A NATURAL DISTURBANCE MODEL FOR THE RESTORATION OF GIANT FOREST VILLAGE, SEQUOIA NATIONAL PARK

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ABSTRACT

Visitor facilities are being removed from a 25 hectare area of giant sequoia-mixed conifer forest in the Giant Forest Grove of Sequoia National Park. A natural disturbance model for restoring the vegetation was sought in the surrounding ecosystem. Forest canopy openings, or gaps, caused by prescribed fire are of similar scale to canopy openings caused by tree removal for buildings and parking lots. In 1994, regeneration of woody species within fire-caused gaps was quantified in order to define this restoration model. Density and height growth for many species were found to vary with the size of the gap and the position within gaps (edge or center). Gaps in the restoration site were surveyed; for each gap a prescription was made for species composition, density, and spatial pattern that falls within the range of variability for these properties in similarly-sized fire-caused gaps. An adaptive management approach, in which different degrees of active restoration are applied within gaps using several different treatments, is being used to determine the minimal amount of human intervention necessary to meet the standard reference condition of natural vegetation in fire-caused gaps. Smaller trials are being applied at the split-plot level to assess the effectiveness of soil restoration treatments.

INTRODUCTION

The Giant Forest grove of giant sequoia-mixed conifer forest is one of the largest of *Sequoiadendron giganteum*'s 75 extant groves, all of which are located on the western slope of the Sierra Nevada (Rundel 1971). Beginning in the early part of this century, a small city complete with gas station, market, hundreds of cabins, campgrounds, and a sewage treatment plant was constructed in Giant Forest. By the 1930's, park managers understood the damage such intense use could cause the ecosystem and began to call for removal and relocation of visitor facilities from Giant Forest. After decades of management efforts, the infrastructure for the relocated development is near completion, the first phase of demolition in Giant Forest has begun, and ecological restoration will begin in 1998. Because Giant Forest is a highly valued natural area, a focal site for ecological research, and a pioneering site for the use of prescribed fire in the National Parks, it is important that the restoration have a sound basis in the science of ecology, i.e., based on a quantified natural model.

One approach to defining a model for ecological restoration is to look to the surrounding ecosystem for a natural disturbance condition which resembles the human disturbance, then quantify

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the vegetation in the naturally disturbed area. After removal of buildings and pavement from Giant Forest Village, the forest canopy will consist of a matrix of mature forest interspersed with canopy openings, or gaps, where patches of mature trees were removed to make way for buildings and parking lots. This canopy disturbance condition is similar to areas in undeveloped portions of Giant Forest where prescribed fire has killed patches of mature canopy trees, creating a gap which is colonized by an even-aged patch of regeneration. Because the canopy disturbance caused by removal of development and the canopy disturbance caused by fire are of similar scale and pattern on the landscape, we quantified the vegetation within fire-caused gaps to use as a model for revegetation or as a reference to evaluate the success of other restoration treatments.

The goal of the restoration is to mimic the effects on the vegetation of a fire burning through this area of the forest. Because fire is the dominant disturbance condition shaping the species composition and structure of the giant sequoia-mixed conifer forest (Stephenson 1996), and because fire-caused gaps have an important role in the forest as favorable regeneration sites for giant sequoia and other pioneer species, restoring vegetation in development-caused gaps to a composition, density, and spatial pattern typical of vegetation in fire-caused gaps is an important first step in returning developed areas of Giant Forest to a natural state.

The degree of human intervention necessary to mimic this vegetation is being investigated through adaptive management. It is probable that a century of human impact to these sites has moved the forest past the threshold where it can recover on its own; formerly-developed sites in the area that have been abandoned for over 30 years show little natural recovery. The impacts mostly likely to hamper natural revegetation include: (1) topsoil erosion, loss of organic matter, and compaction; (2) absence or depletion of the soil seed bank; (3) absence or low density of understory seed sources (shrubs, forbs, and grasses); (4) absence of litter, duff, and fuels to carry a fire hot enough to release the canopy-stored seed of giant sequoia, the dominant species in many fire-caused gaps; and (5) the possibility of exotic species invasion, due to the presence of disturbed soil surfaces and human vectors carrying seed from the Valley. As an adaptive management approach, increasing degrees of active restoration are being applied in a coherent, experimentally-designed manner to determine the least intrusive but still effective means of restoring the area.

DEFINING THE NATURAL DISTURBANCE MODEL

In the summer of 1994, field work was conducted to provide a model of woody species composition, density, and spatial patterns for the ecological restoration of potential canopy gaps in Giant Forest Village by mapping and analyzing the vegetation within fire-caused gaps of various sizes in Giant Forest Grove. Gap size was used to categorize gaps because it was hypothesized that gap size would account significantly for the variation seen in the regeneration within gaps. The size of the gap in a forest canopy affects the light, moisture, temperature, and nutrient regimes in the forest floor beneath the gap (Forman and Godron 1981, Canham and Marks 1985, Runkle 1985). Different species will respond differently to these varying environmental regimes, causing different-sized gaps to contain different species, plants densities, and spatial patterns of regeneration (Drury and Nisbet 1973, Whittaker and Levin 1977, Noble and Slatyer 1980, Sousa 1984, Thompson 1985, Poulson and Platt 1989, Spies and Franklin 1989, Phillips and Shure 1990, Gray 1995). Thus, to use fire-caused gaps as a model for restoration in potential gaps in Giant Forest Village, it was important that the vegetation in a range of gap sizes in Giant Forest Grove be carefully documented.

Project Area

Giant Forest is located on a plateau in the mixed conifer zone of the middle elevations (between about 1950 m and 2320 m) of the southern Sierra Nevada and covers an area of approximately 1012 ha. The most common tree species are white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*Pinus jeffreyi*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*), and giant sequoia (*Sequoiadendron giganteum*). The average annual precipitation, which falls mostly as snow during the winter months, is 113 cm. Average minimum air temperatures range from -6.7°C in February to 11.8°C in August. Average maximum air temperatures range from 3.4°C in December and January to 27.4°C in August. The soils in the Giant Forest Grove of Sequoia National Park are predominantly Pachic Xerumbrepts that are 0.5-1.5 m deep, well drained, acid soils formed in granitic rock residuum (Huntington and Akeson 1987). Typically, the soils are coarse sandy loams with an O horizon $\geq$10 cm thick (Stohlgren et al. 1991).

Prescribed fires have been conducted in Giant Forest since 1979 and have been accompanied by a standardized monitoring program. Consequently, fire dates and boundaries are well documented. The sites sampled in this study burned between 1979 and 1987. The scale, severity, and effects of prescribed fires in Giant Forest are thought to be within the range of historic fire behavior and its effects, despite the century-long accumulation of fuels resulting from fire suppression (Mutch 1994, Demetry 1995, Stephenson 1996). Therefore, it is believed that mimicking the effects of prescribed fire will perpetuate the forest composition, structure, and patch dynamics produced by the historic, or "natural," fire regime.

Methods

Six fire-caused gaps within each of three size categories were selected systematically for a total of eighteen gaps. The size categories were small (0.05-0.1 ha), medium (0.1-0.3 ha), and large (0.3-1.2 ha); these categories were chosen to correspond to observed thresholds in vegetation response to gap size. The presence of scorch on standing dead and down trees was evidence that the gap was caused by fire rather than by other disturbances, such as windthrow. Gaps were selected to represent the variability in vegetation observed within a size category. Gaps were excluded if more than 25 percent of the gap area consisted of exposed rock or if the slope was greater than 20 percent. Gap age was determined from prescribed fire records.

Gap boundaries were delineated using criteria similar to those used by Spies and others (1990) in forests of the Pacific Northwest. Gap boundaries were defined by canopy dominants or codominants which had crowns that were either touching or were within one average crown diameter of each other. In other words, if a tree of average canopy width (defined by the sum of the two half-crown widths) were placed between the two trees in question and the canopies were to touch or overlap, the two trees were considered boundary trees. A mature tree that was farther than one average crown diameter from a neighboring tree was considered part of the gap vegetation and not a boundary tree.

Woody plants within each gap were mapped by obtaining their exact x,y,z coordinates using a Topcon CTS-2 total station, which has sub-centimeter accuracy. All tree seedlings greater than 0.1 meters height were mapped, with the exception of red fir and white fir, which were mapped if greater than 0.2 meters height. This exception was necessary because of the establishment of high densities of fir seedlings following a mast year in 1991, accompanied by favorable climatic conditions. Heights of all mapped seedlings were measured.

All shrubs with canopy dimensions at least 0.1 by 0.1 meter were mapped. Because shrub stems, or individuals, could not always be readily differentiated, shrubs were mapped as elliptic clumps, and the length and width of the ellipse was measured as well as the height of the clump. When a continuous group of a shrub species was encountered which was not roughly elliptical, the perimeter of the shrub polygon was mapped. Shrub cover was later generated by calculating the area of the ellipse or obtaining the area of the polygon from an AutoCAD map.

DESCRIPTION AND APPLICATION OF MODEL

In this section I present the data as it was used as a model for forming prescriptions for restoring the vegetation in development-caused (restoration) gaps. The study also investigated whether species composition, density, and spatial arrangement of trees and shrubs in gaps varied with gap size and in different positions within gaps. Because gap size was found to account for significant variability in the density and growth rates for many species (see Demetry 1995 for methods and results of statistical analyses), gap size was used as the principal criterion for identifying a natural analogue for each restoration site.

The goal of the restoration is to mimic the effects on the vegetation of a fire burning through this area of the forest. For gaps where planting will be conducted, "fire-plus-ten," or the mimicking of species composition, density, and spatial patterns within gaps ten years following fire, is the objective. The ten-year goal was chosen because the mean age of the model gaps was just over ten years. Once the desired vegetation is established, which may entail a period of post-planting care, natural processes (fire, self-thinning/mortality) will be allowed to proceed. Although most of the seedlings planted to mimic the "fire plus ten" vegetation will not survive to be recruited into the canopy, we prefer that natural processes do the thinning rather than managers planting fewer seedlings to account for future mortality (i.e., creating a "fire plus twenty" vegetation).

Restoration Gaps

Restoration gaps (development-caused gaps) were identified and their boundary trees mapped. The size of each gap was determined and each gap classified by size using the same methods as for model gaps. A prescription was formed for each gap, based on the range of variability of the comparable properties in the 6 model gaps of the same size category (small, medium, large). Prescriptions included species of trees and shrubs, the density (total number) of each species, and the spatial arrangement of plants within gaps (proportion in edge vs. center, compass position if applicable, number of clumps, size of clumps, and stem spacing within clumps). Grasses and forbs were minor components of most gaps and were not included in the model, but will be seeded or planted as plugs at low densities into most gaps.

Prescribing Species Composition

The number of tree and shrub species prescribed for each restoration gap was based on the

Table 1. Number of tree and shrub species found in small, medium, and large gaps (range and values for individual model gaps shown).

	Number of Tree Species		Number of Shrub Species	
Gap Size	Range	Gap Values	Range	Gap Values
Small	1-3	1, 2, 2, 3, 3, 3	0-7	0, 3, 4, 5, 7, 7
Medium	3-5	3, 3, 3, 4, 5, 5	4-11	4, 5, 6, 6, 8, 11
Large	4-7	4, 4, 4, 5, 7, 7	7-12	7, 9, 10, 11, 12, 12

number of species found in the same size category model gaps (Table 1). The individual species prescribed were based on the relative frequency of each species in the model gaps (Table 2, Table 3). Table 2 shows that white fir was present in 83 percent of the small gaps, 67 percent of the medium gaps, and 100 percent of the large gaps. Thus, when the prescriptions are completed for all the development-caused gaps, approximately 83 percent of the small gaps, 67 percent of the medium gaps, and 100 percent of the large gaps should contain white fir. For each individual gap, decisions were made based on the surrounding vegetation, aspect, elevation, soil type, topographic position, and similarities to individual model gaps. Thus, gaps located on shallow soils on steep south to west-facing slopes with little to no white fir in the surrounding canopy would not have white fir prescribed, while gaps located on mesic, deep soils on fairly level, north to east-facing slopes with abundant white fir in the surrounding canopy would have white fir prescribed.

Prescribing Species Densities

The model gaps were used to define the range of variability of a species' density within each gap size category, based on a normal distribution (Figure 1). The parameters of the normal

Table 2. Tree species frequency (presence in number of gaps), followed by relative frequency (percent) in parenthesis, for small, medium, and large gaps, and total. Species classifications are from the Jepson Manual (Hickman 1993).

		Frequency			
Scientific Name	Common Name	Small	Medium	Large	Total
Pinus lambertiana	sugar pine	5 (83)	6 (100)	6 (100)	17 (94)
Sequoiadendron giganteum	giant sequoia	4 (67)	6 (100)	6 (100)	16 (89)
Abies concolor	white fir	5 (83)	4 (67)	6 (100)	15 (83)
Calocedrus decurrens	incense cedar	0	4 (67)	3 (50)	7 (39)
Pinus jeffreyi	Jeffrey pine	0	1 (17)	5 (83)	6 (33)
Abies magnifica	red fir	1 (17)	1 (17)	2 (33)	4 (22)
Pinus ponderosa	ponderosa pine	0	1 (17)	2 (33)	3 (17)
Quercus chrysolepis	canyon live oak	0	0	2 (33)	2 (11)
Quercus kelloggii	black oak	0	1 (17)	1 (17)	2 (11)
Total number of species present		4	8	9	9

Table 3. Shrub species frequency (presence in number of gaps), followed by relative frequency (percent) in parenthesis, for small, medium, and large gaps, and total. Species classifications are from the Jepson Manual (Hickman 1993).

		Frequency			
Scientific Name	Common Name	Small	Medium	Large	Total
Ceanothus cordulatus	whitethorn	5 (83)	6 (100)	6 (100)	17 (94)
Arctostaphylos patula	greenleaf manzanita	4 (67)	6 (100)	6 (100)	16 (89)
Ribes roezlii	Sierra gooseberry	4 (67)	6 (100)	6 (100)	16 (89)
Ribes nevadense	Sierra currant	2 (33)	5 (83)	5 (83)	12 (67)
Ceanothus parvifolius	littleleaf ceanothus	3 (50)	4 (67)	3 (50)	10 (56)
Chrysolepis sempervirens	bush chinquapin	3 (50)	2 (33)	5 (83)	10 (56)
Symphoricarpos rotundifolius var. *parishii*	creeping snowberry	3 (50)	2 (33)	5 (83)	10 (56)
Cornus nuttalli	mountain dogwood	1 (17)	2 (33)	2 (33)	5 (28)
Ribes viscosissimum	sticky currant	1 (17)	1 (17)	3 (50)	5 (28)
Sambucus mexicana	elderberry	0	1 (17)	4 (67)	5 (28)
Prunus emarginata	bitter cherry	0	0	4 (67)	4 (22)
Apocynum androsaemifolium	spreading dogbane	0	1 (17)	2 (33)	3 (17)
Rubus glaucifolius	raspberry	0	1 (17)	1 (17)	2 (11)
Rubus parviflorus	thimbleberry	0	0	2 (33)	2 (11)
Salix sp.	willow	0	1 (17)	1 (17)	2 (11)
Amelanchier alnifolia var. *pumila*	smooth serviceberry	0	1 (17)	0	1 (6)
Ceanothus integerrimus	deer brush	0	0	1 (17)	1 (6)
Chamaebatia foliolosa	bear clover	0	0	1 (17)	1 (6)
Corylus cornuta var. *californica*	hazelnut	0	1 (17)	0	1 (6)
Penstemon newberryi	mountain pride	0	0	1 (17)	1 (6)
Prunus virginiana	western chokecherry	0	0	1 (17)	1 (6)
Rosa sp.	rose	0	1 (17)	0	1 (6)
Total number of species present		9	16	19	22

distribution, mean and standard deviation, are shown for trees in Table 4 and shrubs in Table 5. Within the limits of this range, factors such as surrounding vegetation, aspect, elevation, soil type, topographic position, and similarities to individual model gaps were considered in order to locate where in the distribution the value for a particular species in a gap should be. For example, the restorationist may have three medium gaps and needs to determine the density of incense cedar desired for each gap. Gap A is located on a shady, north-facing slope with no surrounding incense cedar; Gap B is located on a relatively flat swale with a few incense cedar on the boundary; and Gap C is located on a steep, southwest-facing slope with rocky, shallow soil and many incense cedar on the boundary. Incense cedar density in medium gaps has a mean of 62 trees/ha and a standard deviation of 78 trees/ha. For Gap A, the restorationist might choose an incense cedar density on the low end of the distribution, between 1 and 2 standard deviations below the mean (e.g., 0 trees/ha, see point A, Figure 1). For Gap B, the restorationist might choose an incense cedar density near the mean (e.g., 60 trees/ha, see point B, Figure 1). For Gap C, the restorationist might choose an incense cedar density on the high end of the distribution, between 1 and 2 standard deviations above the mean (e.g., 190 trees/ha, see point C, Figure 1). When all incense cedar densities in all medium gaps have been chosen, a histogram of these densities should be approximately normal with a mean near 62 trees/ha, with approximately 68% of the densities between 0 and 140 trees/ha (62±78), and with approximately 95% of the densities between 0 and 218 trees/ha (62±(2*78)).

To approximate these distributions when prescribing species densities, I generated random numbers from normal distributions with the means and standard deviations specified, then chose densities from these lists. For example, we expect to restore about 40 medium gaps, so 40 random normal densities for each species were generated and used as a guide when forming prescriptions for medium gaps.

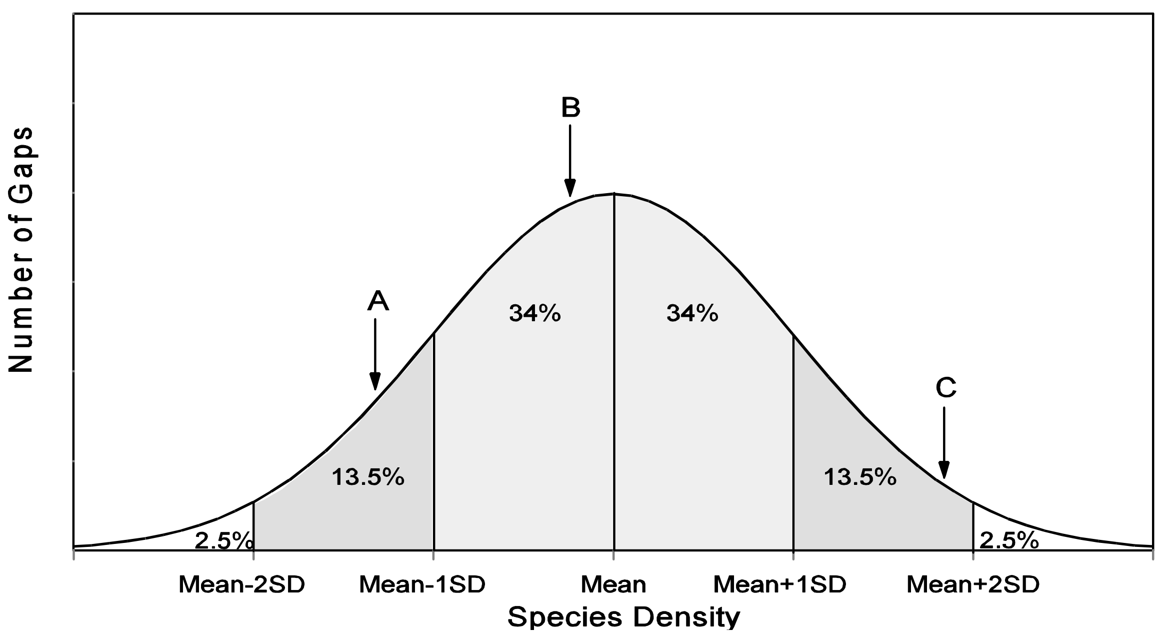

Figure 1. Normal curve, showing how this study defines the range of variability for species density. Such a curve would be used for one species in one gap size category, for which the mean and standard deviation (SD) are defined. 68% of the restoration gaps should have densities within 1 SD of the mean, and 95% of the restoration gaps should have densities within 2 SD of the mean. Points A, B, and C show single density values for a particular restoration gap (see text).

Table 4. Mean density and standard deviations (SD) for conifers in small, medium, and large gaps (n=6).

	Density (trees/ha)					
	Small		Medium		Large	
Species	**Mean**	SD	**Mean**	SD	**Mean**	SD
Giant sequoia	**653**	962	**612**	1250	**2956**	3084
White fir	**62**	51	**70**	136	**107**	128
Sugar pine	**50**	61	**58**	42	**114**	76
Incense cedar	**0**	--	**62**	78	**5**	10
Jeffrey pine	**0**	--	**2**	4	**6**	6
Red fir	**29**	65	**90**	220	**39**	70
Ponderosa pine	**0**	--	**7**	17	**2**	3

The assumption of a normal distribution was moderately supported by the data for most species. The distribution of the 6 density values within a gap size category was often skewed to the right, as when most gaps contained a low density of a species, but one gap had an extreme high density. In this case, the range above the mean produced by the normal distribution will be large but realistic, whereas a portion of the range below the mean will be meaningless because negative values are produced. To correct for this and reproduce the right-skew of the model gaps' distribution, any randomly-generated negative values were given densities below the mean or zero.

Table 5. Mean cover and standard deviation (SD) for shrubs in small, medium, and large gaps (n=6).

	Mean Cover (m^2/ha)					
	Small		Medium		Large	
Species	**Mean**	SD	**Mean**	SD	**Mean**	SD
Whitethorn	**48**	63	**275**	255	**1134**	841
Littleleaf ceanothus	**96**	133	**190**	281	**211**	410
Greenleaf manzanita	**2**	4	**5**	8	**60**	58
Sierra gooseberry	**7**	13	**10**	14	**97**	120
Sierra currant	**0.4**	1	**7**	15	**7**	12
Sticky currant	**0.9**	2	**2**	5	**31**	35
Mountain dogwood	**0.2**	1.5	**5**	12	**118**	288
Elderberry	**0**	--	**5**	13	**7**	11
Bush chinquapin	**120**	194	**576**	1381	**46**	37
Bitter cherry	**0**	--	**0**	--	**0.8**	1
Creeping snowberry	**0.6**	1	**31**	67	**15**	18
Spreading dogbane	**0**	--	**0.4**	0.9	**19**	45

Prescribing Spatial Patterns

Within-gap spatial patterns were examined by dividing gaps into regions where density or growth rates were expected to differ because of gradients of environmental factors within gaps. An edge versus center division was made because moisture is generally higher in centers of gaps, and a compass position division was made because light availability is higher in northern regions of gaps. The distance from each tree seedling to the nearest gap boundary was calculated; the division between edge and center was made at half the maximum distance from edge. The north, south, east, and west divisions were made with offset quadrant axes through the geometric center of the gap.

Results showed that many species, particularly the pioneer-type species, tended to grow with higher densities in gap centers than at gap edges (see Figures 2 and 3 for results for giant sequoia and whitethorn, respectively), while others, such as bush chinquapin and creeping snowberry, had higher densities at gap edges than centers. There were few cases where density varied with compass position. Based on these data, density in gap edge vs. center was prescribed for each species in each restoration gap using a similar process as described for species density. Density in north, south, east, or west quadrants was prescribed if compass position was significant for a species.

Patchiness of growth within gaps was examined using Ripley's K(t) analysis (Moeur 1993). The analysis showed that tree species within gaps grew in clumped patterns in all gap sizes and at all spatial scales. A pattern of hierarchical clumping, with clumps of a few stems positioned within larger-scale clumps, was shown by the analysis (Demetry 1995). With this analysis, which showed at what spatial scale the clumping patterns were strongest, as well as simple examinations of stem plots, prescriptions were made for number of clumps, a range of clump sizes, and a range of stem spacings for each species in each restoration gap. Figure 4 shows a stem map of giant sequoia seedlings and whitethorn cover in one large gap (total area 0.34 ha), and illustrates the clumped patterns of growth as well as the tendency to have higher density (and higher rates of growth, see Demetry 1995) in gap centers.

Non-Gap Areas

In the relatively natural ecosystem surrounding Giant Forest Village, areas between gaps that have sustained fire generally do not contain patches of even-aged regeneration. For this reason, no planting or seeding is planned for disturbed, non-gap areas of Giant Forest Village. However, restoring the natural topography and mitigating soil compaction (cultivating) are planned in order to allow natural revegetation to occur. Restored vegetation within gaps should provide islands of seed sources for shrub, grass, and forb recolonization into non-gap areas.

Soil Impacts and Mitigation

To assess impacts to the soil in the developed areas, chemical and physical properties of soil profiles were compared with profiles in natural areas (gaps) that had sustained fire. Results showed that the primary impacts in developed-site soils are compaction of the A horizon, depletion of organic matter in the A horizon, and loss or alteration of natural aggregate structures. Compaction in natural soils, as measured by a soil penetrometer, ranged from 50 to 200 p.s.i., while compaction in developed-site soils ranged from 409 to 600 p.s.i. Surface compaction was highest in soils beneath pavement (mean=586 p.s.i. at 3 sites) and lowest in sites where development has been removed for 30 years, but no restoration conducted (mean=437 p.s.i. at 3 sites). Organic matter (O.M.) content in

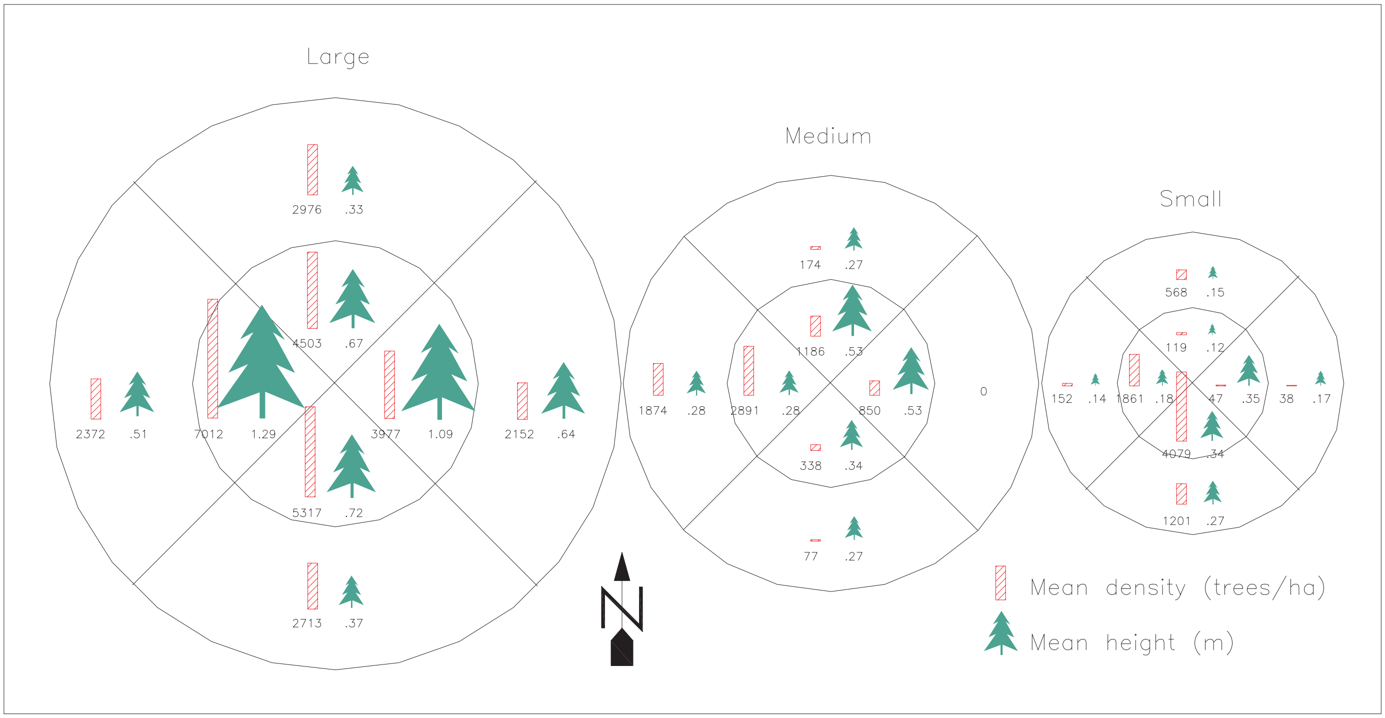

Figure 2. Giant sequoia mean density and height by within–gap position and gap size. Mean density is shown as a bar symbol scaled to density in trees per hectare, and mean height is shown as a tree symbol scaled to height in meters.

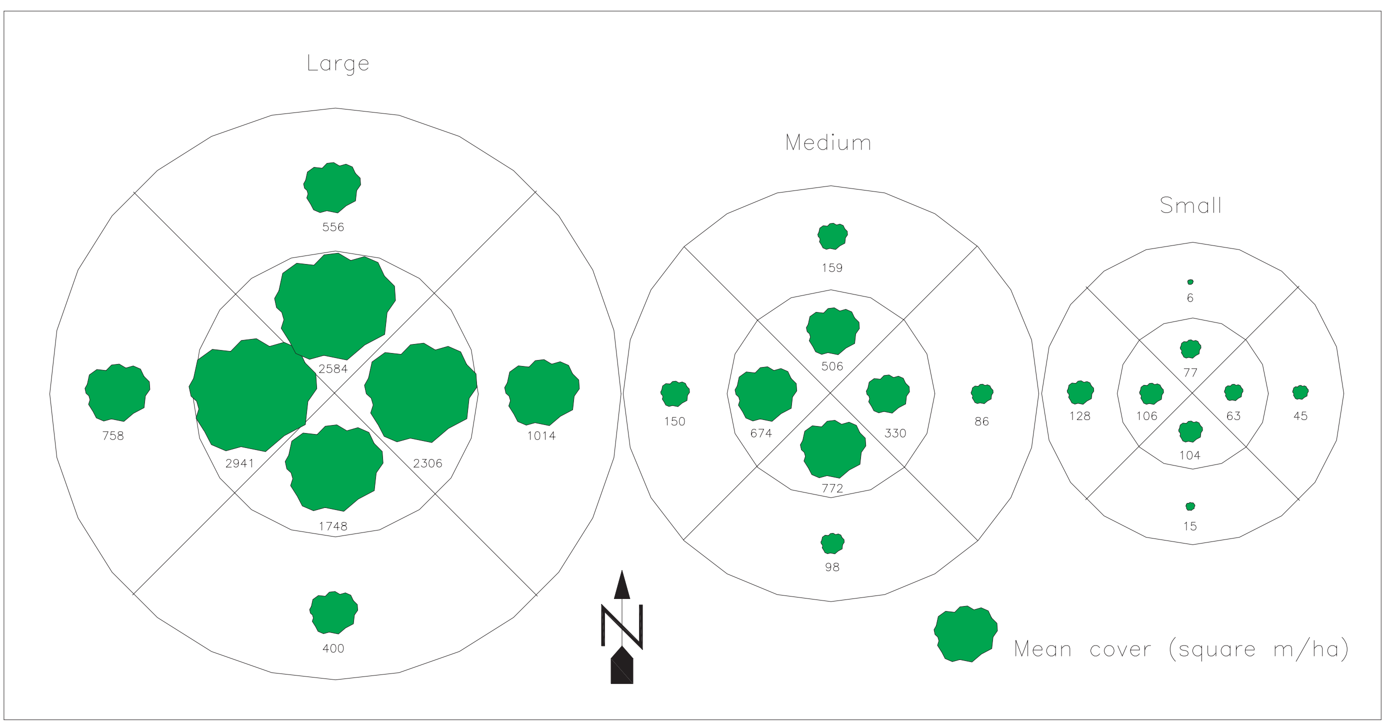

Figure 3. Whitethorn mean cover by within–gap position and gap size. Mean cover is shown as a shrub symbol scaled to cover area in square meters per hectare.

the top 25 cm of disturbed-site soils was below the range of O.M. shown by natural soils (5.4% to 17.1%) for 11 of 14 disturbed-site soils sampled. This reduced O.M. content was due both to topsoil erosion and to a combination of increased decomposition due to trampling disturbance, loss of fine O.M. particles in suspension, and decreased O.M. inputs (e.g., from decreased litter inputs from the reduced overstory and understory). Finally, the A horizons of natural soil profiles contained fine crumb structural aggregates, while disturbed-site soils contained subangular blocky and platy aggregate structures.

To mitigate both soil compaction and restore crumb soil structure, we plan to cultivate (with rototiller-type equipment) soils in the developed areas to a depth of about 25 cm and outside the driplines of mature trees. Because soils must be moist to restore soil structure during cultivation, cultivation will be conducted in the spring after snow-melt, or soils will be sprinkler-moistened prior to cultivation if done in the fall. Organic matter loss and topsoil erosion would best be mitigated by spreading a layer of local, borrowed topsoil on the surface of the most highly impacted sites. However, no borrow source for topsoil exists within Giant Forest. Two alternate methods will be tried in an experimental approach described below, involving amendment with forest bark humus during cultivation, and using low-intensity fire.

ADAPTIVE MANAGEMENT APPROACH TO RESTORATION

Because of the duration and severity of impacts to developed areas of Giant Forest, managers believe that some degree of human intervention is necessary for the recovery of the site. However, an acceptable restoration product might be achieved through less intensive 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 is being taken. The term "adaptive management" refers to "an iterative approach to decision making involving a cycle of planning, implementation, monitoring, research, and subsequent reexamination of management decisions based on new information that may alter existing plans and priorities" (Interagency Ecosystem Management Task Force 1995). Adaptive management explicitly recognizes that managed ecosystems are complex and inherently unpredictable, and that incomplete knowledge of ecosystems is the rule rather than the exception. Experimentation is integrated into management actions not as basic research, but to learn which actions will meet management goals, because no other source for this knowledge exists.

Everett et al. (1994) provide nine steps for adaptive management of forested ecosystems:

(1) Establish measurable goals for management
(2) Explicitly define cause-and-effect relations for natural and management-induced processes
(3) Design sets of actions that will achieve the goals of management.
(4) Implement management actions
(5) Periodically assess progress and cause-and-effect relations
(6) Compare actual system performance with forecasted performance
(7) Evaluate the appropriateness of goals and forecasts of system performance; refine the conceptual model, redesign goals, and develop new management actions if the model and goals require adaptation
(8) Implement new actions
(9) Return to step 5 for reiterative evaluation

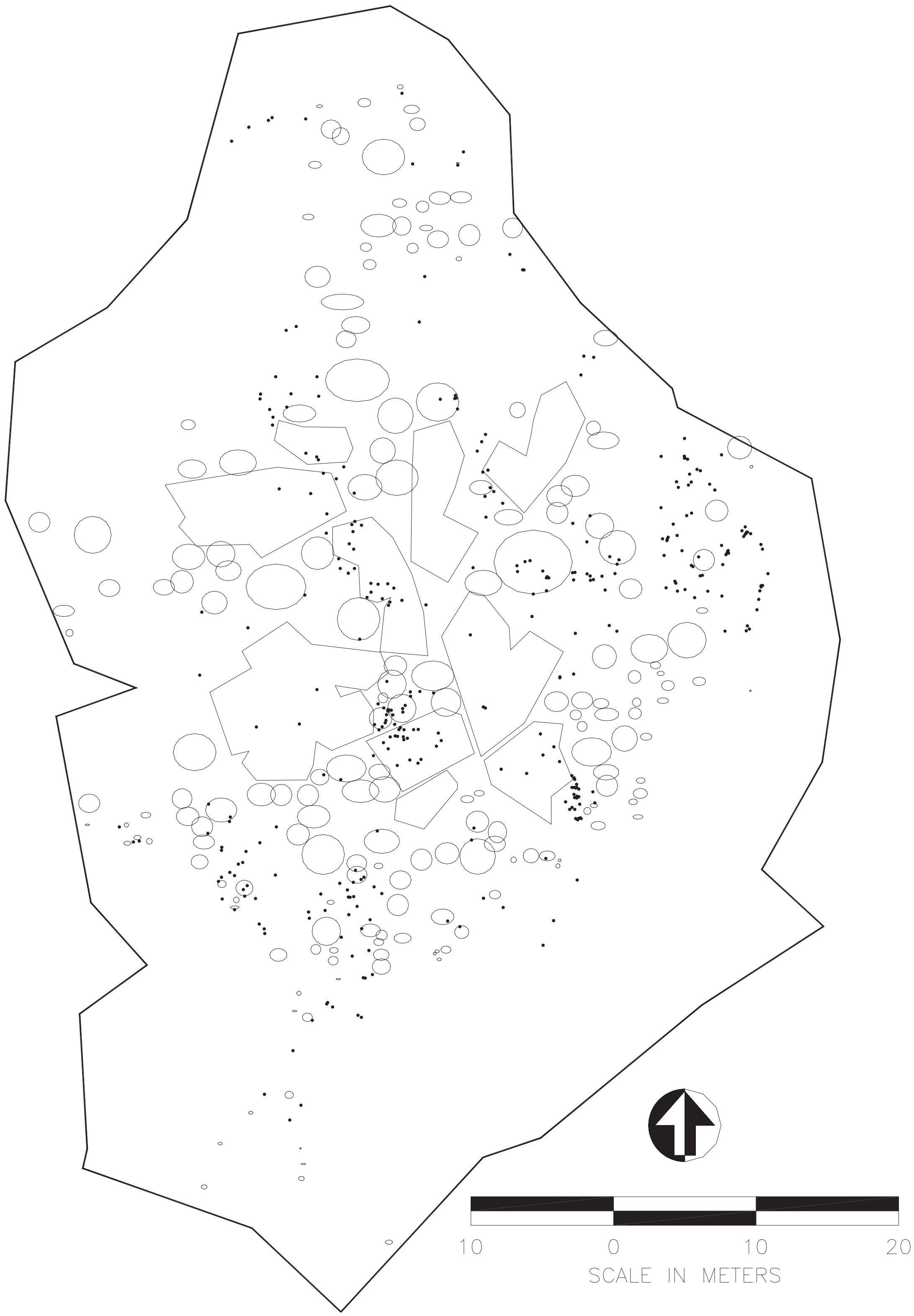

Figure 4. Stem map of giant sequoia seedlings, shown as points, and whitethorn cover, shown as ellipses and polygons, in a large gap. Large irregular polygon is the gap boundary.

The goal of an adaptive management approach in Giant Forest is to apply different degrees of active restoration in a coherent experimental design, so that the minimal amount of human intervention necessary to meet the standard reference condition of natural vegetation in fire-caused gaps can be determined. Because restoration goals have been quantified based on fire-caused gaps, a solid reference condition exists for comparison and evaluation of alternative treatments, making Giant Forest an especially good candidate for adaptive management. Adaptive management will be most important in the early phases of the restoration so that rapid feedback on different restoration treatments can be gathered and new knowledge applied to later phases.

Three basic treatments for restoration gaps in Giant Forest Village are being used, in order of increasing human intervention, with the first two treatments ideally applied in the minimum number of gaps necessary for statistical replication:

(1) No action other than regrading, cultivation, and mulching with litter and duff.

(2) Regrade, cultivate, import light fuel bed and 2 to 3 large slash piles, and burn with the intent of releasing sequoia seed, scarifying the seed bank, and improving the soil. No propagation, soil amendments, mulch, planting, or irrigation.

(3) Propagate; regrade; cultivate; mulch with wood chips; plant tree and shrub seedlings and grass and forb plugs; and irrigate. Use organic matter amendment to the topsoil in one-half of selected gaps in a split-plot design. Use low-intensity burning in one-half of selected gaps in a split-plot design.

The first treatment mitigates the most severe and consistent soil impact in Giant Forest Village, soil compaction, and protects newly decompacted, loose soil from surface erosion. It relies on natural seed dispersal as a source of propagules in gaps. It does not actively put the ecosystem on a trajectory similar to an ecosystem response to fire.

The second treatment adds to the first by providing a source of propagules in the heating and releasing of canopy-stored sequoia seed and the scarifying of soil-stored shrub and forb seed, and by burning with variable, heterogeneous intensities within a gap to provide possible soil benefits (pulse of mineralized, plant-available N; a source of partially decomposed organic matter from incomplete fuel combustion; and a friable, mineral seedbed, required for the germination of giant sequoia). It actively puts the ecosystem on a trajectory similar to an ecosystem response to natural fire, but does so with minimal intervention.

The third treatment aims to simulate the effects of fire on vegetation; it mimics the species composition, density, and spatial patterns of regeneration in different-sized fire-caused gaps by actively planting tree, shrub, forb, and grass seedlings. It is the most active, highest-intervention method of putting the ecosystem on a trajectory similar to an ecosystem response to natural fire.

None of the methods described above directly mitigate the destruction of the topsoil. One sub-treatment within Treatment 3 would mitigate loss of organic matter in the topsoil and topsoil erosion by amending the top 25 cm of soil in half of selected gaps with forest bark humus and nitrogen to rebalance the C:N ratio; the other half of the gap would remain unamended as a control, to see if the added expense of soil amendment is justified with a substantial improvement in plant establishment and growth. A second sub-treatment within Treatment 3 would attempt to indirectly mitigate topsoil destruction by using low-intensity burning to provide possible soil benefits.

Monitoring is an essential and integral component of adaptive management. The purpose of monitoring is to quantify the results of the various treatments in a way that they can be meaningfully compared with each other and with the standard reference condition of vegetation in fire-caused gaps. If monitoring and data analysis reveal that certain treatments are not producing vegetation that is within the range of variability for fire-caused gaps, altering or abandoning these treatments can be considered in the iterative planning, implementation, monitoring, and evaluation cycle of adaptive management. If monitoring indicates that a less intensive treatment produces acceptable results (vegetation within the range of variability for fire-caused gaps), this treatment may be used in gaps in later phases of restoration.

The first phase of demolition in Giant Forest Village will be completed in the fall of 1998, with restoration to follow and continue through spring of 1999. There are 13 gaps to be restored in this first phase, and all are included in an experimental design to compare the effectiveness of the different treatments. Although there are not enough gaps to provide the replicates that a power analysis indicated would be necessary for a fair level of statistical confidence (gaps originally included in the first phase of restoration were removed from the contract package due to funding constraints), there may be enough differences seen among the treatments to indicate their relative effectiveness.

SUMMARY

Finding and quantifying an analogous model or reference condition is an important first step in ecological restoration. Natural disturbance models, in which the early stages of recolonization and community development following natural disturbance are mimicked, are appropriate when the scale and pattern on the landscape of the human disturbance are similar to the natural disturbance. This study provided an example of using regeneration within fire-caused canopy gaps as a natural disturbance model for patchy, development-caused disturbance in a forested ecosystem. In addition to fire, natural disturbances that might be used as models in other ecosystems include hurricanes, wind storms, ice storms, cryogenesis, landslides, avalanches, coastal erosion and dune movement, flash floods, and various biotic processes such as insect outbreaks, disease, and browsing and burrowing animals (White and Pickett 1985, Attiwill 1994). Particularly in ecosystems where the health, diversity, and sustainability of the plant community are dependent on a particular disturbance regime, this approach is ecologically sound, and may be more appropriate than using a mature community type as a model or reference.

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