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Giant sequoia regeneration in group selection openings in the southern Sierra Nevada

Scott L. Stephens[1,a,*], David J. Dulitz[b], Robert E. Martin[a]

[a]Department of Environmental Science, Policy, and Management, University of California, Berkeley, CA 94720, USA
[b]California Department of Forestry and Fire Protection, Mountain Home Demonstration State Forest, Springville, CA 93265, USA

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Abstract

Fire has been linked to the regeneration of giant sequoia (*Sequoiadendron giganteum*) [Lindley] Buchholz but no studies have directly investigated the effects of opening size and fuel treatment on giant sequoia establishment. Giant sequoia seedling density was analyzed in 36 group selection openings harvested in 1993 at Mountain Home Demonstration State Forest, CA. The experiment consisted of four replicates of a randomized 3 × 3 factorial design which investigated the effects of opening size and fuel treatment on giant sequoia regeneration. Small, medium, and large circular openings had average diameters of 15, 30, and 61 m, respectively. A total of 12 large, 12 medium, and 12 small openings were created. Three fuel treatments were randomly applied to the openings: tractor pile and burn, broadcast burn, and lop and scatter. Analysis of variance (ANOVA) detected no significant differences between treatments and seedling density ($p < 0.05$). All the treatments had low giant sequoia seedling density regardless of opening size or fuel treatment. Regeneration was completely absent in all openings with the lop and scatter fuel treatment while small openings had low giant sequoia regeneration density regardless of fuel treatment. Giant sequoia seedling density was low because of below average annual and summer precipitation following the creation of the openings and of low seed dispersal. The group selection silvicultural system attempts to simulate the structural complexity of the prehistoric, patchy, high intensity fire regime that once existed in the mixed-conifer forests of the southern Sierra Nevada but important ecosystem processes such as increased seed dispersal following patchy, high intensity fire and large scale nutrient cycling are not duplicated.

Keywords: Silviculture; Uneven-aged management; Fire ecology; *Sequoiadendron giganteum*

1. Introduction

Many studies of giant sequoia (*Sequoiadendron giganteum*) [Lindley] Buchholz regeneration have focused on the effects of fire (Biswell, 1961; Kilgore and Biswell, 1971) on this shade intolerant species (Stark, 1968; Harvey et al., 1980). Fire scar studies at Sequoia National Park, California, have demonstrated that pre-settlement (pre-1875) surface fires were once frequent with 2–3-year mean fire return intervals in small watersheds of approximately 80–100 ha (Kilgore and Taylor, 1979), and in another study, mean fire return intervals were 2.5–3 years in the giant sequoia groves at Mountain Home Demonstration State Forest,

*Corresponding author. Tel.: +1-805-756-2751; fax: +1-805-756-1402; e-mail: sstephen@calpoly.edu

[1]Present address: Natural Resources Management Department, California Polytechnic State University, San Luis Obispo, CA 93407. Tel.: 805-756-2751; fax: 805-756-1402; e-mail: sstephen@calpoly.edu

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Yosemite National Park, and Sequoia and Kings Canyon National Parks, California (Swetnam et al., 1992; Swetnam, 1993). These fires were typically low intensity with patches of high intensity intermixed (Muir, 1901; Stephenson et al., 1991). Frequent surface fires would keep average surface and ground fuel loads low. Patches of high intensity fire could be produced by the interaction of fire and large fuel loads produced by localized tree mortality caused by insects, disease, windthrow, and senescence.

Canopy openings are required for successful regeneration of shade intolerant species such as giant sequoia (Hartesveldt and Harvey, 1967; Harvey et al., 1980). Patchy, high intensity fires historically created openings in giant sequoia-mixed conifer forests of the southern Sierra Nevada and opening sizes have been estimated to average less than 0.08 ha. (Bonnicksen and Stone, 1982) or to vary from 0.1–0.4 ha (Stephenson et al., 1991). These estimates of opening sizes are probably low because successful regeneration is often limited to only a portion of a given opening, and, over time, the size of the openings may change (Stephenson, 1987). No studies have directly investigated the effects of opening size and fuel treatment on giant sequoia regeneration.

Giant sequoia seed dispersal is influenced by fire and mature trees can contain 2000 serotinous cones (Stark, 1968). Heat produced by surface and crown fires can scorch and kill the canopy and cones. Consequently, dead cones will open in the tree crown dispersing seed into the surrounding forest (Hartesveldt et al., 1975). Previous research has reported that fire injured branches can produce a 'virtual rain' of giant sequoia seeds from the once closed cones (Harvey et al., 1980).

Giant sequoia regeneration appears to occur in two steps: establishment and recruitment (Stephenson, 1994). Establishment refers to successful seed germination, rooting of the seedlings, and survival for the first few summers; recruitment refers to the growth of the seedlings into mature, seed producing trees. Summertime desiccation is presumed to be the main cause of giant sequoia seedling death, and seedling survival is greatest when the first few summers after germination are wet (Harvey et al., 1980; Stephenson, 1994).

Litter layers of 5 cm or larger will reduce giant sequoia seed germination dramatically (Hartesveldt and Harvey, 1967). The duff layer is a habitat for many damping-off diseases which can kill seedlings before they can become established (Parmeter, 1985; Piirto, 1994). After a surface fire has burned over an area, many giant sequoia seedlings may become established (Kilgore and Biswell, 1971) but recruitment will occur only if the specific site has the appropriate environmental conditions. Seedling survival has been observed to be more than 10 times greater in areas that have burned in high severity fires because the reduction in overstory cover and production of bare mineral soils (Harvey et al., 1980; Harvey and Shellhammer, 1991).

Canopy openings can also be created mechanically in giant sequoia groves. The group selection silvicultural system creates relatively small openings in the forest canopy. In California, maximum group size is typically 0.8 ha (McDonald et al., 1997). Group selection generally favours shade intolerant species but if the openings are small, intermediate or shade tolerant species may dominate.

Natural seedling growth in group selection openings may be affected by the size of the opening. In a study in the northern Sierra Nevada with openings of 9, 18, and 27 m in diameter, regeneration in the small openings was dominated by shade tolerant species such as white fir (*Abies concolor*) [Gord. and Glend.]Lindl (McDonald and Abbott, 1994). Height of 9-year old seedlings in ascending order for all openings was incense cedar (*Calocedrus decurrens*) [Torr.] Floren, ponderosa pine (*Pinus ponderosa*) Laws, sugar pine (*Pinus lambertiana*) Dougl., Douglas-fir (*Pseudotsuga menziesii*) [Mirb.] Franco, white fir, hardwoods, and shrubs (McDonald and Abbott, 1994). The opening sizes in this study were small but significant differences in growth were detected between species. Shade intolerant species were rare or absent in the smaller openings. In another study in north-central California, opening size, in general, had little effect on species presence within an opening (McDonald et al., 1997) indicating regeneration may be site or species specific. More research is needed to understand the regeneration dynamics in group selection openings.

Giant sequoia have also been regenerated artificially in group selection openings in the northern Sierra Nevada. Seedlings planted 10–15 years ago in 0.4 ha circular openings have outgrown all other mixed conifer associates (B. Heald, pers. commun., 1997). Average height growth is 50% greater than the nearest competitors (ponderosa and sugar pines), while giant sequoia growth triples or even quadruples the other native mixed conifers. Young-growth giant sequoia at Mountain Home Demonstration State Forest have also outgrown all other mixed conifer species (Dulitz, 1985; Gasser, 1994).

The objectives of this paper are to analyze natural giant sequoia regeneration resulting from a group selection silvicultural system and to determine if opening size and fuel treatment effects seedling establishment.

2. Study location

The group selection openings were created at the California Department of Forestry Mountain Home Demonstration State Forest, Tulare county, California. Two locations were used in the study, Fraiser Mill and Rockcrusher. Fraiser Mill is located on a southwestern aspect with 10–40% slopes, T19S R30E NW 1/4 of section 36, latitude 36°14′, longitude 118°41′, at an elevation of approximately 1950 m. The Rockcrusher site is located on a southwestern aspect with 10–40% slopes, T19S R31E SW 1/4 of section 31, latitude 36°13′ 30″, longitude 118°40′, at an elevation of approximately 2070 m. Mountain Home is located in the southern Sierra Nevada, approximately 10 km northeast of Springville, California. The giant sequoia-mixed conifer forest in this area is composed of giant sequoia, sugar pine, ponderosa pine, white fir, incense-cedar, and California black oak (*Quercus kelloggii* Newb.).

3. Methods

The experiment involved crossed treatments of opening size (three levels) and fuel treatment (three levels) on giant sequoia regeneration density. Four replicates of each opening size class/fuel treatment combination were produced. Group selection openings were harvested in the giant sequoia-mixed conifer forest with a restriction that no old (trees older than 100 years) giant sequoias could be harvested to create an opening. Other constraints included selection of areas with similar aspects and topography, the need of providing adequate areas of live trees between units for isolation, and no opening was installed in an area that was not forested by mature trees. The dimensions of each opening was measured using a 50 m tape. Opening characteristics are summarized in Table 1.

Table 1
Group selection opening characteristics

Opening classification	Average diameter (m)	Diameter range (m)	Opening area (ha)
Small	15	13–18	0.01–0.025
Medium	30	25–35	0.05–0.1
Large	61	51–71	0.2–0.5

Trees were marked for harvesting and removed by a commercial logger in the summer and fall of 1993. All group selection openings had 2–5 mature giant sequoia trees located on the perimeter of the opening. Three fuel treatments were randomly applied to the openings: tractor pile and burn, broadcast burn, and lop and scatter. Fuel treatments were applied in the fall of 1993.

All group selection openings were placed within the Fraiser Mill and Rockcrusher units. These two large units are located approximately 1 km apart on similar aspects, slopes, and elevations. The Rockcrusher unit has eight large, seven medium, and eight small openings and the Frasier Mill unit has four large, five medium, and four small openings. A total of 12 large, 12 medium, and 12 small group selection openings were created.

Natural regeneration density of giant sequoia was measured in the fall of 1995 (two growing seasons after opening creation) in each of the openings. Circular plots with a diameter of 12 m (0.011 ha) were used to sample giant sequoia regeneration. Each large, medium, and small opening had five, three, or one circular plots randomly placed within the opening, respectively. Giant sequoia seedlings were counted in each plot and average seedling density (seedlings/ha) was calculated (Table 2). Two factor ANOVA was used to determine if significant differences exist in seedling density ($p < 0.05$). The factors investigated were opening size and fuel treatment.

Precipitation data collected from 1980–1997 from the closest weather station at the Mountain Home Conservation Camp were analyzed to determine if the post harvest period was wetter or drier than average. This weather station is located approximately 2.5 km west of Mountain Home Demonstration State

Table 2
Giant sequoia seedling density (seedlings/ha) from openings created at Mountain Home Demonstration State Forest, California

Opening size	Fuel treatment		
	Broadcast burn	Tractor pile and burn	Lop and scatter
Small	0	0	0
	0	29.5	0
	0	0	0
	0	0	0
Medium	0	0	0
	110.6	22.1	0
	22.1	22.1	0
	22.1	0	0
Large	0	53.1	0
	17.7	17.7	0
	0	0	0
	141.5	0	0

Forest at an elevation of 1370 m. Average annual precipitation and average precipitation after May 14 were computed. Precipitation data from 1970–1997 at the General Grant giant sequoia grove, Kings Canyon National Park, California, located approximately 65 km north of Mountain Home at an elevation of 2010 m were also analyzed to determine annual and summer precipitation.

4. Results

Broadcast burn and tractor pile and burn fuel treatments consumed approximately 80–90% of natural and activity fuels within the openings, some large fuels with diameters over 25 cm were not completely consumed but small diameter fuels and the forest floor were consumed. The lop and scatter fuel treatment did not displace the duff and litter layers but increased surface fuel loads within the group because of the addition of activity fuels. A fuel height of approximately 0.75 m was produced in the openings by the lop and scatter fuel treatment.

All openings had low giant sequoia seedling density regardless of opening size or fuel treatment (Table 2). Giant sequoia regeneration was absent in all the openings with the lop and scatter fuel treatment and small openings had low giant sequoia regeneration regardless of fuel treatment. Giant sequoia seedling density varied from 0 seedlings/ha to 141.5 seedlings/ha. ANOVA detected no significant differences between treatments and seedling density ($p = 0.35$ for opening sizes, $p = 0.12$ for fuel treatments, $p = 0.62$ interaction).

Precipitation from 1 August to the following 31 July averaged 101.3 cm at the Mountain Home Conservation Camp from 1980–1997 (Fig. 1). Precipitating the year following the harvest (1994) was 75.4 cm which is 74% of the average from 1980–1997 (Table 3). Precipitation from 14 May to 31 August of the same calendar year from 1980 to 1997 averaged 3.4 cm, and in 1994, 1.7 cm of precipitation occurred in this period which is 50% of the average (Fig. 2).

5. Discussion

Giant sequoia seedling density was low because the year following the creation of the openings had below

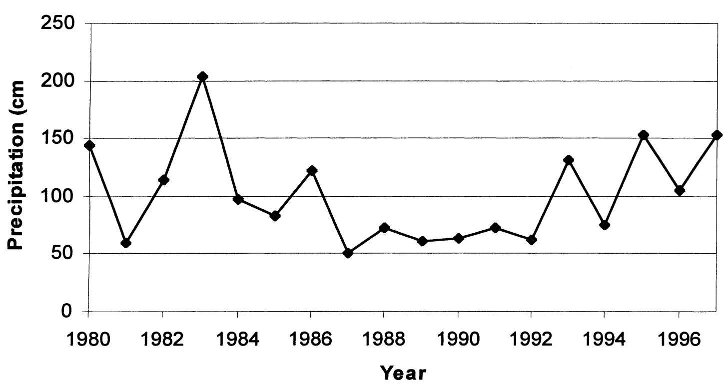

Fig. 1. Precipitation from 1 August to the following 31 July at the Mountain Home Conservation Camp, California.

Table 3
Precipitation at the Mountain Home Conservation Camp, California

Year	Precipitation 8/1–7/31 (cm)	Precipitation 5/14–9/1 (cm)
1980–1997	101.3 (100)[a]	3.4 (100)[a]
1994	75.4 (74.4)	1.7 (50)
1995	152.9 (150.9)	10.8 (317.8)
1996	104.9 (104)	2.2 (64.3)[a]

[a] average value from 1980–1997.
Percent of average.

average annual and summer precipitation and based on field observations, only a small amount of seeds were released by mature giant sequoia trees that were adjacent to the openings. Partially burned litter and duff layers can also provide a good seed bed for giant sequoia seedlings indicating complete combustion of the forest floor in the openings is not a requirement for successful seedling establishment (Stark, 1968).

Broadcast burn and tractor pile burn fuel treatments produced openings with bare mineral soil but the fire treatments used did not produced enough heat to scorch the crowns of the adjacent, giant sequoia trees. Some giant sequoia seed was probably released as cones naturally opened but large amounts of seeds were not released because the crowns were not affected by the fuel treatments.

This contrasts with giant sequoia seedling establishment that occurred in openings created by the Deer Creek prescribed natural fire, Sequoia National Park, California. This fire was ignited by a lightning strike on September 28 and burned until mid-November, 1991. The fire burned into the East Fork giant sequoia grove and some areas of the grove burned with high intensity and several large giant sequoias were scorched to a height of 30 m. After the fire, a giant sequoia seed layer of up to 4 cm deep was observed by the senior author near three large, scorched, giant sequoia trees within an area of approximately 1.5 ha.

In the fall of 1993, 10 0.1 m^2 square plots were randomly placed in two areas that experienced a localized, high intensity fire next to a mature giant sequoia tree. Seedlings were counted in the plots and seedlings density was calculated; combining the measurements from the two areas resulted in giant sequoia seedling density of 119–151 seedlings/m^2 (1.19×10^6–1.51×10^6 seedlings/ha). Giant sequoia seedling densities of 1×10^5/ha have previously been reported following heat-induced seed fall from a high intensity fires in the southern Sierra Nevada (Hartesveldt et al., 1975).

The size of the canopy openings created by the Deer Creek prescribed natural fire were approximately 0.15 ha which is within the range created by the group selection operation and is within the distribution hypothesized by Stephenson (1994). All trees within these openings (primarily white fir) were killed by the fire and most of them were standing snags.

Average annual precipitation at the General Grant giant sequoia grove from 1970–1997 was 110.42 cm, average precipitation from 6/1 to 9/1 over the same

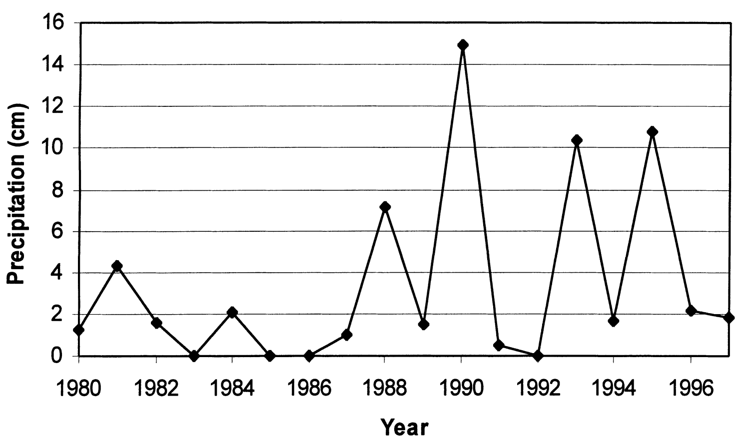

Fig. 2. Precipitation from 14 May to 31 August of the same calendar year at the Mountain Home Conservation Camp, California.

period was 0.80 cm. Annual precipitation in the General Grant location in 1991 was 103.56 cm which is 93.8% of average, and summer precipitation in 1991 was 0.80 cm which is 92.7% of average. Therefore, 1991 was an average year in annual and summer precipitation at the General Grant location.

The openings created by the Deer Creek prescribed natural fire were on a northern aspect which could have reduced summer transpiration and local summer thunderstorms may have contributed more precipitation as compared to the General Grant grove area which is at a similar elevation but is approximately 40 km northwest of the East Fork grove. Summer desiccation has been noted as an important factor in giant sequoia seedling survival (Harvey et al., 1980; Stephenson, 1994), but the northern aspect in the East Fork grove probably reduced this effect.

The creation of the openings by the patchy, high intensity fire, coupled with heavy giant sequoia seed dispersal produced the abundant giant sequoia establishment in the East Fork giant sequoia grove. Average annual and summer precipitation the year following the fire probably did not produce extensive seedling desiccation because of the northern aspect. This is in contrast to the giant sequoia seedling density that occurred on southwest aspects in the group selection openings at Mountain Home which was a maximum of 0.01% of that measured in the openings created by the Deer Creek prescribed natural fire.

High intensity prescribed fire treatments could be applied in conjunction with a group selection silvicultural operation to scorch the crowns of mature giant sequoias. However, most forest management operations would probably not use high intensity fire treatments in conjunction with group selection because of the associated risk and damage to residual trees. Without significant crown scorch, however, giant sequoia establishment may occur at low densities. Artificial regeneration would be the preferred method of regeneration in the openings created by a group selection system without the use of patchy, high intensity prescribed fire.

The group selection silvicultural system is a simplification of the natural fire regime that once existed in these ecosystems. Ecosystem processes such as the combustion of duff, litter, and dead and down fuel over large spatial areas, which increases available nutrients, are approximated only in the relatively small openings that included fire treatments. Group selection systems also do not affect the trees surrounding the openings, but a commercial or pre-commercial thinning operation could be used to reduce tree density near the openings. The thinning operation should also include a prescribed fire treatment to recycle nutrients and to consume surface fuels which will reduce the potential for a large, high intensity wildfire (Stephens, 1998). The use of group selection silvicultural systems alone will not reduce the potential of a large, high intensity wildfires because only a relatively small amount of the landscape will be treated at each cutting cycle and treatments that do not reduce surface and activity fuels within the group will make the fire situation more severe (Stephens, 1998).

6. Conclusions

Giant sequoia seedling density at Mountain Home Demonstration State Forest was low because the year following the creation of the group selection openings had below average annual and summer precipitation and only a small amount of seed was dispersed by adjacent giant sequoia trees. Regeneration was completely absent in all the openings with the lop and scatter fuel treatment while small openings had low giant sequoia regeneration density regardless of fuel treatment. Artificial regeneration would be the preferred method of regeneration in the openings created by a group selection system without the use of patchy, high intensity prescribed fire.

The group selection silvicultural system is a simplification of the natural fire regime that once existed in the giant sequoia groves of the southern Sierra Nevada. The use of group selection silvicultural systems alone will not reduce the potential of a large, high intensity wildfires because only a relatively small amount of the landscape will be treated at each cutting cycle.

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