussion

The tracking between the two watersheds in the oak growth time series (Fig. 2) implies a similar response in the watersheds to the normal year to year variability, suggesting that the prescribed burn caused marked difference in direction of normalized growth in 2005. However, it is difficult to ascertain the true significance here, as the oak growth data extends back through the year 2002, which is not far enough to know if the oaks come from statistically identical populations. One of the other noticeable features of the oak growth time series is the large difference in variability (Fig. 3). This due to differences in sample size. Since I could only use oaks which were part of the Battles NPP study, I had different numbers of oaks in each watershed. The treated watershed only had 23 oaks, whereas the control watershed had 36 oak trees.

The time series for pine growth (Fig. 4) showed a significant difference between the normalized radial growth in 2005 (the single post-burn measurement). This is undoubtedly due to the prescribed burn, as the growth rates track closely and are statistically indistinguishable from each other. Thus, I can reject my hypothesis that I will see a positive impact on pines from fire, and accept the hypothesis that pine growth rates are affected negatively in the first year after the burn. This is an intuitive result, as the fire could have easily damaged trees' cambium, needles, or roots. I was also curious about what trees were most affected by fire. The variation in growth (Fig. 5) demonstrates that the treated and control watersheds experienced almost the identical changes in variation, meaning that the burn affected all trees in a similar way. Small or slow growing trees were not more susceptible to fire damage than the larger or faster growing trees. I attribute good growing conditions in 2005 to the general increased variation observed in both watersheds, because some trees were better suited to take advantage of plentiful (e.g. tall, healthy trees) resources while some are not (e.g. short, diseased trees).

I failed to find any meaningful link between tree growth rates and fuel differences. This is probably due to the small quantity of ground fuels in this savanna system. Additionally, CWD line-intersect sampling is a technique designed for assessing watershed wide biomass – not plot level ground fuels. Certainly there are some similarities, but the approach of using fuel consumption as a proxy for fire intensity requires a method with both sufficient ability to detect fuels which would be consumed by a prescribed burn, and the ability to minimized variation by casting a larger “sampling-net.” Could be reached through a variety of methods, and latter would require either a greater number of plots or a longer transects (effectively, larger plots). Another confounding factor is that the treated watershed had much less variation in ground fuels, probably due to the fire. The fire consumed much of the larger ground fuels, which take a longer time to accumulate than small fuels (twigs, small branches etc.). This effectively homogenized the ground fuel load and favored a lower variability in my sample. The control watershed had much more fuel on the ground – since my CWD method lacked the resolution to adequately represent the fuel loading of the watershed, occasionally the large fuels would be sampled and skew my data. I had intended for part of this study to examine if my methods of measuring downed biomass could be successfully used as a proxy for as the intensity for a fire which burned one year prior to the sampling. Although my results did not suggest that they could, it would be interesting to examine the conditions which would allow for successful implementation of Brown transects or CWD transects to estimate fire intensity.

The relationship between Brown transects as a function of CWD demonstrates that in this savanna, CWD has a greater resolution of small fuels than Brown fuel transects. For a particular range of fuel estimates from Brown transects, CWD has a *greater* range of estimates. Even at the largest fuel load I estimated, the curve has a slope of about 0.9, indicating that CWD estimates still have a greater precision than Brown fuel transects. The CWD protocol measures each individual piece over 1 cm in diameter over a longer transect than the Brown transects. It misses fuels smaller than 1 cm in diameter but it has little effect because these smaller pieces of debris are only a small proportion of the total fuel load. Brown fuel transects estimate fuels by size class, and cannot distinguish between a 3 cm and 7 cm diameter piece of debris.

Further study on these plots would elucidate the long-term growth trends of the trees in this savanna. After recovering from the effects of the fire, the trees in the treated watershed may be able to take advantage of the nutrients released into the soil by the fire, as I had hypothesized I would see in 2005. Again, I recommend continuing data collection on the growth rates of the pines at SFREC to determine if there is a delayed response.

My results provides information on the effects of fire on savanna systems, for possible use as a management tool or to better understand how natural fires would affect this continuous ecosystem – contributing to a greater body of knowledge used to make management and policy decisions for blue oak savanna systems. However, this study's design and intent was as a pilot study for further examination of the tree response to fire at this SFREC. It took advantage of existing data sets to reduce the field requirements. As such, the sample sizes are too small to detect differences, but it has led to a number of interesting questions which bear examining.

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