22 Ecological restoration in a giant sequoia grove

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Background

The Giant Forest sequoia grove in Sequoia and Kings Canyon national parks, California, is one of the largest and most accessible of the 75 groves. It contains several of the largest trees in the world and is experienced by over 1.5 million visitors each year. To serve visitors, a small city was built in the grove in the early 20th century. Recreational use began in 1903 with the completion of a road connecting the Sierra foothills with Giant Forest, which is at an elevation of 6,500 ft. Visitation to the grove increased dramatically over the next three decades, necessitating the development of an infrastructure that, by 1930, amounted to four campgrounds, numerous parking lots, water and sewage systems, a gas station, corrals, restaurants, offices, retail sales outlets, and over 200 cabin and tent-top lodging structures (Dilsaver and Tweed 1990). These crowded conditions began to impair the scenery and serenity of Giant Forest and to damage the giant sequoia ecosystem. By 1930, park managers began to call for removal and relocation of visitor facilities. In 1997, the removal of facilities from Giant Forest began.

The primary impacts to the forest after a century of human development include the following: modification of landforms; topsoil erosion, loss of organic matter, and compaction; absence of surface litter and duff layer; thinning of and distinct openings in forest overstory; absence or low density of forest understory, including grasses, forbs, shrubs, and tree seedlings; and probable absence or depletion of the soil seed bank (Hartesveldt 1965; Demetry 1997).

Restoration objectives and procedures

Demolition of facilities. The first objective was to demolish and remove infrastructure without causing further damage. To date, 282 buildings, 24 acres of asphalt, dozens of manholes, and all exposed sewer and water pipe, underground propane tanks, and aerial utility lines have been removed. Demolition will be complete in 2002. The extent of demolition accomplished through 2000 is shown in Figure 22.1.

Demolition was accomplished by contractors using either heavy equipment or, in sensitive areas, smaller equipment or hand tools. To protect soils and vegetation, contractors were required to install fencing around sensitive sites and residual vegetation. Travel routes were designated on contract drawings to constrain equipment travel and minimize soil compaction. The most effective mechanism for resource protection was a contract provision that assessed monetary damages for causing injury to trees, soils, or vegetation. Daily oversight of operations was provided by a park restoration ecologist.

To protect shallow roots, underground pipes were left in place unless portions were exposed during demolition. In such cases they were removed to 2 ft below the surface and plugged with concrete to prevent channeling of groundwater through the pipes. Manholes were removed completely, if possible. If more damage would occur by removal, the concrete was demolished to 2 ft below the surface, and the remaining

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concrete fractured prior to backfilling to allow water to drain through. Utility attachments to live trees were removed where it could be done without further damage to the tree. Where removal might cause injury, protruding parts were cut flush with the tree and the bracket left in place.

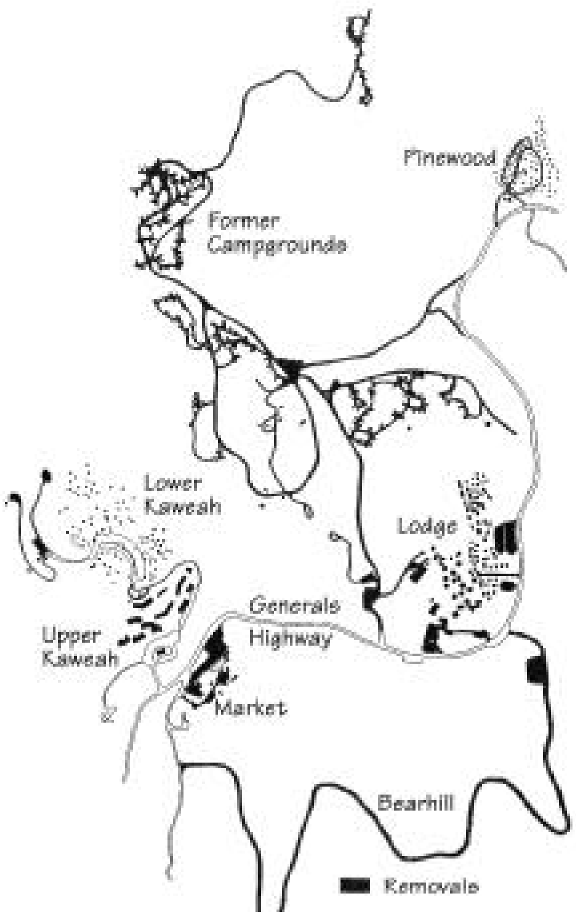

Figure 22.1. Development removed from Giant Forest through 2000 (except Bearhill).

Landform and soils. Objectives for restoring landforms and soils were the following:

1. Re-establish natural contours and drainage patterns by rebalancing cuts and fills with existing soils;
2. Where extant soil is insufficient to restore the landform to a condition that mitigates drainage problems, use other fill in deep layers only, reserving local soil for topdressing; and

3. Restore soil properties to approximate those of surrounding, undisturbed soils. Soil amendments were used with the objective of restoring soil properties rather than accelerating plant growth.

The most severely impacted soil properties were compaction, alteration of aggregate structures, and loss of topsoil organic matter (Demetry 1997). To decompact soils and convert platy and blocky aggregate structures to natural crumb or granular structures, moist soils were cultivated to a depth of 5 to 8 inches. Cultivation was conducted outside the driplines of mature trees and was halted or made shallower if major roots were encountered. To mitigate loss of organic matter in the topsoil, highly decomposed forest bark humus was added to the soil during cultivation in some locations. Contractors conducted soil tests to determine application depth of humus necessary to raise organic matter content to 7-10% by weight. If soil tests indicated that organic amendment would increase the C:N (carbon-to-nitrogen) ratio outside the range seen in reference sites (approximately 30:1), nitrogen fertilizer as slow-release urea or ammonium sulfate was added during cultivation.

Loosened soils were protected with wood chip mulch, soil retention blankets, or native litter and duff, which was salvaged prior to demolition if present or was collected from surrounding areas for restoration of linear features such as roads and trails.

Vegetation. The short-term goal of vegetation restoration in Giant Forest Village is to reproduce the species composition, species density, and spatial pattern of regeneration that would result from a natural fire. The long-term goal is to integrate the site into the natural fire regime typical of surrounding areas of Giant Forest. By ensuring a vegetation structure similar to surrounding sites after one fire, the park maximizes the success of this integration.

This goal uses a natural-disturbance model to define a reference condition for ecological restoration. The model was identified by looking to the surrounding ecosystem for a natural-disturbance condition which resembles the human disturbance that has taken place. In Giant Forest Village, the forest consists of a matrix of mature canopy interspersed with openings, or gaps, where patches of trees were cleared for buildings and parking lots. This condition is similar to areas in undeveloped portions of Giant Forest where prescribed fire has killed patches of mature trees, creating gaps colonized by even-aged patches of shrub and tree regeneration, particularly giant sequoia. Most regeneration following fire occurs as a pulsed, even-aged cohort within gaps, with little regeneration beneath intact canopy. This provides an analogous condition for a revegetation approach where planting is restricted to gaps and conducted within a short time period with one- to two-year-old stock.

This reference condition was quantified in 1994 by mapping and measuring woody vegetation in 18 fire-caused gaps, 7 to 15 years following fire. Gap size was found to account for a significant amount of variability in density, growth rate, and cover of pioneer-type tree and shrub species. More detail is available in Demetry and Duriscoe (1996) and Demetry (1998). Grasses and forbs were found to be a minor component of the vegetation and were not mapped.

Adaptive management. Because of the duration and severity of impacts to developed areas, the park believed that some degree of human intervention was necessary for the recovery of the site. Evidence for this view lies in some formerly developed areas within the grove that were abandoned over 30 years ago and show little natural recovery. However, it was also hypothesized that an acceptable restoration of vegetation might be achieved through less intensive and intrusive means than the seed collection, propagation, planting, seeding, and irrigation process traditionally practiced in the Park's frontcountry revegetation projects. To address this possibility, an adaptive management approach was proposed. The goal of adaptive management was to apply different degrees of active restoration in an experimental manner to determine the minimal intervention necessary to meet the standard reference condition of natural vegetation in fire-caused gaps. Because restoration goals had been quantified, a solid reference condition existed for comparison and evaluation of treatments, making the project an especially good candidate for adaptive management. Experimental treatments were to be applied in early phases of the project and the newly acquired knowledge applied to later phases. Experiments would be carried out at the scale of the gap to best integrate experimentation with management goals.

Three levels of vegetation restoration in Giant Forest Village are being tested, in order of increasing human intervention:

1. *Restore soil only.* In this option, actions are limited to regrading, amending soils in highly disturbed sites, cultivating, and mulching with litter and duff or wood chips. This is considered the minimal treatment. It was used in four experimental gaps in highly disturbed sites, and also in non-gap areas, former campgrounds abandoned for 30 years or more, and in narrow linear road corridor and trail disturbances through established forest.
2. *Restore soil and then burn.* In addition to actions from treatment (1), in this option a light fire fuel bed and several large slash piles were imported and burned with the intent of releasing sequoia seed and scarifying the seed bank. Treatment (2) was used in four experimental gaps in highly disturbed sites.
3. *Restore soil and then plant.* In addition to actions from treatment (1), in this option active planting occurred. Trees, shrubs, grasses, and forbs were propagated from local stock and planted in gaps using prescriptions formed from fire-caused reference gaps (Demetry 1998). Gaps are irrigated for 2 to 3 years to enhance survival. Trees (4 species) were planted as 1- or 2-year bare-root or 1-gal containerized stock, shrubs (12 species) were planted as 10 cu-in leach tube or 1-gal containerized stock, and grasses and forbs (9 species) were seeded or planted as plugs. Treatment (3) was used in the majority of gaps in highly disturbed sites, as it was considered to have the highest probability of success.

The original experimental design for the adaptive management trials called for seven replicates of the three treatments within blocks of gaps of similar size, location, and site conditions, all to be restored in the same year. However, this design was altered in response to funding limitations, contracting constraints, changes in project scope and phasing, and the desire of management to keep the "restore soil" treatment restricted to lower-visibility sites. The number of replicates was reduced to four, resulting in lower statistical power to detect differences when they truly exist. "Plant" and "burn" treatments were applied in 1998 and 1999 in the Lodge site, and the "restore soil" treatment was applied in 2000 in former campground sites (Figure 21.1), resulting in the confounding of treatment effects with year and site effects. It is therefore not possible to attribute causation to treatment alone. However, because it is the goal that any treatment–site–year combination should meet the standard reference condition of vegetation in fire-caused gaps, we believe useful information will still be obtained.

Experimental design and monitoring

Adaptive management trials were conducted to compare vegetation resulting from the three restoration treatments described above and to compare soil properties resulting from the soil amendment treatment with control, pre-restoration, and reference soils.

Restoration treatments were applied in a randomized complete block experimental design with gap size as the blocking factor; there were 4 replicates for each of 3 treatments for a total sample size of 12. Demetry and Duriscoe (1996) found that gap size is a significant source of the variability shown by species densities and heights within gaps; this variability can be accounted for by blocking on gap size. Gaps within size-blocks were randomly selected and assigned to treatments.

To obtain early feedback on treatments, vegetation within the four gaps in each restoration treatment was sampled one growing season after treatment. Grass, forb, shrub, and tree density and cover were sampled within randomly located 1x1-m quadrats, with one quadrat for every 100 sq m of gap area. Number of quadrats per gap ranged from 7 to 40. Data from the quadrats were summed and averaged to arrive at the mean grass, forb, shrub, and tree density and cover for each gap. "Restore soil" gaps were treated in summer 2000, so results for one growing season will not be available until after 2001. Results reported here are for the 8 gaps in the "burn" and "plant" treatments, which were treated in 1998 and 1999.

The soil amendment treatment was applied in a split-plot experimental design in three Lodge gaps receiving the "plant" treatment. In half of each gap, a 0.5-in layer of forest bark humus was spread over the soil surface and mixed in to a depth of 5 in during the cultivation process. Slow release urea (38-0-0) was added at a rate of 20 lbs per 1,000 sq ft to rebalance the C:N ratio to approximately 35:1. The other gap-half was cultivated to a depth of 5 in as a control. In October one year after treatment, samples from the A1 horizon were collected from three locations in each gap-half, mixed, and analyzed for total organic matter. Surface compaction was measured with a soil penetrometer at 20 locations per gap-half in a grid pattern. Soils in amended and control halves of gaps were compared with samples taken in 1996 from the A1 horizon of the same Lodge sites prior to demolition and from natural reference sites.

The Wilcoxon test was used (Siegel 1956; Snedecor and Cochran 1989) as the non-parametric analogue of the paired-samples t-test to detect significant differences between "burn" and "plant" treatment gap vegetation and among reference, pre-restoration, not amended, and amended soils. The probability of type I error was controlled at $\alpha = 0.10$.

In addition to sampling vegetation in quadrats, all planted trees and shrubs in a random sample of "plant" treatment gaps were tagged and measured to provide survivorship and growth data.

Results and discussion of restoration treatments

Grass density was significantly higher in planted gaps than in burned gaps (Figure 22.2, top). No significant differences were detected between forb, shrub, and tree density in planted gaps and burned gaps. Both planted and burned gaps had higher shrub and tree densities than did reference gaps (statistical comparison with reference gaps won't be made until 5 years after treatment), suggesting that both treatments may be successful in achieving woody plant densities typical of fire-caused gaps.

Comparison of plant cover and tree height in planted and burned gaps shows that planting has accelerated vegetative recovery, with significantly greater grass, shrub, and tree cover in planted gaps than in burned gaps (Figure 22.2, bottom). Mean tree height in planted gaps (22 cm) was greater than that in burned gaps (approximately 3 cm), and is approaching mean tree heights in reference gaps (37 cm). Photos taken before and after treatment show woody vegetation visible in planted gaps and not yet visible in burned gaps (Figure 22.3).

Surface compaction in cultivated/amended soils was significantly lower that that in cultivated/not amended and pre-restoration soils, but was still 3.3 times higher than that in reference site soils (Figure 22.4, top). Percent organic matter in cultivated/amended soils was significantly higher than that in cultivated/not amended soils and pre-restoration soils, and no significant difference was detected between organic matter content in amended soils and reference sites (Figure 22.4, bottom).

For soils in a later phase (Upper and Lower Kaweah sites) in which organic matter contents were raised to a mean of 6.4% compared with the mean of 5.9% in the Lodge sites shown here, 1-year soil compaction was only 2.7 times greater than that at reference sites. Data not shown here indicate that loose soils immediately following cultivation become more compact during the following year. The organic amendment may help to maintain soil porosity and keep soils from re-compacting to pre-restoration levels.

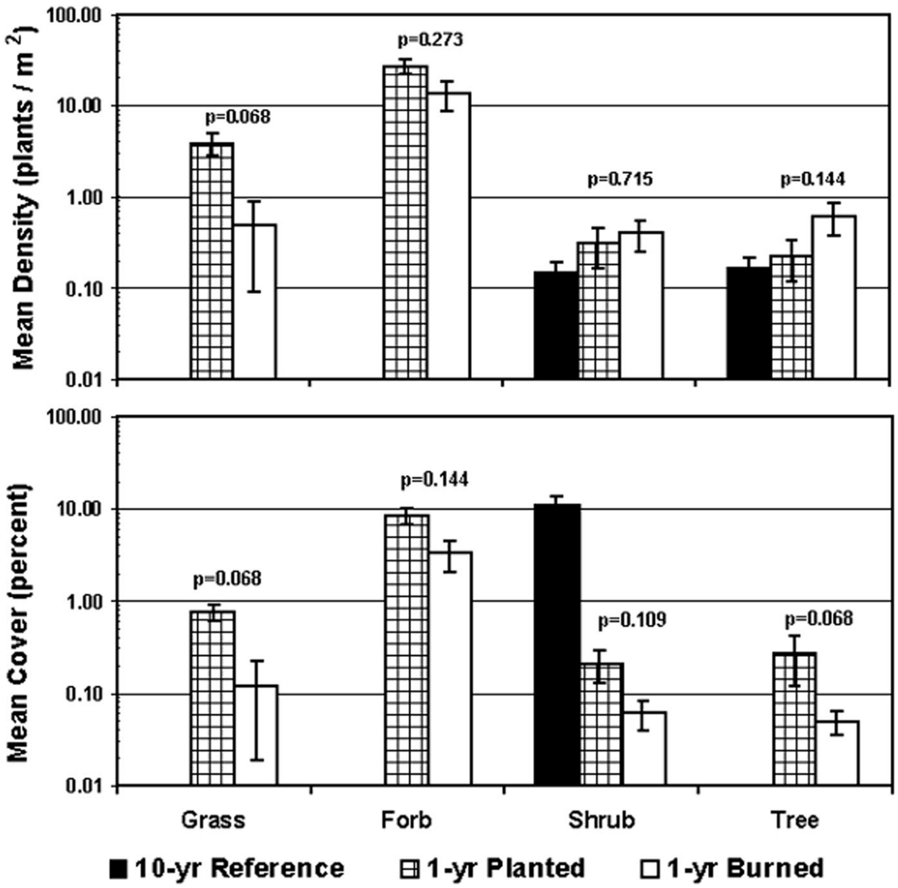

Figure 22.2. Mean density (top) and mean cover (bottom) of grasses, forbs, shrubs, and trees in fire-caused reference gaps approximately ten years after fire (woody species only), and planted and burned gaps one growing season after treatment. For 10-year reference gaps, tree success was also measured as tree height for which mean in reference gaps = 37 cm, mean in 1-year planted = 22 cm, mean in 1-year burned = approximately 3 cm. Error bars show ± one standard error of the mean. P-values shown are results of Wilcoxon tests for paired comparison of planted and burned gaps (see text).

First-year survival of planted trees in the Lodge and Upper and Lower Kaweah sites ranged from 79% for white fir to 100% for incense cedar. First-year survival of planted shrubs ranged from 48% for whitethorn to 100% for mountain dogwood, bitter cherry, and Sierra gooseberry (Table 22.1).

Long-term success of restoration treatments and comparison with reference conditions will continue to be monitored and evaluated at 2, 3, 5, and 10 years after treatment. We expect that the planting treatment might accelerate recovery such that vegetation in planted gaps 5 years after treatment is similar to vegetation in fire-caused gaps 10 years after fire.

Figure 22.3. Top left: Lodge amphitheater site before restoration. Bottom left: Lodge amphitheater site one year after planting treatment. Top right: Lodge cabin site before restoration. Bottom right: Lodge cabin site one year after burn treatment.

In retrospect, it is recommended that unless there is direct control by resource managers over implementation of experimental treatments on similar projects, a better approach to determining the outcomes of different restoration strategies would be to conduct controllable experiments at a smaller scale well in advance of an actual large-scale restoration. However, when constraints are imposed such that pilot experiments are not possible, careful documentation, monitoring, and analysis of restoration treatments applied during project implementation still allow us to learn about the success of those treatments.

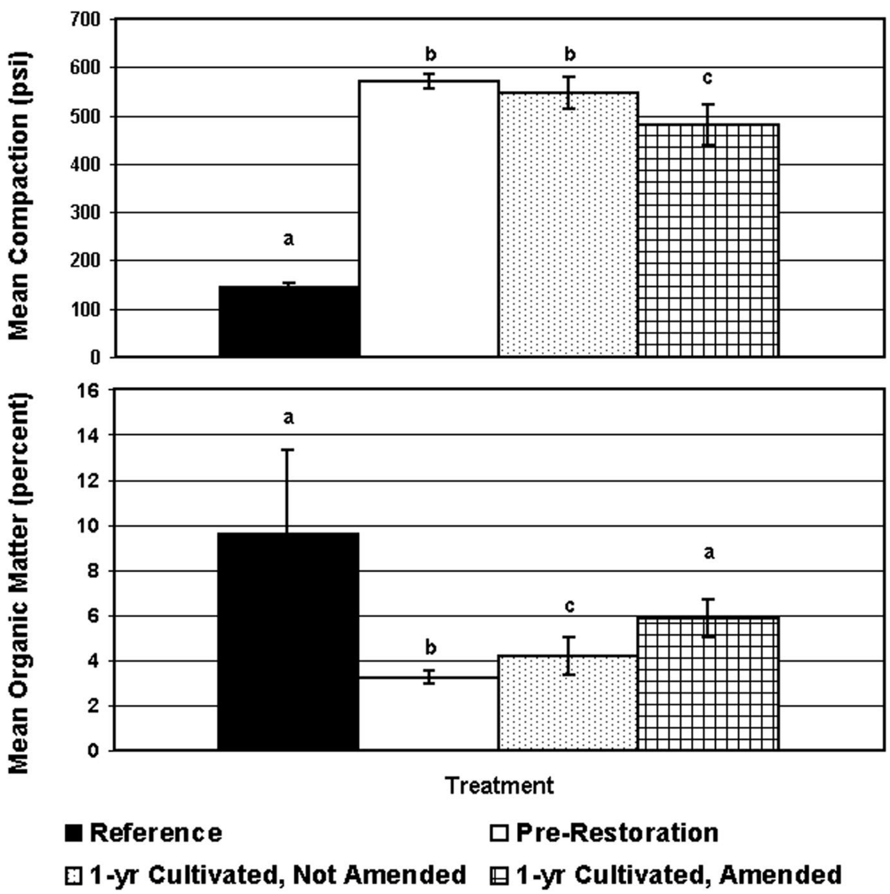

Figure 22.4. Mean surface soil compaction (top) and mean organic matter (bottom) in fire-caused reference gaps approximately ten years after fire, restoration gaps prior to restoration, cultivated but non-amended halves of restoration gaps one year after restoration, and cultivated and amended halves of restoration gaps one year after restoration. Error bars show ± one standard error of the mean. Significant differences resulting from Wilcoxon test for paired comparison of treatments are indicated by different letters (see text).

Name	*Type of stock*	*Number planted*	*Survival rate, 1-year*	*Mean annual growth, Year 1*
white fir *Abies concolor*	bare-root	199	0.79	1.6
incense cedar *Calocedrus decurrens*	bare-root	91	0.91	2.7
	1-gal	9	1.00	1.6
sugar pine *Pinus lambertiana*	1-gal	59	0.83	2.3
giant sequoia *Sequoiadendron giganteum*	bare-root	2,684	0.90	1.3
	1-gal	419	0.90	1.6
greenleaf manzanita *Arctostaphylos patula*	leach tube	108	0.82	10
	1-gal	121	0.93	-97
whitethorn *Ceanothus cordulatus*	leach tube	617	0.48	61
	1-gal	98	0.52	-68
littleleaf ceanothus *Ceanothus parvifolius*	leach tube	30	0.70	254
chinquapin *Chrysolepis sempervirens*	1-gal	7	0.57	-210
mountain dogwood *Cornus nuttallii*	leach tube	16	1.00	50
	1-gal	5	1.00	-37
bitter cherry *Prunus emarginata*	leach tube	11	1.00	-2
Sierra currant *Ribes nevadense*	leach tube	59	0.86	26
	1-gal	28	0.96	-309
Sierra gooseberry *Ribes roezlii*	leach tube	42	1.00	192
	1-gal	30	0.97	1,360
western raspberry *Rubus leucodermis*	leach tube	40	0.83	413
creeping snowberry *Symphoricarpos rotundifolius var. parishii*	leach tube	83	0.76	138

Table 22.1. Survival rate and mean annual growth of planted stock after one growing season for stock planted through spring 2000 in 16 monitoring gaps in Lodge and Upper and Lower Kaweah. Leach tube stock is 10-cu-in leach tubes; 1-gal stock is 4-in-sq tree pots. Mean annual growth is expressed in cm (for tree height) or sq cm (for shrub cover).

References

Demetry, Athena, and Daniel M. Duriscoe. 1996. Fire-caused canopy gaps as a model for the ecological restoration of Giant Forest Village: report to National Park Service, Sequoia and Kings Canyon National Parks. Denver: Denver Service Center Technical Information Center, National Park Service.

Demetry, Athena. 1997. Assessment of soil conditions in the Giant Forest area, Sequoia National Park: report to National Park Service, Denver Service Center. Denver: Denver Service Center Technical Information Center, National Park Service.

———. 1998. A natural disturbance model for the restoration of Giant Forest Village, Sequoia National Park. Pp. 142-159 in *Proceedings of High Altitude Revegetation Workshop No. 13.* Warren R. Keammerer and Edward F. Redente, eds. Colorado Water Resources Research Institute Information Series No. 89. Fort Collins, Colo.: Colorado Water Resources Research Institute.

Dilsaver, Lary M., and William C. Tweed. 1990. *Challenge of the Big Trees: A Resource History of Sequoia and Kings Canyon National Parks.* Three Rivers, Calif.: Sequoia Natural History Association.

Hartesveldt, Richard J. 1965. An investigation of the effect of direct human impact and of advanced plant succession on Sequoia gigantea in Sequoia and Kings Canyon National Parks, California. Contract report to Regional Director, Western Region, National Park Service. Sequoia and Kings Canyon National Parks, Calif.: National Park Service.

Siegel, Sidney. 1956. *Nonparametric Statistics for the Behavioral Sciences.* New York: McGraw-Hill.

Snedecor, George W., and William G. Cochran. 1989. *Statistical Methods.* 8th ed. Ames: Iowa State University Press.