Appendix C:
Response to Public Comments Concerning Scientific Basis for Purpose and Need for Action Received During Public Scoping

A number of scientific concerns were raised before and during the public scoping period between February 17, 2023 and March 19, 2023. After scoping had concluded, the NPS developed statements in response to the concerns, which were then independently peer-reviewed to ensure the response met scientific standards for accuracy and completeness and that the NPS' understanding of the literature is scientifically supported. The NPS asked Dr. A. Keith Miles of the United States Geological Survey (USGS) to coordinate the peer-review. The main purpose of this independent review on the scientific issues was to ensure agency consideration met scientific standards.

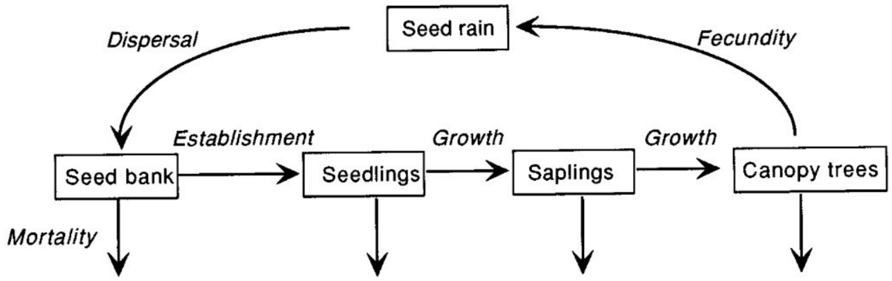
The NPS received the reviews in mid-August of 2023. Both independent peer-reviewers found NPS' responses to be scientifically sound and adequate. One reviewer also provided areas where they felt the agency response could be clarified or further developed with more citations. The NPS has addressed those suggestions in the following revised response.

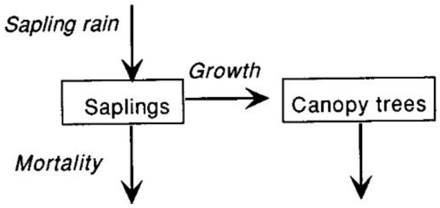
These original concerns and the NPS' peer-reviewed responses are summarized below.

Concern 1: Post-fire sequoia reproduction occurs each year after the fire for many years (decades)—not just the first year (Nelder and Meyer papers are cited as examples). Since the NPS does not have data for many years post fire, the conclusion that there is not enough sequoia reproduction is incorrect.

Response: Assessment of future reproduction in trees is based on assessment of the critical life history stages that must be completed to result in successful reproduction. Forests may be a mix of recruitment limited and/or microsite limited. Jim Clark outlines a mechanistic model for trees that identifies these stages so that they can be evaluated:

1. Seed production (fecundity) resulting in seed rain.
2. Seed dispersal.
3. Seed bank.
4. Germination
5. Germinant survival.
6. Seedling survival until sapling size (see figure on next page from Clark et al. 1999).


a) Seed rain view


b) Sapling immigration view

All of the stages above may have been impacted by recent large scale high severity fire effects, such as are found within the project area as outlined below. Specifically, the major potential impact of these fires on two critical stages: 1) fecundity (due to the death of between 60 and 90% of the cone bearing trees within the project areas), and 2) potential impacts of high severity fire and subsequent drought on seedling establishment, survivorship and growth, and the reliance on giant sequoias on conditions immediately post-fire for successful germination and seedling survivorship, such as bare mineral soil (removal of litter layer through burning), sunlight at the ground surface, and more wettable and friable soils (Harvey and Shellhammer 1991, Stark 1968a, Stark 1968b). The combination of these factors all indicate that seedling densities are most likely to decline as the amount of time since the fire event increases; seedling numbers are not likely to increase dramatically in years 3, 4, 5 etc. since the fire event. And thus, if sampled estimated mean seedling densities do not meet reference densities by two years post-fire, they most likely never will. Below, the NPS provides additional citations and explanation regarding seed and seedling ecology to support this understanding.

Fecundity

Harvey et al. 1980 (Chapter 5) completed cone surveys and seed counts and calculated seed rain for intact sequoia forests. They also estimated at what age sequoia trees contribute the most to fecundity. They estimate, based on their field measurements, that a typical hectare of mature giant sequoia forest likely produces over, on average, approximately 1,590,000 seeds per year in the canopy (Harvey et al. 1980 page 48). Thus, the ecology of giant sequoias typically is not seed limited.

This ecology was seriously disrupted by the large areas of high severity fire effects observed within the project area. In the proposed project area in Redwood Mountain Grove, 90% of all large sequoias were killed by fire. These trees will no longer produce seed and thus the fecundity/seed rain going forward has been seriously impacted. Sequoia trees that were killed through canopy scorching, where heat-killed sequoia cones that are retained on the trees, can and will rain seeds down onto the forest floor possibly for several years after fire. It is unclear how long seeds may be held and survive in opened cones in the canopy. However, no additional seed is being produced in these areas and the dispersal kernel for giant sequoia (discussed below) indicates that significant amounts of seed will likely not be transported into the project area from other areas. The NPS estimated the loss of seed rain into these areas, once initial cones are depleted of seed, as follows: the typical number of seeds/cone x typical number of cones/mature tree x estimated number of trees lost (90% mortality x average density of large sequoias per acre x # of acres burned at high severity). For Redwood Mountain, this results in an estimated loss of 2,910,000,000 seeds lost that will not be replaced for hundreds of years. Harvey et al. 1980 used four feet in diameter or greater as an estimate of mature sequoias and estimated that trees don't reach that size for approximately 400 years.

The seed loss could also be estimated as an annual contribution of loss rather than a per tree loss. In this case, instead calculate seed loss as the loss of 1,590,000 seeds/per year/hectare and multiply by the hectares burned at high severity in the proposed project area in Redwood Mountain Grove (199.51 hectares). The estimate of seed lost annually is then 317,227,843. Regardless, high severity fire that killed such large numbers of mature sequoia trees clearly had an impact on the seed rain available to establish seedlings. Additionally, in groves where a high percentage of trees were killed by crown torching where the canopy was consumed, it is likely that the majority of seeds present in the trees were lost and were not even present in the first two years after fire to contribute seed rain. This is likely one of the contributing factors as to why seeding densities are so low in these groves, such as Board Camp grove (estimated mean seedling density two years post-fire is at 651 seedlings/acre, 1609 seedlings/hectare).

To summarize, for impacts and outlook with respect to fecundity: mortality data shows that future seed rain has been greatly impacted through the death of mature sequoia trees in the proposed project areas. This impact may already be severe and a limitation to regeneration in areas where the majority of trees torched (e.g., Board Camp, Homers Nose, Upper Dillonwood) but will certainly impact seed rain once any remaining dead cones in the canopy release their seeds.

Seed Bank

Sequoias do not have a seed bank but instead retain seeds in cones on living trees. In high severity areas where trees were incinerated, this cone bank was destroyed. Even in areas where trees did not burn completely, cones were opened by high heat.

Seed Release and Dispersal

Giant sequoia have semi-serotinous cones that can stay green and closed on trees for up to twenty years (Bucholtz 1938). Heat from surface fires may increase cone opening and increase seed rain immediately post-fire, and large amounts of seed have been observed falling in high severity patches post-fire (Kilgore and Biswell 1971, Harvey et al. 1980). Thus, seed rain may be highest immediately after fire even in areas where mature sequoia trees were not killed.

If seed is dispersed for sufficient distances, perhaps seed could reach the proposed project areas from adjacent areas that retain living trees. Jim Clark has created two dispersal kernels for giant sequoia based on USGS seed trap data. These dispersal kernels were used to support analyses in Clark et al. 1999 and Clark et al. 2021, although the kernels themselves are not part of the publications. Dr. Adrian Das at USGS received the latest dispersal kernel from 2021 from Clark (Clark to Das personal communication), and Dr. Das communicated to NPS that over 95% of all sequoia seed falls within 50 meters of the parent tree. Given the large size of the high severity areas in the proposed project areas (48 acres to over 400 acres in size), the likelihood of significant numbers of seeds being released and then dispersing into the project areas in the years after fire is very low.

Thus, the mortality of large sequoias from high severity fire effects may have now created a situation where these areas are seed limited in a way that they never were previously.

Seed Germination

Stark (1968a) studied the germination requirements of giant sequoia extensively. She found that seeds placed on unburned litter on or near the surface, and exposed to drying of air currents, did not germinate. Seed germination on mineral soil was the highest followed by seed germination by seeds partially covered on partially burned litter (98% as high as control), while seed germination on ash was fair (51% of control). Thus, litter must be removed by fire or other means to have successful germination. Litter then reaccumulates quickly post-fire, within the first few years (Parsons 1978).

Germinant Survival

Stark (1968a) found that seedlings seldom reach the surface if seeds are germinated 2.4 to 3.6 centimeters below the soil surface and, similarly, seedlings do not survive if they germinate on deep litter. Additionally, she found that seeds collected from cones on the ground in 42 groves showed 22.5% germination, yet others have repeatedly found few to no seedlings in unburned groves (zero seedlings in unburned control plots, Kilgore and Biswell 1971), indicating that although appropriate conditions for germination may occur in unburned groves, germinants may not survive.

Seedling Survivorship and Growth to Sapling Size

Stark (1968b) extensively studied conditions favoring seedling growth and survivorship of one year old planted seedlings in both the field and greenhouse. She found that seedlings grow best in full sun and that litter that fell on seedlings after germination reduced death from high temperatures. York et al. (2009) found that sequoia seedlings planted in opening on ash substrates also had more rapid growth than seedlings planted on the edge or adjacent to ash substrates. There was no effect on survivorship. The need for full light and the benefit of ash substrate on rapid growth again suggest that post-fire conditions are ideal for seedling growth.

Overall Patterns of Timing of Reproduction in Giant Sequoia from Other Studies:

Harvey et al. 1980 (Chapter 5) summarize the information available at that time regarding giant sequoia reproduction and ecology. They note several findings: 1) Sequoias are reliant on seeds from cones held on mature trees for reproduction (the species does not resprout); 2) Seeds germinate as soon as conditions are favorable, and seeds that germinate on litter and humus have very low survival; 3) Seeds may benefit from soil conditions immediately post-fire, notably increased penetration, wetting, and friability of soils after heating by wildfire. They conclude the seedling establishment section with the following statement, "We therefore infer that conditions are most favorable to giant sequoia reproduction for a period of two to three years after a disturbance to the forest floor. After that time very few seedlings manage to survive even though some seeds germinate each spring" (Harvey, Shellhammer, Stecker 1980, p. 54). Additional information and details on why the mechanisms of reproduction and existing evidence suggests that the vast majority of sequoia reproduction occurs in years one and two post-fire is summarized below.

Giant sequoias rely on fire for regeneration. Heat from fire opens the cones, and fire creates conditions on the ground that favor germination and establishment, including bare mineral soil (removal of litter layer through burning), sunlight at the ground surface, and more wettable and friable soils (Harvey and Shellhammer 1991).

How quickly these conditions disappear after a fire occurs is not clear. Few researchers have tracked seedling cohorts more than a single year after a fire. Harvey and Shellhammer tracked emergence and survival for cohorts the first and second year after fire, but their 1991 paper only reports relative survivorship standardized to 1000, not actual numbers of seedlings germinating. As also quoted above, in their 1980 summary book of their research on giant sequoia ecology, Harvey and Shellhamer report regarding seedling ecology that, "We therefore infer that conditions are most favorable to giant sequoia reproduction for a period of two to three years after a disturbance to the forest floor. After that time very few seedlings manage to survive even though some seeds germinate each spring" (Harvey, Shellhammer, Stecker 1980, p. 54). The only other dataset that we are aware of that tracked seedlings per plot for several years after fire are the NPS Fire Monitoring plots. These plots were summarized, analyzed, and peer-reviewed as part of the SEKI Natural Resources Condition Assessment on giant sequoias published in 2013 (York et al. 2013a, p. 10). The inset in Figure 2 of York et al. 2013a shows naturally regenerating seedlings in plots placed after prescribed fires. These fires vary in the fire intensity throughout the burn area and include areas of low, moderate, and high fire intensity. The mean at year one is in the 30,000 seedlings per hectare range, indicating that many areas surveyed contain high intensity burn conditions favorable for sequoia germination. The authors conclude, "Although sample size (and therefore certainty in the mean) decreases with time, there is a clear initial pulse of seedlings establishment followed by a steep decline during the first five years following fire" (York et al. 2013a, p. 10).

The data included in York et al. 2013a, as well as additional plots, were corrected and reanalyzed recently by Stephenson et al. (2023, in preparation). These data show a rapid decline in sequoia seedling densities from year one to year two which continues through the survey period, which goes for 20 years, postfire. Like York et al. 2013a, Stephenson et al. conclude that the vast majority of sequoia regeneration occurs in year one post-fire with the possibility of additional regeneration in year two followed by sharp declines in year five (FMH plots are measured at year 1-, 2-, and 5-years post-fire).

One commenter suggested that Meyer and Safford (2011) found multiple aged seedlings after both wildfire and harvest disturbances in giant sequoia groves, concluding that this study indicates that successful regeneration continues for many years after the disturbance. While the publication shows a wide variety of seedling size, it does not track or report seedling age. The NPS reached out to Meyer, the first author, to ask whether they aged seedlings and if not, if he felt that the size differences indicated different ages and were supportive of the idea that seedlings had continued to establish at high numbers for many years after the fire or harvest. This is what he said:

> Unfortunately, we did not age regeneration or young trees in our sequoia study from 2011 – we didn't have the funding or time to do this. So, I can't say anything about seedling/sapling/young tree ages with any certainty. But I can offer my thoughts, general observations, and some further clarifications.
>
> I highly suspect that the sequoia regeneration we observed from our study at Redwood Mountain and Case Mountain was derived from the first post-fire year with perhaps some minimal regeneration the second post-fire year – consistent with previous studies on post-fire sequoia regeneration patterns over time. I'm guessing that much of the variation in the heights and diameters of small trees and saplings of sequoias are due to differences in growth rates driven by the underlying site productivity and moisture/light availability – and not an indication of many different post-fire cohorts of sequoias. The latter seems like a bit of a stretch. A single post-fire cohort in year 1 (and minimal year 2 cohort) is a more parsimonious explanation than assuming repeated post-fire regeneration events in sequoia where new seedlings will have to establish under difficult circumstances – such as limited

> mineral soil with significantly more shading and greater shrub and other vegetation cover. Then there's the question of whether we can really expect all that much delayed seed dispersal by mature [sequoia].
>
> At Redwood Mountain in our 2011 study, there were a few patches where we found low densities of sequoia seedlings that could potentially represent a later post-fire cohort. However, these patches contained few seedlings and occurred mostly in the same cluster of plots with older sequoia regen representing about 36% of the sampling area (including plots with >1 [sequoia] seedling). So, even if we assume there was a second cohort of post-fire sequoia seedlings (which I wouldn't assume), they were: (1) quite limited in proportional density to older regeneration (~1% of all regen based on belt transects), and (2) limited in spatial distribution to those few plots where there was already existing, older sequoia regeneration (based on regen plots). In other words, smaller seedlings didn't just magically appear and establish in areas where there was no prior post-fire sequoia regen, even if we assume there was delayed [sequoia] seed dispersal several or more years post-fire.
>
> The same patterns were generally observed in the mechanically harvested groves. Although there are unique circumstances to each grove, such as Case Mountain where regen patterns were likely influenced by their unique treatment history and site conditions.

One other piece of evidence suggests that conditions for successful giant sequoia establishment rapidly disappear following fire. Multiple studies have shown that post-fire areas that have bare soil and, preferably soil heated by fire, are the areas where the greatest number of sequoia seedings are observed one year post-fire (Harvey, Shellhammer, Stecker 1980). This indicates that these conditions, including bare soil, are critical to giant sequoia seedling germination or survival. Additional studies have shown (reviewed in Harvey et al. 1980) that seeds that germinate on litter have high mortality rates from desiccation.

Although some sequoia regeneration is possible for several years post fire, the NPS understands that most regeneration occurs within the first one to two years post-fire, and regeneration several years post-fire in areas without regeneration within the first two years is highly unlikely given the following summary of the above information:

- Sequoias reproduce from seed that comes from cones held on trees (reviewed in Harvey et al. 1980).
- Seedlings do not show dormancy and germinate as soon as they become wet (Stark 1968a and reviewed in Harvey et al. 1980).
- A large seedling pulse occurs one to two years after fire (reviewed in Harvey et al. 1980, York et al. 2013a, Stephenson et al. 2023) (see above for mechanisms on why this is).
- Seeds that germinate on litter or humus have very high mortality rates (Stark 1968a and reviewed in Harvey et al. 1980).

Concern 2: Sequoia reproduction is the most abundant in high severity areas. Recent high severity fire in sequoia groves is therefore not concerning and no action is needed.

Response: Data collected after prescribed broadcast burns and pile burns indicates that giant sequoia seedling germination and survivorship is often the highest in localized areas of high fire intensity and resulting high fire severity. This is the conclusion of Harvey and Shellhammer (1991) and is also discussed in Harvey et al. (1980) and Stephenson, Parsons, and Swetnam (1991) as well as other studies and publications. High fire intensity burns up litter, heats the tree canopy resulting in increased cone opening and seed deposition, and in areas where fire severity is higher, results in canopy opening and increased light to the forest floor through the death of some of the canopy trees such as white fir or incense cedar. All of these conditions appear beneficial for giant sequoia reproduction and survival and have, in the past, resulted in successful establishment of giant sequoias. The NPS does not dispute the statement that giant sequoia reproduction is often the most abundant in high severity areas.

The issue of concern with recent fires, including the KNP and Castle fires, is the scale of high severity patches observed after the fire. Since giant sequoias rely on seed—dispersed from cones retained on living giant sequoia trees—to establish seedlings (sequoias do not resprout and do not have a soil seedbank), if 1) areas exist where no living giant sequoia tree remains and 2) seed dispersal is limited in distance, and 3) seed rain and resultant seedling germination and survival are not sufficient immediately post-fire (see discussion above for estimates of lost seed production due to mature sequoia mortality), then the opportunity to reestablish sequoias in the burned area is limited, if not lost entirely. In summary, it is not just about the low count of seedlings as of 2022, it is also about the depletion of future potential seed input, as well as the recovery of an unsuitable organic seedbed and competing vegetation which is expected to decrease any future seed germination and seedling survival.

To address issue Number one (areas with no living giant sequoia trees), the NPS performed field surveys and resampling sequoia tree inventory trees where possible. This data is summarized in Soderberg et al. 2023, in review, and shows that many contiguous areas exist where no living sequoia trees remain. To address issue Number two (limited seed dispersal in sequoias), there are four lines of evidence in giant sequoia ecology that indicate that the vast majority of seed dispersal is over very short distances.

1. Sequoia groves show fine scale genetic differentiation on the scale of one hundred to two hundred meters (DeSilva and Dodd 2021). This genetic differentiation at a local scale indicates limits in genetic mixing which could be the result of limited seed dispersal.
2. Second, as described in response to Concern 1 above, Clark et al. 2021 summarized and analyzed seed trap data from USGS plots containing giant sequoias and used this data to create a seed dispersal curve for the species. This curve indicates that over 95% of all seed lands within 50 meters of the parent tree (dispersal kernel from Clark pers. comm. Used in Clark et al. 2021).
3. Third, researchers such as Rundel have looked for grove expansion at the edges of existing groves and have found no evidence of groves expanding (summarized in Harvey et al. 1980). This may be due to abiotic or other biotic factors, but especially after prescribed fire or wildfire, it may also indicate a lack of longer distance dispersal.
4. Finally, the seeds do not contain any mechanisms for animal dispersal or other forms of long-distance dispersal, and they do not have good dormancy. All of these factors lead us to conclude that the vast majority of seeds do not travel far from the reproductive tree and that, in order to get the large number of seeds required to re-establish a stable reproducing population, you need reproductive trees in close proximity.

For information on the NPS' evaluation of whether current seedling numbers are sufficient, see below.

Concern 3: How is the NPS measuring seedling density in these post-high severity fire areas?

Response: Immediately after the Castle and KNP fires (year one post-fire), NPS and partner scientists visited some of sequoia groves that burned in each fire. Site visits were concentrated on areas where remotely sensed imagery indicated large areas of high fire severity within a sequoia grove but also included low and moderately burned grove areas. These field visits were limited by fires and smoke. Initial post-fire site visits for the Castle Fire included Upper Dillonwood and Garfield Groves as well as Board Camp Grove. During these visits, the NPS and partner scientists did not see very many sequoia seedlings and nowhere near the densities that the NPS and partners have observed after other wildfires and prescribed fires. Based on these observations, NPS staff worked with USGS to design and carryout mortality and seedling density surveys in six groves and a fisher habitat corridor where satellite imagery indicated large areas of high severity fire effects following the KNP and Castle Fires. These surveys were carried out in Board Camp two years post-fire; Redwood Mountain, Suwanee, and New Oriole Lake Groves and the Fisher Habitat Corridor one year post-fire; and work is continuing in 2023. All KNP groves will be surveyed a second time to detect year two sequoia seedling cohorts, and the unsurveyed Castle Fire groves (Dillonwood and Homers Nose Groves) will be surveyed during the summer of 2023. The methods involved stratified random placement of 11.7- or 17.25-meter radius round plots throughout the high severity portions of large groves (Redwood Mountain Grove) and throughout the entire grove for smaller groves (Board Camp, Suwanee, and New Oriole Lake Groves). Plot size was dependent on seedling density and was designed to avoid large numbers of zero values and to encompass spatial variation in seedling density. The full methods and results can be found in Soderberg et al. 2023 (in review, data has been reviewed by USGS according to standards for data release) and are reported below.

To survey post-fire regeneration, the NPS placed plots throughout the Board Camp, Suwanee, and New Oriole Lake groves and within high severity burn regions of Redwood Mountain Grove (areas with >75% basal area loss, Rapid Assessment of Vegetation Condition after Wildfire (RAVG) 2022; https://burnseverity.cr.usgs.gov/ravg/) using the Generalized Random Tessellation Stratified (GRTS) algorithm (Stevens & Olsen, 2004) with an equal probability stratified sampling design (Figure 2). The NPS used RAVG initial assessment (generally ≤45 days after fire containment) data based on the relative differenced normalized burn ratio (RdNBR; Miller & Thode, 2007) for the sampling design because extended assessment data (growing season following the fire) was not available before sampling commenced. However, the two metrics are largely consistent (Miller & Quayle, 2015). Plots in Redwood Mountain were limited to high severity areas because the large size of the grove made a full sampling impractical and high severity areas were of greater concern to resource managers based on previous studies of postfire conifer regeneration in Sierra Nevada mixed conifer forests (Shive et al., 2018).

The NPS surveyed plots in the 2021 SQF fire-affected Board Camp grove on April 27-28, 2022. The NPS surveyed the 2022 KNP fire-affected Redwood Mountain, Suwanee, and New Oriole Lake groves within a 6-week span on Sept. 1-7, Sept. 25 – Oct. 5, and Oct. 12, 2022, respectively. During field sampling, plot locations were found and recorded with a high-accuracy GPS device (Javad Triumph-2, Eos Arrow Gold GNSS Receivers). At each site, the NPS tallied seedlings within fixed radius plots (Board Camp: 17.84m radius, 1/10thha, 20 plots; Redwood Mountain: 11.35m radius, ~1/25th ha, 45 plots, 17.84m radius, 1/10thha, 1 plot; Suwanee: 11.35m radius, ~1/25th ha, 30 plots; New Oriole Lake Grove: 11.35m radius, ~1/25th ha, 20 plots; total sampled area: ~6 hectares). Generally, a plot radius of 11.35m was used, with an increased radius of 17.84m used when seedling counts were sparse (i.e., entirety of Board Camp grove, when ≤2 seedlings were counted within initial 11.35m plot). Any tree less than 1.37m in height was considered a seedling, though no seedlings in these surveys exceeded 30cm tall. Given that (1) sequoias very rarely regenerate without fire (Haertsveldt et al., 1975, Shellhammer & Shellhammer, 2006), (2) severe fire likely killed all existing seedlings, and (3) the small stature of all the seedlings counted, the NPS were confident that all seedlings had recruited postfire. In Board Camp, since sampling occurred two years after the fire, existing seedlings could have established in the first year after fire (first cohort seedlings) or in the second year after fire (second cohort seedlings). At Board Camp, the NPS distinguished between cohorts based on the presence of cotyledon leaves, which can still be found on seedlings for some time after establishment. Based on the lack of cotyledon leaves on any Board Camp seedlings the NPS observed, the NPS found no evidence of second cohort seedlings in the Board Camp grove despite a robust sampling effort.

Our seedling surveys covered ~10.0%, ~4.3%, and ~5.5% of the total area in Board Camp, Suwanee, and New Oriole Lake groves, respectively. Within the much larger Redwood Mountain grove, ~1.5% of the high burn severity area was surveyed. Within the 20 plots in SQF (2020) fire affected Board Camp grove, the NPS counted 3221 seedlings across ~2.0 ha of census area. None of the seedlings were identified as second cohort (germinated the second year following fire) strongly suggesting very little additional regeneration in the second year after the fire. Within the 46 plots in Redwood Mountain grove, the NPS counted 19282 seedlings across ~1.9 ha of the ~350ha of high severity burn area. Within the 30 plots in Suwanee grove, the NPS counted 14239 seedlings across ~1.2 ha. Within the 20 plots in New Oriole Lake grove, the NPS counted 13025 seedlings across ~0.8 ha (Table 1). In general, seedling surveys within the KNP (2021) affected Redwood Mountain, Suwanee, and New Oriole Lake groves yielded substantially higher numbers than those at Board Camp, as expected given that Board Camp only had only first cohort seedlings that had experienced at least an additional 6 months of exposure to mortality.

Concern 4: What level of regeneration is considered sufficient to reestablish groves and why? A commentor thinks there is sufficient regeneration present. The NPS does not. Why?

Response: In order to evaluate whether measured seedling densities in the proposed replanting areas are sufficient to restore giant sequoias in these areas, the NPS compared survey results, which generated both a mean seedling density and were used to generate a probability of meeting a reference density, along with calculation of reference densities for giant sequoias from an analysis of 42 sites in eight different sequoia groves which burned in 26 different fires spanning a 48 year period in Sequoia and Kings Canyon National Parks (Stephenson et al. 2023, in prep). These plots were analyzed in the context of a stable stage population model initially generated by York et al. (2013) and reanalyzed in Stephenson et al. 2023 (in prep). These analyses indicate that approximately 60,000 sequoia seedlings per acre are needed the first year post-fire which drops to approximately 40,000 sequoia seedlings/acre the second year post-fire. The NPS' observed seedling densities in the proposed planting areas are nowhere near these values.

- "Post-fire reference densities for giant sequoia seedlings" has been approved by USGS, and has been made publicly available in a cite-able form on the EcoEvoRxiv preprint server here: https://ecoevorxiv.org/repository/view/5457/, and
- David Soderberg et al. applied some of the results in a key related manuscript on "Assessing giant sequoia mortality and regeneration following high severity wildfire," publicly available in a cite-able form here: https://ecoevorxiv.org/repository/view/5433/

Concern 5: NPS plots are too small. Therefore, NPS' conclusion that there is not enough reproduction is false.

Response: Plot sizes were large and were adjusted in the field to ensure that the NPS did not have a zero dominated dataset as can happen when measuring seedling densities because they are so patchy. The NPS used 11.75-meter diameter and 17.84-meter diameter plots. Smaller diameters were used if seedings were encountered within this radius. If 11.75-meter plots had zero seedlings, then the NPS increased the plot size to 17.84 meters in diameters. The NPS are aware of the methodological and analysis issues associated with using plots that are too small to capture the scale of natural variation in regeneration and the NPS designed the sampling and analysis approach to address these issues.

Seedling density is often highly variable in space and can be spatially clustered (see for example, Ziegler et al. 2017). There have been a number of analyses of the best way to sample spatially variable clumped distributions such as forest regeneration including Clark et al. 1999 and Hanson and Chi 2021. The general conclusions of these two studies and others that larger plots, more plots for a greater sample area, and samples distributed across multiple sites, for a longer duration improve the accuracy of the samples to estimate the population mean. USGS designed our sampling protocol to ensure that individual plots were large enough to capture regeneration and include the scale of natural variation, that samples were spatially balanced and randomly distributed within the proposed project areas, and that the total number of plots added up to a relatively large proportion of the area being sampled. Generally, plots are larger than many seedling regeneration plots (which can be as small as one meter square) and the NPS sampled a larger area in total than many previous studies. The NPS used such large plots because seedling regeneration in Board Camp (which the NPS sampled first) was so low and patchy. The sampling design and data analysis that the NPS used was provided by USGS for NPS and was peer-reviewed by USGS and found to meet scientific standards.

In total, NPS seedling surveys covered ~10.0%, ~4.3%, and ~5.5% of the total area in Board Camp, Suwanee, and New Oriole Lake groves, respectively. Within the much larger Redwood Mountain grove, ~1.5% of the high burn severity area was surveyed. Within the 20 plots in SQF (2020) fire affected Board Camp grove, the NPS counted 3221 seedlings across ~2.0 ha of census area. None of the seedlings were identified as second cohort (germinated the second year following fire) strongly suggesting very little additional regeneration in the second year after the fire. Within the 46 plots in Redwood Mountain grove, the NPS counted 19282 seedlings across ~1.9 ha of the ~350ha of high severity burn area. Within the 30 plots in Suwanee grove, the NPS counted 14239 seedlings across ~1.2 ha. Within the 20 plots in New Oriole Lake grove, the NPS counted 13025 seedlings across ~0.8 ha (Table 1). In general, seedling surveys within the KNP (2021) affected Redwood Mountain, Suwanee, and New Oriole Lake groves yielded substantially higher numbers than those at Board Camp, as expected given that Board Camp only had only first cohort seedlings that had experienced at least an additional 6 months of exposure to mortality.

Concern 6: Seeds are dispersed by more than wind, including by animals, and can come from a long distance. Thus, NPS' conclusion that regeneration will not occur because living trees are not close is false.

Harvey et al. (1980) intensively studied birds and small mammals within Kings Canyon and their impacts on sequoia seeds and seedlings. They also review other published literature regarding animal impacts to sequoia seeds and seedlings. For other than Douglas squirrel (discussed below), they conclude that "birds and mammals exert little effect on giant sequoia seeds either on the ground or on seedlings. The principal reason for this appears to be their small size." Thus, the NPS don't find evidence that seeds are likely to be carried long distances by birds or small mammals.

Harvey et al. (1980) has a full chapter on the relationship between Douglas squirrel and giant sequoia. Douglas squirrel have been observed cutting and caching large numbers of sequoia cones by numerous authors (reviewed in Harvey et al. 1980). In their extensive, multi-year study of Douglas squirrel use of giant sequoias, Harvey et al. (1980) found that, similar to other places where they occur, Douglas squirrels were territorial with the heart of their territories being 1-2 mature trees, typically a large white fir and a large sequoia. Territory size varied from 0.69 acres to wandering over 2 to 4 acres in a year when squirrel densities were particularly low. Squirrel caches were located at the base of the tree from which the cones were cut or in nearby wet areas. Thus, the likelihood of Douglas squirrels occupying these high severity areas where the majority of living trees are dead seems very low (there is not sufficient food in the form of mature, cone-bearing sequoias and other conifers) and the likelihood of squirrels creating caches in these zones of high tree mortality that are significant distances away from living trees also seems unlikely. Even in intact forest, given the patterns of Douglas squirrel caches (near the tree they were cut from or in close by wet areas) it seems unlikely that Douglas squirrels would disperse seeds long distances.

In NPS' field data collection, the NPS did observe high densities of seedlings in some drainage areas, indicating that seeds can be carried downstream longer distances and deposited in drainage areas. Unfortunately, many of these seedlings were already being undermined by scouring or buried by erosion, so these sites may not be viable long-term. See the summary above for evidence that vast majority of seed dispersal is local.

Concern 7: Seedling survival rates will be high because most seedlings will survive in high severity areas which have ideal conditions for regeneration. The commenter also states the NPS is using the wrong seedling survival rates to calculate how many seedlings you need to reestablish a grove.

Response: The NPS disagree that natural seedling survival rates in the large high severity fire areas that are proposed for replanting will be high. Although the NPS agree that previous studies have found that sequoia seedling survivorship was highest in areas that had been pile burned and were thus potentially similar to high severity wildfire, given the large size of these high severity areas, it is unknown what the impacts of these conditions will be on sequoia seedling survivorship. This issue was considered and summarized in Stephenson et al. 2023 (in prep) and is quoted here:

> Do NPS reference densities – which, of necessity, reflect the effects of past mixed-severity fires during a more climatically benign period – provide a useful yardstick for judging seedling densities observed after historically large and severe wildfires? More specifically, considering the high death rates of sequoia seedlings during their first years and decades after germination (Harvey et al. 1980, Harvey and Shellhammer 1991, Shellhammer and Shellhammer 2006, York et al. 2013a), do we have reason to believe that the low seedling densities found in the severely burned portions of Board Camp and Redwood Mountain groves might still be adequate to eventually replace the sequoia populations that were locally extirpated by the wildfires? The NPS addresses this question by considering expected sequoia seedling survival relative to (1) the size of fire-created forest gaps, (2) the presence or absence of a post-fire leaf litter mulch, and (3) a warming climate.

Relative to small fire-created gaps (<0.1 ha), Demetry (1995) found that sequoia seedlings had greater average size (and thus growth rates) in progressively larger gaps, up to ~1.2 ha in size (the largest gap she sampled). Seedlings with higher growth rates, in turn, have higher survival rates (Harvey et al. 1980, Harvey and Shellhammer 1991). Relative to mixed-severity fires of the past, can the NPS thus expect higher average seedling survival within the very large (e.g., >10 ha, and even >100 ha) gaps created by recent wildfires? Not necessarily. Snow accumulation and retention are usually maximized in forest gaps of intermediate sizes (e.g., up to ~1 to 5 ha) (Golding and Swanson 1978, Troendle and Meiman 1984, Stevens 2017), which in turn maximizes snowmelt moisture available to sequoia seedlings. In contrast, gaps that are larger than ~1 to 5 ha, and particularly the very large gaps created by recent severe wildfires, retain less snow and melt out earlier (Stevens 2017, Gleason et al. 2019, Smoot and Gleason 2021, Hatchett et al. 2023), lengthening and deepening the summer drought experienced by the sequoia seedlings that germinate in those gaps. The earlier snowmelt in these very large gaps will likely be amplified by a warming climate (see below). The more severe summer drought in very large gaps – induced by earlier snowmelt – could be further exacerbated by the reduced relative humidity and increased temperature, solar radiation, and wind speed found in gaps (Ma et al. 2010, Bigelow and North 2012, Wolf et al. 2021). Certainly, within the very large gaps created by recent wildfires there will be many scattered microsites capable of supporting rapid seedling growth and high survival rates, but this does not mean that, at the scale of the entire landscape, seedling densities lower than our reference densities can be assumed to be adequate to regenerate the locally extirpated sequoias.

Sequoia seedling survival is lower when the soil surface lacks a layer of leaf litter (Stark 1968). In the absence of litter, soil temperatures can be up to 10ºC to 15ºC higher, and soil moisture at 10 cm depth as much as 25% to 60% lower – conditions that will typically contribute to increased sequoia seedling deaths related to soil fungi, heat canker, and desiccation (Stark 1968, Harvey et al. 1980). In forest gaps created by crown scorch – that is, where most trees were killed by the convective heat of a surface fire – the dried leaves (needles) of the dead trees quickly begin to fall and create a new litter layer that contributes to seedling survival. These were the typical post-fire conditions in the plots used to derive our reference densities. In contrast, during the recent wildfires some areas of sequoia groves burned in large, historically unprecedented crown fires that consumed most of the forest canopy. In these crown fire areas, reduced post-fire litter accumulation could contribute to reduced seedling survival relative to the post-fire conditions upon which our reference densities were based (cf. Welch et al. 2016).

Finally, temperatures have been rising in the southern Sierra Nevada (Edwards and Redmond 2011, Das and Stephenson 2013) and are expected to continue to rise (Gonzalez 2012). Even in the absence of directional shifts in precipitation, warming has already contributed to earlier snowmelt at the elevations where giant sequoias occur (Andrews 2013, Mote et al. 2018), which in turn lengthens the summer drought experienced by sequoia seedlings. In addition to lengthening the summer drought, rising temperatures increase the atmosphere's evaporative demand for water, thus increase drought severity (Williams et al. 2015, Williams et al. 2022). Young sequoia seedlings today and in the future are thus expected to experience, on average, longer and more severe drought periods – and associated reductions in survival – than those that were censused for our reference densities.

Given the preceding considerations, and until any new, compelling evidence might suggest otherwise, the NPS find no reason to believe that the Board Camp Grove and Redwood Mountain Grove seedling densities, which are significantly lower than our reference densities, can be assumed to be adequate to regenerate the locally extirpated sequoia populations.

Finally, the NPS would add that the dataset that was used to generate the reference densities comes from eight different prescribed fires which burned with a range of fire intensity, resulting in a range of fire severity. So, the dataset used to generate these reference densities included both high, low, and moderate severity fire areas and was not focused on low severity fire.

Concern 8: What is the scientific basis for planting in October? Planting in October will greatly reduce survivorship.

Response: Once site assessments are completed and site planting plans finalized, the NPS would move forward with planting seedlings as soon as possible—in the following fall or spring season—to establish seedlings prior to extensive regrowth of dense, tall, uniform shrub cover with the intent of mimicking, as closely as possible, natural post-fire conditions under which sequoia and other mixed conifer seedlings thrive. For this reason, the NPS would consider planting in Redwood Mountain Grove, Board Camp Grove, and the fisher corridor immediately to the south of Redwood Mountain Grove (where analyses indicate action is both necessary and warranted) as early as fall 2023. For any of the replanting areas though, the NPS could plant either in late October, just before the season's first snow, or in early spring, as sites become accessible and when soil moisture is highest, to improve chances of planting success. Although conifers are most often planted in spring, with hotter, drier summers becoming more frequent (see Stephenson et al. 2023 in preparation), fall may be a more effective planting time since it avoids the summer drought. For this reason, the NPS could plant in fall and/or spring. If determined planting is appropriate under the decision tree, the NPS would likely plant in Suwanee, New Oriole Lake, Dillonwood, and Homer's Nose Groves in spring or fall of 2024 or 2025.

Concern 9: One commenter stated they had observed a lot of seedlings—more than enough to reestablish 2.61 mature sequoias per hectare. Therefore, the NPS does not need to replant.

Response: See discussions above regarding how the NPS established reference densities for giant sequoias.

Concern 10: High severity fire is common and part of the sierran ecosystem. Therefore, this fire was within natural range of variation, was good for the groves, and needs no human action to repair because there was no damage.

Response: While the NPS agrees that high severity fire is part of the pre-Euromerican settlement ecology of Sierra mixed conifer forest and giant sequoias groves in particular, the spatial extent of high severity fire effects seen in the Castle and KNP fires as well as many other fires in the Sierra Nevada within the past decade is outside of the natural range of variation for giant sequoia groves and threatens their ability to successfully re-establish post-fire. Fires before Euro American settlement generated a large matrix where fire effects were of low to moderate severity with small opening where high severity fire killed canopy trees. These gaps ranged in size from hundredths of a hectare to up to a few hectares in size (Stephenson et al. 1991, Stephenson 1994, Stephenson

1996). In such fires, many large living sequoias remained within the surrounding forest matrix to disperse seed into the fire-created gaps. In the Castle and KNP complex fire, large areas of high severity fire were created that contain no living sequoias (KNP BAER report and SEKI replanting EA). Additionally, three fires, the Castle, KNP, and Windy fires, killed approximately 13-19% of the entire large sequoia population (Shive et al. 2022), an unprecedented negative impact to the giant sequoia population. These impacts to a long-lived, fire adapted species such as giant sequoia can be characterized as negative. And as one of the purposes of Sequoia and Kings Canyon National Parks is to perpetuate giant sequoia groves and ensure their longevity for future generations, these impacts can certainly be characterized as negative and potentially in need of repair.

Additional evidence that these recent fires are not within the natural range of variation and are having detrimental effects on forest ecology are summarized below. Taken from Soderberg et al. (in review, 2023):

> "Throughout western North America, changes in land use patterns combined with the effects of severe drought – specifically, over a century of fire exclusion and large-scale tree mortality events – have led to shifts in forest structure and fire regimes throughout fire-prone forest ecosystems (Stevens et al., 2017, Parks & Abatzoglou, 2020, Hagmann et al., 2021). A resultant increase in ground and standing fuels, coupled with increasing temperatures and aridity, have facilitated an increase in wildfire-affected landscapes across the western United States (Westerling, 2016), with profound fire-induced changes within forest ecosystems of California (Safford et al., 2022). In recent years, the southern Sierra Nevada mountains of California have been impacted by multiple fires of large extent that contained large patches that burned at high severity (Steel et al., 2022).
>
> Two of the largest recent fires within the southern Sierra Nevada, the SQF- fire of 2020 and the KNP-Complex fire of 2021 (hereafter referred to as the "SQF" and "KNP" fires) had cumulative burn areas of ~106,000 hectares, of which ~47,000 hectares were classified as 'high severity' (MTBS; www.mtbs.gov). While fire is an important and natural process in fire adapted forest communities such as those in the Sierra Nevada (Stephens et al., 2007) – facilitating important ecosystem functions such as fuels reduction, landscape heterogeneity, and regeneration – large patches of high severity fire are not typical for mixed conifer forests and can lead to deleterious ecological outcomes, such as reduction of seed source, biodiversity, and wildfire and climate resilience (Cova et al., 2022). Large wildfires are not absent from the fire records of California forests, but the severity and scale of recent fire events have been outside the historical range of variation (Keeley & Syphard, 2021, Safford et al., 2022, Stephens et al., 68 2022). As such, these fires have had negative impacts on forest structure and ecosystem services, including for species of special interest such as the giant sequoia (*Sequoiadendron giganteum*) (Shive et al., 2022). "

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