Preliminary estimates of sequoia mortality in the 2020 Castle Fire

Authors: Nathan Stephenson[1], Christy Brigham[2]

[1] U.S. Geological Survey, Western Ecological Research Center
[2] National Park Service, Sequoia and Kings Canyon National Parks

Contributors (in alphabetical order):

Sue Cag, Conservationist
Anthony Caprio, National Park Service, Sequoia and Kings Canyon National Parks
Joshua Flickinger, National Park Service, Sequoia and Kings Canyon National Parks
Linnea Hardlund, Save the Redwoods League
Rodney Hart, U.S. Forest Service, Region 5 Remote Sensing Lab
Paul Hardwick, National Park Service, Sequoia and Kings Canyon National Parks
Linda Mutch, National Park Service, Sierra Nevada Inventory and Monitoring Network
Kristen Shive, The Nature Conservancy
Amarina Wuenschel, U.S. Forest Service, Southern Sierra Province

SUMMARY

Although some of California's giant sequoia trees have stood for thousands of years and are adapted to withstand frequent low and mixed severity fires (Stephenson 1996), preliminary estimates suggest that the 2020 Castle Fire killed between 31% to 42% of large sequoias within the Castle Fire footprint, or 10% to 14% of all large sequoias across the tree's natural range in the Sierra Nevada. This translates to an estimated loss of 7,500 to 10,600 large sequoias (those with trunk diameters of 4 ft or more). These estimates may change as new data are collected.

BACKGROUND AND NEED

A substantial proportion of all sequoia groves burned with unprecedented severity in the 2020 Castle wildfire, resulting in the deaths of many sequoias of all sizes. It will likely take years to thoroughly quantify the effects. In the interim, credible initial estimates of the fire's effects on sequoias are needed to report to managers and the public and to inform management priorities. This document aims to provide such estimates.

METHODS SUMMARY

(1) Using a satellite-derived fire severity index, estimate grove area that burned at different severities in the Castle Fire, as a proportion of all grove area in the Sierra Nevada.
(2) Explore the relationship between proportions of grove *area* that burned at different severities and proportions of *large sequoias* that burned at those severities.
(3) Using survey data from the Castle Fire and two earlier fires, estimate the proportions of large sequoias within the Castle Fire that were killed in each fire severity class.
(4) Combining the results of Step 1 and Step 3, estimate the proportions of all large sequoias *in the Sierra Nevada* that were killed in the Castle Fire.
(5) From the results of Step 4 and additional data sources, estimate total *numbers* of large sequoias that were killed in the Castle Fire.

We conclude with a brief discussion of why our current estimates differ from previous estimates.

GENERAL DATA SOURCES

Grove boundary maps. Given the low accuracy of previous grove boundary maps, Rodney Hart (GIS Remote Sensing Analyst, USFS Region 5 Remote Sensing Lab) completed an initial remapping of all the natural sequoia groves in the Sierra Nevada to a common standard (see Appendix 1). For all analyses presented here, we use the 16 April 2021 version of the grove maps. **The initial remapping showed that total grove area in the Sierra Nevada = ~28,958 acres (a number that will likely change somewhat as the maps are refined and ground-truthed).** For reasons given in Appendix 1, this is substantially less than the 47,129 acres shown in an older, widely used map layer (https://irma.nps.gov/DataStore/Reference/Profile/2259632). Confirming the importance of accurate maps, we found that calculated percentage of grove area that burned at high severity was *less* using the new grove maps than using the old maps, probably because the old maps included areas of drier, non-sequoia forest types that were more susceptible to severe fire.

Fire severity maps. **Spatially explicit Castle Fire severity was estimated using the satellite-derived RAVG CBI4 composite burn index** (RAVG website), from Landsat prefire imagery acquired on August 9, 2020 and postfire imagery acquired on October 10, 2020. These data provide an initial, un-ground-truthed fire severity estimate; more refined estimates typically become available from other sources more than one year post-fire.

Sizes of sequoias analyzed. We limited our analyses to large (mature) sequoias. Following Harvey et al. (1980, pp.47-48), **we defined large (mature) sequoias as those with trunk diameters of 4 ft or more.** Harvey et al.'s analyses of mature sequoia densities were based on Sequoia and Kings Canyon national parks' (SEKI) Sequoia Tree Inventory (STI, described below), which rounded trunk diameters to the nearest foot. Harvey et al.'s 4 ft or larger definition thus included all sequoias >3.5 ft (>1.07 m). The same will hold for our analyses (below) that use the STI data, but not for other data sources.

Sequoia Tree Inventory (STI) data. Many grove areas of the Sierra Nevada – and most areas that burned in the Castle Fire – did not have complete inventories of their large sequoias. Yet for some calculations we require estimates of typical grove conditions, such as typical densities of large sequoias. For such calculations we used the Sequoia Tree Inventory (STI) that was conducted in SEKI in the 1960s and 1970s. **The STI inventoried and mapped all sequoias in 9,651.64 acres within SEKI – representing 33.33% of all grove area in the Sierra Nevada – and recorded 25,181 large sequoias (4 ft or more in diameter)**. (*NOTE*: Although SEKI currently has 10,769.93 acres of sequoia groves – or about 37.2% of all grove area in the Sierra Nevada – SEKI's STI encompassed only ~90% of that, largely because grove area has been added to the parks since the STI was completed [Dillonwood Grove, and parts of East Fork, Atwell, and Squirrel Creek groves], and some small grove areas were missed in the original STI [e.g., Douglass and Forgotten groves, and parts of Surprise Grove and a few other groves].)

(1) ESTIMATING GROVE AREA THAT BURNED AT DIFFERENT SEVERITIES

Using Hart's new grove maps and the CBI4 severity data for the Castle Fire, Josh Flickinger (Cartographic Technician, SEKI) calculated that, of the 9,531.12 total grove acres within the Castle Fire perimeter, about half (49.72%) burned at low severity or had no detectable change, and about half (50.28%) burned at moderate or high severity. Nearly 30% (29.48%) of grove area within the Castle fire burned at high severity. Flickinger's severity map is shown in Fig. 1.

***For the Sierra Nevada as a whole*, an estimated 32.91% of all grove area burned in the Castle Fire, and an estimated 9.70% of all grove area burned at high severity.**

Relevant estimates are given in Table 1.

Table 1. Grove areas burned at different severities in the Castle Fire.

CBI4 severity class	Grove area (acres) that burned in the Castle Fire	Percentage of Castle Fire grove area	Percentage of all the natural grove area in the Sierra Nevada
High	2,810.23	29.48%	9.70%
Moderate	1,982.46	20.80%	6.85%
Low	3,840.83	40.30%	13.26%
No change detected	897.60	9.42%	3.10%
TOTAL	**9,531.12**	**100%**	**32.91%**

NOTE: Total grove acres from this table will not precisely conform to total grove acres from the new grove maps by Hart, because the somewhat coarse 30 m x 30 m resolution of the CBI4 data did not align perfectly with the fine-resolution edges of the grove boundary maps.

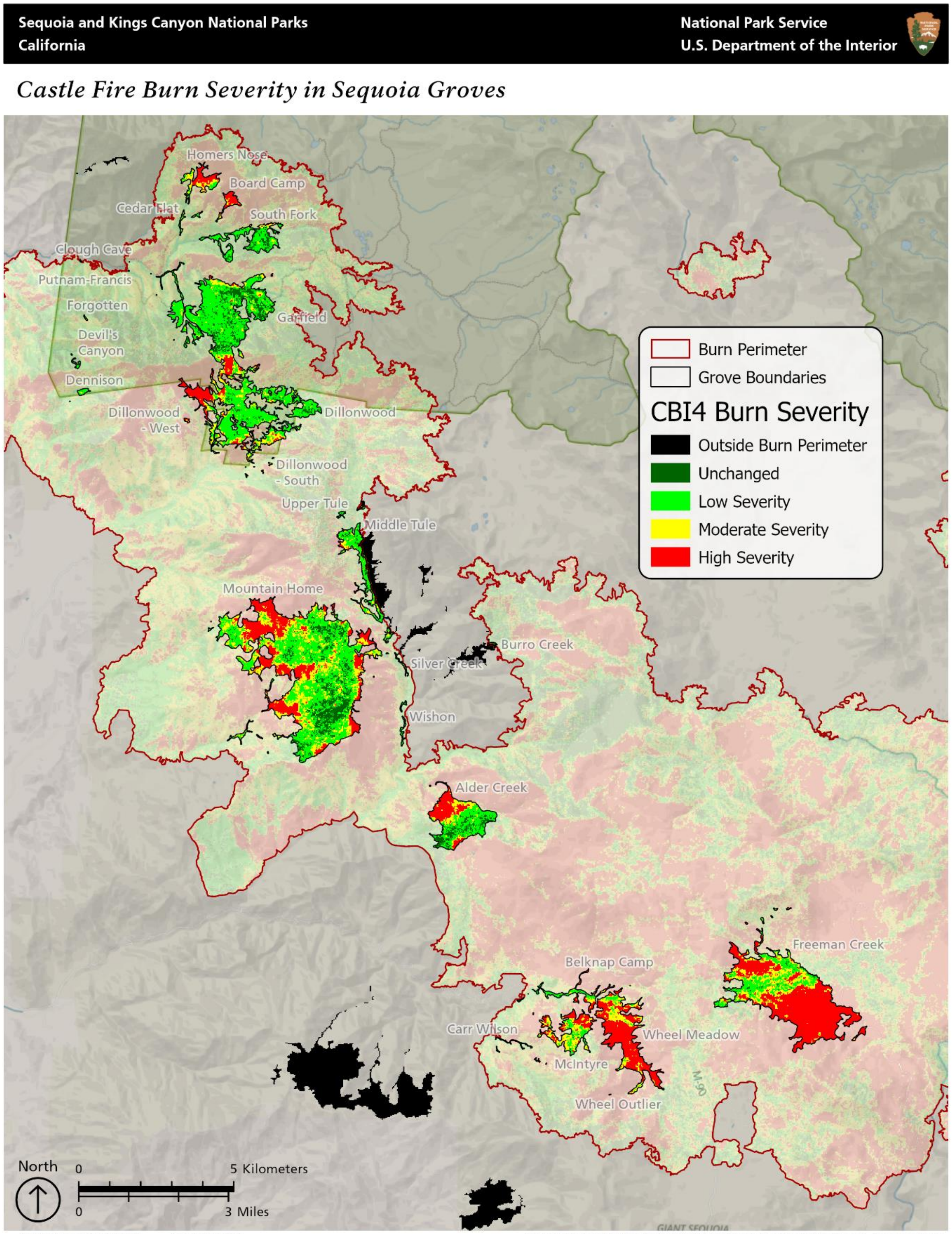

Fig. 1. Castle Fire RAVG CBI4 burn severity in sequoia groves, based on Rodney Hart's (USFS) revised grove boundaries. Lighter shading indicates Castle Fire burn severity outside of the sequoia groves. Map by Josh Flickinger, NPS.

(2) EXPLORING SOURCES OF UNCERTAINTY IN THE RELATIONSHIP BETWEEN PROPORTIONS OF GROVE *AREA* THAT BURNED AT DIFFERENT SEVERITIES, AND PROPORTIONS OF *LARGE SEQUOIAS* THAT BURNED AT THOSE SEVERITIES

Subsequent steps in our calculations will require us to convert the proportions of area that burned at different severities to the proportions of large sequoias that burned at those different severities. By far the simplest approach is to simply assume that the correspondence is exactly one to one. For example, because 9.70% of all grove area in the Sierra Nevada burned at high severity, we could assume that 9.70% of all large sequoias in the Sierra Nevada also burned at high severity. However, we wished to explore uncertainties in this assumption at two scales: within the Castle Fire, and across the Sierra Nevada.

Detailed assessments are presented in Appendix 2. Below, we briefly summarize our assessments and conclusions. **Given the lack of consistent evidence to the contrary, we assume a one-to-one relationship between proportion of area that burned at a given severity and the proportion of large sequoias that burned at that severity**. As more and better data become available in the future, this assumption can be revisited.

Within the Castle Fire, were "random" fine-scale variations in sequoia density likely to affect broad-scale conclusions? Densities of large sequoias can vary substantially at fine spatial scales (e.g., <100 acres). However, our simple analyses of the STI data (Appendix 2) suggest that the cumulative grove areas within the various Castle Fire burn severity classes – ranging from ~900 acres ("no change detected" class) to ~3,880 acres ("low severity" class) – are large enough that we can assume that, all else being equal, effects of "random" fine-scale variations in sequoia density were probably small, especially relative to other sources of uncertainty. We thus did not explicitly consider this source of uncertainty in our calculations.

Within the Castle Fire, did fire severity vary systematically with sequoia densities? If the Castle Fire burned most severely in areas of low sequoia density (perhaps because those areas were drier, or had more drought-killed pines and firs), the proportion of grove area that burned at high severity would *overestimate* the proportion of the population of large sequoias that burned at high severity. Conversely, if the fire burned most severely in areas of high sequoia density (perhaps because denser forest was more prone to crown fire), the proportion of grove area that burned at high severity would *underestimate* the proportion of the population of large sequoias that burned at high severity. In either case, we would need to account for the differences in our estimates of proportions of all sequoias killed. However, our analyses of three relatively large data sets (spanning 561 to 1780 acres, and 526 to 4241 sequoias) suggest that there was no large, consistent difference between proportions of area burned at the different severities and proportions of sequoias that burned at those severities (Appendix 2). We thus made no adjustments.

Were sequoia populations in the Castle Fire growing in environmentally similar conditions to sequoia populations elsewhere in the Sierra Nevada? If the groves that burned in the Castle Fire grew in areas that were, on average, environmentally dissimilar to other groves, their densities of large sequoias could conceivably differ systematically from those of other groves. If this were the case, adjustments would need to be made when estimating Castle Fire sequoia deaths as a proportion of all sequoias in the Sierra Nevada. However, we conclude that we have no *a priori* reason to believe that Castle Fire groves had meaningful, environmentally induced differences in densities of large sequoias (Appendix 2), and thus made no adjustments.

How might the effects of past sequoia logging influence range-wide estimates? By one estimate, giant sequoias were logged in about 23% of all grove area in the Sierra Nevada, mostly between 1880 and 1920 (Stephenson 1996). Based on data described in Appendix 2, we conclude that the rapid growth of young sequoias that became established after logging likely means that many logged areas currently have *greater* densities of large sequoias (four or more feet in diameter) than unlogged old-growth areas. (However, the same cannot be said for "monarch" sequoias >10 ft diameter, which almost certainly still have greatly reduced densities in logged areas.) Of course, for various reasons it also remains possible that some other logged groves in the Sierra Nevada currently have lower densities of large sequoias than unlogged areas. Ultimately, our poor understanding of the range of conditions in logged areas, and our lack of accurate maps of logged areas both inside and outside of the Castle Fire, mean we currently cannot systematically estimate possible effects of logged areas on our conclusions. This issue warrants future research.

(3) ESTIMATING PROPORTIONS OF LARGE SEQUOIAS WITHIN THE CASTLE FIRE THAT WERE KILLED IN EACH SEVERITY CLASS

Although future field research will greatly enhance available data, only a few data sets are currently available that allow us to determine proportions of sequoias killed within each of the satellite-derived fire severity classes (i.e., data sets with counts of sequoias that survived and that died within each CBI4 severity class within a given area). Because only two data sets are available from the Castle Fire itself, we additionally analyze one data set each from the 2017 Railroad Fire (Nelder Grove) and a portion of the 2017 Pier Fire (Black Mountain Grove). Collectively, the four data sets include >1000 individual sequoias. Data sources, analysis of individual datasets, and discussions of them are provided area by area below.

Separately for each data set, we calculate the proportions of sequoias killed within each severity class. We then average the proportions across the data sets.

Alder Creek Grove, 2020 Castle Fire, <1 year post-fire:

Sue Cag (conservationist residing in the Alder Creek Grove) completed a post-Castle Fire census of all sequoias about 6 ft or more in diameter within the Alder Creek Grove (the data we use here are dated 1 May 2021; Cag, written communication). In addition to classifying sequoias as clearly alive or clearly dead, Cag classified some as "heavily damaged," suggesting that at least some of those were unlikely to survive, or may already be dead. Cag recorded locations of each sequoia with a GPS unit, and Josh Flickinger (SEKI) classified each of Cag's trees according to its CBI4 fire severity class (Table 2).

Table 2. Alder Creek Grove sequoia mortality and survival <1 yr post-fire by CBI4 fire severity.

Post-fire status, sequoias >~6 ft diam.	High severity	Moderate severity	Low severity	No change detected	TOTAL
Dead, % (number)	97.30% (144)	55.06% (49)	3.48% (7)	0% (0)	38.02% (200)
Severely damaged, % (number)	2.70% (4)	22.47% (20)	10.45% (21)	4.55% (4)	9.32% (49)
Alive, % (number)	0% (0)	22.47% (20)	86.07% (173)	95.45% (84)	52.66% (277)
TOTAL	100% (148)	100% (89)	100% (201)	100% (88)	100% (526)

Sequoia National Park groves, 2020 Castle Fire, <1 year post-fire:

Tony Caprio (Fire Ecologist, SEKI) used a combination of post-fire drone imagery, photos from a November 2020 helicopter flyover, and previously georectified giant sequoia stem maps (the STI) to show that CBI4 values of 4 (high severity) appeared to correspond with ~100% mortality of sequoias 4 ft or more in diameter within several grove areas in Sequoia National Park that burned in the Castle Fire (Caprio, written communication). (NOTE: This assessment might change when crews are finally able to examine the sequoias from the ground.) Although available imagery did not allow Caprio to assess the status of each of the 369 large sequoias that the STI indicated were within high-severity areas, he was able to assess a large proportion of them (e.g., Fig. 2). Caprio found it more difficult to determine sequoia status (alive or dead) from aerial images within areas that burned at moderate or lower severities; hence, no status data are currently available for those severities.

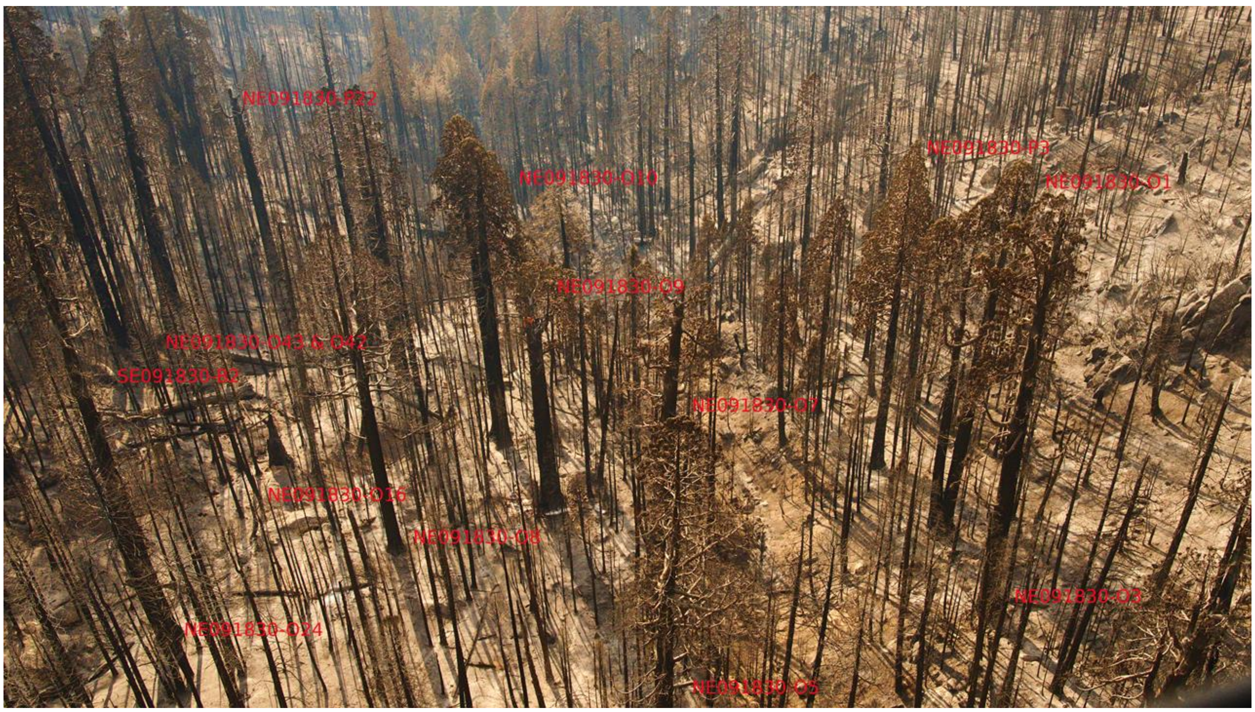

Fig. 2. An example of an aerial image (one of several 2 Nov. 2020 photos of Homer's Nose Grove) analyzed by Tony Caprio (NPS). Red text shows the unique STI identification number for each labelled giant sequoia, which Caprio was able to positively identify using the georectified STI maps and thus align precisely with fire severity maps. Image by Tony Caprio (NPS).

Nelder Grove, 2017 Railroad Fire (including delayed mortality up to 3 years post-fire):

Amarina Wuenschel (Southern Sierra Associate Province Ecologist, USFS Region 5) and Kristen Shive (then of the Save the Redwoods League, currently The Nature Conservancy) oversaw collection of data on the 2017 Railroad Fire's effects on Nelder Grove sequoias, re-inventorying a survey that had been conducted by John Hawksworth between 1980 and 1995. Wuenschel (written communication) subsequently provided a classification of sequoias >4 ft in diameter according to CBI4 fire severity class (Table 3).

Table 3. Nelder Grove sequoia mortality and survival ~3 yr post-fire by CBI4 fire severity.

Post-fire status, sequoias >4 ft diam.	High severity	Moderate severity	Low severity	No change detected	TOTAL
Dead, % (number)	100% (34)	22.22% (2)	5.88% (2)	0% (0)	41.30% (38)
Alive, % (number)	0% (0)	77.78% (7)	94.12% (32)	100% (15)	58.70% (54)
TOTAL	100% (34)	100% (9)	100% (34)	100% (15)	100% (92)

A selected higher-severity portion of Black Mountain Grove, 2017 Pier Fire (including delayed mortality up to 3 years post-fire):

Kristen Shive (then of the Save the Redwoods League, currently The Nature Conservancy) oversaw collection of data on the 2017 Pier Fire's effects on sequoias in a small part of Black Mountain Grove that burned at higher severities. Shive (written communication) subsequently provided a classification of large sequoias (≥4 ft in diameter) according to CBI4 fire severity class (Table 4).

Table 4. Black Mountain Grove sequoia mortality and survival ~3 yr post-fire by CBI4 fire severity.

Post-fire status, sequoias ≥4 ft diam.	High severity	Moderate severity	Low severity	No change detected	TOTAL
Dead, % (number)	74.55% (41)	24.53% (26)	11.90% (5)	0% (0)	35.12% (72)
Alive, % (number)	25.45% (14)	75.47% (80)	88.10% (37)	100% (2)	64.88% (133)
TOTAL	100% (55)	100% (106)	100% (42)	100% (2)	100% (205)

Averages across sites:

Some caveats are associated with averaging the percentage mortality values of the three sites (four sites for high severity). First, data from the two Castle Fire data sets (Alder Creek and SEKI) were collected less than one year following fire, and thus lack delayed sequoia mortality. In contrast, the other two data sets (Nelder Grove and Black Mountain Grove) include three years of delayed mortality. Second, the Alder Creek data set may be conservative, given that some "heavily damaged" sequoias may already be dead but were not counted as dead in the calculations. Finally, SEKI's sequoia mortality data were only available for high-severity areas, and thus were only included in calculations of average high-severity mortality.

The averages (and ranges) are shown in Table 5.

Table 5. Averages and ranges of sequoia mortality by fire severity class.

	High severity (4 data sets)	**Moderate severity (3 data sets)**	**Low severity (3 data sets)**	**No change detected (3 data sets)**
Average % dead	92.96%	33.94%	7.09%	0%
Range	74.55 - 100%	22.22 - 55.06%	3.48 – 11.90%	0 - 0%

(4) ESTIMATING PROPORTIONS OF LARGE SEQUOIAS *IN THE SIERRA NEVADA* THAT WERE KILLED IN THE CASTLE FIRE

Separately for each data set of the preceding section, for each severity class we now estimate proportions of all of the Sierra Nevada's large sequoias that would have been killed in areas that burned at that severity in the Castle Fire (Tables 6 through 9). For example, if a particular data set found that 90% of sequoias in high-severity areas died, and we know that 9.70% of all grove area in the Sierra Nevada burned at high severity (from the section "Estimating grove area that burned at different severities," above), then we would estimate that 0.90 x 0.0970 = 0.0873, or 8.73% of all large sequoias in the Sierra Nevada died in the high-severity areas of the Castle Fire, as estimated based on that data set. We then sum the results across all severity classes to estimate the total proportion of the Sierra Nevada's large sequoias that died, again as based on that particular data set. We repeat the process for the averages of the four data sets, and then summarize results.

Table 6. Estimated percentage mortality of all large sequoias in the Sierra Nevada, based on the Alder Creek Grove data (Table 2).

CBI4 severity class	**% sequoias >~6 ft diam. killed in the severity class, Alder Creek Grove**	**Percentage of all the natural grove area in the Sierra Nevada in the severity class**	**Est. % of all large sequoias in the Sierra Nevada that were killed**
High	97.30%	9.70%	9.44%
Moderate	55.06%	6.85%	3.77%
Low	3.48%	13.26%	0.46%
No change detected	0%	3.10%	0%
		Sum = 32.91%	**Sum = 13.67%**

Sequoia National Park groves, 2020 Castle Fire, <1 year post-fire:

Given that we currently only have estimates of mortality in high-severity areas of SEKI groves, SEKI data can only offer a minimum, underestimated value of range-wide mortality. Specifically, 100% mortality across 9.70% of the Sierra Nevada's grove area = 9.70% of all the Sierra Nevada's large sequoias died in high-severity areas of the Castle Fire. It seems virtually certain that adding sequoia mortality from SEKI's moderate- and low-severity areas would be sufficient to push the estimate above 10%.

Table 7. Estimated percentage mortality of all large sequoias in the Sierra Nevada, based on the Nelder Grove data (Table 3).

CBI4 severity class	% sequoias >~5 ft diam. killed in the severity class, Nelder Grove	Percentage of all the natural grove area in the Sierra Nevada in the severity class	Est. % of all large sequoias in the Sierra Nevada that were killed
High	100%	9.70%	9.70%
Moderate	22.22%	6.85%	1.52%
Low	5.88%	13.26%	0.78%
No change detected	0%	3.10%	0%
		Sum = 32.91%	**Sum = 12.00%**

Table 8. Estimated percentage mortality of all large sequoias in the Sierra Nevada, based on the Black Mountain Grove data (Table 4).

CBI4 severity class	% sequoias ≥4 ft diam. killed in the severity class, Black Mountain Grove	Percentage of all the natural grove area in the Sierra Nevada in the severity class	Est. % of all large sequoias in the Sierra Nevada that were killed
High	74.55%	9.70%	7.23%
Moderate	24.53%	6.85%	1.68%
Low	11.90%	13.26%	1.58%
No change detected	0%	3.10%	0%
		Sum = 32.91%	**Sum = 10.49%**

Table 9. Estimated percentage mortality of all large sequoias in the Sierra Nevada, based on the averages across the sites (Table 5).

CBI4 severity class	Average % large sequoias killed, from preceding section	Percentage of all the natural grove area in the Sierra Nevada in the severity class	Est. % of all large sequoias in the Sierra Nevada that were killed
High	92.96% (4 data sets)	9.70%	9.02%
Moderate	33.94% (3 data sets)	6.85%	2.32%
Low	7.09% (3 data sets)	13.26%	0.94%
No change detected	0% (3 data sets)	3.10%	0%
		Sum = 32.91%	**Sum = 12.28%**

Summary:

Based on the three data sets with complete data, the estimated proportion of the Sierra Nevada's large sequoias that died in the Castle Fire ranged from 10.49% to 13.67%. Rounding the lower value down and the higher value up, **we estimate that 10 to 14% of all large sequoias in the natural sequoia groves of the Sierra Nevada died in the Castle Fire**.

We similarly estimated that 31% to 42% of all large sequoias with the perimeter of the Castle Fire died (Appendix 3).

(5) ESTIMATING THE TOTAL *NUMBERS* OF LARGE SEQUOIAS THAT WERE KILLED IN THE CASTLE FIRE

Many grove areas of the Sierra Nevada have not had 100% inventories of their giant sequoias. Thus, to estimate numbers of large sequoias affected by the Castle Fire, we must extrapolate sequoia numbers from areas that do have 100% inventories. We thus extrapolate from the 100% STI conducted in SEKI in the 1960s and 1970s, described in the section on "General data sources," above. *This inventory embraced about 1/3 of all grove area in the Sierra Nevada*.

We first present results of the extrapolation, and then briefly discuss some uncertainties associated with the extrapolation. Future work will likely narrow those uncertainties.

<u>Estimating numbers of large sequoias by extrapolating SEKI's STI data</u>:

Using Rodney Hart's new grove boundary maps (Appendix 1), Josh Flickinger calculated that SEKI currently has 10,769.93 acres of sequoia groves, or about 37.2% of all grove area in the Sierra Nevada. However, SEKI's STI only encompassed roughly 90% of that (9,651.64 acres). Thus, calculating densities of large sequoias from SEKI's STI requires using 9,651.64 acres, not the full acreage of sequoia groves currently within SEKI.

SEKI's STI reported 25,181 large sequoias (Stohlgren 1991, Appendix I), where "large" means trunk diameters >3.5 ft (>1.07 m); following past convention we round to the nearest foot and call these sequoias "four feet or larger". Thus, to extrapolate from SEKI's STI to other grove areas, we multiply the other grove acreage by 25,181/9,651.64 = **2.61 large sequoias/acre**. Thus:

28,958 acres of groves in the Sierra Nevada x 2.61 large sequoias / acre = **estimated 75,580 large sequoias within the natural sequoia groves of the Sierra Nevada.**

From the preceding section, an estimated 10% to 14% of all large sequoias in the Sierra Nevada, or 7,558 to 10,581 large sequoias, died in the Castle Fire. Rounding the lower value down and the higher value up, **we estimate that 7,500 to 10,600 large sequoias died in the Castle Fire.**

<u>Sources of uncertainty in estimating the numbers of large sequoias that died</u>.

The preceding estimates are associated with several sources of uncertainty, the most important of which are briefly considered below. **The combined effects of these sources of error could lead to either underestimated or overestimated numbers of large sequoias killed in the Castle Fire, but we currently have no robust way to assess which is more likely**. Instead, the following discussion can help guide future research to reduce uncertainty.

Uncertainties in the proportions of sequoias that died in the Castle Fire. See the preceding sections for discussions of these uncertainties.

Changes in the ~50 years since SEKI's Sequoia Tree Inventory (STI) was conducted. In the ~50 years following SEKI's STI, normal diameter growth of sequoias (causing some sequoias to "graduate" into larger size classes) coupled with normal background mortality may have slightly shifted sequoia population structures, but we currently have no way of confidently assessing this. Perhaps the most significant changes will have been driven by three recent wildfires: the 2015 Rough Fire, 2017 Pier Fire, and 2017 Railroad Fire. All three fires may have killed dozens to hundreds of large sequoias, but their effects are still being assessed. Thus, numbers of large sequoias estimated by extrapolating SEKI's STI might best represent sequoia numbers preceding these wildfires (i.e., preceding 2015).

Past sequoia logging. By one estimate, giant sequoias were logged in about 23% of all grove area in the Sierra Nevada, mostly between 1880 and 1920 (Stephenson 1996). As discussed in more detail in Appendix 2, the rapid growth of young sequoias that became established after logging likely means that many logged areas currently contain a *greater* density of large sequoias (four or more feet in diameter) than unlogged old-growth areas. (The same cannot be said for "monarch" sequoias >10 ft diameter, which almost certainly still have greatly reduced densities in logged areas.) Of course, for various reasons it remains possible that some other logged groves currently have lower densities of large sequoias than unlogged areas.

Although the STI dataset includes some logged areas (particularly in Big Stump and Atwell Groves), extrapolating the full STI data to all of the Sierra Nevada comes with at least two logging-related uncertainties. First, the STI data are ~50 years old, meaning that many more second-growth sequoias in logged areas have probably "graduated" into 4-ft-or-larger size classes since then, and extrapolating from the STI data might therefore somewhat underestimate total numbers of large sequoias in the Sierra Nevada (Appendix 2). Additionally, the proportion of logged grove area in SEKI might be less than that outside of SEKI, further complicating interpretation. These uncertainties will likely only be resolved by updated mapping of logged areas and new sequoia inventories.

Possible systematic geographic differences. A final possibility is that there are broad, perhaps environmentally driven geographic differences in densities of large sequoias. If this is the case, densities derived from SEKI's STI – even though the STI embraced ~1/3 of all grove area in the Sierra Nevada – may not be representative of the remaining ~2/3 of grove area in the Sierra Nevada. Although we suspect such differences, if they exist, are likely small (Appendix 2), future studies should assess this possibility.

WHY OUR ESTIMATES DIFFER FROM EARLIER ESTIMATES

The preceding estimates of proportions and numbers of large sequoias killed in the Castle Fire are greater than earlier estimates that appeared in some NPS presentations and BAER reports. The approach used to derive the earlier estimates – and the associated errors that contributed to underestimation – were as follows:

(1) *Estimate the density of large sequoias in areas that burned at high severity in the Castle Fire*. This step used data from the November 2020 NPS BAER report (NPS 2020). In that report, Table 12 (p. 100) reported that 340 large sequoias fell in a subset of areas that burned at high severity within SEKI, as determined by SEKI's spatially explicit STI data. Table 10 (p. 93) reported that 483.8 acres (195.8 ha) of grove area burned at high severity in SEKI. These two numbers from the BAER report were used to estimate 340/483.8 = **0.70 large sequoias per acre** in high-severity areas (a number that was not calculated or reported in the BAER report itself). However, three sources of error conspired to make this a substantial underestimate of actual sequoia density. First, the 340 sequoias were from the STI's "point" data layer, but failed to include some additional large sequoias found in the STI's "polygon" data layer, which boost the total number to 369 large sequoias. Second, the reported SEKI grove acres that burned at high severity included *all* areas within Park boundaries, which in turn included some large areas that had no STI data (especially in Dillonwood Grove). And third, grove areas that burned at high severity were determined using SEKI's old grove maps that included significant areas of non-sequoia forest (Appendix 1). The last two sources of area both served to substantially inflate the amount of high-severity grove acreage actually represented by the STI data: using Hart's new grove boundary maps *limited to those areas with STI data*, we find that the denominator for

our calculation should be 175.5 acres, not 483.8 acres. Thus, a more accurate estimate of the density of large sequoias in SEKI's high severity burn areas that had STI data is 369/175.5 = **2.10 large sequoias per acre**, three-fold higher than the initial estimate. **Thus, all else being equal, errors at this step alone would ultimately contribute to a 3-fold underestimation of proportions and numbers of sequoias killed (see below)**. Finally, SEKI's total high severity burn area with STI data (175.5 acres) was small enough that random fluctuations of sequoia densities could be an issue (Appendix 2). **Thus, fine-scale fluctuations in sequoia densities (Appendix 2) could help explain why the corrected density of sequoias in SEKI high-severity burn areas – 2.10 large sequoias per acre – still falls below the average value of 2.61 large sequoias per acre for the entire ~9,652 acres of the STI.**

(2) *Assume 100% mortality of large sequoias in high-severity areas, and 0% mortality in areas that burned at other severities*. The assumption of 100% mortality in high-severity areas was based on Caprio's work in SEKI, described earlier. Although it was also clear to Caprio that some sequoias died in lower-severity areas, he was not able to confidently quantify the proportion based on his aerial imagery. Thus, the assumption of 0% mortality in all other severity classes was knowingly conservative. For example, we know that 9.70% of all grove area in the Sierra Nevada burned at high severity in the Castle Fire. Applying the assumption of 100% sequoia mortality in those areas, and 0% elsewhere, yields an estimated 9.70% of all large sequoias dying. However, if we use the averaged mortality estimates by severity class from the section "Estimating proportions of large sequoias *in the Sierra Nevada* that were killed in the Castle Fire," we get 12.28%, even though the averaged estimated mortality in high-severity areas is only ~93%, not 100% . **Thus, all else being equal, by assuming 0% sequoia mortality in all Castle Fire areas that did not burn at high severity, previous calculations underestimated the proportion of sequoias that died.**

(3) *Multiply the density of large sequoias in SEKI high-severity areas (Step 1, above) by the acreage of the Castle Fire outside of SEKI that burned at high severity*. This step estimated numbers of sequoias outside of SEKI that died in the Castle Fire, and may have counteracted some of the underestimation of the preceding steps by *overestimating* acres that burned at high severity. Acres that burned at high severity were overestimated because the old grove map layer was used, which included substantial areas of non-sequoia forest that burned at high severity (see Appendix 1). However, some grove areas in the Castle Fire (such as parts of Alder Creek Grove and Mountain Home Grove) may have inadvertently been left out of this step of the calculations, which could lead to underestimation. **Thus, while we know that further errors were introduced at this step, their magnitude and direction are uncertain**.

(4) *Add the estimated number of sequoias from Step 3 to the 340 SEKI sequoias (the number should have been 369; see Step 1) to estimate total number of large, dead sequoias in the Castle Fire*. **The net effect of all the preceding steps was to underestimate the numbers and proportions of large sequoias that died in the Castle Fire**.

ACKNOWLEDGEMENTS

The vision of managers and scientists to create giant sequoia grove maps and inventory individual trees laid the foundation for this work. This work would not have been possible without a legacy of financial support from too many agencies, nonprofits, and other cooperators to name individually over the century of government management of giant sequoias. We also acknowledge stewardship of these forests, including giant sequoias, by California Native

Americans for millennia. We hope this report will be just the beginning of a second century of sequoia stewardship. Data used in this report reside with the individuals named in the main text; please contact C. Brigham or N. Stephenson for further information. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Appendix 1:
Remapping all Sierra Nevada sequoia grove boundaries to a consistent standard

BACKGROUND AND NEED

The consistent remapping of all the Sierra Nevada's sequoia groves was motivated by a need to quantify the effects of the 2020 Castle wildfire on giant sequoia populations. To accurately estimate effects of the fire, we needed fine-resolution maps showing precisely where sequoias occur in the Sierra Nevada. Yet existing maps failed to meet our needs, in at least two broad ways.

(1) Existing maps of grove boundaries almost universally included large areas of non-sequoia forest.
An old map layer (https://irma.nps.gov/DataStore/Reference/Profile/2259632) delimited 47,129 acres of sequoias groves throughout the Sierra Nevada, exceeding the newly remapped grove area (28,958 acres) by a factor of 1.63. Old grove areas were overrepresented for various combinations of reasons, described below.

* *Maps often purposely encompassed broader administrative boundaries, not areas of actual sequoia occurrence*. E.g., for Giant Sequoia National Monument (GSNM), (i) mapped groves typically included 500-ft administrative buffers, (ii) when 500 ft could not be precisely measured (e.g., when mapping wilderness groves from helicopter), mappers often purposely erred toward buffers larger than 500 ft, (iii) many of the buffered groves were then further lumped into "grove complexes" that included additional non-grove area, and (iv) in some cases, convenient but only loosely related administrative boundaries were used as grove boundaries; for example, the administrative boundary of the Freeman Creek Grove (~1692 acres) was defined as the boundary of the much larger Freeman Creek Botanical Area (~4191 acres) (see Fig. 1-1).
* *Given past geographic uncertainties, maps were purposely conservative, erring on the side of being inclusive*. E.g., SEKI grove boundaries were an inclusive composite of three past grove maps, each with its own geographic errors (1979 Wallner map, STI map, and sequoia distributions as recorded in the more recent SEKI vegetation map) (Fig. 1-2). The union of previous maps led to overrepresentation of where sequoias occur.
* *Other reasons*. (i) Sometimes maps were simply in error (e.g., SEKI's vegetation map shows a large addition to Redwood Mountain Grove that apparently does not exist). (ii) Maps of some groves did not exclude sequoia-free areas within groves ("donut holes"). (iii) Many maps were either intentionally or unintentionally made at coarse resolution – e.g., with a single boundary drawn around a few distinct clumps of sequoias, thus including all the non-sequoia forest between the clumps.

Using the substantially over-mapped grove areas would introduce undesirable errors in calculations. For example, we found that the estimated proportion of grove area that burned at high severity was greater using the old maps than using the new maps, probably because the old maps included drier non-sequoia forests that were more prone to burning at high severity. Additionally, overestimated grove areas would lead to errors in estimated sequoia population sizes.

(2) **The magnitude of errors in grove maps varied geographically, usually according to grove jurisdiction.** For example, total GSNM grove area was overreported by a factor of 1.80, whereas total SEKI grove area was overreported by a factor of 1.44. These differences

would introduce substantial errors into critical calculations, such as when estimating numbers of sequoias range-wide based on data from jurisdictions that have complete sequoia tree inventories.

CHARACTERISTICS OF THE NEW MAPS

The objective of the new mapping effort was to show, at fine resolution, where sequoias occur on the landscape, excluding non-sequoia forest. An advantage of the new maps is that they allow users with different goals to add customized grove buffer zones specific to their needs.

All grove mapping was accomplished by Rodney Hart (GIS Remote Sensing Analyst, USFS Region 5 Remote Sensing Lab), based on remotely sensed imagery. Hart had substantial initial experience identifying giant sequoia crowns in remotely sensed imagery. Specifically, preceding the current effort he had identified ~40,000 individual sequoia crowns while georectifying SEKI's Sequoia Tree Inventory maps. In this effort, 2017 aerial LiDAR data provided spatial context to identify consistent patterns of sequoia characteristics in color aerial photographs. The most useful images were taken in the spring, when sequoia foliage stands out in stark contrast to neighboring trees. Additionally, sequoia gestalt is distinctive when viewed from above and in profile when a shadow is visible on the ground. Finally, in the process of using the massive "training" dataset, subtle repeating sequoia landscape patterns became evident to Hart, helping him know where to look for potential outlier trees from main grove areas.

Grove boundaries were delineated snugly around the outer crown edges of the outermost sequoias in an area following localized geomorphological patterns. Sequoias had to be within ~150 m of each other to maintain a continuous grove boundary line. If trees were >150 m apart, depending on circumstances, either a grove "embayment" was drawn between them or they become parts of separately mapped clumps of sequoias, the latter most commonly seen in riparian-confined sequoia populations.

QUALITY CHECKS

As of 25 May 2021, no formal ground-truthing had yet occurred, although systematic ground-truthing is planned for the summer of 2021.

However, a few independent lines of evidence suggest the maps are broadly accurate, without large errors of omission or commission. First, individuals with intimate local knowledge of sequoia groves were consulted and deemed maps of selected groves to be good reflections of reality. Second, as was the case for most groves, Hart remapped the Freeman Creek Grove "blind" to where sequoias actually occurred within the much larger Freeman Creek Grove administrative boundary. We later discovered an existing USFS map showing where the Freeman Creek sequoias were, which conformed well with Hart's map (Fig. 1-1).

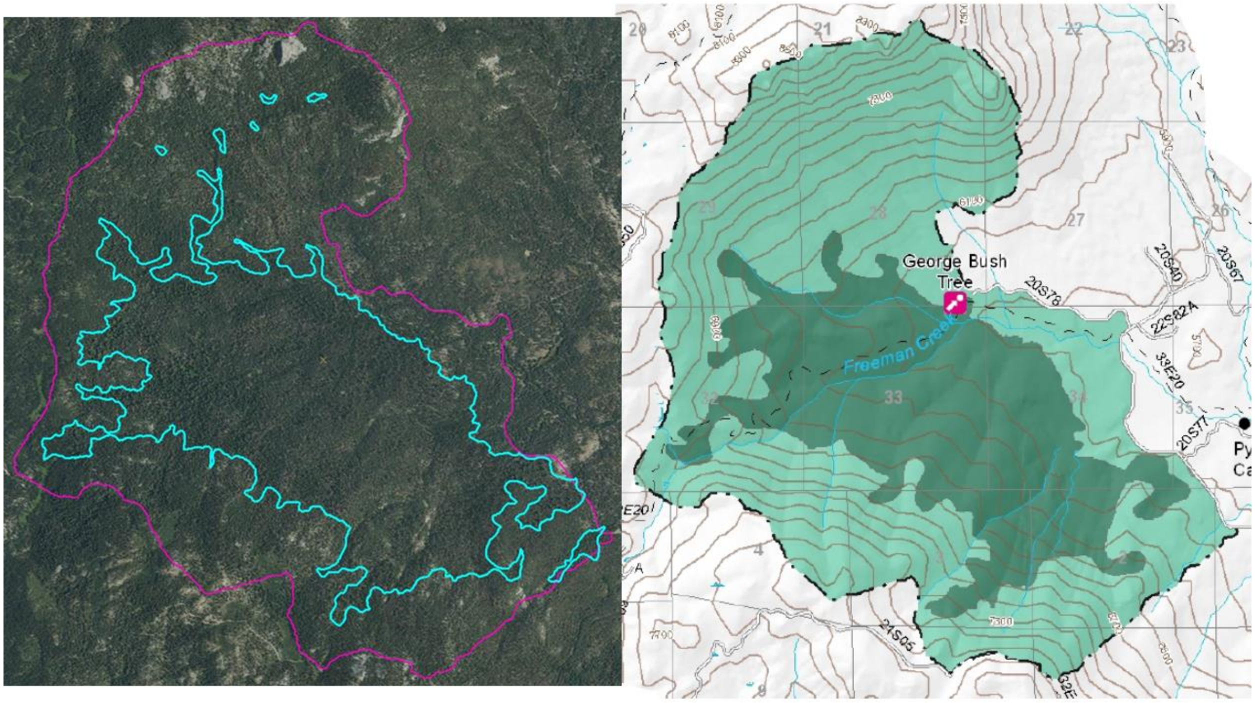


Fig. 1-1. *Left frame*: Magenta outline shows the Freeman Creek Grove's administrative boundary, which coincides with the Freeman Creek Botanical Area boundary. Cyan outlines show areas of giant sequoia occurrence identified by Rodney Hart, using remotely sensed imagery. (Image by Rodney Hart, USFS.) *Right frame*: Dark green shading is the "Freeman Creek Grove Approx. Giant Sequoia Treeline" within the Botanical Area (light green), from Appendix F of Giant Sequoia National Monument's *Final Environmental Impact Statement*. The independently derived grove boundaries conform relatively well with one another, although Hart mapped the grove "blind" to the existing map.

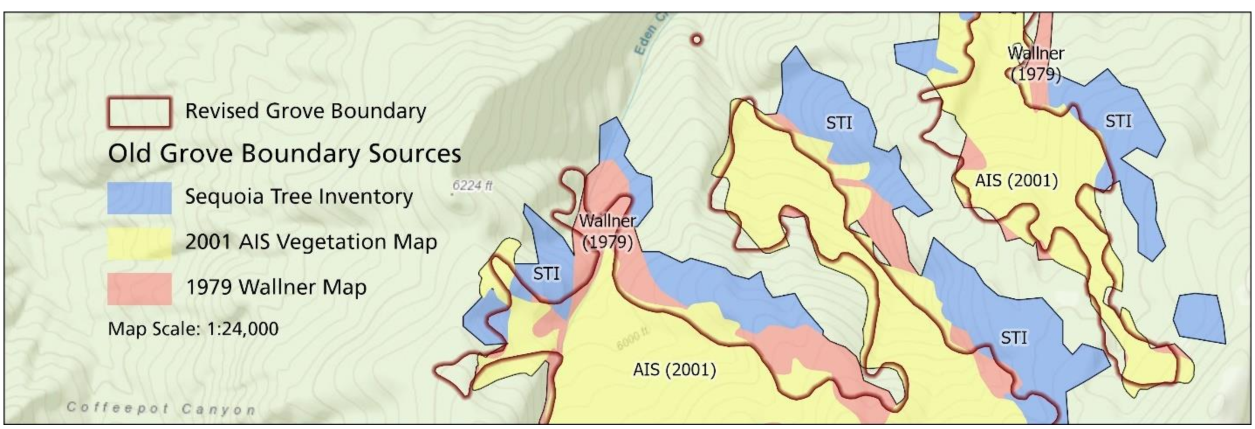


Fig. 1-2. A portion of Eden Creek Grove in Sequoia National Park, showing the three different grove map layers whose union defined the "old" Eden Creek Grove boundary, and also showing the new ("revised") grove boundary as delineated by Rodney Hart (USFS). Each of the old map layers had its own errors and geographic uncertainties that, when combined, led to overestimated grove area and inclusion of non-sequoia forest within putative grove boundaries. Image by Josh Flickinger, NPS.

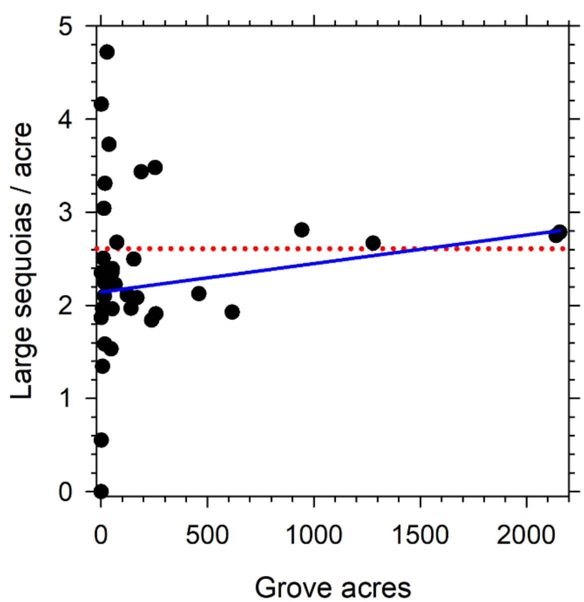
Appendix 2:
Converting proportions of area burned at different severities to proportions of large sequoias that burned at those severities

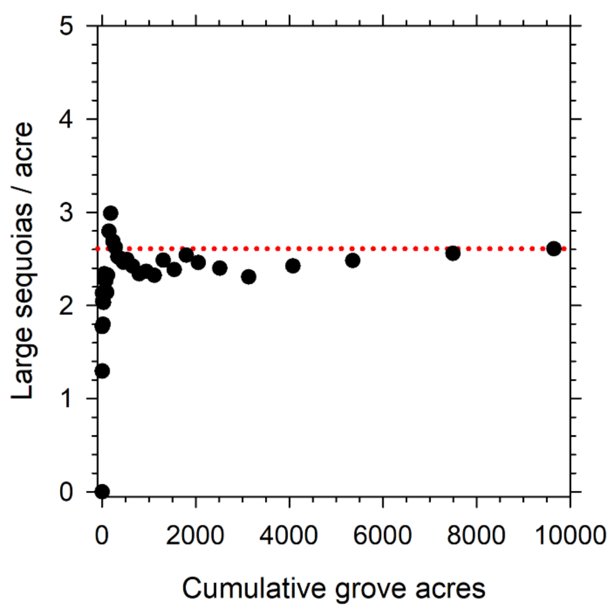
PURPOSE

Our calculations require us to convert the proportions of area that burned at different severities into the proportions of large sequoias that burned at those different severities. The simplest approach would be to assume that the correspondence is exactly one to one. For example, because 9.70% of all grove area in the Sierra Nevada burned at high severity in the Castle Fire, we could assume that 9.70% of all large sequoias in the Sierra Nevada also burned at high severity. However, we wished to explore the validity of this assumption at two scales: within the Castle Fire, and across the Sierra Nevada.

Within the Castle Fire, were "random" fine-scale variations in sequoia density likely to affect broad-scale conclusions?

Densities of large sequoias can vary substantially at fine spatial scales (e.g., less than 100 acres). But some simple analyses of the STI data (below) suggest that the cumulative grove areas within the various Castle Fire burn severity classes – ranging from ~900 acres ("no change detected" class) to ~3,880 acres ("low severity" class) – are large enough that we can assume that, all else being equal, effects of "random" fine-scale variations in sequoia density were probably small, especially relative to other sources of uncertainty. We thus did not explicitly consider this source of uncertainty, although future work should shed further light on it.





In the left frame above, each dot represents a single grove in SEKI's STI. The dotted red line indicates the density of large sequoias (2.61/acre) *within all groves combined*. The solid blue line is the least-squares fit to the data. Two things are evident. First, small groves tend to have slightly lower densities of large sequoias than large groves, although the variance is substantial. Second, and most important for our purposes, grove-to-grove variance in large-sequoia density declines substantially with increasing grove area, with groves ≥~900 acres showing little variance.

In the right frame above, each dot represents density of large sequoias by *cumulative* grove area, sequentially adding groves starting with the smallest grove, then adding the second smallest grove, and so on until the largest grove is finally added. Variance becomes muted at about 500 cumulative acres, and then stays muted through the full 9,651.64 cumulative acres covered by the STI. For the zone of muted variance (500 cumulative acres and above), densities are somewhat lower at lower cumulative acres, because groves are being added sequentially from smallest to largest, and smaller groves *on average* have somewhat lower densities.

More rigorous cumulative analyses could add groves randomly, or add patches of groves randomly, until all area was sampled. However, we deemed the current analyses adequate to conclude that **at the scales of our analyses of Castle Fire severity classes (~900 to ~3,880 cumulative acres per severity class), fine-scale variations in sequoia densities largely average out, and are thus unlikely to substantially affect our conclusions**.

Within the Castle Fire, did fire severity vary systematically with sequoia densities?

If the Castle Fire burned most severely in areas of low sequoia density (perhaps because those areas were drier, or had more drought-killed pines and firs), the proportion of grove area that burned at high severity would *overestimate* the proportion of large sequoias that burned at high severity. Conversely, if the fire burned most severely in areas of high sequoia density (perhaps because denser forest was more prone to crown fire), the proportion of grove area that burned at high severity would *underestimate* the number of large sequoias that burned at high severity. In either case, we would need to account for the differences in our conversions of proportions of area that burned at different severities into estimates of proportions of all sequoias killed.

To explore the possibilities, first we present results of analyses of each of three relatively large data sets relating Castle Fire severity to sequoia densities. We then interpret the results collectively.

(i) *SEKI sequoia groves*: Using Hart's new grove boundaries for the SEKI grove areas that burned in the Castle Fire *and that had spatially explicit STI maps of large sequoias*, Josh Flickinger (SEKI) calculated the percentages of area and large sequoias (4 ft or larger) that burned at different severities, shown in the following table. (These numbers differ from those initially reported in SEKI's BAER report (NPS 2020), which used the old grove maps that included areas of non-sequoia forest.)

CBI4 severity class	% of burned SEKI grove area with STI data (acres)	% of STI sequoias 4 ft diam. or larger (number of sequoias)
High	9.86% (175.47 ac)	8.70% (369)
Moderate	13.50% (240.19 ac)	11.74% (498)
Low	59.75% (1063.27 ac)	61.16% (2594)
No change detected	16.90% (300.68 ac)	18.39% (780)
TOTAL	100% (1779.61 ac)	100% (4241)

(ii) *Alder Creek Grove*: Sue Cag (conservationist residing in the Alder Creek Grove) completed a post-fire census of all sequoias about 6 ft or more in diameter within the Alder Creek Grove, recording the location of each sequoia with a GPS unit (the data used here are dated 1 May 2021). Josh Flickinger (SEKI) analyzed Cag's sequoia data relative to the Castle Fire severity map (table below).

CBI4 severity class	% of Alder Creek Grove area (acres)	% of sequoias ≥~6 ft diam. (number of sequoias)
High	28.03% (157.23 ac)	28.14% (148)
Moderate	14.43% (80.95 ac)	16.92% (89)
Low	39.85% (223.51 ac)	38.21% (201)
No change detected	17.68% (99.19 ac)	16.73% (88)
TOTAL	100% (560.88 ac)	100% (526)

(iii) *Belknap Complex groves (Carr Wilson, McIntyre, Belknap Camp, and Wheel Meadow groves), Giant Sequoia National Monument*: To help USFS assess Castle Fire effects, Rodney Hart (USFS, see Appendix 1) used *pre-fire* remotely sensed imagery (from 2013 and 2016) to identify all visible, probable sequoia crowns in the four groves comprising the Belknap Complex, identifying 4199 putative sequoia crowns in total, and 1818 putative sequoia crowns ≥30 ft diameter (i.e., largest sequoias only). Amarina Wuenschel (Southern Sierra Associate Province Ecologist, USFS Region 5) analyzed the data relative to the Castle Fire severity map (table below). Given inherent uncertainties in identifying individual sequoia crowns in remotely sensed imagery (errors of both omission and commission), the results should be interpreted with some caution.

CBI4 severity class	% of Belknap Complex grove area (acres)	% of all putative sequoia crowns (number of all crowns)	% of putative sequoia crowns ≥30 ft diam. (number of crowns)
High	58.65% (620.50 ac)	55.78% (2342)	55.06% (1001)
Moderate	26.78% (283.38 ac)	26.27% (1103)	27.50% (500)
Low	13.99% (148.01 ac)	17.29% (726)	16.56% (301)
No change detected	0.58% (6.15 ac)	0.67% (28)	0.88% (16)
TOTAL	100% (1058.04 ac)	100% (4199)	100% (1818)

Interpretation: Among the three data sets, in no severity class is the percentage of sequoias that burned at a given severity consistently greater or lesser than the percentage of area that burned at that severity. Additionally, differences are relatively small. Thus, in the absence of large, consistent differences, **we assume a one-to-one relationship between proportion of area that burned at a given severity and the proportion of the sequoia population that burned at that severity**. As more and better data become available in the future, this assumption can be revisited.

Were sequoia populations in the Castle Fire growing in environmentally similar conditions to sequoia populations elsewhere in the Sierra Nevada?

If the groves that burned in the Castle Fire grew in areas that were, on average, environmentally dissimilar to other groves, their densities of large sequoias could conceivably differ systematically from those of other groves. If this were the case, adjustments might need to be made when estimating Castle Fire sequoia deaths as a proportion of all sequoias in the Sierra Nevada.

However, the large majority (96%) of all grove area in the Sierra Nevada lies south of the Kings River. Within this southern, core part of the giant sequoia range, the Castle Fire (i) burned a large fraction (~1/3) of all grove area; (ii) burned centrally (slightly south of center) along a north-south axis, and (iii) burned groves at all positions along an east-west axis. We conclude that **we have no *a priori* reason to believe that Castle Fire groves had meaningful, environmentally induced differences in densities of large sequoias**, although this conclusion warrants more careful examination as data improve in the future.

How might the effects of past sequoia logging influence range-wide estimates?

By one estimate, giant sequoias were logged in about 23% of all grove area in the Sierra Nevada, mostly between 1880 and 1920 (Stephenson 1996). However, this estimate is associated with its own uncertainties, arising from the uncertain quality of the old maps and records used to derive the estimate. Additionally, the estimate doesn't distinguish between areas in which the overwhelming majority of large sequoias were logged (e.g., Converse Basin Grove) *versus* areas that had more selective (partial) sequoia logging (e.g. parts of Mountain Home Grove). Better delineations of logged areas, and quantification of the intensity of logging within those areas, would improve future estimates of numbers of large sequoias affected by fire.

Regardless, the rapid growth of young sequoias that became established after logging may mean that many logged areas currently contain *greater* densities of large sequoias (four or more feet in diameter) than unlogged old-growth areas. (The same cannot be said for "monarch" sequoias >10 ft diameter, which almost certainly still have greatly reduced densities in logged areas.) For example, Stohlgren (1992) analyzed conditions in Big Stump Grove (Kings Canyon National Park) as recorded by the STI in 1968, roughly 80 years following logging. Using Stohlgren's reported diameter growth rates and size structure data, it is simple to calculate that after the >50 years that have elapsed since the 1968 inventory, Big Stump Grove now likely contains a greater density of large (4 ft or more) sequoias than nearly all unlogged groves in SEKI, even if we assume an unreasonably high annual mortality rate (0.5% / yr) for the young, rapidly growing Big Stump sequoias. Of course, for various reasons it is possible that some other logged groves in the Sierra Nevada currently have lower densities of large sequoias than unlogged areas.

Regardless of current conditions in logged areas, the STI was conducted ~50 years ago, and Stohlgren's (1992) data suggest that, at the time of the STI, the logged Big Stump Grove had a density of 4-ft-or-larger sequoias that fell within the range of unlogged SEKI groves, but toward the low end of that range. Thus, when we extrapolate from SEKI's STI, we might be somewhat underestimating the numbers of large sequoias that currently exist range-wide. Additionally, the proportion of logged grove area in SEKI might be less than that outside of SEKI, further complicating interpretation. These uncertainties will likely only be resolved by updated mapping of logged areas and new sequoia inventories.

Thus, while past logging could potentially influence our results, we currently lack the information needed to estimate even the direction of those potential effects.

NPS. 2020. *Emergency Stabilization & Rehabilitation Plan, Castle & Rattlesnake Fires, Sequoia and Kings Canyon National Parks, CA*. 178 pages.

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Appendix 3:
Estimating proportions of large sequoias that were killed within the Castle Fire's perimeter

The following exercise follows the approach of step 4 of the main text, but rather than estimate sequoia mortality as a proportion of all sequoias in the Sierra Nevada, it estimates mortality only as a proportion of all sequoias within the Castle Fire's perimeter.

Alder Creek Grove, 2020 Castle Fire, <1 year post-fire:

CBI4 severity class	% sequoias >~6 ft diam. killed in the severity class, Alder Creek Grove	% of all Castle Fire grove area in the severity class	Est. % of all large sequoias in the Castle Fire that were killed
High	97.30%	29.48%	28.68%
Moderate	55.06%	20.80%	11.45%
Low	3.48%	40.30%	1.40%
No change detected	0%	9.42%	0%
		100%	**Sum = 41.53%**

Sequoia National Park groves, 2020 Castle Fire, <1 year post-fire:

Given that we currently only have estimates of mortality in high-severity areas of SEKI groves, SEKI data can only offer a minimum, underestimated value of range-wide mortality. Specifically, 100% mortality across 29.48% of the Castle Fire's grove area that burned at high severity = 29.48% of large sequoias within the Castle Fire's perimeter. It seems virtually certain that adding sequoia mortality from SEKI's moderate- and low-severity areas would be sufficient to push the estimate above 30%.

Nelder Grove, 2017 Railroad Fire (including delayed mortality up to 3 years post-fire):

CBI4 severity class	% sequoias >4 ft diam. killed in the severity class, Nelder Grove	% of all Castle Fire grove area in the severity class	Est. % of all large sequoias in the Castle Fire that were killed
High	100%	29.48%	29.48%
Moderate	22.22%	20.80%	4.62%
Low	5.88%	40.30%	2.37%
No change detected	0%	9.42%	0%
		100%	**Sum = 36.47%**

A selected higher-severity portion of Black Mountain Grove, 2017 Pier Fire (including delayed mortality up to 3 years post-fire):

CBI4 severity class	% sequoias ≥4 ft diam. killed in the severity class, Black Mountain Grove	% of all Castle Fire grove area in the severity class	Est. % of all large sequoias in the Castle Fire that were killed
High	74.55%	29.48%	21.98%
Moderate	24.53%	20.80%	5.10%
Low	11.90%	40.30%	4.80%
No change detected	0%	9.42%	0%
		100%	**Sum = 31.88%**

Averages across the data sets (see the caveats in the main text):

CBI4 severity class	Average % large sequoias killed	% of all Castle Fire grove area in the severity class	Est. % of all large sequoias in the Castle Fire that were killed
High	92.96% (4 data sets)	29.48%	27.40%
Moderate	33.94% (3 data sets)	20.80%	7.06%
Low	7.09% (3 data sets)	40.30%	2.86%
No change detected	0% (3 data sets)	9.42%	0%
		100%	**Sum = 37.32%**

Summary:

Based on the three data sets with complete data, the estimated proportion of large sequoias that died within the Castle Fire's perimeter ranged from 31.88% to 41.53%. Rounding the lower value down and the higher value up, **we estimate that 31% to 42% of all large sequoias died within the perimeter of the Castle Fire**.