Shade informs the size and distribution of incense cedar (*Calocedrus decurrens*) in a fire-managed montane forest

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The biological diversity observed in forest ecosystems can be influenced by environmental factors. This diversity may be threatened by long term fire suppression which can result in dramatic shifts in forest composition. In an observational study following cedar recruitment, we found that cedar sapling abundance was the greatest under the shaded conditions of adult cedars in comparison to their oak and pine counterparts. Investigating landscape-scale impacts of environmental conditions resulting from continuous fire suppression allow us to predict how forest composition may change in the future. We advocate for more prescribed burns to prevent the loss of biodiversity in California’s montane forests.

*Keywords*: fire suppression, incense cedar (*Calocedrus decurrens*), southern California forest, San Jacinto Mountains

INTRODUCTION

Forest ecosystems are biologically diverse and exhibit complex trophic webs. Forests serve many purposes such as homes for organisms like insects, fungi and small mammals, and can also provide natural biological controls in order to combat pests and diseases. When a forest's diversity is compromised, its health can also be at risk. Tree diversity allows for more niche space and can enable the coexistence of more species that can potentially serve to maintain a healthy ecosystem (Ampoorter et al. 2020). Thus, the drastic changes such as a decrease in biodiversity are especially severe to forests due to the interconnectedness of the ecosystem.

The species composition of California’s forests has historically been regulated by intermittent fire produced either by lightning ignition or through prescribed burns from indigenous people prior to the 1800’s (Kimmerer & Lake 2001). Fires can increase biodiversity by eliminating competitors and creating new opportunities for organisms to access resources (Kelly & Brontons 2017). However, decades of fire suppression—land management practices that decrease the risk of fire—have drastically altered these processes.

Fire suppression is one example of modern human disturbance that is decreasing biodiversity in forests. Forests that were once regulated by fire cycles are now being shaped by competitive interactions between tree species (Bigelow et al. 2018). One study
showed that burned forest plots had more than twice as many native plant species than non-burned plots (ESA 2010).

Fire suppression leads to increased canopy cover and thicker litter layers—conditions that are favored by shade tolerant trees. Shade tolerant trees such as incense cedars (*Calocedrus decurrens*) can outcompete other species by germinating more frequently in darker areas (Parsons & DeBenedetti 1979). Incense cedars have already become more abundant in forest ecosystems as a result of long-term fire suppression (Collins et al. 2011). Negative ecological consequences may arise when a single tree species begins to dominate a formerly mixed forest community. For example, the behavior, abundance, and distribution of various species rely heavily on oaks so their replacement by shade tolerant species would leave lasting impacts on a large community of wildlife (Rodewald 2003).

Unlike other trees, incense cedar saplings have a distinctly higher tolerance for shade as well as resistance to fire and moist litter (Minore 1988). These factors combined, result in an ecosystem that will be resistant to fires, thus making it difficult for other tree species to emerge. Incense cedars can be a useful tree species to predict how forest composition may change in response to a lack of fire.

Our study explored the consequences of fire suppression on cedar saplings in the San Jacinto Mountains. The San Jacinto Mountains region now averages an additional 17–34 years between two consecutive fires due to fire suppression (Safford and Van de Water 2014). We noticed an abundance of juvenile cedar saplings in shady areas, under many species of trees but particularly under oak (*Quercus chrysolepis* and *Quercus kelloggii*) and adult incense cedar trees. We also noticed these cedar saplings were more abundant than any other tree sapling species. These observations lead us to ask what environmental factors influence cedar sapling size and distribution. Additionally, what microenvironmental factors (e.g., litter and duff) influence recruitment rate. Lastly, we wanted to know what adult trees provided optimal habitats for saplings.

We hypothesized that beneath cedar adult trees there would be higher recruitment rates of sapling cedars than any other tree species. Similarly, we predicted we’d see high numbers of pine and oak recruitment beneath their respective parent tree as well. We also hypothesized there would be an optimal litter and duff composition where germination would favor the growth of cedars. Lastly, we predicted under higher percent canopy coverage we would see greater densities of cedar saplings.

**METHODS**

*Field Sampling Procedure*

Our research was conducted at the James San Jacinto Mountains Reserve, in the San Jacinto mountains of Southern California, Riverside County (33.8081° N, 116.7769° W). The James Reserve is a montane forest that is home to a diverse range of evergreen and deciduous tree species, such as oak (*Quercus spp.*), pine (*Pinus spp.*) and cedars (*Calocedrus sp.*). Data was collected throughout the reserve from May 3–9, 2021. The reserve sits between 1,623 and 1,692 meters of elevation and receives about 660 cm of precipitation a year.
We randomly selected focal trees throughout the James Reserve trails and roadsides, with our replicate selection beginning 3 m away from road edges. In total we sampled 30 of each focal tree species, resulting in 90 replicates. We did not distinguish between different species of oak and pine trees. Instead, we used a single pine classification and a single oak classification. Within the “oak” group we sampled from canyon live oak (Quercus chrysolepis), and black oak (Quercus kelloggii). Within the “pine” group we sampled from Jeffrey pine (Pinus jefferi), sugar pine (Pinus lambertiana), coulter pine (Pinus coulteri), and ponderosa pine (Pinus ponderosa). Incense cedar (Calocedrus decurrens) was the only cedar species present.

After identifying our focal tree, we noted the species and measured the diameter at breast height (DBH). We took individual counts of all oak, pine, and cedar saplings within the three-meter radius space of the focal tree. We measured a maximum of 10 saplings of each tree type (oak, pine, cedar).

We recorded the stem diameter measurement for 10 saplings of each tree genus one cm above the base of each sapling. We considered any stem diameter measurement below 200 mm to be a sapling, and anything 200 mm and above was considered an adult tree. Saplings below one-mm in diameter were recorded as one-mm to account for their presence.

Lastly, canopy cover was measured in four cardinal directions (north, south, east, west) around the focal tree using the “Canopy Capture” mobile application (Copyright 2018; Nikhil Patel) (Fig. 1). The values were taken at waist height, pointing the phone in the direction of the focal tree. These four canopy cover values were averaged out to a single measurement of canopy cover.

![Canopy Capture Examples](https://example.com)

**Figure 1. Examples of the CanopyCapture app densiometer.** These are screenshots of the CanopyCapture application we used to measure the percent canopy coverage surrounding each focal tree. The algorithm accurately calculates the open areas as highlighted in red and gives an approximate percentage of canopy cover which we then averaged.

** Sapling Age Estimates **

To see if size and age of cedar saplings were related, we estimated the age of saplings beneath focal trees. We cut an additional subset of five cedar saplings from under each focal tree genus, oak, pine, and cedar, in total collecting 15 saplings. The subsampled saplings all had a diameter of 5 ± 1 mm. We cut each sapling at the base of the plant 1 cm above the litter layer. Next, we flattened and smoothed out the cut ends of each sapling using three grits of sandpaper from a coarse to a fine grit. After obtaining a smooth surface, we wet the end and counted the rings using a hand lens (Fig. 2).
Figure 2. Counting incense cedar sapling rings. Pictured on the left are the rings of a cedar sapling under the magnification of a hand lens. Trunks were wet then analyzed for age by counting rings. Pictured to the right are cedar saplings, each sampled from near one of the three focal trees we observed (pine, cedar, oak).

**Statistical Analyses**

Using JMP version 16.0.0 (SAS Institute, 2019), we conducted two linear regressions. The first linear regression tested the impacts of cedar density on average cedar diameter. An additional linear regression was conducted to test the impacts of canopy cover on average cedar diameter.

Additionally, we ran a one-way ANOVA to assess the impact of different focal tree species on sapling density. We also ran a one-way ANOVA looking at the impact of different focal tree species on their respective canopy coverage. Additionally, we employed a post-hoc Tukey-Kramer HSD to further assess differences among the impacts of the three focal species compared in our ANOVAs.

**RESULTS**

We observed substantially more cedar saplings than either oak or pine. Cedar saplings were larger in diameter when growing at lower densities (N = 30, R² = 0.0077, p = 0.021) (Fig. 3). Additionally, cedar saplings were bigger in diameter in areas where there was less canopy cover (N=30, R² = 0.1098, p= 0.0054) (Fig. 4). The density of cedar saplings was similar beneath both oaks and cedars but was substantially smaller under pines (cedar: n = 30, oak: n = 30, pine: n = 30, F = 6.1 p = 0.0038) (Fig. 5). Canopy cover was the highest in cedars and oaks, but varied significantly under oaks; pines had the lowest amount of shade compared to the other focal tree genera (cedar: n = 30, oak: n = 30, pine: n=30, F = 5.9, p = 0.0040) (Fig. 6). Furthermore, canopy cover did not affect cedar sapling density (N=30, R²=0.0045, p=0.5688).

Lastly, the 15 sub-sampled cedar saplings were between 9–12 years old. The average cedar sapling age under oak was 10.6 years old, average under pine was 12.0 years old, and average under cedar being 9.20 years old.

Figure 3. Cedar saplings are smaller on average in densely populated areas. As cedar sapling density increases, cedar sapling diameters decrease. (N = 30, R² = 0.0777, p = 0.0213).
DISCUSSION

Our results indicate that cedar distribution is informed by their shade tolerance. We saw that the highest densities of saplings were beneath the shadiest focal trees (Figs. 5 & 6). Patterns observed here based on the James Reserve are consistent with the known shade tolerance of incense cedar (Parsons & Debenedetti, 1979). Our research also provides an example of the law of constant final yield as we saw that in higher density patches of cedar saplings the average diameter of saplings was thinner (Weiner and Freckleton 2010) (Fig. 3).

The density of cedar saplings was very similar under both cedar and oak focal trees. This is a unique pattern and can be explained by the similar observed oak and cedar shade densities. However, we would like to further research this trend as we hypothesize the soil composition beneath oak trees may be providing a more neutral soil pH aiding in
germination and growth for cedars. Conifer litter is substantially more acidic than deciduous litter; even if cedars are adapted to germinate in acidic soil, they might be able to outcompete oak saplings in less acidic conditions (Burgess-Conforti, 2019). If this is the case, adult oak trees play a large role in cedar recruitment in these areas which could accelerate cedar population growth. Future studies should account for the effects of other factors such as tree pests and soil conditions. Investigating these additional factors would provide a more accurate representation of what is necessary to maintain the diversity of an ecosystem.

Another plausible explanation for the equal density of cedar saplings beneath both cedar and oak trees could lay within the Janzen-Connell hypothesis. The Janzen-Connell hypothesis states that, where seedlings are abundant, seed predation and density-dependent disease are the highest (Janzen 1970). Meaning that the cause for similar numbers of cedar saplings under oaks and cedars could be a result of sapling predation and disease. Oak trees might simply be far enough away from adult cedars to avoid these effects. Distance from parent tree may result in a “sweet spot” of cedar sapling survival under oaks.

Anecdotally, we observed fewer pine saplings overall, which may indicate pine trees are not faring as well on the James Reserve as the adult densities might predict. This is a concerning pattern, as it may be hinting toward reduced biodiversity in the San Jacinto Mountains in the future.

Moreover, without natural or prescribed burns restructuring the forest, we could see incense cedar outcompete and transform the composition of the James Reserve. The effects of fire suppression also are problematic as they can increase the magnitude of wildfires. In the short term, high cedar sapling abundance caused by fire suppression may add to the fuel load and increase the risk of fire (Parsons & DeBenedetti, 1979). On the other hand, a critical mass of shade tolerant trees produces a moist litter layer, potentially increasing the length of time between fires (Bigelow et al. 2017). The gradual accumulation of litter caused by long-term delays in a landscape’s natural fire regime might lead to catastrophically strong wildfires in the future. Most scholars have determined that occasional low intensity fires are beneficial for most forest systems, high intensity fires are not (Barton 2001, Richter et al. 2019). Additional management considerations practices should be taken knowing that shade tolerant trees disrupt fire cycles and can make forest fires more severe.

Knowing that the detrimental effects of incense cedar overabundance are rising due to fire suppression can help inform conservation and restoration work in the future. Moving forward, it is important to consider the ecological benefits that come with the occasional forest fire. Ecosystems like that at the James San Jacinto Mountains Reserve, considered to be a “jewel of biodiversity,” rely heavily on forest fires to maintain this level of diversity (James San Jacinto Mountains Reserve 2021). Ensuring routine fires would allow us to maintain habitats that are suitable for the growth and interaction of both plants and animals. Based on the findings of our study, we recommend implementing prescribed burns to reintroduce the beneficial effects of fire to the San Jacinto Mountains.
Prescribed burns would cull the saplings without adverse effects on the cedar population; adult incense cedars are fairly fire resistant and would not be harmed by low or moderate-intensity fires (Dunn & Bailey 2016).

Studying the historic fire patterns of places of a given landscape can be a good indicator for when we should consider prescribing fires. Reintroducing fire to California’s montane forests will ensure their biodiversity is maintained for years to come.

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