Communication

Giant Sequoia Reproduction in a Large High-severity Fire Patch, Sierra Nevada, California, USA

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**Abstract:** The giant sequoia (*Sequoiadendron giganteum*), naturally occurring in mixed-conifer forests of the southern and central Sierra Nevada mountains of California, USA, is the world’s largest species of tree. Giant sequoia reproduction has been severely lacking over the past century, due to fire exclusion in the sequoia groves, creating a significant threat to the conservation of this endangered tree species. This species has a well-documented relationship with mixed-severity fire, and tends to reproduce most abundantly in mixed/high-severity fire patches. However, giant sequoia reproduction in large high-severity fire patches has not been previously studied. I conducted a preliminary investigation of giant sequoia reproduction in a large high-severity fire patch, and nearby low/mixed-severity fire areas, in the Nelder Grove, which burned in 2017 in the Railroad fire. I found that giant sequoia reproduction was higher, more dominant, and growing faster in the large high-severity fire patch than in the low/mixed-severity fire areas, and that sequoia seedling/sapling density was positively correlated with percent shrub cover. These findings are good news for giant sequoias, particularly after some mature sequoias were killed in recent large fires. More research is needed in other large high-severity fire patches to determine whether a similar reproduction response occurs elsewhere.

**Keywords:** giant sequoia; wildfire; high-severity; Sierra Nevada; forests

1. Introduction

The giant sequoia (*Sequoiadendron giganteum*) is the largest tree species on the planet, and it is also one of the rarest. Listed as an endangered species by the IUCN, only about 70 naturally-occurring giant sequoia groves remain (the number varies somewhat depending on the methods used to define groves by various agencies and entities). These groves span a total cumulative area of only 11,724 ha, on the western slope of the southern and central Sierra Nevada mountains, in California, USA, according to a recent U.S. government estimate, nearly all of which occurs on U.S. national forests and U.S. national parks [1].

The conservation of giant sequoias is closely linked to wildland fire. It has long been recognized that giant sequoia reproduction benefits from wildfires, which facilitate release of seeds from cones, turn thick duff and litter on the forest floor into a nutrient-rich bed of mineral, and increase seedling access to sunlight by killing some portion of the canopy trees [2-3]. Indeed, a primary conservation threat to this species has been a “massive failure of sequoia reproduction in groves protected from fire” over the past century due to fire suppression policies [3].

Mixed-severity and smaller high-severity fire patches, in particular, create good conditions for giant sequoia reproduction, as sequoias regenerate more abundantly, and grow more rapidly, in such areas, while low-severity fire results in very sparse levels of reproduction that may not be significantly different from unburned conditions [3-4]. While giant sequoia reproduction has been reported to be high in smaller high-severity fire patches [3], up to 20 ha in size [4], there is a lack of research on reproduction in larger high-severity fire patches.

In the context of this gap in knowledge, U.S. land management agencies hypothesize that larger high-severity fire patches represent a significant conservation threat to giant sequoias, given the potential for such patches to kill mature sequoias and the unknown capacity for this species to reproduce within large high-severity fire patches, where live tree seed sources are far away [5]. Based on this hypothesis, the U.S. Forest Service, which oversees the management of approximately half of all extant giant sequoia groves [5], currently emphasizes continued aggressive wildfire suppression, low-severity prescribed fires, and commercial timber sales conducted under the rubric of fuel reduction and restoration, either as forest thinning and group selection, or post-fire logging operations [5].

Despite evidence indicating poor giant sequoia reproduction in low-severity fire areas and logged forests [4,6], growing evidence suggesting questionable efficacy of fuel-reduction logging as a fire management strategy [7-9], and the well-documented conservation threat to giant sequoia persistence from fire suppression [3], this management approach nevertheless persists in the face of uncertainty regarding the relationship between giant sequoias and large high-severity fire patches.

I conducted a preliminary analysis regarding giant sequoia reproduction in a large high-severity fire patch, and nearby low/mixed-severity fire areas, within the 5,023-ha Railroad fire of 2017 in the Nelder Grove of giant sequoias on Sierra National Forest, south of Yosemite National Park. I hypothesized that giant sequoia post-fire reproduction in the large high-severity fire patch would follow the same pattern previously documented for smaller high-severity fire patches. Specifically, I hypothesized that giant sequoia reproduction in the large high-severity fire patch would be more abundant, would comprise a larger proportion of total post-fire conifer regeneration, and would be taller than in the low/mixed-severity fire area. I also investigated whether any correlation exists between percent shrub cover and giant sequoia reproduction.

2. Materials and Methods

I surveyed the portions of the Nelder Grove that burned in the 2017 Railroad fire. This area, ranging from 1495 to 1575 m in elevation, is comprised of mixed-conifer forests dominated by ponderosa pine (*Pinus ponderosa*), sugar pine (*P. lambertiana*), white fir (*Abies concolor*), incense-cedar (*Calocedrus decurrens*), giant sequoia (*Sequoiadendron giganteum*) in certain locations, and California black oak (*Quercus kelloggii*), with shrubs mainly consisting of mountain whitethorn (*Ceanothus cordulatus*), deer brush (*C. integerrimus*), and greenleaf manzanita (*Arctostaphylos patula*).

The fire-affected areas in the Nelder Grove were not planted with sequoia or other tree seedlings following the fire, so all conifer reproduction was natural. I gathered data at plot locations on a grid with plot center points spaced 100 m apart in both the low/mixed-severity fire area and the large (~470 ha) high-severity fire patch (Figure 1). In both of these fire-severity conditions, I located the first plot at the base of the giant sequoia (live or dead) closest to the access road, orienting the grid to include the most plots without going beyond the fire boundaries and without locating plot center points >50 m from the nearest giant sequoia (live or dead). In one giant sequoia clump, within the low/mixed-severity area, this yielded only one plot, given the lack of other nearby sequoias, while it yielded multiple plots in another portion of the low/mixed-severity area and the large high-severity fire patch. In the low/mixed-severity area, I oriented the grid NE/SW, while in the large high-severity fire patch I oriented the grid N/S (Fig. 1). Each plot had a 10-m radius. I measured all distances with a laser hypsometer.



**Figure 1.** The Nelder Grove study area within the Railroad fire of 2017.

Within each plot, in July of 2021 (approximately four years post-fire), I recorded the distance (m) and height (m) of the closest post-fire regenerating giant sequoia and non-sequoia conifer seedling/sapling to the plot center. I converted this distance into stems/ha for the closest sequoia and non-sequoia conifer seedling/sapling, respectively, in each plot by treating the distance as a radius and determining the area. For instance, if the closest sequoia seedling/sapling was two meters from the plot center, the area would be pi times the radius (two meters) squared = 12.56 m2, and the density would be one seedling/sapling per 12.6 m2, or 796/ha. If there were no sequoia or non-sequoia conifer seedlings/saplings in the plot, I recorded the stems/ha as zero for that category in that plot.

Next, I recorded all sequoia and non-sequoia conifers, live and fire-killed, in the following diameter-at-breast height size classes: 25-50 cm; 51-100 cm; and 101-200 cm. I calculated the basal area, live and fire-killed, of sequoias and non-sequoia conifers by using the mid-point of each diameter category.

I also recorded percent shrub cover in each plot, in the following categories: <25%, 25-50%, 51-75%, and >75%.

I determined whether giant sequoia seedling/sapling density (stems/ha) was higher in the large high-severity fire patch compared to the low/mixed-severity areas using a Mann-Whitney test [10] (one-tailed test). I also used a Mann-Whitney test to determine whether the proportion of total post-fire conifer regeneration that is comprised by giant sequoias (sequoia seedling/sapling stems/ha divided by total conifer seedling/sapling stems/ha) was higher in the large high-severity fire patch than in the low/mixed-severity areas (one-tailed). Next, I used a Spearman’s rank correlation test [11-12] to determine whether giant sequoia seedlings/saplings were taller in plots with higher conifer basal area mortality from the Railroad fire (one-tailed). Last, I used a Spearman’s rank correlation test to determine whether there was any correlation between giant sequoia seedling/sapling density and percent shrub cover, using the mid-point of the percent shrub cover categories. For this last analysis, there was no basis in the existing scientific literature to predict how or whether shrub cover would influence giant sequoia reproduction, so I used a two-tailed test for this analysis.

3. Results

Giant sequoia reproduction was significantly higher in the large high-severity fire patch than in the low/mixed-severity fire areas in the Railroad fire (U = 44.5, P = 0.006, Table 1). Similarly, in the large high-severity fire patch, giant sequoias comprised a significantly higher percentage of the total post-fire conifer regeneration than in the low/mixed-severity areas (U = 49, P < 0.001, Table 2).

Post-fire naturally regenerating sequoia seedlings/saplings were also significantly taller in plots with higher levels of basal area mortality from fire (rs = 0.623, P = 0.270, Table 3), and sequoia reproduction was higher in plots with higher percent shrub cover (rs = 0.836, P < 0.001, Table 4).

**Table 1.** Giant sequoia reproduction density (stems/ha of seedlings/saplings) in plots within the large high-severity fire patch (Large HS) versus the low/mixed-severity (L/M) fire areas.

|  |  |  |
| --- | --- | --- |
|  **Large HS** | **L/M** | **Large HS Ranks1 L/M Ranks2** |
|  796  | 199 |  1.5 4.5 |
|  3185  | 0 |  1.5 8.0 |
|  796  | 796  |  4.5 10.0 |
|  354  | 354 |  4.5 12.5 |
|  354  | 0  |  4.5 12.5 |
|  3185  | 0 |  8.0 12.5 |
|  796 | 0 |  8.0 12.5 |

 1 R1 = 32.5

 2 R2 = 72.5

**Table 2.** The percentage of total post-fire conifer regeneration comprised by giant sequoias in the large high-severity fire patch (Large HS) versus the low/mixed-severity (L/M) fire areas.

|  |  |  |
| --- | --- | --- |
|  **Large HS** | **L/M** | **Large HS Ranks1 L/M Ranks2** |
|  100  | 3 |  2.5 8.0 |
|  100  | 0 |  2.5 9.0 |
|  69  | 20  |  2.5 10.0 |
|  100  | 10 |  2.5 12.5 |
|  74  | 0  |  5.0 12.5 |
|  99  | 0 |  6.0 12.5 |
|  100 | 0 |  7.0 12.5 |

 1 R1 = 28.0

 2 R2 = 77.0

**Table 3.** Giant sequoia seedling/sapling height (m) and percent conifer basal area (BA) mortality from fire.

|  |  |  |
| --- | --- | --- |
|  **Height** |  |  **% BA Mortality**  |
|  0.2  |  |  13  |
|  0.2 |  |  36  |
|  0.2 |   |  100  |
|  0.5 |  |  87  |
|  0.5 |  |  100  |
|  0.5 |  |  100  |
|  1.0 |  |  100  |
|  1.0 |  |  100 |
|  1.5 |  |  100 |
|  1.5 |  |  100 |

**Table 4.** Giant sequoia seedling/sapling density (stems/ha) and percent shrub cover.

|  |  |  |
| --- | --- | --- |
|  **Density** |  |  **% Shrub Cover**  |
|  0  |  |  13  |
|  0 |  |  13  |
|  0 |   |  13  |
|  0 |  |  13  |
|  199 |  |  13  |
|  354 |  |  13  |
|  354 |  |  38  |
|  354 |  |  88 |
|  796 |  |  38 |
|  796 |  |  38 |
|  796 |  |  63 |
|  796 |  |  88 |
|  3185 |  |  88 |
|  3185 |  |  88 |

4. Discussion

In the Railroad fire of 2017, giant sequoia reproduction in the Nelder Grove followed a similar pattern to that described previously for much smaller high-severity fire patches [3-4]. Giant sequoia reproduction was more abundant and more dominant (relative to other conifers), and was growing faster, in the large high-severity fire patch than in the low/mixed-severity fire areas.

The height of giant sequoia seedlings and saplings varied widely, ranging from 0.2 m to 1.5 m, even within the large high-severity fire patch. This indicates that new sequoia reproduction occurred in successive years after the Railroad fire, consistent with the findings of Meyer and Safford (2011) [4] in a 20-ha high-severity fire patch. That giant sequoias undergo post-fire regeneration in stages, over the course of years after a high-severity fire, is important to note. Areas that have little or no sequoia reproduction at one year post-fire may nevertheless have substantial reproduction in later years.

Results here are preliminary. Giant sequoia reproduction has not previously been investigated in a large high-severity fire patch. More research is needed in other large high-severity fire patches, in other fires, including the 70,487-ha Castle lightning fire of 2020 and the 35,752-ha KNP Complex lightning fire of 2021, both of which swept through multiple sequoia groves. Moreover, while my plots were quite large relative to most post-fire conifer regeneration research (e.g., [13-14]), the areas of the Nelder Grove that were occupied by giant sequoias, and which burned in the Railroad fire, were spatially limited and my sample sizes were small in both the large high-severity fire patch and the low/mixed-severity fire areas. Further, the result regarding percent shrub cover is unexpected, and more research is needed to determine the extent to which sequoia reproduction is most abundant with high shrub cover in other giant sequoia groves with recent high-severity fire.

Multiple lines of evidence from different sources document the occurrence of large high-severity fire patches historically, before fire suppression, in mixed-conifer forests of the Sierra Nevada, including patches hundreds, and sometimes thousands, of hectares in size [15-16]. It is beyond the scope of this analysis to investigate whether, or to what extent, large high-severity fire patches may have occasionally occurred historically in giant sequoia groves, but this will be a key question to address in future research. It is worth noting that giant sequoias defined as “mature”—those larger than 107 cm in diameter [1-2]—are often somewhat younger than commonly believed, based on available data on size class distribution [17] and documented growth rates. A portion of the extant mature giant sequoias are, of course, ancient monarchs of such a size that they are likely to be one or two millennia old [17-18]. Most mature sequoias are much younger [17-18]. While it can take approximately 200-250 years for giant sequoias to reach the 107-cm diameter size threshold [2,18] considered to be “mature” [1-2], giant sequoias can reach this size in less than a century [19-20], and sequoias >250 cm in diameter can be as young as 200 years old in good growing conditions [20].

Similar to recent results regarding natural regeneration of coast redwoods (*Sequoia sempervirens*) in high-severity fire patches [21], the results here are encouraging for the conservation of giant sequoias. Though approximately three dozen mature sequoias were killed in the Railroad fire [1], there are now thousands of young giant sequoias that are rapidly growing in the post-fire landscape, especially in the high-severity fire area, even a few hundred meters from the nearest live-tree edge, broadly consistent with findings for some other western North American conifer species [22-23]. Though my results are preliminary, and though a portion of mature giant sequoias have been killed in recent large fires [1], my findings are nevertheless good news for an endangered species that has been experiencing a “massive failure” of reproduction for a century, due to wildfire exclusion [3].

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**Data Availability Statement:** All data are reported herein.

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