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# Mediated Settlement Agreement for Sequoia National Forest, Section B. Giant Sequoia Groves: *An Evaluation*

## INTRODUCTION

The Sierra Nevada Ecosystem Project (SNEP) was charged with examining the *Mediated Settlement Agreement for the Sequoia National Forest* (MSA), Section B, Sequoia Groves (Sequoia National Forest, 1990;), and making "recommendations" for scientifically-based mapping and management of giant sequoia groves and those additional lands, if any, needed to ensure the long-term health and survival of giant sequoia ecosystems. Recommendations are advisory, with science informing management of a variety of potential, appropriate management strategies. As an ecosystem assessment, the SNEP scientists also examined giant sequoia ecosystems range-wide in the Sierra Nevada, not only on the Sequoia National Forest. Stephenson (1996, SNEP Volume II) presents a discussion of giant sequoia ecology and management in an affiliated paper for the Sierra Nevada Ecosystem Project.

Specific tasks of the authors to enable an evaluation of giant sequoia groves under the Mediated Settlement Agreement (MSA) included:

1. compilation of an ecological database, geographic information system (GIS) with spatial grove boundaries, and scientific bibliography for giant sequoia for all giant sequoia groves on the Sequoia National Forest and for the entire Sierra Nevada;
2. an assessment of current grove mapping methodologies used by the Sequoia National Forest and by other administrative units;
3. an evaluation of the MSA, Section B, from both ecological and policy perspectives;
4. review of grove management practices and responses to these, and coupling of these to the ecological database as the basis for future design of adaptive management regimes for ecosystem management of giant sequoia across its range; a range of potential management tools is discussed herein;
5. review of the implications of the Sequoia National Forest moving towards ecosystem management of the groves and

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the entire Forest, and provision of a written evaluation of the Sequoia National Forest's draft giant sequoia ecosystem management plan as requested by the Forest;

6. a review of past and present human use of the groves, human values, and various methods of potential public information dissemination and education, as a need identified by both the authors and the Sequoia National Forest.

The evaluation herein and in Stephenson's chapter (1996 , SNEP report) on giant sequoia ecosystems is functionally and conceptually linked to many different parts of the SNEP evaluation, and informed by many chapters (1996, SNEP reports).

## GIANT SEQUOIA GROVE DATABASE

The management of giant sequoia by the Sequoia National Forest has been informed historically by the state of scientific knowledge of the species' distribution, life history, productivity, and role in the coniferous forest ecosystems of the Sierra Nevada. A brief overview of the literature is included in appendix 8.1, with the biogeography of giant sequoia [Sequoiadendron giganteum (Lindley) Buchholz; Taxodiaceae Family] discussed in appendix 8.2.

One of the Sierra Nevada Ecosystem Project's major tasks was to compile the existing information on the Sierra Nevada ecosystem. For the giant sequoia groves of the Sierra Nevada (figure 1 and table 1), we constructed a relational database on the geography, ecology and management history of each grove. We also created a bibliographic database on giant sequoia ecology and management. Due to space constraints, these large database files are not included as tables herein. They will be included on the SNEP CD-ROM under compilation by Mike Diggles of the U.S. Geological Survey, Menlo Park. They are also files in the SNEP ARC/Info GIS available through (1) the Alexandria project at UC Santa Barbara (http://alexandria.sdc.ucsb.edu), (2) the UC Davis GIS Center on campus, and (3) the CERES of the California State Resources Agency (http://ceres.ca.gov/snep/). The giant sequoia database is also available as a FoxPro database file from Deborah Elliott-Fisk (lead author, e-mail dlelliottfisk@ucdavis.edu), with the bibliographic database available from Professor Elliott-Fisk in hard copy, as a Word text file, or as an EndNote 2 bibliographic database file.

### Grove Database

As the various public and scientific issues of concern for giant sequoia groves are diverse for the giant sequoia ecosystem, and since these groves are managed by different groups with different goals and different data collection systems, we made an effort to comprehensively compile the existing grove data from individual grove managers.

To determine data availability, we sent out a questionnaire to all grove managers. We also queried all managers about the Sequoia National Forest Mediated Settlement Agreement (MSA) and their views on management issues at the Sequoia National Forest (see MSA discussion below). Additionally, we sent questionnaires to twenty-two giant sequoia "experts" from around the country to gain information on groves in which they had worked.

A draft questionnaire was compiled and then reviewed by the SNEP team. A letter of inquiry and the questionnaire were then sent to all managers and owners of giant sequoia groves (table 2) in December 1994, including Sequoia and Kings Canyon National Parks, Yosemite National Park, Sequoia National Forest, Sierra National Forest, Tahoe National Forest, Bureau of Land Management (Bakersfield District), Calaveras State Park, Mountain Home Demonstration State Forest, Tulare County Parks and Recreation, Tule River Indian Reservation, and a few private landholders.

The survey posed open-ended questions in ways to allow the widest of possible responses to facilitate open and unconstrained answers. In cases where unambiguous answers were possible, we asked fixed questions (e.g., on physical descriptors such as latitude or maximum elevation). The questionnaire asked for information on grove descriptive characteristics, including location, elevation, geology, soils, slope, aspect, acreage, largest trees, named trees, approximate age distribution, associated plant communities, and major vegetation zones. It also asked about grove condition, past and present disturbance (e.g., logging, grazing, insects, pathogens, fire, trampling, human settlements, and alterations), and management regimes, and posed some broader questions on public relations and the MSA for the Sequoia National Forest.

Responses were received over the next six months. Data and summaries of long responses were entered into a FoxPro relational database (available from the authors and on the SNEP CD-ROM in progress). Lengthy data sets and answers were scanned as memo files and captured in digital format for future reference.

Unfortunately, no written responses were returned by private landholders, although the authors have had verbal discussions with some of these individuals. Tulare County, which manages Balch Park (within Mountain Home Demonstration State Forest), chose not to fill out the questionnaire. From the giant sequoia "experts," we received only one reply to the questionnaire, but additional unpublished information was provided by many of these individuals. The entire database includes grove information, management information, public relations information, and opinions on the MSA. A subset of this database, specifically the grove information, has been linked with the grove coverage map.

The database has entries for seventy-three giant sequoia groves. What constitutes a "grove" was defined by each man-

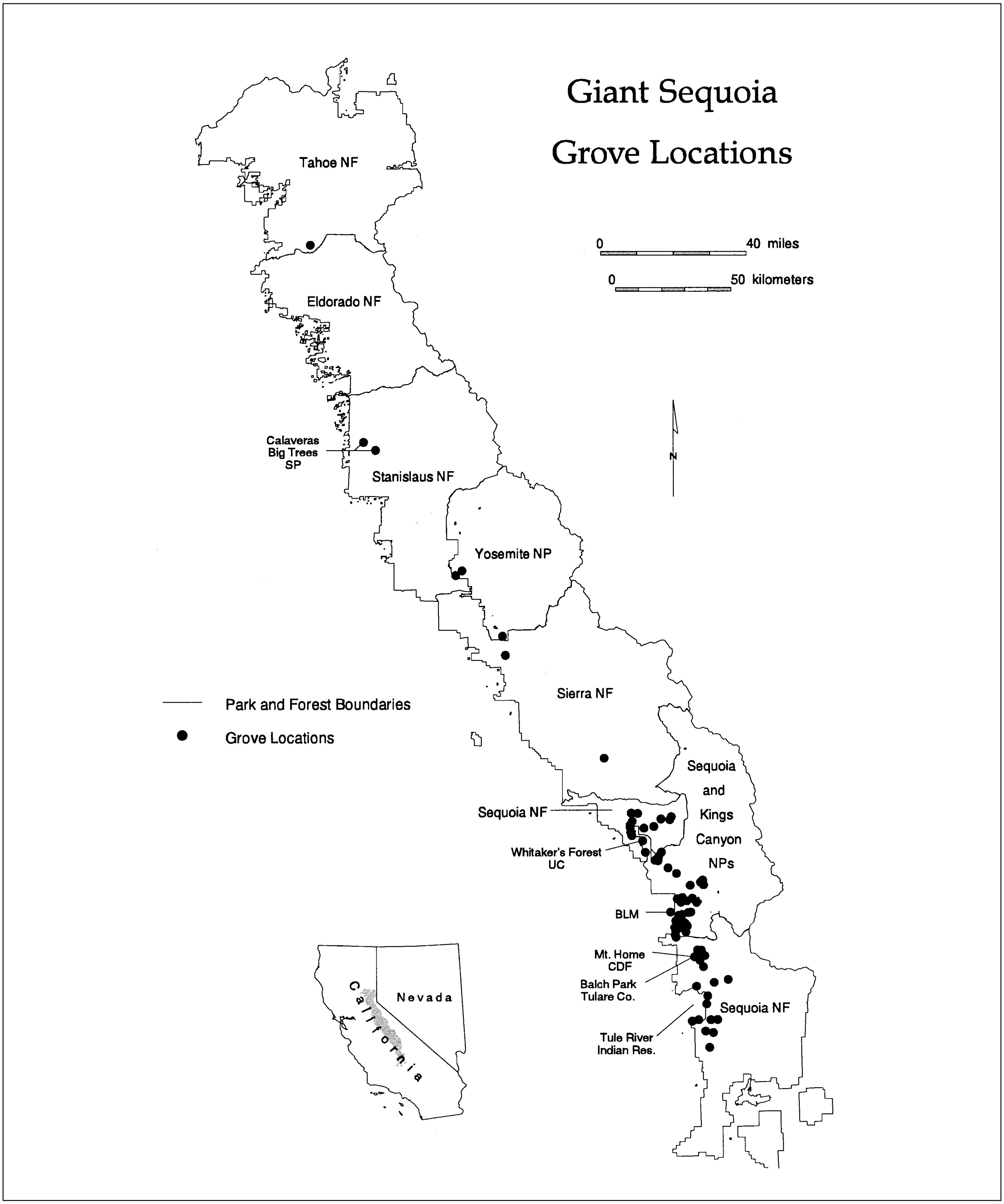



**FIGURE 1**

Locations of giant sequoia groves in the Sierra Nevada. (From volume II, chapter 55.)

TABLE 8.1

| Grove Name | Acres | Administrative Unit |
|---|---|---|
| Abbott Creek | 20 | Sequoia National Forest |
| Agnew | 112 | Sequoia National Forest |
| Alder Creek | 420 | Sequoia National Forest |
| Atwell | 1,335 | Sequoia National Park |
| Bearskin | 186 | Sequoia National Forest |
| Belknap complex | 3,077 | Sequoia National Forest |
| Big Stump | 257 | Kings Canyon National Park |
| Big Stump | 485 | Sequoia National Forest |
| Black Mountain | 2,771 | Sequoia National Forest |
| Black Mountain | 500 | Tule River Indian Reservation |
| Boulder Creek | 80 | Sequoia National Forest |
| Burro Creek | 299 | Sequoia National Forest |
| Burton | 40 | Sequoia National Forest |
| Cahoon Creek | 14 | Sequoia National Park |
| Case Mountain | 55 | Bureau of Land Management |
| Castle Creek | 197 | Sequoia National Park |
| Cherry Gap | 190 | Sequoia National Forest |
| Clough Cave | 0.50 | Sequoia National Park |
| Coffeepot Canyon | 5 | Sequoia National Park |
| Converse Basin | 4,520 | Sequoia National Forest |
| Cunningham | 32 | Sequoia National Forest |
| Deer Creek | 144 | Sequoia National Forest |
| Deer Meadow | 276 | Sequoia National Forest |
| Dennison | 11 | Sequoia National Park |
| Devils Canyon | 6 | Sequoia National Park |
| Dillonwood | 572 | Sequoia National Forest |
| East Fork | 751 | Sequoia National Park |
| Eden Creek | 361 | Sequoia National Park |
| Evans | 4,370 | Sequoia National Forest |
| Forgotten Grove | 1 | Sequoia National Park |
| Freeman Creek | 4,186 | Sequoia National Forest |
| Garfield | 1,130 | Sequoia National Park |
| Giant Forest | 1,800 | Sequoia National Park |
| Grant | 154 | Kings Canyon National Park |
| Grant | 130 | Sequoia National Forest |
| Homers Nose | 245 | Sequoia National Park |
| Horse Creek | 42 | Sequoia National Park |
| Indian Basin | 449 | Sequoia National Forest |
| Kennedy | 200 | Sequoia National Forest |
| Landslide | 50 | Sequoia National Forest |
| Little Boulder | 80 | Sequoia National Forest |
| Lockwood | 130 | Sequoia National Forest |
| Long Meadow | 568 | Sequoia National Forest |
| *continued* | | |
| Lost | 54 | Sequoia National Park |
| Maggie Mountain | 68 | Sequoia National Forest |
| Mariposa | 333 | Yosemite National Park |
| McIntyre | 180 | Sequoia National Forest |
| McKinley | 100 | Sierra National Forest |
| Merced | 40 | Yosemite National Park |
| Middle Tule | 293 | Sequoia National Forest |
| Mountain Home | 2,644 | Mountain Home State Demonstration Forest |
| Mountain Home | 1,255 | Sequoia National Forest |
| Mountain Home | 200 | Tulare County Balch Park |
| Muir | 272 | Sequoia National Park |
| Nelder | 400 | Sierra National Forest |
| New Oriole Lake | 21 | Sequoia National Park |
| North Calaveras | 60 | Calaveras Big Trees State Park |
| Oriole Lake | 147 | Sequoia National Park |
| Packsaddle | 527 | Sequoia National Forest |
| Peyrone | 902 | Sequoia National Forest |
| Pineridge | 94 | Sequoia National Park |
| Placer County | 5 | Tahoe National Forest |
| Powderhorn | 5 | Sequoia National Forest |
| Putnam-Francis | 0.10 | Sequoia National Park |
| Red Hill | 765 | Sequoia National Forest |
| Redwood Creek | 105 | Sequoia National Park |
| Redwood Meadow | 223 | Sequoia National Park |
| Redwood Mountain | 3,154 | Kings Canyon National Park |
| Redwood Mountain | 1,040 | Sequoia National Forest |
| Redwood Mountain | 280 | UC Whitaker Forest |
| Sequoia Creek | 21 | Kings Canyon National Park |
| Silver Creek | 32 | Mountain Home State Demonstration Forest |
| Silver Creek | 101 | Sequoia National Forest |
| Skagway | 94 | Sequoia National Park |
| South Calaveras | 445 | Calaveras Big Trees State Park |
| South Fork | 210 | Sequoia National Park |
| Squirrel Creek | 2 | Sequoia National Park |
| Starvation | 181 | Sequoia National Forest |
| Surprise | 4 | Sequoia National Park |
| Suwanee | 100 | Sequoia National Park |
| Tuolumne | 35 | Yosemite National Park |
| Wheel Meadow | 500 | Sequoia National Forest |
| Wishon | 170 | Sequoia National Forest |

ager, so our grove numbers differ from others (e.g., Rundel 1972a; Willard 1995). For example, Sequoia and Kings Canyon National Parks used tree data and went into detail on the number of trees in each area (with the smallest number being one). The Sequoia National Forest, conversely, used their mapping procedure definitions from the MSA to distinguish their groves. There was not time for our workgroup to rectify these differences under the time constraints of SNEP.

## Discussion of Grove Database

There are seventy-three giant sequoia groves (some of which are grove complexes) in the Sierra Nevada (figure 1 and table 1). All of these groves occur along the western slope of the Sierra Nevada, with the northernmost grove the Placer County Grove (39.0583 °N) on the Tahoe National Forest and the southernmost grove the Deer Creek Grove (35.8714 °N) on the Sequoia National Forest The most westerly grove is again the Placer County Grove (120.51 °W), and the most easterly grove is the Freeman Creek Grove (118.5155 °W) on the Sequoia National Forest.

The large Freeman Creek grove (1,674 Ha [4,186 ac] buffered Botanic Area) also the has the highest maximum elevation (2,595 m asl) and a northeast aspect, while the small Clough Cave Grove (.2 Ha [0.5 ac]) has the lowest minimum elevation (1,081 m asl) and a northeast aspect. The large Dillonwood grove (approaching 800 Ha [2,000 ac]) has the greatest elevational within-grove range (1,210 m) with a westerly aspect, with the small Squirrel Creek grove (.08 Ha [0.2 ac]) has the lowest elevational range (24 m) and a southeast aspect.

In reference to grove aspect range-wide, forty-three of the groves have a northern aspect (northwest to northeast), with twenty-seven of these a northwest aspect. It is unusual for a grove to have a southern aspect.

Although a common myth is that the groves occur on flat, interfluve ridge-tops, only thirteen of the groves occur on slope of 10° or less, with the bulk of the groves occuring on 11–25.5° slopes (fifty-two groves). Five groves occur on slopes greater than 30°.

Both the surficial geology and soils found within the groves

**TABLE 8.2**

| Administrative Unit/Manager | Grove Name | Management Status |
|---|---|---|
| Bureau of Land Management | Case Mountain | Range |
| Calavers Big Tree State Park | North Calaveras | Park |
| Calavers Big Tree State Park | South Calaveras | Park |
| Kings Canyon National Park | Big Stump | Park |
| Kings Canyon National Park | Sequoia Creek | Park |
| Kings Canyon National Park | Grant | Park |
| Kings Canyon National Park | Redwood Mountain | Park |
| Mountain Home State Demonstration Forest | Silver Creek | Virgin |
| Mountain Home State Demonstration Forest | Mountain Home | Multiple use |
| Sequoia National Forest | Tenmile | MSA |
| Sequoia National Forest | Powderhorn | MSA |
| Sequoia National Forest | Abbot Creek | MSA |
| Sequoia National Forest | Cunningham | MSA |
| Sequoia National Forest | Burton | MSA |
| Sequoia National Forest | Landslide | MSA |
| Sequoia National Forest | Maggie Mountain | MSA |
| Sequoia National Forest | Boulder Creek | MSA |
| Sequoia National Forest | Little Boulder | MSA |
| Sequoia National Forest | Silver Creek | MSA |
| Sequoia National Forest | Agnew | MSA |
| Sequoia National Forest | Grant | MSA |
| Sequoia National Forest | Lockwood | MSA |
| Sequoia National Forest | Deer Creek | MSA |
| Sequoia National Forest | Wishon | MSA |
| Sequoia National Forest | McIntyre | MSA |
| Sequoia National Forest | Starvation | MSA |
| Sequoia National Forest | Bearskin | MSA |
| Sequoia National Forest | Cherry Gap | MSA |
| Sequoia National Forest | Kennedy | MSA |
| Sequoia National Forest | Deer Meadow | MSA |
| Sequoia National Forest | Middle Tule | MSA |
| Sequoia National Forest | Burrow Creek | MSA |
| Sequoia National Forest | Alder Creek | MSA |
| Sequoia National Forest | Indian Basin | MSA |
| Sequoia National Forest | Big Stump | MSA |
| Sequoia National Forest | Wheel Meadow | MSA |
| Sequoia National Forest | Packsaddle | MSA |
| Sequoia National Forest | Long Meadow | MSA |
| Sequoia National Forest | Dillonwood | MSA |

*continued*

are diverse. Although we are lacking detailed geological data for twenty-six of the groves, for the remainder, thirty-three occur on Mesozoic granitics of varying composition, with nine groves on older metasedimentary formations and one grove on volcanics. This largely reflects the percentage availability of these rocks types with the geographic range of the species. Soil types are typically more diverse than the surficial geology, as time, relief and climate play important roles in pedogenesis. Common soil series are Shaver, Holland, Chaix, Chawanakee, Tollhouse, and Monache, classied largely as dystric xerochrepts (moderately deep, coarse loamy soils), pachic xerumbrepts (deep, coarse loamy soils), and generally well-drained soils forming from granitic rocks. A few older, more acidic humults are found on plateau-interfluve areas. Research on the soils and geology of the groves continues, with Yosemite National Park initiating soil mapping in its groves in the summer of 1995. In addition, Don Potter, Forest Service Zone Ecologist based out of the Stanislaus National Forest, has also initiated soil sampling and mapping for select groves in the Sierra and Sequoia National Forests in his work on soils of the mixed conifer forest.

Native American occupation has been detailed in some excavated grove areas (e.g., Mountain Home and Yosemite's Mariposa grove), and other areas have evidence of past use; yet, detailed archeological reconnaissance of all groves has not been done. Early Euroamerican settlements consisted of mining and logging camps, hotels, and private cabins in various groves. Present-day settlements include homes, vacation cabins, motels, camping facilities and day-use facilities. Forty-one of the groves have been settled by humans in historic and prehistoric times.

Current conditions show that many groves may be prone to intense fire as the result of historic logging and fire suppression practices. Thirty-two of the seventy-three groves have been logged. Logging impacts vary depending upon past ownership and management. Any future logging in grove areas is a question of management objectives, societal acceptance, and understanding of scientifically-justified forest practices. Using certain types of logging for fuel reduction, to maintain forest sustainability / health and to aid regeneration of shade intolerant species is considered an option for discussion by forest managers in many cases, alone or in conjunction with prescribed burning.

Logging of young giant sequoia is currently on-going in

**TABLE 8.2 continued**

| Administrative Unit/Manager | Grove Name | Management Status |
|---|---|---|
| Sequoia National Forest | Red Hill | MSA |
| Sequoia National Forest | Peyone | MSA |
| Sequoia National Forest | Redwood Mountain | MSA |
| Sequoia National Forest | Mountain Home | MSA |
| Sequoia National Forest | Black Mountain | MSA |
| Sequoia National Forest | Belknap complex | MSA |
| Sequoia National Forest | Freeman Creek | Botanic area |
| Sequoia National Forest | Evans | MSA |
| Sequoia National Forest | Converse Basin | MSA |
| Sequoia National Forest | Putnam-Francis | Park |
| Sequoia National Forest | Clough Cave | Park |
| Sequoia National Forest | Forgotten Grove | Park |
| Sequoia National Forest | Squirrel Creek | Park |
| Sequoia National Forest | Surprise | Park |
| Sequoia National Forest | Coffeepot Canyon | Park |
| Sequoia National Forest | Devils Canyon | Park |
| Sequoia National Forest | Dennison | Park |
| Sequoia National Forest | Cahoon Creek | Park |
| Sequoia National Forest | New Oriole Lake | Park |
| Sequoia National Forest | Horse Creek | Park |
| Sequoia National Forest | Lost | Park |
| Sequoia National Forest | Pineridge | Park |
| Sequoia National Forest | Skagway | Park |
| Sequoia National Forest | Suwanee | Park |
| Sequoia National Forest | Redwood Creek | Park |
| Sequoia National Forest | Oriole Lake | Park |
| Sequoia National Forest | Castle Creek | Park |
| Sequoia National Forest | South Fork | Park |
| Sequoia National Forest | Redwood Meadow | Park |
| Sequoia National Forest | Homers Nose | Park |
| Sequoia National Forest | Muir | Park |
| Sequoia National Forest | Eden Creek | Park |
| Sequoia National Forest | East Fork | Park |
| Sequoia National Forest | Garfield | Park |
| Sequoia National Forest | Atwall | Park |
| Sequoia National Forest | Giant Forest | Park |
| Sierra National Park | McKinley | Botanical area |
| Sierra National Park | Nelder | Historical area |
| Tahoe National Forest | Placer County | Botanical area |
| Tulare County Batch Park | Mountain Home | County park |
| Tule River Indian Reservation | Black Mountain | Multiple use |
| UC Whitaker Forest | Redwood Mountain | Research |
| Yosemite National Park | Tualamne | Park |
| Yosemite National Park | Merced | Park |
| Yosemite National Park | Mariposa | Park |

select areas of Mountain Home and possibly on some private lands. Light logging of white-woods is occuring on private lands surrounding some public agency groves, and some salvage cutting of white-wood hazard trees, to be left as down timber, is projected for two Sequoia National Forest groves, as agreed upon by all concerned parties.

Road development is well documented and not much expansion is planned for the future, but some may be done around grove peripheries on private land. Some removal of roads, trails, and other structures to create a more "natural" state is planned for areas in the Yosemite National Park and Calaveras State Park groves and in Giant Forest of the Sequoia National Park. Trampling occurs in some areas, mostly from trail use in heavily visited groves. The potential for development of homes and other structures remains as well as the potential for giant sequoia logging on private lands.

Fire is seen as a major threat to many giant sequoia groves due to decades of fire suppression and resulting fuel accumulation. However, with no precise fuel sampling for many groves, the extent of the fire risk is largely unquantified. Percent dead standing and percent dead down trees are incomplete in our database as well. The Sequoia National Forest has undertaken a systematic fuels inventory of all of its giant sequoia groves as stipulated under the MSA, but this inventory is at present incomplete. Kings Canyon National Park has received funding for a five-year, prescribed fire project that will effect groves in the Mineral King area as in the Atwell Grove. Other groups with prescribed burning programs are continuing their efforts, such as at Yosemite National Park and Calaveras Big Trees State Park.

Detailed fire history studies have been compiled using tree-rings for several areas (Sequoia and Kings Canyon National Parks, Sequoia National Forest, Mountain Home Demonstration State Forest), and this research will continue in certain areas (e.g., Caprio and Swetnam 1993; Caprio et al 1994).

Insect and disease information is not detailed. Key organisms for giant sequoia communities, like annosus root rot and white pine blister rust, are noted briefly. Bark beetles also receive little attention. Other potential inhabitants and diseases have been studied minimally in specific groves (e.g., Piirto 1994; Stecker 1973). Most recently, Sandlin (1993) found that *Phytophthora citrophora* can be a root rot and a foliar blight in greenhouse-grown sequoia with overhead watering.

Grazing history is very generalized in most cases, although we know that historic grazing impacts in some groves were significant, and fifty-eight of the groves have been grazed, although fifteen of these have minimal grazing. Current grazing concerns are with stock traffic through the groves and trampling, since few herbaceous understory plants occur in the largely closed-canopy groves today. There is little data on the number of sheep or cattle occurring at certain times in the groves, as some of the U.S. Forest Service groves are within large range allotments but specific grove use is unknown. No specific studies of grazing effects near groves have been done either, which is not helpful in addressing the trampling concerns (section IV on management and Menke, 1996, SNEP report).

Less intrusive visitor experiences continue to gain in popularity. Yosemite, Calaveras and Sequoia and Kings Canyon parks are planning removal and changes of human structures in their groves, such as the removal of structures from Giant Forest in Sequoia National Park. In regard to trampling along paths, the rerouting of paths and fencing is being done to minimize damage to the root zone.

Development in areas surrounding the groves, and within their spatially defined ecosystem, may occur, which will effect neighboring groves differently depending upon individual circumstances (e.g., the position of these impacts within the grove watershed, adjacency to tree roots, etc.).

## Giant Sequoia Bibliography

Sources for our bibliography included Melvyl [the University of California (UC) on-line library catalog], Life Sciences CD-ROM, Agricola CD-ROM, Sequoia-Kings Canyon National Park research library and general library, Yosemite National Park research library, David Parsons' (U.S. Forest Service [USFS]) personal compilation, Bob Rogers' (USFS) personal compilation, Don Fullmer's (USFS) search of the USFS Pacific Southwest Research Station (PSW) references available through the National Agricultural Library, the 1992 Giant Sequoia Symposium proceedings, Dwight Willard's book *Giant Sequoia Groves of the Sierra Nevada* (1995), previous bibliographic compilations, selected information from the University of Arizona Laboratory of Tree-Ring Research, John and Marge Hawksworth, the Sierra National Forest, the Tahoe National Forest, the Mountain Home Demonstration State Forest, UC Berkeley's Whitaker's Forest, references from books, and pieces of primary research literature.

References were entered into the EndNote Plus 2 bibliographic database program (Macintosh and DOS versions available). Abstract, language, location of item, and detailed page numbers were included, as available. Keywords specific to this bibliography were added for easier searches (table 3). A total of 716 references were entered, with 15 general pointers to other available references too disjunct or incomplete to be included singly. Broad topics of review are life history and growth habits of the species, physiology, environment, stresses, study techniques, evolution, genetics, anthropogenic effects and value systems, paleontology and organisms. Some of these categories are broken down into a general keyword list (table 3), which includes the bibliography numbers for references with the particular keyword (cross-referenced with the bibliography). Even more detailed keywords are available for search in the digital database (e.g., EndNote library).

Topics with numerous references include fire, ecology, history, management, and cultivation of giant sequoia in other countries. We found moderate numbers of references on wood, growth, genetics, reproduction, tree-rings, distribution, ozone, disease, and climate. Few references were found for geology, soils, mammals, birds, grazing, anthropogenic effects (covering roads and recreation as well), roots, and decomposition processes. No explicit surveys of reptile and amphibian life were found. A summary of the literature is presented in appendix 8.1.

**TABLE 8.3**

Key Words for Bibliographic Database:

| | | |
|---|---|---|
| air pollution | evolution | ozone |
| anthropogenic effects | fire | protection |
| climate | fungi | reproduction |
| cones | genetics | roots |
| cultivation | growth | succession |
| damage | insects | soils |
| disease | logging | wildlife |
| distribution | management | wood |
| ecology | Native American issues | |

Data Fields for Relational Grove Database:

grove name
location: latitude, longitude, UTM, watershed, nearest tributary, topographic position
acreage
maximum and minimum elevation, slope angle, aspect
surficial geology
soils
largest trees, named trees
presence of seedlings, saplings, young trees, monarchs
plant communities, vegetation zones
fuel sampling
logging, grazing and fire histories
human settlements and activities
regeneration capability
insect infestations
fungal and lower plant diseases
percent dead snags and percent dead down
threats and impacts of fuels/fire, roads, logging and trampling
management regime

# MAPPING OF GIANT SEQUOIA GROVES AND GIS COMPILATION

## Stipulations of the Mediated Settlement Agreement

The Mediated Settlement Agreement for the Sequoia National Forest (Sequoia National Forest 1990), Section B, outlined several steps for the Forest to take in order to "protect, restore, and preserve their giant sequoia" (pages 6–28, Sequoia National Forest 1990). The first Section B task for the Forest was to undertake a detailed and accurate mapping of the giant sequoia groves so that boundaries could be delimited and signed and designated protection (primarily from logging and road construction) more readily enforced. This was a major concern of environmental interests due to past Forest logging practices. The Forest also agreed to pull its giant sequoia groves out of the timber base pending full revision and approval of the Forest Land Management Plan.

The MSA outlined some of the requirements for the Forest's mapping procedure. In the spirit of the MSA, a Grove Boundary Team was to be formed, comprised of one representative each from the Sierra Club, the Save-the-Redwoods League, the timber industry and the Forest Service. This Team is in charge of approving boundary lines and any alterations to grove identification protocols. For the grove itself, a "hypothetical perimeter" line was to be placed around the outermost giant sequoias. For this perimeter line, any giant sequoia 1 ft or larger diameter breast height (dbh), located within 500 ft of at least 3 other giant sequoias 1 ft or larger dbh was to be included in the grove of concern. The first buffer encircling the grove hypothetical perimeter was designated the "administrative grove boundary" of 300 or 500 ft. Outside this first buffer, a second zone was defined as a "grove influence zone", and was comprised of another 300 or 500 ft. Any isolated giant sequoia under 3 ft dbh and located within the grove influence zone are protected from logging. The Forest will try to protect the "small" giant sequoia outside the grove influence zone as well, but no additional buffer zones were required. Topographic features could determine boundaries of these zones instead of a 300 or 500 ft distance, but anthropogenic features could not unless agreed to by the entire Team. Under the MSA, these boundaries were the minimum protection criteria, and secondary to Spotted Owl Habitat Area, roadless area, condor site, botanical area management, and other areas of special designation.

Grove identification was to follow Rundel's (1972a) grove identifications, unless groves were close enough to manage as a single large grove, termed a "complex." If neighboring groves were merged into a grove complex, then the hypothetical perimeter line followed the outermost trees in the entire complex. Rundel-identified groves were not to be fragmented into smaller groves. Outliers to groves were to be dealt with on a case by case basis depending upon location. Detached naturally occurring groups (ten or more trees, with at least four trees of 3 ft or greater dbh) outside grove influence zones and not included as a Rundel grove were to be designated as "new groves" and given a 300-ft administrative grove boundary plus a 300-ft grove influence zone.

For several groves on the Sequoia National Forest, detailed guidelines were laid out for mapping the boundaries as they related to other types of management, but most groves received simple boundary mapping criteria. The Black Mountain Grove was connected to the Black Mountain Roadless Area, and given a 500-ft administrative grove boundary plus a 500-ft grove influence zone (table 4). The Belknap / McIntyre / Wheel Meadow Grove Complex was to be considered as one large grove, with a 500-ft administrative grove boundary plus a 500-ft grove influence zone. The Greater Evans Grove Complex was to be considered one large grove including Lockwood, Evans, Kennedy, Burton, Little Boulder, and Boulder groves, with a 500-ft administrative grove boundary plus a 500-ft grove influence zone. The Freeman Creek Grove and Watershed area had a Botanic Area, with the surrounding area under planning, with a 500-ft administrative grove boundary. The Indian Basin Grove was given a 500-ft administrative grove boundary plus a 500-ft grove influence zone, with some exceptions for logging to increase humans around Princess Campground. Other 500 ft administrative

**TABLE 8.4**

Width of administrative buffer beyond outermost tree perimeter, Sequoia National Forest giant sequoia groves.

| 500 Feet | 300 Feet | To Be Determined |
|---|---|---|
| Bearskin | Alder Creek. | Agnew |
| Belknap Complex | Cherry Gap | Burro Creek |
| Belknap | Cunningham | Deer Meadow |
| McIntyre | Mountain Home | Dillonwood |
| Wheel Meadow | Powderhorn | Freeman Creek |
| Big Stump | | Maggie Mountain |
| Black Mountain | | Middle Tule |
| Converse Basin | | Silver Creek |
| Deer Creek | | Wishon |
| Evans Complex | | |
| Evans | | |
| Boulder Creek | | |
| Kennedy | | |
| Little Boulder | | |
| Lockwood | | |
| Grant | | |
| Grant | | |
| Abbott Creek | | |
| Indian Basin | | |
| Landslide | | |
| Long Meadow | | |
| Packsaddle | | |
| Peyrone | | |
| Red Hill | | |
| Redwood Mountain | | |
| Starvation Complex | | |
| Starvation | | |
| Rundel's Powderhorn | | |

grove boundaries plus 500-ft grove influence zones were to go around Bearskin, Big Stump, Deer Creek, Grant, Landslide, Long Meadow, Packsaddle, Peyrone, Red Hill, Redwood Mountain, Starvation Creek, and Tenmile groves. Six hundred acres of Converse Basin recommended for preservation were given a 500-ft administrative boundary. The Powderhorn, Alder Creek, Abbott Creek, Cherry Gap, Mountain Home (USFS portion), and Cunningham groves all received a 300-ft administrative grove boundary and a 300-ft grove influence zone. Remote groves within wilderness or roadless area protection were not required to have precise boundary determinations (Agnew, Burro Creek, Deer Meadow, Dillonwood, Maggie Mountain, Middle Tule, and Silver Creek groves).

## The Grove Mapping Process for Sequoia National Forest

The Grove Boundary Team members chosen to fulfill the terms of the Mediated Settlement Agreement were Glen Duysen (timber industry representative), Robert Jasperson (Save-the-Redwoods League representative), Joe Fontaine (Sierra Club representative), and Lew Jump (Forest Service representative and Team Leader). Bob Rogers took over as Forest Service representative and Team Leader after the first year.

Early exploration of mapping procedures by the Forest involved review of the potential usefulness of standard forest inventory interpretation from aerial photographs, LANDSAT image analysis, and the use of on the ground District knowledge of grove and tree locations. All of these procedures gave unsatisfactory draft grove boundaries when field checked. The best procedure for initial grove delimitation was determined to be aerial photo-interpretation by the U.S. Forest Service's Nationwide Forest Application Project (NFAP). This work was done under contract in 1991. Here, professional photo-interpreters used color positive transparencies of aerial photographs at 1:12,000 scale, with 7X magnification for grove mapping. After being shown several examples of known giant sequoia in these photographs, such that a qualitative photographic signature could be established, the interpreters placed colored dots on what they believed to be the giant sequoia crowns in the photos. Two categories were used to show presence of giant sequoia: sure and suspected. The interpreters were not told where to look for the groves, so they reviewed the entire Sequoia National Forest in their photographic analyses. They also made several trips to the Forest to ground check their results.

With the photo-interpretation well under way, on the ground grove mapping and boundary delineation and placement began in 1992, with what were believed to be "easy" groves to complete. After examining NFAP maps, mapping crews were sent to the field to check potential outlier trees, find the outermost trees for the hypothetical perimeter, and set boundary lines. The perimeter was verified and flagged, and then the administrative boundary (i.e., the first "buffer" zone) was flagged, mapped, posted, and surveyed using a global positioning system (GPS). This entire process was difficult and time-consuming. Due to personnel restrictions, modifications to the procedure were unfeasible, so work continued in the same manner in 1993. After these two years, only thirteen of the thirty-eight Sequoia National Forest groves were completely mapped. Knowledge gained in 1993 provided background for procedural changes proposed for the 1994 field season, With the Forest deciding that it needed a more efficient and less costly method for mapping the remaining "difficult" groves, Bob Rogers presented a modified procedure to the Grove Boundary Team which was approved and implemented in 1994.

NFAP photo-interpretation was still the main data source for giant sequoia ground locations. Secondary sources included 1989 maps from the Save-the-Redwoods League, 1988 district maps updating the forest inventory, and personal knowledge. The first step in the new procedure was to sketch, on a 1:24,000 U.S. Geological Survey (USGS) topographic quadrangle map a "first approximation" of the administrative grove boundary *without* including areas identified by NFAP as "suspected" tree locations. Topographic and anthropogenic features were acceptable to use in following lines, with arbitrary lines created as a last resort. This map was then to be reviewed by the responsible District Ranger on the Forest. The second step was to field check the suspected NFAP locations for giant sequoia outside the first approximation. Where the trees were found to be present, the administrative boundary was then adjusted to include them in a "second approximation." This second approximation line was mapped, flagged, and field-checked by having the crew spread out and walk parallel to the line (e.g., as for traditional archeological surface inventories) to insure that no giant sequoia were present from the hypothetical perimeter to the administrative boundary, or from the administrative boundary to the potential grove influence zone boundary. As it was verified, a second color flagging was attached to the administrative boundary. The final administrative boundary was then mapped, posted, and GPS traversed. GPS files were converted and downloaded into the Forest Service's DRIS GIS.

In addition, aerial GPS traverses, using both helicopter and fixed-wing airplanes, were performed on the remote groves over wilderness and roadless areas. The flight area above the grove was explored, and then the outermost giant sequoia tree-line (i.e., hypothetical perimeter) determined from the NFAP mapping and local knowledge was traversed and closed. No buffer boundaries were mapped. Segment descriptions were noted in detail, except for the Agnew and Deer Meadow groves (see the Sequoia National Forest reports from 11/30/94, 12/9/94, and 1/18/95). An unnamed grove, now called "Wishon," was found during aerial GPS mapping and is included in a roadless area.

General grove designation changes since the Mediated Settlement Agreement (1990) was enacted include the designation of the Starvation Complex grove (which includes Rundel's Powderhorn grove), South Peyrone grove (unnamed previously), Wishon grove (unnamed previously), and the Powderhorn Tree, which are all considered groves. Tenmile grove is believed to be non-existent.

The presence of stumps did not alter the grove boundaries in any way, as large numbers of stumps were not found outside the area inhabited by existing giant sequioa trees, but stumps were noted in the field log and located on the map. For future grove mapping, in areas with large numbers of stumps beyond the distribution of living giant sequoia trees (e.g., Converse Basin, Cherry Gap, Abbott, and perhaps Grant groves), these stumps will be located within the grove influence zone as potential areas of future giant sequoia growth.

With all groves now mapped by the Forest, administrative grove boundary approval by the Boundary Team remains pending for a few groves.

## SNEP Evaluation of Sequoia National Forest Grove Mapping

From examination of the various map products (e.g., NFAP air photo tree and grove delimitations, LANDSAT image analysis, examination of field-based maps,and other products), of the procedures used, and based on discussions with the Grove Mapping Team, Sequoia National Forest staff, the interested public, and site visits to several mapped groves, the SNEP team supports the Sequoia National Forest's grove mapping as dictated under the MSA and approved by the Grove Mapping Team and Forest Supervisor. The U.S. Forest Service air-photo interpreters, field crews, Land Management Planning GIS staff, and the Grove Boundary Team and its volunteer support staff have all done an excellent, detailed and highly accurate delineation of the Forest's giant sequoia groves.

Giant sequoia managers on other Forests and in the Parks have expressed interest in using these same methods to accurately map their giant sequoia groves. The authors support this effort and believe that it will bring much consistency to grove demarcation, enabling better site-specific grove ecosystem management for the future.

It is important in further Forest efforts to accurately locate using GPS technology *all* boundary lines, including the grove hypothetical perimeters, administrative boundaries, and grove influence zones, especially if there is any deviation of these buffer zones from the designated straight-line distance requirments. The Forest has not been consistent in *which* boundary line it has actually tranversed with GPS units. Furthermore, beyond the requirements of the MSA, it would be of value for the Forest to map grove watersheds, airsheds and other aspects of the functional giant sequoia ecosystems.

## Status of Grove Mapping and GIS Compilation for All Administrative Giant Sequoia Units in the Sierra Nevada

The authors have compiled a GIS for all giant sequoia groves in the Sierra Nevada utilizing the software ARC / Info on Sun Sparc, UNIX-based workstations. This is part of the SNEP GIS project. The two primary elements of this GIS are digital maps (spatial information) and attendant database attributes for each grove. This section will describe the methods employed in the development of the digital map base.

Giant sequoia groves are managed by eleven public agencies and a number of private entities. This has resulted in substantial difficulty in the compilation of the digital map data due to wide variation in the methods these groups have used to both delimit their groves, individual trees, and various administrative units, and in the accuracy of the techniques they have used to further depict these on maps of various scales. It is extremely important that the user of our database understand that the digital map, or coverage, is our best compilation of digitized hard copy maps and digital spatial coverage files on giant sequoia grove boundaries. It is also important to note that giant sequoia mapping has been undertaken by these various agencies following different objectives. Some of the boundaries are intended to represent a line drawn around the outermost trees in a grove, while others included "buffer zones" for special administrative purposes. Also, in many cases, administrative boundaries are manifested by unnaturally straight or right angle delineations of grove boundaries. Lastly, there is great dispute regarding what constitutes a giant sequoia "grove" or if the very concept of a grove is even useful from more than a management perspective (see following section on biological hierarchies).

The specific mapping objectives, methods and resolution employed by the various public agency administrative units are described below. References are cited as possible, but in many cases there is no published reference available, and as such personal communication is noted.

### Sequoia National Forest

The most intensive effort to accurately map giant sequoia groves has taken place on the Sequoia National Forest, as outlined above. As stated in the Forest's MSA (1990, page 9), "it is desirable that the Sequoia National Forest shall inventory all giant sequoias (3 feet or larger dbh) in each Grove by size and approximate location in order to provide a suitable database for future protection of the sequoias." This process, as summarized here, is described in greater detail by Bob Rogers (Sequoia National Forest), as well as in the above section of this manuscript. As noted previously, various groves have no buffers, 300-ft buffer zones, or 500-ft buffer zones (table 4).

For our digital maps of the groves in the SNEP GIS, preliminary maps were provided by Bob Rogers for the Converse Basin, Redwood Mtn., Evans, Boulder Creek, Kennedy, Little Boulder, Lockwood, Alder Creek, Landslide, Abbott, Grant, and Cherry Gap groves on 7.5 minute USGS topographic quadrangles based on the NFAP mapping data and limited field reconaissance. These polygons were then digitized into our spatial coverage, with these grove boundaries less accurate than those further field verified and traversed using GPS. Mapping of these final Forest groves is now completed and will be imported into our GIS project.

### Sequoia And Kings Canyon National Parks

Through a series of contracts during the 1960s and 1970s, field crews mapped all identifiable giant sequoia trees. These crews laid out lines and measured perpendicularly from those lines (with a tape or by pacing) to produce x-y coordinates for the trees. These 1"= 200' (1:2,400) scale maps were spliced together and grove polygons were created by connecting the outermost trees in a cluster. The density of what constituted a cluster was only roughly estimated (e.g., there was no 500-ft inter-tree distance rule for outermost tree inclusion). In 1979, the polygons were reduced to scale and transferred to 15 minute USGS topographic quadrangles (scale 1:62,500) using a Pantograph by Doug Walner of the National Park Service (NPS) under the supervision of Tom Warner, not by the original contractors. These maps were later digitized and incorporated into the Parks' GIS in the spring of 1995 by the Park's GIS expert Pat Lineback (David Graber and Nate Stephenson 1995 personal communication).

### Sierra National Forest

At the request of the SNEP team, polygons depicting the giant sequoia groves as represented by the outermost tree perimeter were estimated using orthophotos and recollection from field visits. Wayne Hance and John Exline of the Forest staff were responsible for delimitation of the Nelder and McKinley Groves, respectively. These were drawn on 7.5 minute USGS topographic quadrangle maps (scale 1:24,000) and digitized. In the memo from the Regional Forester dated June 19, 1992, it is stated that the Forest will delimit and map its groves following the procedures developed by Sequoia National Forest in compliance with the MSA. This mapping has not yet been done to our knowledge as the Forest has awaited the finalization of the grove mapping procedure by the Sequoia National Forest, which is now complete.

### Tahoe National Forest

A polygon representing the outermost tree perimeter was estimated by Richard Johnson of the Forest staff using recollection from field visits of the single Placer County Grove. This was drawn on 15 minute USGS topographic quadrangle map (scale 1:62,500) and digitized. In the memo from the Regional Forester dated June 19, 1992, it is stated that the Forest will delimit and map its groves following the procedures developed by Sequoia National Forest in compliance with the MSA. This mapping will be done in the future and will be very straightforward for this small grove.

### Yosemite National Park

Giant sequoia polygons were digitized from registered mylars (overlaid on 7.5 minute USGS topographic quadrangle maps; scale 1:24,000) depicting Yosemite National Park's vegetation types. The polygons enclose the outermost trees in the groves. Mapping was done in the field without the aid of a global positioning system.

### Mountain Home Demonstration State Forest

Polygons representing the outermost tree perimeter were estimated by David Dulitz using recollection of field visits spanning over 20 years. These were drawn on 15 minute USGS topographic quadrangle maps (scale 1:62,500) and digitized.

### Calaveras Big Trees State Park

Grove polygons representing the outermost tree perimeter were manually transfered from forest inventory maps (received from forest ecologist Wayne Harrison) to a registered Stanislaus NF recreation map (1/2 inch = 1 mile; scale 1:125,000), and digitized.

### Whitaker's Forest (University Of California), Bureau Of Land Management Case Mountain Grove , Tule River Indian Reservation Groves, Tulare County Parks (Balch Park), And Select Private Lands

The grove polygons on these lands were located in the NFAP giant sequoia coverage compiled for the Sequoia National Forest and imported into the main coverage and digitized.

### Summary of Overall Spatial Coverage

The resulting spatial coverage was edited for errors and projected into the California Albers' Projection. The spatial resolution of grove boundaries varies as the result of whether or not accurate field delimitations of the groves were done, what field criteria were used in defining groves, how outlier trees were treated, whether GPS technology was employed to accurately record point locations, and at what scale maps were produced where GPS technology was not utilized.

The number of polygons in the resulting coverage does not correspond to the number of grove names used for three reasons. First, property ownership boundaries through groves were maintained, so that there might be two adjacent polygons for the same grove. This was done primarily because the administrative agencies often provided unique data sets based on the differing management histories. Second, some groves were mapped and depicted using multiple polygons. Last, some of the Sequoia National Forest groves are aggregated into single polygons representing grove complexes.

The spatial coverage for each grove is used as a geographic overlay with other spatial coverages (e.g., soils, surficial bedrock, slope and aspect) to obtain data on grove elevations, topography, physical environment, and other environmental variables. The accuracy of grove boundaries thus becomes very important for various research purposes so that we can better understand giant sequoia grove ecosystems.

## HUMAN USE OF GIANT SEQUOIA ECOSYSTEMS

Giant sequoia and humans are both biological organisms that are a part of the functional ecosystems of the Sierra Nevada, and people have a long association with these spectular trees. The human dimensions of giant sequoia ecosystems have changed through time, as our perceptions and uses of the trees and the groves as both ammenities and commodities have changed, as the intensity of our activities has changed, and as we have impacted the regional environmental quality of the Sierra Nevada. Changing individual, group and societal values are of paramount important to the Mediated Settlement Agreement. These changes have not followed any clear trend, but do follow the general pattern or cycle of individual, family and societal development (figure 2), with:

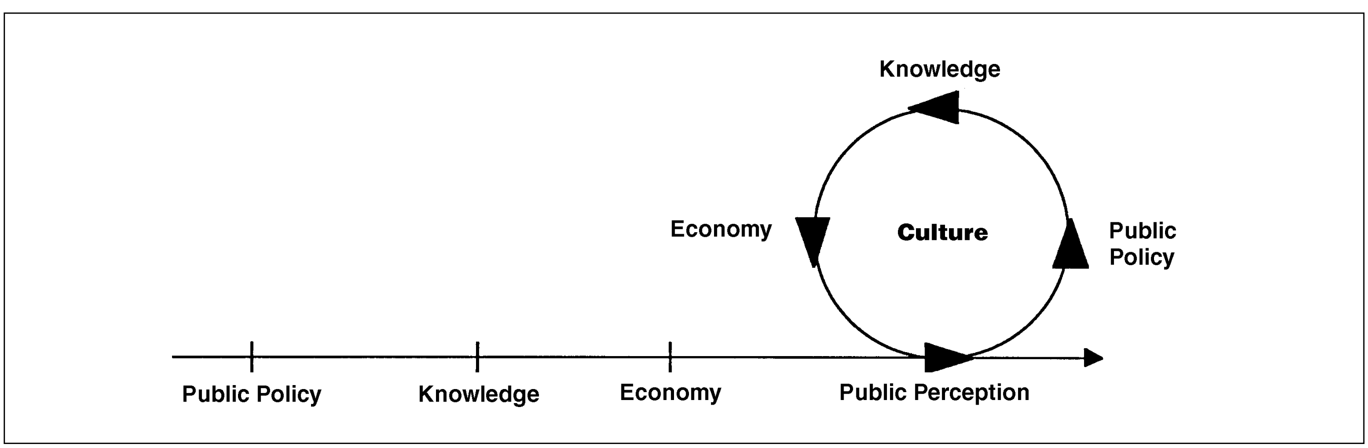
1. our *knowledge* changing, as we are provided with new information (e.g., the discovery of giant sequoia, scientific data today attesting to a lack of reproduction in most groves, fire as an important and frequent natural process in the groves);
2. this knowledge informing our *culture* and allowing it to further evolve (e.g, cultural acceptance of logging in the groves, our reverance for long-lived organisms increasing the public's interest in giant sequoia);
3. our knowledge and culture providing us with the *technology* to conduct different practices (e.g., the construction of highways, the logging, removal and milling of very large trees);
4. our *personal values* influencing our use of the groves and of this technology (e.g., increased logging);
5. *economics* as a force providing us with a range of choices based on our value systems for managing the groves and using the technology at hand (e.g., for aesethic values under a conservation ethic if funds allow purchase of groves for reserves, capitol available to log groves using various methods and the cash value of the lumber making this economically viable);
6. our *perception* as to whether these existing or new uses of groves are good, bad or of some general value (e.g., clearcutting as a good forest practice within giant sequoia groves, development of new tourist facilities with groves acceptable);
7. use of our knowledge, culture, technology, personal values and economics to then establish new *policy* (e.g., creation of reserves, funding of aggressive fuels reduction programs); and
8. the implementation of these policies through various *actions* (e.g., a prescribed burn program, the removal of grove facilities).

The outcome of our actions provides us with a new knowledge base, which may influence our culture, our values, encourage us to develop new technologies and create new policies, etc., as this cycle of interaction continues. It is thus no surprise that human interaction with the groves has changed through time, as influential individuals come and go, economic opportunities wax and wane, and political forces change. These interactions are chronicled here from a historic viewpoint.

Humans have a long history of association with the giant sequoia ecosystem, spanning at least the last 10,000–12,000 years according to our archeological and paleoecological data from the western Sierra Nevada region. Although our knowledge of Native American use of the groves is really quite limited, there is evidence for prehistoric occupance of some groves and occupance adjacent to others. Archeological materials have been found within the Atwell, Case Mountain, Giant Forest, Mariposa, McKinley, Mountain Home, Nelder,

**FIGURE 2**

Evolution of human dimensions of giant sequoia ecosystems.



North Calaveras, and Redwood Mountain groves. The longest record, approximately 3,000 years of occupation, is from the Mariposa Grove in Yosemite National Park, where the most detailed archeological work has been done (Hull 1989).

We do know through discussions with contemporary Native Americans that giant sequoia were viewed as a part of the circle of Earth life and of their ecosystem, as all living things are. The big tree (toos-pung-ish) (Hea-mi-withic) held special values (Franco 1994), and what our EuroAmerican cultures view as "ammenity" values: spiritual, aesthetic, and non-destructive recreational. Although materials from the giant sequoia were used by Native Americans no more frequently than other conifers, the groves and monarchs were special places to visit, think and pray. Native American cultures have the greatest respect for ancient ones, whether they are their elders proper, the ancient rocks of the earth, or ancient trees such as the monarchs (Franco 1994).

Early explorers, largely of European descendent, were astounded upon discovering the giant sequoia monarchs. The first publication noting the large "redwood" is Leonard's (1839) account of the 1833 Walker expedition across the Sierra Nevada. As noted by Hartesveldt et al. (1975), the trees they encountered were probably either the Tuolumne Grove or Mariposa Grove of what is now Yosemite National Park (see also Willard 1995). This is followed by the more infamous discovery by Dowd (Sonora Herald 1852) of the Calaveras groves. Over the next forty years, many large monarchs were felled for exhibition, with the initial conservation outcry starting in 1853. However, the destruction of huge expanses of groves began soon thereafter in the mid 1850s, as lumbering spread throughout the Sierra Nevada (Hartesveldt et al. 1975), with elaborate railroad, flume, and mill construction through remarkable engineering feats allowing the destruction of these large trees and their progeny. Although significant, intensive logging of fourteen groves occurred before 1900, logging continued through about 1950, with an additional twelve groves logged, and by 1950 about one-third of the giant sequoia acreage had been logged (Meyer for California State Legislature 1952), with major cutting in the large Atwell, Converse Basin, Dillonwood, Mountain Home, and Redwood Mountain groves. Logging of the groves slowed greatly in the 1950s, 1960s and 1970s, only to reemerge and become an issue of concern to environmentalists in the Sequoia National Forest groves in the 1980s, where heavy whitewood logging within several groves began. In is interesting to note that forty-one of the seventy-three groves are unlogged, and that four more only have incidential tree removal due to road construction. The great majority of these groves (thirty) are in the National Parks (see following paragraph), with the Forest Service groves that remain unlogged (ten) largely in wildnerness and of relatively small size (5–300 ac). The South Calaveras Grove of Calaveras Big Trees State Park is also unlogged. It should also be noted here that many of the logged groves still have significant unlogged areas of old-growth giant sequoia forest within them.

In 1864, through special legislation (Hartesveldt et al. 1975), the federal government deeded the Mariposa Grove to the State of California, along with Yosemite Valley, for public recreational use and enjoyment. After a long lull and political battles to protect more Sierra Nevada environments, federal legislation was again passed in 1890 to establish Sequoia and General Grant National Parks, and then Yosemite National Park. The authors of these bills and the sentiment of the local California politicians made this happen very rapidly and opportunistically. According to Berland (1962) in Hartesveldt et al. (1975), destruction of great expanses of giant sequoia for timber helped move these acts forward. These were clearly conservation efforts, and the passage of this legislation in 1890 was the most important policy protecting giant sequoia in our history.

This was followed by the later protection of the North Calaveras Grove under the 1909 federal legislation creating the Calaveras Bigtree National Forest, and its subsequent addition to the State Park system in 1931 through the environmental activist, fundraising efforts of the Save-the-Redwoods League and the Calaveras Grove Association. The South Calaveras Grove was later purchased with public funds in 1954 and added to the State Park (Hartesveldt et al. 1975).

A small group of committed conservationists continued to push to preserve additional giant sequoia lands, with the League persistent in their efforts. National Forest System lands were both purchased outright and transferred by proclamation to Sequoia and Kings Canyon National Park (Hartesveldt et al. 1975). In addition, both Sequoia National Forest and Sequoia and Kings Canyon National Parks have continued to acquire privately held giant sequoia lands and add them to their public land base. This effort continues today, especially in regard to private in-holdings. Furthermore, political efforts continue to confer additional protection to National Forest System groves, with the individuals changing but several non-profit environmental groups (e.g., Save-the-Redwoods League, Sierra Club) remaining in the battle.

As users of our giant sequoia forests, we have continued to demand recreational opportunities in the groves and to individual named monarchs which necessitate some paved and gravel road grove access, convenient visitor interpretive facilities and overnight accomodations, and use of our personal automobiles to reach the groves. Many visitors want to be able to photograph the monarchs, which has encouraged removal of undergrowth white woods in particular and active vegetation management of some heavily visited groves, such as the Mariposa Grove of Yosemite National Park. A segment of the human population also demands groves within wildnerness areas and in remote, "unspoiled" states. Giant sequoia groves are also encompassed in the larger effort to preserve remnant old-growth forests.

In conclusion, we are fortunate to date that the relatively large number of groves and the diversity of their environmental settings and management has allowed us to maintain a range of human dimensions of these ecosystems, and opportunities to fulfill us all of our individual values we place on the groves. However, some of our values relate to specific groves and our personal, family or cultural histories with them. When these "personalized" groves are subject to logging, prescribed fire, or other human intrusion, it angers concerned citizens (as shown by lawsuits filed, the MSA, and the public's response to our questionnaire), and as such, grove management approaches and policies must not only focus on giant sequoia Sierra Nevada-wide, but on individual groves and their place in our ecosystem.

## ECOLOGICAL STATE OF THE GIANT SEQUOIA GROVES

Giant sequoia-mixed conifer ecosystems are complex and dynamic. The dominant tree species in this ecosystem include white fir (*Abies concolor*), sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), incense-cedar (*Calocedrus decurrens*), and giant sequoia (*Sequoiadendron giganteum*). Other species that are associated with these ecosystem include Douglas-fir (*Pseudotsuga menziesii*), red fir (*Abies magnifica*), Jeffrey pine (*Pinus jeffreyi*), and California black oak (*Quercus kelloggii*). We assess the current state of these ecosystems in the Sierra Nevada, and review how past, present and future management decisions have or may effect these ecosystems.

### Effects of fire

The structure and dynamics of giant sequoia-mixed conifer forests of the Sierra Nevada were once dominated by frequent surface fires. Before the ecosystems of the Sierra Nevada were put under the policy of fire suppression in the early 1900s (Husari 1996, SNEP report), the range of fire behavior and resulting ecosystem effects was much more diverse when compared to the present.

Large, high intensity fires did occur in the giant sequoia-mixed conifer ecosystem in the past. These events probably occurred when weather conditions were extreme such as in the 1297 AD fire that occurred in Mountain Home Grove (Stephenson et al. 1991). In this fire only the largest giant sequoias survived; most other mixed conifer associates were killed. Investigations of the historical role of fire in these systems have revealed that fires burned through the giant sequoia groves in the southern Sierra every 4–13 years (Kilgore and Taylor 1979; Christensen et al. 1987). These fires were typically of low intensity with patches of high intensity (Muir 1901; Stephenson et al. 1991; Skinner et al. 1996, SNEP report). More than 3,200 fire scars and an additional 2,400 fire dates based on other indicators from the last three millennia have been analyzed from five different giant sequoia groves (Swetnam et al. 1992). This analysis of all fire indicators in the Circle Meadow area of Giant Forest resulted in a mean fire interval of 4.1 years, giving further evidence of the historical importance of fire in structuring these ecosystems.

Frequent fires in these ecosystem resulted in forests with low surface fuel loads. Historically, the majority of fires in these systems were of low intensity and large, stand replacing fires were uncommon.

Fire suppression has resulted in fuel accumulation and has increased the associated risk of large crown fires in the Sierra Nevada. Fire suppression has also increased the horizontal and vertical fuel continuity in these ecosystems and today they are much more vulnerable to high intensity crown fires when compared to 100 years ago. Increased fuel loads in conjunction with high fuel continuity can produce extreme fire behavior and effects when coupled with low humidity and high temperatures. Many areas in the Sierra Nevada that have old-growth forests are now vulnerable to such intense fires.

The fires that occurred pre-historically occurred under varying climatic regimes and as such were themselves diverse in character. They burned in a variety of sizes, severities, intervals, and to a lesser extent, seasons. The resulting diverse ecosystem structures, in turn, produced the conditions necessary for future diverse fires.

Fire suppression in the last century has resulted in drastically reduced pyrodiversity (Martin and Sapsis 1992) in the giant sequoia-mixed conifer ecosystem. Most low and medium intensity fires are suppressed by wildfire agencies. Nationally, only 2% of all fires in U.S. Forest Service jurisdiction required large-scale suppression efforts in 1994 (Husari 1996, SNEP report). Only the most extreme fires burn, since suppressing these fires is almost impossible given high fuel loads coupled with extreme fire weather. In 1994, 94% of the total burned acres on National Forest System lands resulted from 2% of the fires (Husari 1996, SNEP report). This gives further evidence that only the largest, most intense fires are currently play a significant role in forest processes.

The ecosystem effects of these high intensity fires lack diversity. Most of these fires are stand replacing crown fires, with very few of them low intensity surface fires. The lack of low and medium intensity fire events that once were very common has resulted in ecosystems with increased tree density and changing species composition. Shade tolerant species are presently favored, and they are increasing in abundance in most giant sequoia-mixed conifer ecosystems.

Native Americans influenced the prehistoric fire regime in the giant sequoia / mixed conifer ecosystem. They shortened the intervals between fires in many areas for specific land management objectives (K. Anderson 1993). Over 75% of the plant material used by most tribes of the Sierra Nevada depended upon epicormic branches or adventitious shoots from a diverse group of native plants (K. Anderson 1993). New shoots were long, flexible and straight, had few bark blemishes, and were not forked, making them excellent material for basket making. Unless the shrubs and trees were coppiced, either by fire or pruning, they would not produce material of superior quality.

Native Americans also specifically burned areas with California black oak (*Quercus kelloggii*) to reduce the loss of acorns to insects such as filbert worms (*Melissopus latiferreanus*) and filbert weevils (*Curculio* spp.) (K. Anderson 1993). Many of the Native American-ignited fires probably spread extensively through the giant sequoia-mixed conifer ecosystems.

The physical effects of fire on trees depend on the characteristics of both the trees and the fires (Ryan 1990). The extent of damage to leaves, buds, stems, and fine roots largely determines the likelihood of death. Damage to living tissues is dependent on the duration of elevated temperature. An internal temperature of 60 °C for one minute is considered lethal for plant tissues (Hare 1961). Larger trees are more resistant to fire damage because of thicker bark, taller foliage, and the increase in heat sink capacity with an increase in diameter (Martin 1963; Costa et al. 1991). The increase in fire resistance varies with tree size and differs among species (van Wagtendonk 1983; Stephens 1995).

Heating of specific tree tissues during a fire can be related to fire characteristics that describe critical durations, amounts, and fluxes of heat. Fireline intensity (Byram 1959) is related to convectional heat transfer to foliage and buds. Fuel consumption delimits the total energy released by the fire. Greater consumption of surface fuels prolongs heating of cambial and root tissues and in general, increases mortality. In addition, high fireline intensities and fuel consumption increase and prolong the radiative heat loading on all above ground plant tissues.

Young growth giant sequoia has the ability to survive extreme crown scorch. In one study, young growth giant sequoia varying in dbh from 10–100 cm were subjected to different levels of overstory damage (Stephens 1995). No mortality occurred in giant sequoias that had their crown volumes scorched between 0–90%. All giant sequoias receiving 100% crown volume scorch died in this study indicating giant sequoia of this age and size do not recover from 100% crown schorch

Thermal injury of roots may be an important source of injury to trees and other perennial plants from fire. The significance and relationship of root injury to tree mortality is not well understood and requires further research.

Historically, the understory of the giant sequoia-mixed conifer ecosystem was much more open because of the frequent surface fires. Understory response to prescribed fire here depends on the amount of litter and duff consumed (Kauffman 1986, Valentino 1988). Spring prescribed burns in old-growth ponderosa pine forests with high duff and litter fuel loads resulted in higher mortality as compared to fall burns (Swezy and Agee 1990). Burning reduced fine root dry weight by 50–75% one and then five months after the treatment. Burnout of litter and duff may have ecological significance in the giant sequoia-mixed conifer ecosystem due to high fuel load and proximity to surface roots and stem cambial tissue. Summer and fall prescribed fires in giant sequoia groves in Sequoia National Park have not resulted in old-growth giant sequoia mortality indicating this species may be more resistant to the effects of fine root mortality caused by duff and litter burn-out

The removal of fire from the ecosystem has changed the structure and dynamics of the Sierra Nevada forests. The reintegration of fire into the ecosystem will require careful thought, action, and monitoring.

## Regeneration

The giant sequoia-mixed conifer forests were once composed of a mixture of very large trees with patches of regeneration (Sudworth 1900; Stephenson et al. 1991). Historically, giant sequoia-mixed conifer forests were thinned from below by surface fires. Fire induced tree mortality was common in these systems and was fundamental in structuring the mixed conifer forest. Most large trees were not killed by the frequent surface fires but the smaller size classes of trees were thinned and snags and down trees were both created and consumed. The number of snags that once existed in this forest is still under debate. This thinning process was essential in reducing tree density to levels such that other disturbance factors such as insects, disease, and drought, did not lead to catastrophic loss of the forest (Kolb et al. 1994).

Several species in the mixed conifer forest require periodic disturbance for successful establishment and recruitment. These species include giant sequoia (*Sequioadendron giganteum*), ponderosa pine (*Pinus ponderosa*), black oak (*Quercus kelloggii*), and to a lesser extent, sugar pine (*Pinus lambertiana*). Litter layers of 5 cm or larger will reduce giant sequoia seed germination dramatically (Hartesveldt and Harvey 1967). The duff layer is an excellent habitat for many damping-off diseases which kill seedlings before they can become established. The duff layer stores very little water and many germinating seedlings die because of insufficient moisture during the summer drought period. 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.

Shade intolerant species such as giant sequoia and ponderosa pine require high light-levels to grow, since their photosynthesis compensation points are higher than shade tolerant species such as white fir (Stark 1968; Harvey et al. 1980). Recruitment of shade intolerant species will occur in gaps in the forest, but will not occur under a mature forest canopy (Hartesveldt and Harvey 1967; Harvey et al. 1980).

Gaps in the mixed conifer forest canopy are caused by tree fall, insects, disease and localized mortality during fires. Without this type of disturbance, recruitment of shade intolerant species will occur at a slow rate and over time, shade intolerant species will be replaced by shade tolerant species. This is evident today with the increased numbers of white fir and incense cedar in the smaller size classes (Parsons and DeBendeetti 1979) and decreased or absent giant sequoia recruitment (Stephenson 1994). Gap size will have a tremendous effect on seedling recruitment and growth. Seedling survival is more than ten times greater in areas that have burned in high intensity fires (Harvey et al. 1980; Harvey and Shellhammer 1980). Historically, the size of the opening created by localized high intensity fires varied between 0.1–0.4 ha (Stephenson 1994). This estimate of opening size is 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 since they are also dynamic (Stephenson 1987).

Giant sequoia seedling mortality is very high in the first few years (Harvey and Shellhammer 1980) after establishment. Given the high rate of mortality, the number of individuals in the current century would have to be much greater for the population to be sustainable. This level of regeneration is not occurring in the majority of giant sequoia ecosystems. For example, giant sequoia reproduction has declined in Sequoia and Kings Canyon and Yosemite National Parks in the 20th century (Stephenson 1994). These areas have been under a policy of fire suppression until recently: 1968 for Sequoia and Kings Canyon and 1972 for Yosemite. Some sites in this study were logged extensively at the turn of the century (Atwell grove). Approximately 44% of the giant sequoias inventoried in this study were established in the 19th century with another 12% established in the 18th century. This is in contrast to only 7% of the living sequoias becoming established in the 20th century (data from Stephenson, 1994). Data from this study clearly indicate that there is a problem with giant sequoia regeneration.

Tree density has increased dramatically in many giant sequoia groves in the last 100 years (Parsons and DeBenedetti 1979). Removal of the high frequency disturbance regime has benefitted the shade tolerant species such as white fir and incense cedar over the shade intolerant species of ponderosa pine and giant sequoia. California black oak has also been effected by the decrease in pyrodiversity in the mixed conifer ecosystem. California black oak is adapted to fire by its ability to resprout. Without disturbance, black oak can be overgrown by shade tolerant conifers and killed due to low light levels.

## Effects of disease

Annosus root rot (*Heterobasidion annosum*), a fungus, may also be a major ecological threat to giant sequoia (Piirto 1994). The type S intersterility group infects giant sequoia, spruce, and fir. In greenhouse seedling inoculation studies, isolates of *H. annosum* collected from true fir and giant sequoia were capable of causing pathogenesis on either species (Piirto et al. 1992). The fungus causes both butt rot and tree mortality.

The pathogen can become established through freshly cut stump surfaces by means of airborne spores. From infected stumps, the pathogen kills surrounding trees by infecting their roots from root contacts and graphs. In true fir, the pathogen does not need freshly cut stumps to become established. It is very common in pure stands of white fir in the Sierra Nevada.

This pathogen can be transmitted through root contact and since the same intersterility group infects both white fir and giant sequoia, the groves may be much more vulnerable to this disease today than in the past. White fir is now very common in many giant sequoia groves, and it may provide a vector to transmit annosus root rot to old and young growth giant sequoia trees. Many other diseases associations are known to occur with giant sequoia (Piirto et al. 1984; Parmeter 1987), but the significance, ecological role and influences of them are not well understood (Piirto et al. 1992).

Sugar pine is an associate of the giant sequoia-mixed conifer ecosystem that is being selectively impacted by white pine blister rust (*Cronartim ribicola*), an introduced disease. White pine blister rust was introduced from Asia to a single point on Vancouver Island in the early 1900s and is now epidemic throughout the Sierra Nevada. *Ribes* species are the alternate hosts to white pine blister rust fungus, and at least nineteen different species grow in the mixed conifer forest (Kinloch and Scheuner 1990). Early attempts to eliminate white pine blister rust by eradication of *Ribes* were unsuccessful.

Over 80% of the growing stock of sugar pine is located in the mixed conifer forest of the Sierra Nevada (USDA 1978). Sugar pine generally comprises 5–25% of the stocking in its native range (Kinloch and Scheuner 1990). The “common race” of white pine blister rust fails to infect or develop on sugar pine seedlings and saplings that have one (or perhaps more) dominant allele(s) at a resistance locus (“Rr”) (Libby and Millar 1989). The “R” alleles occur at low frequency (less than 1% to an apparent maximum near 14%, with 3–5% being common) in most sugar pine populations (Libby and Millar 1989). A higher percentage of trees resistant to blister rust are found in the southern range of the sugar pine where giant sequoia is also most abundant.

A different race of white pine blister rust was discovered in 1978 near the town of Happy Camp in northern California (Kinloch and Comstock 1980). This “race” of white pine blister rust successfully attacks seedlings that have the “Rr” or “RR” genotype. Since it was discovered in 1978, the new race of blister rust has not migrated out of the area in which it was discovered (Kinloch and Dupper 1987). This has occurred with abundant stands of sugar pine and *Ribes* surrounding the new “race”. It is possible that this particular “race” is specifically adapted to infect major-gene-resistant sugar pine that were planted in the 1960s at Happy Camp (Kinloch and Dupper, 1987). Defense strategies must be general and should not focus just on the current races of rust or on the resistance genes now being found in sugar pine (Libby and Millar 1989).

Data show that once a seedling reaches some maturation level the susceptibility to the common and new race of blister rust is reduced. Trees may become infected, but many are not killed by the rust (Kinloch and Dupper 1987). The genetics of the host resistance is not well understood, but it seems likely to be associated with variability of several loci (Libby and Millar, 1989).

This disease is presently reducing the density of sugar pine in the giant sequoia-mixed conifer ecosystem and has the potential of reducing biodiversity.

## Effects of air pollution

Air pollution, specifically ozone concentration, can change physiological responses in giant sequoia seedlings (Miller et al. 1992). Container grown seedlings were exposed to charcoal filtered air, 1X and 1.5X ambient ozone concentrations for the entire summer season in Giant Forest, Sequoia National Park. Very slight levels of visible ozone injury to cotyledons and primary leaves were observed at the 1X ozone concentration; however, at 1.5X ambient the symptoms of foliar injury were extensive (Miller et al. 1992).

The end of season harvest of seedlings exposed to the 1.5X ambient treatment showed no significant reduction in root, shoot, or total plant weights. Gas exchange measurements showed that the 1.5X ambient treatment increased the light compensation point, lowered $CO_2$ exchange rate at light saturation, and increased dark respiration, compared to the control (Miller et al. 1992).

A two month branch-chamber fumigation of a 120 year-old giant sequoia with charcoal filtered air and ozone treatments at 1X, 2X, and 3X ambient did not yield visible injury or any detectable changes in photosynthetic rates (Miller et al. 1992), indicating that as giant sequoia ages, it becomes less susceptible to ozone foliar injury.

Other mixed conifer forest species, specifically ponderosa pine and jeffrey pine, are much more susceptible to ozone injury than giant sequoia. These three-needled pines show foliar injury to the present levels of ozone in the southern Sierra Nevada (Peterson et al. 1987). This foliar injury to pines is linked to elevated ozone concentrations with photochemical air pollution, and is characterized mainly by chlorotic mottle symptoms, leading to lower rates of photosynthesis and early loss of needles and, in extreme cases, by diminished annual ring width (Peterson et al. 1987). Within stands, the dominant and codominant trees are less injured than smaller or suppressed trees which experience more competition for light, water and nutrients. The region east of Fresno, particularly the Grant Grove and Giant Forest Grove region of Sequoia and Kings Canyon National Parks, has been shown to have the most severe ozone damage in the Sierra Nevada (Stolte et al. 1991).

While adult giant sequoia are evidently unharmed by increased levels of ozone, seedlings can be. This could effect seedling survival and recruitment. Ponderosa pine and jeffrey pine are more susceptible to increased ozone concentrations, and this could influence the species composition of the giant sequoia-mixed confer forest through time. With fire suppression favoring the establishment and growth of shade tolerant species such as white fir and incense cedar, the further reduction in competitive ability of ponderosa pine and jeffrey pine due to ozone stress exacerbates the conversion to stands with more white fir and incense cedar (Miller 1996, SNEP report).

## Summary

In summary, the giant sequoia ecosystems of the Sierra Nevada are in an ecologically vulnerable state, with the health of these systems far from optimal. Regeneration of giant sequoia in the last century has been minimal and much below levels needed to maintain the historic demographic structure. This lack of regeneration is largely due to our fire suppression policies, as giant sequoia is a shade intolerant species that requires a mineral seed bed, forest canopy openings, and adequate soil moisture for germination and establishment. In-growth of shade tolerant species has created poor conditions for juvenile giant sequoia. In addition, experimental work shows that increased ozone levels result in lower net photosynthesis of giant sequoia seedlings. Annosus root rot is a plant disease that may impact giant sequoia as well.

# THE HISTORY OF GIANT SEQUOIA GROVE MANAGEMENT

In our review of the Mediated Settlement Agreement recommendations and directions, we saw the need to review giant sequoia grove management practices to inform adaptive management and monitoring regimes for future ecosystem-based management. With this background information, an experimental protocol can be developed for the most appropriate management methods to ensure the long-term sustainability of the giant sequoia population and its composite groves. Agencies should solicit expert scientific feedback on various experimental management regimes (i.e., prescriptions) and establish common monitoring methods to enable the restoration of natural structure, function and process to giant sequoia groves across their range through time. Better scientific information for the giant sequoia grove ecosystems is needed to inform management of this highly visible species of concern.

The scientific literature on giant sequoia grove management presents largely the outcomes from (1) "hands-off" management under fire suppression, or (2) the application of logging or (3) prescribed fire to the groves. The role of logging and fire have been largely evaluated separately.

Agency and private owner management techniques have varied according to the goals set. All groves are subject to the consequences of indirect human impacts such as air pollution, regional loss of biodiversity, spread of exotic organisms, etc.

## Early Management Systems and Impacts on the Groves

The literature on Native American management of giant sequoia groves suggests that human impacts to the groves were insignificant other than the largely indirect and occasionally direct use of fire as a management tool in the forest understory. Native Americans used fire to clear the forest floor to promote the growth and regeneration of targeted species for food stuffs and basketry materials. Fires were intentionally set on a frequent basis in the foothill zone of the Sierra Nevada, and whether targeting the giant sequoia groves or not, probably burned through them, carrying upslope into the mixed conifer forest and occasionally into the upper mixed conifer-red fir dominated communities (K. Anderson 1993). In recent decades, a tribal group has also extracted timber from the giant sequoia groves they manage on the Tule Indian Reservation, but their management goals do not center on the giant sequoia, but on the long-term sustainability of the grove ecosystem and in particular on the management of forest floor shrubs and herbs.

The EuroAmerican invasion of the Sierra Nevada, largely in the latter half of the nineteenth century, resulted in massive alteration of grove ecosystems by deliberate logging of trees, diversion and damming of streams, grazing transhumance, and construction of roads and facilities within giant sequoia groves or upslope of them. These early direct and indirect management activities altered giant sequoia ecosystem processes and forest structure. The early work of dendrologist George Sudworth (1900) gives sound documentation of the impact of 50 years of EuroAmerican management on some of the southern Sierra Nevada giant sequoia groves.

Sudworth performed a tree inventory of select groves within the giant sequoia-mixed conifer ecosystems of the southern Sierra Nevada at the turn of the century (1898–1901 AD). Sudworth sampled standardized plots, and in many cases after he recoreded tree species and diameter breast height, he also recorded notes on tree regeneration within his plots and noted impacts from human use. The following notes are from his original field note books in mixed conifer and giant sequoia-mixed conifer (six groves) ecosystems of the southern Sierra Nevada:

- September, 1900. "Westside of north fork of Kings river, one half way up slope. No reproduction, sheep grazed till 2 years ago and burned over."
- September, 1900. "Bubs creek near Charlotte creek mouth (tributary of Kings river), an exceptionally dense stand. No reproduction, complete shade, fire marks ."
- September, 1900. " Near sugar pine mill. Area cut, no reproduction, all timber sound but fire marked."
- September, 1900. "1 mile west of sugar pine sawmill. In rich sandy loam, abundant reproduction, .5–4 ft of all species. All timber severely fire marked at collar."
- October, 1900. " Headwater of Chiquita creek; typical of this area down to the middle fork of the San Joaquin river. 60 concolor seedlings 3–6 ft high. No humans, sheep and cattle grazing of long standing."
- October, 1901. "Heavy shade, no reproduction, humans, 8–10, steep, rocky loam soil, east slope."

Sudworth's notes indicate there were significant impacts on these ecosystems at the turn of the century. He noted recent evidence of fire in the majority of the plots, and that these fires were probably ignited by sheepherders to increase forage for their livestock. These fires coupled with sheep browsing probably reduced regeneration in these grove ecosystems. In one plot, he noted that regeneration of all tree species was present and in another, only white fir regeneration was found. This indicates that the impacts of browsing and burning were not uniform throughout the entire region.

Sudworth also stated that excessive sheep browsing in riparian areas was affecting the hydrology of the giant sequoia groves. He believed springs and perennial streams were being affected by excessive sheep browsing and this resulted in more xeric conditions.

One note in his field book suggests that he may have been measuring stands that were dominated by large trees. One of the plots was "an exceptionally dense stand". Earlier Sudworth noted his plots were "representative" of the forest, but there is some suggestion that he may have biased his samples to include areas dominated by very large trees.

In 1900, an early report on giant sequoia groves indicated only 10 groves of giant sequoia were known to exist in the Sierra Nevada (Perkins 1900), and Sudworth had visited six of these. Only a few of the groves were in government ownership at this time and logging was a major threat to the groves (Perkins 1900). Sequoia and General Grant National Parks which were created to conserve giant sequoia each had an operating sawmill near them at the turn of the century. A total of 1,172 ac were privately held inside these parks, and the majority of the other groves were in private ownership by people who had every right, and in many cases every intention, to cut them into lumber (Perkins 1900).

Most early logging operations in giant sequoia wasted a great deal of wood. When the trees were felled the trunk and upper extremities frequently broke into almost useless fragments (Perkins 1900). If the tree did not break apart at impact, gunpowder was used to blast the trunk apart into pieces that could be handled by the field crews. This waste coupled with the waste that also occurred at the mill resulted in less than half of the standing volume of each giant sequoia harvested being converted into wood products (Perkins 1900).

Slash produced by early logging operations in the giant sequoia / mixed conifer ecosystems was enormous. It was frequently 5 or 6 ft thick and was thought at the time to be a certain source of future fires (Perkins 1900). Early logging operations certainly contributed to large, intense fires because of the increase in surface fuel load and increased ignitions from field crews. Forest operations that do not treat the resulting slash will result in fuel conditions that are more severe than before the system was treated.

It is thus evident that many giant sequoia / mixed conifer ecosystems were impacted by livestock, fire, and logging at the turn of the century. Some groves such as Converse Basin were almost completely clear-cut at this time. Sheep browsing was also intense in these ecosystems at this time and fires were frequently ignited by the herders to increase forage production. The combination of sheep browsing and herder ignited fires probably reduced regeneration in these ecosystems.

## Current Management Systems

### Timber Management: Logging in Giant Sequoia Groves

Many of the giant sequoia groves of the Sierra Nevada have been altered by past logging. This report summarizes the logging history and timber management of the groves for various time periods (tables 5–12). Information in this report was obtained through a survey of the land owners and land management agencies that currently manage the groves. Information was not obtained from Balch Park (the Tulare County park within the State's Mountain Home Demonstration State Forest), the private land owner of part of the large Dillonwood Grove, and the Tule River Indian Reservation (Parker Peak and North Cold Groves), because these landowners chose not to provide these data.

Logging has occurred in many different giant sequoia groves. The majority of harvests of large giant sequoias occurred before 1900. Recent logging has concentrated on the species of white woods found in the mixed conifer-giant sequoia ecosystem. Over half of the giant sequoia groves in the Sierra Nevada have never been logged: forty-one of seventy-three (56%), plus four more (cumulative total 62%) with only incidential tree removal due to road construction.

Mountain Home Demonstration State Forest is the only agency that continues to have an active timber harvest program in the giant sequoia-mixed conifer ecosystem. Mountain Home has used uneven-aged silvicultural methods and prescribed fire since the land was acquired (and already heavily logged over) in 1946.

The diversity of logging practices through time in the giant sequoia groves has resulted in diverse forest structures. As such, a common management prescription will not be appropriate for all groves, with the groves currently in various states or conditions.

### Prescribed Burning, Biomassing, and Fuel Wood Treatments

Information has been collected on the average number of acres treated with prescribed fire, biomassing, and fuel wood treatments for the National Parks and National Forests of the central and southern Sierra Nevada. These data were not restricted to giant sequoia groves. Information has also been obtained on how many project-related National Environmen-

**TABLE 5**

Fourteen groves were logged before the turn of the century (ca. 1900). Many of these groves or portions of the groves were clear-cut.

| | |
|---|---|
| Atwell | SAWMILL OPEN 1870s; MAJOR CUT 1890s |
| Big Stump | CLEAR-CUT, LATE 1880s |
| Grant | CENTENNIAL STUMP (1876) ONLY |
| Mountain Home | Start 1870, more w/road 1885 |
| Nelder Grove | 1874 start, 1879–92 RW* removal |
| Whitaker's Forest | RW and WW* around 220 monarchs 1875–78 |
| Abbott | Heavy, RW/WW*, all acres |
| Big Stump USFS | Heavy, RW/WW, 485 acres |
| Cherry Gap | Heavy, RW/WW, 190 acres |
| Converse Basin | Heavy, RW/WW, 1500 acres |
| Dillonwood | Heavy, RW/WW, 500 acres? |
| Grant USFS | Heavy, RW/WW, 130 acres |
| Mountain Home USFS | Heavy, RW/WW, 500 acres? |
| Redwood Mountain USFS | Heavy, RW/WW, 1000 acres? |

*Note: RW = giant sequoia; WW = white woods, includes white fir, incense cedar, sugar pine, and ponderosa pine.

**TABLE 6**

Eighteen groves were logged from 1901–50. Both clear-cut and partial cutting was reported during this time period,with both giant sequoias and white woods were logged.

| | |
|---|---|
| Alder Creek | Light, WW and RW*, 400 acres |
| Atwell | LIMITED CLEANUP LOGGING through 1930S |
| Belknap Complex | light, WW,100 acres? |
| Black Mountain | Light, RW/WW (priv),100 acres? |
| Case Mountain | began in 1940's including many large sequoias |
| Converse Basin | Heavy, RW/WW, 1500 acres |
| Deer Creek | Light, WW, 144 acres |
| Dillonwood | Heavy, RW/WW |
| Evans Complex | Heavy, RW/WW, 1000 acres? |
| Indian Basin | Heavy, RW/WW, 449 acres |
| Lost | HIGHWAY CUT THROUGH GROVE 1932 |
| McKinley Grove | Possibly some logging when building McKinley Grove Road |
| Mountain Home | 1940s RW logged again |
| Mountain Home USFS | Heavy, RW/WW, 100 acres? |
| Nelder Grove | shingle mill, cut down RW |
| Redwood Mountain | 1930s SELECT CUT AT BARTONS POST CAMP |
| Redwood Mountain USFS | Light, WW, 100 acres |
| Starvation Complex | Light, WW, 20 acres? |
| Whitaker's Forest | 1946 2.2 MMBF WW |

*Note: RW = giant sequoia; WW = white woods, includes white fir, incense cedar, sugar pine, and ponderosa pine.

**TABLE 7**

Six groves were logged from 1950–60. All groves are reported to be lightly logged except the Dillonwood grove. Both giant sequoia and white woods were logged.

| | |
|---|---|
| Black Mountain | Light, RW/WW* (priv),100 acres? |
| Case Mountain | Continued into mid 1950s |
| Converse Basin | Light, WW, 100 acres |
| Dillonwood | Heavy, RW/WW |
| Mountain Home | WW, 1.75 MMBF |
| Mountain Home USFS | Light, WW |
| Red Hill | Light, WW, 100 acres? |

*Note: RW = giant sequoia; WW = white woods, includes white fir, incense cedar, sugar pine, and ponderosa pine.

**TABLE 8**

Nine groves were logged from 1960–1970. Most logging was reported to be light except in the Black Mountain, Long Meadow, and Mountain Home (CDF) groves. Only white woods were logged during this decade.

| | |
|---|---|
| Belknap Complex | light, WW*,100 acres? |
| Black Mountain | heavy, WW,100 acres? |
| Freeman Creek | light, WW,100 acres? |
| Grant USFS | light, WW, 100 acres? |
| Indian Basin | light, WW, 100 acres |
| Long Meadow | heavy, WW, 20 acres |
| McKinley Grove | dropped 2 dead white fir / were not salvaged |
| Mountain Home | summary WW, 2.88 MMBF |
| Mountain Home USFS | light, WW |
| Red Hill | light, WW, 100 acres? |

*Note: WW = white woods, includes white fir, incense cedar, sugar pine, and ponderosa pine.

**TABLE 9**

Thirteen groves were logged from 1970–80. Only white woods are reported logged during this decade. Logging reported to be light except for the Mountain Home, Black Mountain, Evans Complex, Landslide and Starvation Complex groves.

| | |
|---|---|
| Alder Creek | Light, WW*, 100 acres |
| Belknap Complex | Llight, WW salvage,100 acres? |
| Black Mountain | Heavy, WW,100 acres? |
| Converse Basin | Light, WW, 100 acres? |
| Evans Complex | Heavy, WW, 300 acres? |
| Indian Basin | Light, WW, 100 acres |
| Landslide | Heavy, WW, 10 acres? |
| Mariposa | White fir 1971 |
| McKinley Grove | Area logged surrounding the grove up to watershed boundary |
| Mountain Home | Summary WW, 1.75 MMBF |
| Mountain Home USFS | Light, WW |
| Packsaddle | Light, WW, 50 acres? |
| Starvation Complex | Heavy, WW, 10 acres |
| Whitaker's Forest | 50MBF |

*Note: WW = white woods, includes white fir, incense cedar, sugar pine, and ponderosa pine.

tal Protection Act (NEPA) documented acres are in the National Forests land management plans. The people listed here provided specific information on their respective programs: Gary Cones (Stanislaus National Forest), Louise Larson and Dave McCandliss (Sierra National Forest), Scott Williams (Sequoia and Kings Canyon National Parks), Ed Duncan (Yosemite National Park), and Aaron Gelobter (Sequoia National Forest).

The information listed below will not capture all of the variables associated with these complex treatment programs, but is intended to assess the current status of treatment programs in the forests of the southern Sierra Nevada. In reference to prescribed burns, it is important to remember that costs of individual burns can vary greatly based on their objectives and constraints, and therefore, information on the specific type of burn is included here with the associated cost information whenever possible.

**TABLE 10**

Thirteen groves were logged from 1980–90, with the majority of trees cut white woods but some giant sequoia cut in Converse Basin and Dillonwood groves. Heavy logging reported in Bearskin, Black Mountain, Converse Basin, Freeman Creek, Long Meadow, Peyrone and Redwood Mountain.

| | |
|---|---|
| Alder Creek | Light WW*, 200 acres |
| Bearskin | Heavy, WW, 20 acres |
| Belknap Complex | Light, WW salvage, 50 acres? |
| Black Mountain | Heavy, WW,150 acres? |
| Converse Basin | Heavy, RW/WW, 100 acres? |
| Dillonwood | Light, RW/WW (priv), unknown acres |
| Freeman Creek | Heavy, WW, 100 acres? within WS |
| Long Meadow | Heavy, WW, 200 acres |
| McKinley Grove | Logging occurred in grove in 1984 as part of Muley Sale |
| Mountain Home | Summary WW, 1.3 MMBF |
| Mountain Home USFS | Light, WW, 100 acres? |
| Peyrone | Heavy, WW, 100 acres |
| Red Hill | Moderate, WW, 200 acres? |
| Redwood Mountain USFS | Heavy, WW, 60 acres |

*Note: RW = giant sequoia; WW = white woods, includes white fir, incense cedar, sugar pine, and ponderosa pine.

*National Parks*—Yosemite National Park began a management-ignited prescribed burning program in 1970 and a prescribed natural fire program in 1972. From 1970–94, park staff ignited 130 prescribed burns. Prescribed burn unit size has varied between 4–6,000 ac for an average of 1,320 ac burned per year. Costs of prescribed burning have varied greatly depending on specific burn objectives and associated constraints. The average cost per acre from 1982–88 for management-ignited prescribed fires is reported to be $19.00 per acre.

From 1972–94 Yosemite managed 469 prescribed natural fires. More than half of these fires were less than 0.25 ac. Five percent of these fires grew over 1,000 ac which accounted for approximately 60% of the area burned. The average cost per acre from 1982–88 for prescribed natural fires was $23.00 per acre, slightly higher than the per acre cost for management-ignited prescribed fires. Costs are again variable. In the fall of 1993, 900 ac were burned in a remote area of the park in 1.5 hours using aerial ignition for a total cost of $0.23 per acre. Prescribed burns conducted in areas with significant natural resources can cost up to $300 per acre.

For Sequoia and Kings Canyon National Parks, calculation of prescribed burning costs is now done to include all costs to the taxpayer for the planning, preparation, execution and evaluation of management ignited prescribed fires. In 1992, 1104 ac were burned in the giant sequoia-mixed conifer ecosystem her for a total cost of $22 per acre, before an escape occurred that cost $700,000 to suppress. In 1993, a much smaller unit (33 ac) was burned in the giant sequoia-mixed conifer ecosystem for $356 per acre. Also in 1993, 75 ac were burned in the Grant Grove for an average cost of $189 per acre. Costs vary a great deal depending on the size of the unit and constraints.

The cost of burning relatively small units in the giant se-

**TABLE 11**

Seven groves are currently being logged. Most of the grove managers report that only light logging is occurring.

| | |
|---|---|
| Alder Creek | Light on private land, WW*, 100 acres |
| Belknap Complex | Light, WW salvage, 50 acres? |
| Black Mountain | Light, WW (res), unknown acres |
| Dillonwood | Light, WW (priv), unknown acres |
| Mountain Home CDF response | Summary 91-94, WW, 1.03 MMBF |
| Mountain Home USFS response | Light, MHSF, ? |
| Silver Creek | Limited harvesting occurred on the fringes of grove |
| Whitaker's Forest | 15MBF/YR |

*Note: RW = giant sequoia; WW = white woods, includes white fir, incensecedar, sugar pine, and ponderosa pine.

**TABLE 12**

Plans exist for logging four groves into the future. Mountain Home (CDF) is the only grove that reports that significant logging will occur in the future.

| | |
|---|---|
| Alder Creek | Light on private land, WW, unknown acres |
| Black Mountain | Light, WW (res), unknown acres |
| Mountain Home | 3 MMBF biennially |
| Mountain Home USFS | Light, MHSF, ? |
| Whitaker's Forest | changing |

*Note: WW = white woods, includes white fir, incense cedar, sugar pine, and ponderosa pine.

quoia-mixed conifer ecosystem is approximately equal in Yosemite and Sequoia and Kings Canyon National Parks. The cost of burning larger units in either park are also very similar if suppression is not required.

*National Forests*—The Stanislaus National Forest treats more acres with fuel reduction treatments that any other National Forest or National Park in the Sierra Nevada. From 1984-1994, 18,300 ac were treated with management-ignited prescribed fires. The area treated varied from 300–10,000 ac per year. Currently the forest has 30,000 ac under NEPA documentation, and has come very close to the achieving the objectives in the forest land management plan. Cost of the prescribed fires in the mixed conifer ecosystem has varied from $15–269 per acre, with an average cost of $35–40 per acre. Unit size has varied between 25–2,500 ac, with an average size of 300 ac.

The Stanislaus National Forest also has an active biomass program that has treated 1,000–3,000 ac per year, with an average of 2,000 ac treated. This program has removed an average of 8–10 MMBF per year. The biomass program is expected to increase in the future. Constraints might be the cost of preparing units (e.g., layout and marking and congeration plant economics). Designation by description of the types of trees to be removed instead of individual tree marking might solve the layout and marking problem. Furthermore, the Stanislaus National Forest has an active fuel wood program with 5.8–6.2 MMBF removed annually. The size of the area treated with the fuel wood program is approximately 5,000 ac per year.

The forest will continue to use a combination of understory thinning and prescribed burning to reduce forest fuel loads. The forest has identified losses from intense wildfires as its number one priority in landscape planning efforts. Support from line officers and staff has helped to remove many barriers encountered in this program. Recent large wildfires in this area have also helped to convince local residents of the importance of fuel reduction programs.

The Sierra National Forest is currently not using prescribed under-burning in the giant sequoia groves. Small white woods were removed on 27 acres of the McKinley Grove in the mid-1980s as a fuels reduction effort. Approximately half of the slash produced from this operation was hand piled and burned for a cost of $600 per acre. The slash was lopped and scattered in the other half of the unit for an average cost of $100 per acre. Average cost of under-burning here in the mixed conifer ecosystem is $85 per acre. In the giant sequoia groves, excessive fuels will require pre-treatments before prescribed burning can be used. In some areas of the Nelder Grove, fuel loads of 100 tons per acre have been found. Possible pre-treatments include hand piling at a cost of $300 per acre, feller buncher at $380 per acre, and mastication at $280 per acre.

Most prescribed fires conducted recently in the mixed conifer ecosystems on the Sierra National Forest were less than 40 ac, with an average size of approximately 15 ac. Currently, the Forest is planning to under-burn much larger units of 500–1,000 ac with an average size of 600 ac. It is estimated to cost between $40–100 per acre to burn these larger units, and no giant sequoia groves are included in these projected burns. The forest currently has 4,000 acres of under-burning in the mixed conifer ecosystem (no giant sequoia) under NEPA documentation, and is currently working on adding an additional 5,000 acres of mixed conifer (again, without giant sequoia).

The Sierra National Forest currently does not have a biomass program. The three to four local co-generation plants that were in the local market were recently bought by PG&E and closed down. Some problems encountered in the past with this operation included chip vans that were too big to negotiate forest roads and steep grades. The forest would like to have an active biomass program, but the marginal economics of co-generation plants may not make this possible. The forest has a fuel wood program and 6,000 permits are sold annually. Each permit removes approximately 2 cords of wood, but this operation has had a negligible effect in reducing forest fuel loads.

The Sierra National Forest staff believe that combinations of silvicultural treatments with prescribed fire will be the best approach to reduction of fuel loads in the giant sequoia-mixed conifer ecosystems. Treatments such as thinning from below and commercial thinning can be done and followed by prescribed burning to reduce fuel loads. An adaptive management plan is currently being developed for the Kings River Ranger District that will use small group selection units and under-burning to reduce forest fuel loads.

In the Sequoia National Forest, prescribed under-burning is currently not being used in the giant sequoia groves. The largest constraint to prescribed burning at the present time is the MSA (1990), which requires the completion of grove mapping, grove fuel inventories, and grove specific managment plans subject to NEPA evaluation for each grove before prescribed burning or any other management actions are undertaken. In the past, it has cost between $229–350 per acre to burn in the giant sequoia-mixed conifer ecosystem here. The size of unit treated has varied from 3–40 ac.

Currently the Sequoia National Forest does not have a biomass program. There is no co-generation plant located within an economically feasible distance to the Forest. The Forest does have a fuel wood program that is harvesting 2,900 MBF annually on approximately 1,000 ac. The Forest would like to use a combination of under-burning followed by harvesting of dead or dying trees to reduce fuel loads in the giant sequoia groves.

*Summary*—The three national forests in the central and southern Sierra Nevada use different methods in fuels management for the giant sequoia-mixed conifer and mixed conifer ecosystems. The Stanislaus National Forest is treating the largest number of acres and the Sequoia National Forest is treating the least. Constraints from the MSA (Sequoia National Forest 1990) have limited the number of acres treated in the Sequoia and Sierra National Forests. Direction from the Regional Forester in his memo of June 19, 1992 gives the three national forests with giant sequoia groves (the Tahoe, Sierra and Sequoia National Forests) the primary management objective of the MSA (1990) for the groves: protect, preserve and restore the groves for the benefit and enjoyment of future generations. Furthermore, the policy that is set forth is that the groves will be protected as natural areas, be buffered, be withdrawn from the sustained (regulated) timber production land base and from other forms of consumptive entry. In addition, through a Presidential Proclamation by George Bush on July 14, 1992 , the direction provided by the Regional Forester was further endorsed.

## IMPLICATIONS OF THE MEDIATED SETTLEMENT AGREEMENT FOR SEQUOIA NATIONAL FOREST ON GIANT SEQUOIA GROVE STATUS AND MANAGEMENT

Following the charge given to the SNEP to evaluate the Mediated Settlement Agreement for Sequoia National Forest (MSA), Section B, Sequoia Groves (Sequoia National Forest, 1990), and make “recommendations” for scientifically-based mapping and management of giant sequoia groves and those additional lands, if any, needed to ensure the long-term health and survival of giant sequoia ecosystems, we undertake an evaluation here of the management practices and administrative actions which pre-dated and initiated the mediation efforts, and comment on Sequoia National Forest’s recent management practices and administrative actions as related to the MSA to date. We note here that many other parts of the MSA are relevant to the discussion of management of giant sequoia ecosystems. A series of potential future directions for grove management are also presented.

The SNEP team made a number of assumptions in conducting our evaluation of the MSA:

1. giant sequoia were pivotal (e.g., central) in the MSA negotations;
2. the MSA is in place; it cannot be changed without signatures of all parties, which functionally means that it is extremely difficult to change it; it is not a perfect document from an ecosystem management perspective, which is recognized by many parties to it;
3. the workgroup wishes to solicit public input and information exchange as part of our evaluation, even though the overall SNEP is not a NEPA process and will not produce a preferred alternative;
4. the Sequoia National Forest is interested in implementing ecosystem management;
5. for much of the public, the MSA did not solve the giant sequoia issue;
6. no single “correct” management regime to preserve, protect and restore giant sequoia groves is likely to be determined or necessary;
7. giant sequoia groves outside of Sequoia National Forest need to be incorporated into planning and ecosystem management processes; interagency and multi-owner (including private ownership) support of grove adaptive management (including restoration and protection) would be beneficial; private property rights should be respected and protected in this process; and
8. the focus of the SNEP effort is on naturally occurring populations of giant sequoia, not on plantations (even if these are within the species natural range); Sequoia NF and other forests may wish to evaluate plantations and their management later or as a part of the SNEP silvicultural evaluation.

### Background

The MSA (Sequoia National Forest 1990) is the result of a response by the Sequoia National Forest to address public complaints, objections to the 1988 Forest Land Management Plan (LMP) for Sequoia National Forest and its accompanying EIS, and litigation. The U.S. Forest Service had not entered into a mediation settlement agreement such as this in the past prior to revising an EIS/LMP. As such, the MSA is really a test of how successful or unsuccessful mediation is in resolving forest issues and regaining the trust of commodity industries, environmental organizations, and the public.

Several significant actions led to decision by the Forest to pursue mediation. In February 1988, the Regional Forester adopted the LMP for Sequoia National Forest, basing his decision on the final Environmental Impact Statement (EIS) and explaining this in a Record of Decision (ROD) (Sequoia National Forest 1990). Numerous appellants challenged the LMP and the EIS (United Four Wheel Drive Association, Sierra Club et al., Scenic Shoreline Preservation Conference, Inc., Save-the-Redwoods League, Tule River Indian Tribe, California Native Plant Society, American Motorcyclist Association, District 37, Sierra Forest Products et al., Phantom Duck Club, California Association of 4WD Clubs, California Off-Road Vehicle Association, California Attorney General for the People, High Desert Multiple-Use Coalition), and the Forest responded to these challenges. At the same time, the Forest entered into an agreement with the California Department of Fish and Game to settle its appeal (No. 2403; see Sequoia National Forest 1990).

On the basis of the numerous challenges to the LMP, then Forest Supervisor James Crates decided to seek the help of a professional mediator to see whether the Forest and appellants should attempt to negotiate a mediation settlement. The Forest Service and the appellants chose to begin the mediation process, with negotiation conducted at numerous meetings between March 1989 and June 1990, with extensive research done between the meetings. It was obvious during this process that Forest data was lacking that was needed to address many of the issues of concern, validate the LMP, and refine it over time (Sequoia National Forest 1990).

The parties to this mediation agreed to settle their appeals by "(1) presently disposing of some issues on merits, and (2) setting up processes for developing needed information, monitoring Plan implementation, and addressing other issues over time " (Sequoia National Forest 1990, page 3). It is important to note as stated in the MSA that the parties entered into the agreement "pursuant to compromise because of the unique factual circumstances in the Sequoia National Forest and in settlement of disputed claims to avoid prolonged and complicated litigation and to further public interest" (Sequoia National Forest 1990, page 3). It is also important to realize that the MSA terminates when the LMP is revised.

The MSA is largely a document which presents a series of new procedures for the Forest to follow as it begins to collect more extensive inventories and monitoring of various elements of the Forest's ecosystem. Human resources and support dollars are needed to conduct these various tasks, and with declining resources, loss of staff through an early retirement incentive program, and through transfers, the Forest even though it brought in a new Forest Supervisor, Sandra H. Key, found itself limited in what it could accomplish on the ground, as dictated in the MSA. Former Forest Supervior Crates signed the MSA, retired, and left the new Forest Supervisor Key with implementing it. Key has now left and is replaced by yet another Forest Supervisor during this eight year period between issuance of the LMP and the publication of the SNEP report. Six years have now passed since the MSA was signed.

At the time of signature of the MSA in 1990, the goal of the Forest Service was to finalize an amendment incorporating the MSA into the LMP, again go through the NEPA process, prepare the amendments and an EIS, and complete this process in two years (Sequoia National Forest 1990, page 4). This has not occurred, as discussed below, due to fiscal reductions, loss of personnel and other constraints. The MSA did allow for a process whereby if the Forest could not complete certain tasks by specified dates, the Forest was to notify all parties. It was recognized that "events arising from causes beyond the reasonable control of the Forest Service may preclude the Forest Service from completing the specified task by the specified deadline" (Sequoia National Forest 1990, page 4). This failure to complete could be challenged in court. Further litigation was not recluded.

There are numerous references in the MSA to specific groves and their management. However, the overall goal is to "protect, preserve and restore the Groves for the benefit and enjoyment of present and future generations", recognizing that "Giant Sequoia Groves in Sequoia National Forest ("Groves") are a unique national treasure..." (Sequoia National Forest 1990, page 6). The Converse Basin grove is treated differently than any other grove due to its long history of logging, and the MSA states that "With the exception of designated areas to be preserved, this area of the Forest will continue to be available for commercial logging" (Sequoia National Forest 1990, page 6). It is important to note in this agreement that the groves and a buffer zone around them were removed from the timber base (i.e., restricted from logging) until various conditions are met. A directive issued by then Regional Forester (Ronald E. Stewart) on June 19,1992 (2470 Silvicultural Practices) put the giant sequoia groves on the other Region 5 forests (Tahoe National Forest, Sierra National Forest) under the same policy and management direction. This was further endorsed through a Presidential Proclamation issued July 14, 1992 by George Bush on Giant Sequoia in National Forests.

In reference to grove management, the MSA charged the Forest with the inventory of all giant sequoias over 3 ft dbh by size and approximate location, with the inventory and evaluation of each grove for fuel accumulation, and with prioritization of the groves for fuels reduction. No dates were set nor implied for completion of these processes. Furthermore, the Forest was prohibited from any new road construction, logging or mechanical/motorized entry (Sequoia National Forest 1990, page 10). The only logging activity permited is "logging conducted for the limited and specific purpose of reducing the fuel load in the Groves pursuant to a Grove specific fuel load reduction plan and Grove specific EIS" (Sequoia National Forest 1990, page 10). Methods used to remove specific trees as part of an adopted fuel reduction plan are to be the most environmentally sensitive techniques available (Sequoia National Forest 1990, page 10). All "old-growth pine, fir, incense cedar and black oak components of the stand" and old-growth giant sequoia are to be protected during any such operations (Sequoia National Forest 1990, page 10).

Definition of the groves, the grove influence zone, posting of the grove administrative boundaries, and grove specific standards have been described previously in the section titled Mapping of Giant Sequoia Groves and GIS Compilation.

Regeneration of cut-over groves is also addressed in the MSA, as one of the goals of the MSA is restoration of the groves. The primary objective here is to "restore these areas, as nearly as possible, to the former natural forest condition" (Sequoia National Forest 1990, page 27). To aid this objective, "Research projects may be permitted if consistent with this Agreement... and are subject to NEPA" (Sequoia National Forest 1990, page 28).

When the MSA was signed in June 1990, it established some very clear direction for future managment of the giant sequoia groves of Sequoia National Forest. Clearly, the MSA is an agreement of compromise, and only an interim agreement on future Forest management, but the mediation process put the Forest up-front to further work with the public and address all their concerns. It is anticipated that extensive public-input and consensus building will need to occur before any grove adaptive management activities are undertaken. Thus, the "people skills" are just important as the "scientific accountability" of the Forest staff. Supervisor Key brought a background in ecology and very strong people skills to the Forest, and furthermore organized her staff and management team to move forward.

The following individuals were signatories for their respective organizations to the MSA:

1. Ken Alex, People of the State of California, Ex. Rel, Attorney General
2. Louis Blumberg, The Wilderness Society
3. Carla Cloer, Sierra Club, Kern / Kaweah Chapter
4. Jerry Counts, American Motorcycle Association District #37
5. Glenn H. Duysen, Sierra Forest Products (Kent Duysen current contact)
6. David Edelson, National Resources Defense Council
7. Bruce Hafenfeld, Hafenfeld Ranch and California Cattlemen's Association
8. Michael E, Haglund, Haglund & Kirtley, Attorneys for Sierra Forest Products and Sequoia Forest Industries
9. Nicola Larson, Tule River Indian Council (Irma Hunter current contact)
10. Bradless S. Welton and John B. DeWitt, Save-the-Redwoods League (Robert Jasperson current contact)
11. Brett Matzke, California Trout, Inc. and Kaweah Flyfishers
12. Julie E.McDonald, Sierra Club Legal Defense Fund
13. Suzanne Schettler, California Native Plant Society (Erin Noel current contact)
14. Tim Ryan, Phantom Duck Club
15. Ron Schiller, High Desert Multiple-Use Coalition
16. Patrice Davison, California Association of Four Wheel Drive Clubs (Gene Struebing current contact)
17. James H. Anthony, Sequoia Forest Industries (Steve Worthly current contact)
18. Lee J. Chauvet, California Department of Parks and Recreation (Clark Woy current contact)
19. Paul F. Barker, Region 5, U.S. Forest Service

*Advisory Signature:* James A. Crates, Sequoia National Forest.

Members of this group, some of which have been replaced within their organizations, now work a committee known as the Multiple Use Liasion Committee ("MULC"). This committee calls an annual meeting to discuss with the Forest any issues of concern.

## Evaluation of the MSA Process and Outcome: Meetings and Questionaires

Evaluation of the MSA has been undertaken using both a historical and hierarchical approach. After carefully examining the MSA document, the SNEP team arranged a series of meetings with staff from the Sequoia National Forest, Region 5 U.S. Forest Service, other forests and parks, the National Biological Survey, the MSA signatories, members of special interest groups on all sides of the issues, independent scientists, and the general public. These meetings were held between January 1994 and March 1995. In addition to receiving information orally from the participants at these various meetings, the workgroup had numerous phone conversations and e-mail / mail exchanges with various persons. The worksgroup solicited further information using a structured survey questionnaire, and made visits to Forest and Park offices to collect unpublished data. Every effort was made to compile a comprehensive data set under the time and budgetary constraints imposed by the SNEP process. Digital databases and a GIS were compiled and will be made public upon completion of SNEP. Much of this data is included here in an abbreviated form in the appendices to this report.

### Questionnaire to and meetings with the MSA signatories and MULC

Here, the SNEP team sought to determine the various participants reactions to the MSA process and the resultant agreement. We asked those involved in the mediation process to make suggestions about future actions under the MSA and pending amendment / revision of the LMP. We also asked for opinions on ecosystem management under the new U.S. Forest Service Region 5 draft guidelines.

Following brief conversations with a number of MSA signatories and their current affiliates, as well as Forest Service staff, we compiled a questionnarie to solicit further responses. Questions were drafted and sent to members of the workgroup and the Sequoia National Forest staff for comment in early December 1994, and revisions were then made to the questionnaire. We asked open-ended questions in ways to allow the widest possible responses to solicit open and unconstrained answers. A cover letter and a copy of our workplan was enclosed and mailed with the questionnaire sent out to the 18 MSA signatory parties in December 1994. The questionnaire asked 9 questions. Responses were summarized and input into a FoxPro relational database.

Furthermore, the SNEP team had extended conversations with a number of signatories to the MSA. In addition, we were joined by MSA signatories and MULC members on a field trip June 10, 1994 to the Black Mountain Grove, and on February 3, we held an all day SNEP workgroup meeting with the MSA signatories, MULC group, and select invited associates.

*Results*—We received 8 responses from MSA signatory parties to our questionnaire; shortened summaries of the results are as follows:

1. What were your objectives and goals when you came into the mediation process with Sequoia National Forest? Answers were diverse and included seeking a balance of commodities and values, ending the impass of LMP appeals, maintaining multiple use of the resources, stopping damage to the groves immediately, protecting giant sequoia and other areas, and maintaining a viable timber program. This diversity of responses was expected given the various interests of the signatory parties.

2. Were you satisfied with the mediation process? How completely satisfied? Five people were satisfied, 2 were neutral and 1 was unsatisfied.

3. Were you satisfied with the mediation outcome for Section B—Giant Sequoia Groves? The identification of grove boundaries? The function and usefulness of the 300–500 ft administrative boundary and the additional 300–500 ft grove influence zone? Two people were satisfied, 2 were neutral and 4 were unsatisfied.

4. What are your thoughts on moving beyond the MSA to ecosystem definitions for groves and ecosystem management? How would this be best done? What should the process be? There was a consensus to get beyond the MSA, and multiple ways to do so were presented.

5. What is your opinion on the Forest Service doing an EIS for management of each grove? Two people felt it was a good idea, 5 felt it was not, and 1 thought that clumping the groves geographically would be best.

6. Do you have problems trusting the Sequoia National Forest management? Four believed that there were problems with the agency and 4 thought there were no problems.

7. How can we better educate private interests and the public about giant sequoia issues? Many ideas were presented, including educational programs (targeting school children especially), good use of media, and that this is not a problem that needs addressing.

8. Do you believe that fuels, including some understory trees, need to be removed in giant sequoia groves to protect them from crown fires and open up the forest floor to increased giant sequoia regeneration? Should this be done using "sensitive" means of mechanical fuel reduction, traditional commercial logging practices, fire or some combination of these methods? All felt that removal of fuels was important, but that specific conditions should be assessed for use of fire and mechanical work. Most respondents did not want traditional logging in the groves.

9. What are any other thoughts you may have? Comments included politics being a problem, working with local communities necessary, an emphasis on managing groves for the future mandated, evaluation of all impacts to the groves, and that groves must be protected.

Extensive verbal comments were made at our June 10, 1994 and February 3, 1995 meetings. Their was broad sentiment among this group for protecting giant sequoia and acquiring better scientific information, from both ecological and management perspectives, to do this. No single individual ever stated that giant sequoia should be logged, although concerns were voice on fuel loading, canopy closure, and the need to remove green and dead trees to promote giant sequoia regeneration. Some sentiment was voiced for a hands-off approach, but it was minor.

*Discussion*—The MSA signatories whom reponded to our questionannaire (8 of the 18; the Forest Service was not sent a questionnaire) found it conceptually difficult to only address their satisfaction with the MSA process, as they conceptually linked the process to the result. Some of them were more satisfied with the MSA direction defined for grove management than for other topics of interest (e.g., grazing, riparian management, off-road vehicle use), and vice-versa. Specific individuals feared that they gave up too much within the giant sequoia groves for the sake of compromise on other MSA elements. The MSA process brought some satisfaction to the participants, but implementation of the MSA is a major concern for many of these individuals. Relations between the signatory parties and the Forest Service seem to have improved for some parties and not improved for others. There is serious concern on whether the Forest will amend or revise the LMP, how this will be done, and when it will be done. Even though the need is recognized for fuels reduction in certain groves and for restoration in others, it is unclear to many participants how the Forest will be able to undertake even a single grove project and do an EIS without a full revision of the LMP. These are very important questions.

### Questionnaire To and Meetings with the General Public

Management of giant sequoia is an issue of concern to many members of the informed public. We sought to determine the interest, ideas and knowledge level of a group of the "supposedly" interested public about the MSA process and results relating to giant sequoia. We also asked about ecosystem management issues for giant sequoia.

*Methods*—Draft questions were composed and sent to members of Sequoia National Forest and the SNEP team for comment in early December 1994. Changes and suggestions were input. We asked open-ended questions in ways to allow the widest of possible responses to facilitate open and unconstrained answers from the public. Eight questions were posed to the public. The first four questions addressed the MSA and the remaining four questions addressed new ecosystem management approaches and needs.

Letters and questionnaires were sent out in December 1994 to six hundred and sixty-seven members of the interested public from a list of people who had been involved in public input for the 1988 Sequoia National Forest Land Management Plan. Fifty-six letters were returned with no new forwarding address, so six hundred and eleven of the mailings were actually received by the addressees. These same persons received a letter announcing a public meeting in February 1995 in Porterville. Responses were summarized and input into a FoxPro database.

In addition, a public meeting was announced and advertised (through mailings, postings and press releases) for Saturday, February 4, 1995 at Porterville College. This meeting lasted approximately six hours, and drew 60 participants.

Furthermore, the workgroup hosted a roundtable discussion for 3 hours with the public at our SNEP Public Workshop with the Science Team February 21, 1995 at the University of California, Davis.

*Questionnaire Results*—Ninety-five questionnaires were answered and returned. The summary of results for MSA-related questions is as follows:

1. Were you satisfied with the mediation process for Sequoia National Forest? How satisfied? Thirty percent were satisfied, 42% were not, and 28% did not know about it or did not respond.
2. Were you satisfied with the mediation outcome for the MSA Section B—Giant Sequoia Groves? The identification of grove boundaries? The function and usefulness of the 300–500 ft administrative boundary and the additional 300–500 ft grove influence zone? Twenty-three percent were satisfied, 54% were not, 23% did not know about it or did not respond.
3. What are your thoughts on moving beyond the MSA to ecosystem definitions for groves and ecosystem management? How would this be best done? What should the process be? Seventy-two percent believed in moving beyond the MSA, 3% questioned ecosystem management, and 25% did not know about it or did not respond.
4. What is your opinion on the Forest Service doing an EIS for management of each grove? Thirty-five percent believe it is fine—each grove is different so need separate checks (4% of these said have an outside group do the work), 49% did not believe it should be done for every grove (7% of these said have an outside group do the work, 10% said it was a waste of money).

*Discussion*—The dominant view of the interested public is that the MSA was a stopgap measure and a way to reform forest management of giant sequoia. Many of the respondents were not familiar with the entire MSA documents or specific parts of it. Those whom were very versed on the MSA urged moving beyond it. In general, displeasure with the MSA was voiced. Many comments were made on the need for individual grove by grove study, while others thought all the groves were pretty much the same and could be studied as a group. Concerns were expressed about the groves being removed from the timber base, fuels accumulation, soil erosion, the tree species and their genetic composition that were planted in the groves that the Forest had logged within, withthrow of trees, lack of a full understanding of giant sequoia genetics which may make grove units of concern biologically meaningless, the full range of human values being accomodated for within the range of groves, and damage to particular groves that given individuals have visited repeatedly over their lifetimes. The proposed giant sequoia legislation was a topic of interest for a few individuals.

### Overall summary

The mediation process brought many of the interested parties to the discussion table to attempt to formulate a consensus management direction for Sequoia National Forest in reference to its giant sequoia groves. The groves were removed from the timber base, accurately mapped in the field, with these field maps digitized, with further description data on the groves obtaining through the intensive field mapping process. The Forest has begun, as required by the MSA, a fuels inventory of the groves. Yet, with the MSA was signed six years ago and the Forest is four years behind in its scheduled completion of tasks outlined.

In addition to the human and fiscal resource limitations mentioned above, important interim changes in Region 5 forest policy, under CASPO and now the draft EIS for the California Spotted Owl, and with the SNEP science team explicitly requested to evaluate the MSA Section B on the groves, the Forest has chosen to wait to see what the Region's management directives are, and what the SNEP's overall science and adaptive management ideas will be before initiating new grove inventory, assessment, and monitoring projects. Former Forest Supervisor Key made it clear to the SNEP workgroup and her staff that she was awaiting SNEP's findings before the MSA section B would be amended within the LMP. Future management, monitoring, and science-based study needs are discussed following our presentation here of available management tools and techniques.

## Evaluation of the MSA: Sequoia National Forest Data Availability, Management Practices, and Future Approaches

The Sequoia National Forest is rich in its number of giant sequoia groves and grove complexes, yet very data poor when it comes to scientific data on the characteristics and also the management histories of the groves. The ecological and management data we were able to acquire for the groves with a search of the files at Sequoia National Forest with the assistance of several key staff is listed in Acknowledgements.

Complete biological inventories of various taxa and guilds have not been undertaken for the Sequoia National Forest groves, with this generally true of groves managed by other units as well. Plant community and associaton information is very limited as well, with the density and dominance of various canopy and understory species undocumented for most of the groves. None of the groves have been studied from an ecosystem perspective in regard to their structure and function, and inputs, throughputs and outputs. Although concerns are voiced in regard to erosion above groves in their watersheds, and fuel loading especially below the groves, neither scientific studies nor planning efforts have focused on these larger ecosystem units, nor really even the grove units themselves. Most of the management oriented information from timber sales, grazing allotments, hazard tree removal, road construction, etc., is not grove specific, but for landscape units being treated that include usually only part of a grove.

The Sequoia National Forest has completed a very accurate mapping of its giant sequoia groves and grove complexes, including buffer areas surrounding the groves. As such, the Forest now knows where the groves are and can carefully incorporate this information using a GIS or CAD system into their planning documents and process. We urge the Forest to carefully consider the inaccuracies of other spatial data sets they may bring in to their GIS or CAD systems that may not be as accurate as the grove boundaries. Manipulative activities should be very carefully checked through ground truthing to catch any inconsistencies in the spatial resolution of non-grove layers.

The MSA requires the Forest to do fuel inventories of all groves. Although this effort is currently underway, more resources need to be directed towards completing it in a timely and accurate fashion. As stated earlier, many of the groves have substantial fuel loads, and it is important to know where and what these are.

We also urge the Forest to undertake a scientifically valid description of their grove ecosystems, gathering statistically sound data on the biota of the groves, the physiognomy of the forest, plant communities, soil types and depth, surface and sub-surface hydrology, dead vs. standing vs. downed biomass, fuels, and the presence of disease and damage from fungi, insects, air pollutants and other agents. We cannot imagine the Forest clearing the EA or EIS process in adaptive management of the groves and any grove activities if it does not have this basic descriptive data grove by grove.

It is important to remember that the grove ecosystem extends beyond the boundaries of the grove itself. It would be useful for the Forest to create three-dimensional view of the groves draped across a digital elevation model such that inputs from upslope and downslope of the groves can be studied.

Alternative management treatments should be reviewed for all groves, including a hands-off or no-touch approach, the use of prescribed fire only to reduce fuels and promote regeneration, the use of mechanical thinning tools to again reduce fuels and promote regeneration, and a combination of fire and mechanical treatments. We strongly suggest the Forest designing a series of well thought out experiments in one, two or three groves that they can learn from. EAs or even EISs may have to be written and approved to undertake these efforst.

These experiments may have to be small scale and intensive, as it is important for the Forest to gain the trust of the public in any adaptive management schemes it may design. It may also be of benefit for the Forest to undertake a project in a grove that is partially managed by another agency, such as the National Park Service.

Furthermore, all groves should be evaluated individually as to giant sequoia regeneration status, tree species dominance and growth rate, biodiversity components, general health, human values, and priorities Forest-wide.

Lastly but as importantly, the Forest must undertake an active program of education and outreach on giant sequoia ecosystems and their management. It is important for all parties, whether they are from environmental or timber interests, to have a common background and be well-informed by the Forest on scientifically-supported management practices. Congressional staff, special interest groups, and the general public should all be clientele for these programs. An educational CD-ROM on giant sequoia is under construction by the authors of this report in collaboration with Sequoia National Forest.

An interagency and agency-University-public school approach to giant sequioa science, management and education may be especially valuable. An MOU has already been signed by the National Park Service, U.S. Forest Service, National Biological Service, State Department of Forestry and Fire Protection, and the University of California for cooperative research on giant sequoia / mixed conifer ecosystems.

### Treatments and Tools that Can Be Applied to Giant Sequoia/Mixed Conifer Ecosystems

To sustain giant sequoia / mixed conifer ecosystems, they should be restored to structures that allow the incorporation of natural disturbances such as fire, insects and disease, without catastrophic destruction of grove functions. The following mechanical and prescribed fire treatments can be applied to giant sequoia ecosystems for this purpose as part of a well-researched adaptive management program. Special care should be taken if mechanical equipment is to be used in or near giant sequoia groves. Planning and control of the placement of tractive equipment is important to ensure that neither soil displacement or compaction take place in the area of watercourses (Gasser 1994). All operations should be done during the dry season and low ground pressure equipment should be used in operations (Gasser 1994). Combinations of treatments can be used to meet specific grove management objectives.

*Mechanical treatments*—Mechanical treatments may be used to reduce forest fuels and open up the canopy or understory to better promote regeneration and decrease competition. Alternative techniques are described here.

Chainsaw felling of ladder fuels and lopping and scattering of the slash in one mechanical treatment approach. With this treatment, biomass would not be removed, but fuel geometry would be modified. Surface fuel load would be increased after treatment, and vertical fuel continuity would be reduced.

Horse logging is a mechanical technique that has low site impact but is relatively slow. Logs must be cut into short lengths, and horse skidding requires a slight downhill grade as well. Skid trail length is also limited, and logs larger than 30 in in diameter are difficult to handle. Skid trails are small and easily restored after logging by raking. This technique may be appropriate inside the giant sequoia groves with limited slopes (< 20%) and could be used to thin giant sequoia stands (e.g., reduce the density of white woods).

Tractor logging is a technique that moderately impacts the site, but is relatively fast. Tractors can be operated on areas with slopes up to 35–40%. This produces larger skid trails and higher disturbance. Tractors with steel track drive systems produce more surface disturbance when turning as compared to rubber tire skidders, but may produce less soil compaction due to the higher surface area of the drive system. There is no practical limit on the size of logs that can be handled using this system, and this system can be used in both even-aged and uneven-aged silvicultural systems. Mechanical disturbance of the site can be minimized with proper planning and by using highly trained personal. Skid trails can be mechanically raked after treatment and small logs and water berms can be installed to reduce erosion on the skid trials. Most soil erosion comes from skid trails and road building in a well designed tractor logging operation but this can be reduced to low levels with proper design.

A running skyline or yarder logging system is appropriate for slopes exceeding 35–40%. A locking carriage system should be used to reduce damage to residual trees. All logs are yarded to a central location and damage to residual trees can be very high in steep terrain. A running skyline system is approximately 3 times more expensive to operate than a tractor system, but has the advantage of being practical on steep slopes. Since all logs are skidded into a central location, the production of corridors that are visible on the landscape may become a problem.

A zig-zag yarder is a small cable yarding system that is appropriate for thinning and biomass operations. This uses a system of small portable pulleys that are attached to standing trees. The size of the material to be moved is limited to approximately 25 cm in diameter. The zig-zag yarder produces very narrow skid trails that can be restored with shovels and rakes. This system could be used inside giant sequoia groves to remove small ladder fuels, but cannot be used to treat trees that are over 25 cm in diameter.

Feller-buncher systems are large machines can efficiently remove trees up to 70 cm in diameter and can be on slopes up to 30%. The machines have a great deal of control in falling timber since they actually lay it on the ground. A forwarder / processor could be used to thin mixed conifer exosystems. This system has the advantage of not requiring skid roads to remove harvested material.

Helicopter logging is the most expensive logging system, and it may be appropriate for inaccessible or steep sites or sensitive watersheds. The system does not produce any skid trails or new access roads and therefore produces the least amount of site disturbance. It is much easier to be selective in tree removal using this system as compared to a running skyline system. If a steep area is to be treated, then helicopter logging may be the best choice since residual damage to remaining trees and soil erosion will be kept to a minimum. Treatment of logging slash can be a problem in remote sites.

Several of the above mechanical treatments could be used to remove biomass from the giant sequoia-mixed conifer ecosystem. Clean chips could be used if a mill was located close enough to be economically feasible. Clean chips can be used to produce pulp or chip boards and are much more valuable than dirty chips. Dirty chips are transported to a cogeneration plant and are used in the production of electricity. Recent Public Utility Commission decisions will make many of the cogeneration plants in the Sierra Nevada economically unfeasible. Production of chip board products could make biomass operations feasible.

*Prescribed fire treatments*—Prescribed burns are a valuable tool for manipulating forest biomass, structure and ecosystem function. Low consumption, low intensity burns can be used in the early spring after snow melt. Large size-class fuels will not have time to dry and will not burn easily. Small fuels (1 and 10 hour) (Brown 1974) will dry much more quickly, and this type of prescribed fire will consume most of the smaller fuels. Duff consumption will vary depending on moisture content. If duff is burned with a high moisture content, then only the top few centimeters will be consumed. This treatment will reduce the amount of fine fuels. Fine fuels are the quickest to respond to changes in the weather and in many cases they drive extreme fire behavior. The ecological effects of spring prescribed fires requires further study. Burning in a season that historically experienced very little fire may have ecological consiquences. If ecological effects are considered to be small, then large areas of the mixed conifer forest could be treated following snow melt using strip headfires without much overstory damage.

In contract, low consumption, high intensity burns, also refered to as a “jackpot” burns, are conducted after the first significant rain or snow of the season, followed by a few clear, dry days when areas of excessively high fuel loads can be treated. The first precipitation of the year will affect the moisture content of the smallest fuels but will not change the moisture content of the larger size classes (100 and 1000 hour) as quickly. Drip torches can be carried through the forest and areas of high fuel load ignited. The moisture content of the adjacent small fuels (1 and 10 hour) will be high enough to retard the spread of the fire. Areas of large fuel loads can be treated with this system with limited overstory damage.

A potential problem with this type of prescribed fire is the unpredictability of our weather systems. If the first snow or rain is followed by several days or weeks of warm, dry, weather, then fire control problems may occur. Also if the first precipitation event of the season is large, then the use of prescribed fire is not practical. In areas with excessively high dead and down fuel loads, this method may be an excellent first treatment.

Another type of prescribed fire is the high consumption, low intensity burn. This prescribed fire treatment will be typically applied in the fall before the first significant precipitation event. Fuel moisture levels will be relatively low for all sized classes, but fireline intensity will be moderated by firing pattern. Consumption of dead and down fuels will be high due to low moisture content; duff and litter consumption may approach 100%. Fire effects on overstory vegetation will be variable depending on fuel consumption and flame lengths (Stephens 1995). Small areas of high intensity fire could be produced with this type of prescribed fire, and seedlings and small trees can be thinned. To produce an overall low intensity burn will require a great amount of labor and time. Flanking and backfires will be used to keep fireline intensity low.

Lastly, high consumption, high intensity burns are sometimes conducted. This prescribed fire treatment will be applied in the fall before the first significant precipitation event. Fuel moisture will be low and duff and dead and down fuel consumption will approach 100%. Fire effects of the overstory vegetation will be high. Large trees may be entirely scorched or sometimes consumed. If ladder fuels are present, then localized crown fire patches will be produced. Some areas of excessively high fuel loads could produce crown fires with areas in the tens of acres, or possibly larger. Tree density will be dramatically reduced. Regeneration of shade intolerant species should occur if a seed source is present. Ignition pattern will be by strip headfire or spot ignition. Spot ignitions can be done using a heli-torch in large units.

Once the desired structure is obtained in the grove, periodic use of prescribed fire should keep the ecosystem in a lower seral state, or modify its trajectory as required by the management objectives. Enough information is known about the prehistoric fire regime in giant sequoia-mixed conifer ecosystems (Stephens 1995; Skinner et al. 1996, SNEP report) that appropriate fire intervals could be specified in the planning and adaptive management process. However, as fire regimes have varied in the giant sequoia-mixed conifer ecosystems through past centuries (Swetman et al. 1992), what is viewed as the appropriate time interval (e.g., fire climte regime) to mimic through prescribed burning must be carefully chosen before the fire regime can be simulated.

## Moving to Ecosystem Management

Ecosystem management can be defined as the skillful, integrated use of ecological knowledge at various scales to produce desired conditions, resource values, products and services in ways that also sustain the diversity and productivity of these ecosystems (Fullmer, 1994 personal communication, Sequia National Forest). It is well recognized that disturbance is a critical process in giant sequoia-mixed conifer ecosystems (Skinner et al. 1996, SNEP report), and it must be considered to effectively develop strategies for ecosystem management. It is important to review how successful past, current and proposed management strategies simulate ecosystem processes.

Ecosystems are complex. Complete information on how they function is not available. Management alternatives can be designed to *simulate* some of the major processes and functions, but these are very much of a simplification. Therefore, these alternatives should not be viewed as complete surrogates of the original systems.

## Historic Disturbance

Investigation of historic disturbance regimes before the influence of European settlers can provide fundamental information for the development of ecosystem management strategies. Disturbance agents include fire, insects, disease, tree-fall, and drought. Historically, the structure and dynamics of giant sequoia-mixed conifer forests of the Sierra Nevada were once dominated by frequent surface fires (Skinner et al. and Stephenson 1996, SNEP report). Fire suppression has largely excluded this important ecosystem process. Management schemes that seek to integrate fire back into the ecosystem need to evaluate how much of a particular type of vegetation should be burned and what kinds of fires are appropriate. The use of historic fire data helps managers make these decisions. Mechanical methods can also be used in conjunction with fire to simulate and aid the restoration of ecosystem processes.

Fire regimes describe spatial and temporal fire behavior and its associated effects on ecosystems. Components of a fire regime are outlined below:

1. Mean fire interval or mean fire return interval: This is the arithmetic average of all fire intervals in a designated area during a designated period of time. In many cases, the distribution of fire events, not simply the mean, is important. Rare events can sometimes effect ecosystems for extended periods of time.

2. Season of burn: This describes the time of year that fires occurred (e.g., fall, spring). The season in which the fire occurs will have profound effects on the ecosystem. Not only will the characteristics of the fire be different, but the phenological state of vegetation will also be different resulting in different fire effects.

3. Fire severity: This is the degree to which the ecosystem has been altered or disrupted by fire. There is no concise definition of this term with appropriate units. In general, it can be thought of as the degree of crown scorch, fuel consumption and mortality of plant species resulting from fire.

4. Dimension of fires. This describes the sizes of fires. Another aspect of dimension of fires is the amount of unburned area within fires. Generally, not all of the area contained in a fire perimeter is burned.

Fire scar studies in the Redwood Mountain grove of Sequoia National Park demonstrated that pre-settlement (pre-1875) surface fires were frequent with 2- to 3-year mean fire intervals within watersheds of approximately 800–100 ha, and 5- to 9-year mean fire intervals in sites of 3–16 ha (Kilgore and Taylor, 1979).

Recent fire-scar studies have been conducted in five giant sequoia groves in Yosemite National Park, Sequoia and Kings Canyon National Park, and Mountain Home Demonstration State Forest (Swetman et al. 1992). Maximum fire frequencies within the sampled areas of giant sequoia were as high as 3–4 per decade from AD 500–AD 1875 (Swetman et al. 1992). Occasional fire free intervals of 20–30 years occurred in the record. Many fires occurred on consecutive years in these giant sequoia groves, but these fires were probably less than 1 ha in size. The fire regime in giant sequoia / mixed conifer ecosystems was diverse and varied over the centuries from AD 500–AD 1875 (Swetman et al. 1992). Most fire scars (66%) in giant sequoia occurred in the latewood which corresponds to first week of September to the fourth week of October (Swetman et al. 1992). Twenty-two percent of the fires occurred approximately from the first week of June to the last week of August, and 10% occurred when the tree was dormant corresponding to mid-October to mid-November (Swetman et al. 1992). Most fires occurred from late summer to early fall in the five groves studied.

Most fires were low severity surface fires with small patches of high severity fires intermixed. Occasionally, large fires of high severity burned in the giant sequoia / mixed conifer ecosystem (Caprio et al. 1994). A large, high severity fire occurred in the Mountain Home grove in 1297 AD. The number of scarred trees and growth release suggested this fire event was of unusual high severity, not equaled in the last 2,000 years (Caprio et al. 1994). The post-fire growth release at Mountain Home was apparent for about 100 years after the fire indicating that these infrequent, intense events can effect ecosystems for extended periods of time. Large, high severity fires were uncommon in these systems.

The dimensions of fires are difficult to estimate. The fire history record from giant sequoia in the Sierra Nevada is one of the richest available, but more information is needed to estimate fire dimensions. The high severity fire that occurred in 1297 AD in the Mountain Home grove was estimated to cover an area of several square kilometers (Caprio et al. 1994). Fires probably burned much larger areas, but information on the spatial extent of historic fires is limited.

### Use of Tools to Mimic Historic Disturbance and Restore Giant Sequoia Ecosystems

Different vegetation management tools can be used for diverse objectives in the giant sequoia / mixed conifer ecosystem. Prescribed fire and both classical and new silvicultural practices are reviewed and analyzed to determine if they are appropriate in ecosystem management of the giant sequoia-mixed conifer forest.

The use of low consumption, low intensity burns in the early spring has been proposed, but historically very few fires occurred in this season. Fire severity will be low and lack diversity. The size of the fire could be quite variable, conforming to part of the historic fire regime spectrum. This type of fire could be used to begin to reduce surface fuel loads in the giant sequoia-mixed conifer ecosystem. The ecological effects of low consumption, low intensity burns may be limited, but large tree mortality may be relatively high do to fine root mortality.

The use of low consumption, high intensity burns, also referred to as a “jackpot” burns has been done by various managers. After the first significant rain or snow of the season, followed by a few clear, dry, days, areas of excessively high fuel loads can be treated. Historically, many fires did occur during this time of year but the majority of these fires burned larger areas naturally. Fire severity will be low because only small areas will be burned in most prescribed burn programs, and severity will lack diversity. This treatment could be used to effectively reduce fuel loads created by localized tree mortality.

The use of high consumption, low intensity burn is another approach. This prescribed fire treatment will be typically applied in the fall before the first significant precipitation event. Historically, many fires occurred during this time of year. The size of the fire could be quite variable conforming to the historic fire regime. Fire severity will have moderate diversity depending on firing pattern, fuel conditions and weather. Large areas could be treated with this type of prescribed fire.

The use of high consumption, high intensity burns has a very high risk but a significant effect. This prescribed fire treatment will be applied in the fall before the first significant precipitation event. Historically, many fires occurred during this period. The size of the fire could be quite variable conforming to the historic fire regime. Fire severity could be diverse depending on ignition patterns, fuel conditions and weather. This may be an inappropriate first treatment in areas with excessive fuel load and fuel ladders due to possible extreme fire behavior and effects.

Mechanical methods are tools for a variety of silvicultural systems. For even-aged silvicultural systems, clearcutting, the removal of all tree vegetation in an area, will produce even-aged stands with uniform regeneration. It can be used to regenerate a site that is severely infected with insects, disease or destroyed by crown fire. Regeneration is planted and this system favors shade intolerant species. The disturbance regime simulates a high severity stand replacing crown fire, but lacks the structural complexity that is present after such an event. After a crown fire occurs, the structural complexity of the ecosystem is far greater than that created by a clearcut. Clearcutting leaves very few snags and dead and down logs, with those that are left are frequently spread widely throughout the unit. Most high severity fires will miss patches of trees and shrubs adding to the structural complexity of the site. New forestry techniques can be used to approximate the complex structures that are present after a high-severity fire but since these events rarely occurred in giant sequoia-mixed conifer ecosystems, this system will not be appropriate for wide-spread forest management.

Seed tree treatment leaves an appropriate number of trees for a seed source for natural regeneration. When saplings are approximately 2–3 feet tall, harvest of the seed trees results in an even-aged stand. Removal of the seed trees reduces competition for the remaining seedlings. This generally favors shade intolerant species. The disturbance regime begins to simulate a high intensity surface fire regime, but after seed trees are removed, it has the same structural complexity as a clearcut. As in the clearcut, this treatment lacks the structural complexity that occurs after a high severity fire.

Shelterwood treatment leaves the appropriate number of trees to facilitate regeneration. The overstory will provide microclimate modification and a seed source; artificial regeneration can also be used. The number of trees left depends on the specific site. When saplings are approximately 2–3 feet tall, removal of the shelterwood trees generally favors shade tolerant species. The disturbance regime begins to simulate a high intensity surface fire regime, but after seed trees are removed, it has the same structural complexity as a clearcut. As in the clearcut, the treatment lacks the structural complexity that occurs after a high severity fire.

Uneven-aged silvicultural systems can also be used in adaptive management. Single tree selection involves the removal of individual trees of all species and size classes. Single tree selection will produce uneven-aged stands with regeneration in all age classes. Problems can occur in this system with damage to trees left after the treatment. The disturbance regime of this system can simulate a low or moderate intensity surface fire regime, depending on the number of trees removed. This can be used to simulate the effects of a low or medium intensity surface fire that historically thinned the giant sequoia-mixed conifer ecosystem from below. It does not produce the small even-aged groups historically found in the giant sequoia / mixed conifer ecosystem.

In constrast, group selection, the removal of a relatively small group of trees, generally varying from 0.1–1.0 ha is similar to a small clear-cut ,but the forest around the group selection units will be managed with the group, whereas in a clear-cut it is managed as a separate unit. This treatment favors shade intolerant species. The disturbance regime can simulate a moderate or patchy high intensity surface fire regime. With appropriate spatial and temporal scales, this system begins to simulate the small high intensity events that occurred in the giant sequoia / mixed conifer ecosystem. The treatment is a simplification of the natural regime because all trees in the group are harvested resulting in a decrease in structural complexity in the unit. This treatment also does not effect the forest matrix that occurs around the groups that was historically thinned from below by frequent surface fires.

### Ecosystem management goals

Ecosystem management is an attempt to maintain the historical structural complexity and suite of processes that occurred in these ecosystems before EuroAmerican influence. Management should also leave the appropriate biological legacies (Franklin 1993) to maintain ecosystem structures and processes.

Managers must use the appropriate spatial scales when developing land management plans. The larger the management unit, the more able managers are to simulate natural processes. Management based on landscape units such as regional watersheds may provide the appropriate spatial scale for long-term processes.

Within giant sequoia-mixed conifer ecosystems, different land owners will have diverse land management objectives. These objectives can be met with a variety of management alternatives. The list below gives some of the possible treatments that could be used for different ecosystem management objectives:

1. Management ignited prescribed fire: Fire treatments will first be applied to reduce fuel load and fuel continuity. The most appropriate fire treatments include low consumption, low intensity burns and low consumption, high intensity burns. These treatments could be followed with combinations of high consumption, low intensity burns and high consumption, high intensity burns. The land manager must expect these treatments to produce significant tree mortality and bark char. At first, low intensity fires or jackpot ignitions could be used to reduce ladder and surface fuels, but fires that produce localized torching will have to be introduced to provide the appropriate ecosystem dynamics for successful shade intolerant regeneration.

2. Combination of group selection and single tree selection treatments: Single tree selection treatments will simulate the historic thinning from below that occurred from frequent surface fires. This treatment will be applied in the matrix surrounding the group selection units and will reduce tree density. Species composition can also be manipulated in the matrix with more shade tolerant species removed. The group selection units will simulate the historic small high intensity fires that occurred in the giant sequoia / mixed conifer ecosystems. The number of trees removed will depend on the specific site. Factors to be taken into account to include slope, aspect, vegetation structure and vegetation type. Information from fire history studies can be used to estimate the historic fire regime that once occurred at the site. This information can be used to develop site specific objectives.

3. Combinations of mechanical and prescribed fire treatments: Group selection and / or single tree selection treatments could be applied followed by a prescribed fire. The combination of mechanical and prescribed fire treatments will depend on the land management objectives and the characteristics of the area to be treated.

Treatments should be strategically assigned to the landscape since it will not be possible to treat the large acreage of the Sierra Nevada giant sequoia-mixed conifer forest except over many decades. Information about the historic pattern of fire frequency can be used to locate specific areas that should be treated early in such a strategy (McKelvey et al. 1996, SNEP report).

### Demonstration Model: The Effects of Fuel Treatments on Potential Fire Behavior and Effects, Crane Creek Watershed and the Tuolumne Grove, Yosemite National Park.

One of our goals in the evaluation of the MSA and giant sequoia ecosystem health and management was to model a grove on the Sequoia National Forest and simulate various treatments of it over time using computer models. The Forest did not want us to undertake this project, so instead, we were able to work with the National Park Service and beyond the bounds of the MSA direction and controversy per se. This is fine, as the goal here is simply to demonstrate fire and fuel treatments and effects on an existing giant sequoia grove. The grove and grove ecosystem modeled herein are the Tuolumene Grove in Yosemite National Park as part of the Crane Creek watershed and Crane Flat. The objective of this section is to model fire behavior in a giant sequoia / mixed conifer ecosystem and to test how effective different fuel treatments are in reducing the potential of extreme fire behavior.

Wildfires in the western United States consumed approximately 4 million acres in 1994 and the costs of suppressing these fires approached 800 million dollars. The majority of these fires were high intensity, stand replacing fires. Fires of this magnitude and effects will continue to burn in these systems unless ecosystem structure (most importantly surface fuels and fuel continuity) are modified by management.

Very little data and no scientific experiments are available to analyze the effectiveness of different fuel treatments on potential fire behavior. In some cases, fire professionals can give specific examples of how a wildfire changed its behavior in areas that had received fuel treatments. A specific example is the 1988 Buckeye fire in Sequoia National Park. This fire began in chaparral below Giant Forest and quickly moved uphill toward the giant sequoia groves. The perimeter of Giant Forest had previously been treated with prescribed fire and when the wildfire reached the treated areas it dropped to the ground and was suppressed. More examples of how management activities have reduced fire behavior are given in this report (van Wagtendonk 1996, SNEP report).

A fire simulation program has been developed recently that can be used to investigate the effectiveness of different fuels treatments on the landscape. FARSITE (Finney 1994) is a deterministic, spatial fire model that uses fuels, slope, aspect, elevation, canopy cover, height to live crown base, crown density and weather as inputs. The input data required by FARSITE is significant but the model is based largely on physics. The model has also been tested under field conditions (Finney and Ryan 1995). A review of the development of fire models is given in the agents of change SNEP group (van Wagtendonk 1996, SNEP report).

## Simulation and model assumptions

FARSITE is a significant improvement in modeling fire behavior on landscapes but still has limitations. FARSITE uses BEHAVE (Rothermel 1972, 1983) to model surface fire behavior. BEHAVE does not use information from fuels larger than 7.62 cm in diameter (3 inches) when calculating fire behavior. Large fuels can produce significant ecosystem effects due to long burn out periods and the heat produced from the combustion of these fuels can be an important factor in the initiation and spread of crown fires (Rothermel 1991, 1994). FARSITE also assumes fire spread can be approximated by a elliptical wave (Finney 1994). Field observations of fire spread have agreed with elliptical predictions. (Anderson et al., 1982).

BEHAVE is a surface fire model. Modifications of this system has allowed crown fire modeling but this area of the model has not been verified as rigorously as the surface fire component. Problems exist in modeling crown fire mainly due to limited quantitative research in the behavior of these complex events.

Data are also limited in the number of fire brands produced by torching trees and the percentage of these brands that actually start spot fires. Currently, the model will only produce fire brands from aerial fuels and not from surface fuels. Fuel systems with a large dead and down component or shrub fields such as chamise can produce fire brands under certain conditions.

Wind and weather inputs to FARSITE are simplifications of actual conditions. FARSITE uses daily maximum and minimum temperatures and humidities and the time that each of these occur in simulations. This is a simplification of the actual weather stream but was done to reduce data requirements for the simulation (Finney 1994). Wind direction and velocity can be given for any time scale in the simulations but the stream is constant throughout the simulation area. FARSITE does allow the user to use multiple weather and wind streams when data is available.

FARSITE uses raster based geographic information system (GIS) files as inputs. The spatial resolution of the raster files can be set by the user but once set the attributes of each cell are constants. In this study, the spatial resolution is 30 meters by 30 meters and each cell has a fuel model, aspect, elevation, slope, canopy cover, crown density and height to live crown base assigned.

The fuel model assumes homogeneous fuel loads within each raster cell. Small scale differences in topography, canopy cover and fuels will affect fire behavior but these small scale differences are not incorporated into the model. Accurate data for such small differences would be very difficult and expensive to obtain. The simulations also assume a constant height to live crown base and crown density for different treatments which is a simplification of actual conditions (Van Wagner 1993).

## Methods

FARSITE was used to model the effects of different fuel treatments in the Crane Creek watershed at Yosemite National Park. The GIS information was provided by park scientists (Jan van Wagtendonk). Yosemite National Park currently has the most accurate and highest resolution spatial fuel information in the Sierra Nevada. The Yosemite National Park fuel map was produced by remote sensing. Thermatic mapper images were taken from one season and analyzed to produce a map with 30 m x 30 m resolution. This method will incorporate many landscape features that have a significant effect on fire behavior such as rock outcrops, changes in topography and changes in fuels. It also produces a map with fine resolution and is much more representative of the actual landscape than a conventional vegetation map.

Original BEHAVE fuel models were assigned to each 30 m x 30 m polygon in the Crane Flat watershed. The watershed is dominated by NFFL fuel models 8, 9, and 10 that were assigned depending on overstory density and surface fuel load. Relatively small areas of NFFL models 2 and 4 are also found in the Crane Flat watershed.

Crane Creek originates below the Tuolumne giant sequoia grove in Yosemite National Park and the elevation in this area varies from 1510–1900 meters. The UTM coordinates of the modeled area are (248000, 4185000), (248000, 4183000), (254000, 4185000), and (254000, 4183000) resulting in an area of 16 $km^2$ for each simulation. Each simulation was run in the same area with the ignition point 2 km west of Crane Flat campground on highway 120. The duration of each simulation was 24 hours. Ninety-fifth and 75th percentile weather information was obtained from Yosemite National Park (Jan van Wagtendonk, personal communication) and is summarized in tables 13 and 14.

The ignition point was placed in the lowest region of the Crane Creek watershed within the park and the fire was allowed to move upslope into the mixed conifer zone. All fire simulations were unconstrained by suppression activities. Outputs from the simulation include fire line intensity (Byram 1959), heat per unit area, rate of spread, area burned and if

**TABLE 13**

Weather information used in fire simulations of the Crane Creek watershed.

| | 75th Percentile | 95th Percentile |
|---|---|---|
| Maximum Temperature (F) | 65 | 90 |
| Minimum Temperature (F) | 45 | 60 |
| Maximum Humidity (%) | 60 | 40 |
| Minimum Humidity (%) | 20 | 10 |
| Time of Maximum Temperature and Humidity (hour) | 1400 | 1400 |
| Time of Minimum Temperature and Humidity (hour) | 500 | 500 |
| Wind Direction (degrees) | 285 | 285 |

**TABLE 14**

Wind information used in fire simulations of the Crane Creek watershed.

| Time (hour) | 75th Percentile Windspeed (mph) | 95th Percentile Windspeed (mph) |
|---|---|---|
| 0 | 2 | 12 |
| 100 | 2 | 12 |
| 200 | 2 | 14 |
| 300 | 3 | 14 |
| 400 | 3 | 14 |
| 500 | 4 | 14 |
| 600 | 4 | 15 |
| 700 | 4 | 15 |
| 800 | 4 | 16 |
| 900 | 4 | 16 |
| 1000 | 5 | 17 |
| 1100 | 5 | 18 |
| 1200 | 5 | 18 |
| 1300 | 6 | 18 |
| 1400 | 6 | 18 |
| 1500 | 6 | 18 |
| 1600 | 6 | 18 |
| 1700 | 5 | 18 |
| 1800 | 5 | 18 |
| 1900 | 4 | 17 |
| 2000 | 3 | 17 |
| 2100 | 3 | 15 |
| 2200 | 2 | 14 |
| 2300 | 2 | 12 |

spotting and torching occurred during the simulation. This information was used to compare the effectiveness of the different treatments on the giant sequoia / mixed conifer ecosystem.

Differences in treatments were simulated by changing fuel characteristics (total load, load by size class, depth), height to live crown base and crown density. Crown density values were derived from published work (Brown 1978). Table 15 summarizes the characteristics of the custom fuel models (Burgan and Rothermel 1984) used in the simulations. Fire rate of spread adjustment factors (fuel adjustment factor) were used to calibrate simulated fire spread to actual conditions (van Wagtendonk and Botti 1981: Rothermel and Rinehart 1983) and are also given in table 15.

## Treatments

1. No treatment, extensive ladder fuels present. This condition has occurred in many areas of mixed conifer forests and giant sequoia / mixed conifer forests due to fire suppression. Fuel load and vertical fuel continuity are high. Surface fuels consist of unmodified NFFL models (Anderson 1982). Height to live crown base set to 1 meter to simulate extensive ladder fuels.

2. Prescribed burn. Simulates fuel conditions after a high consumption, low intensity prescribed burn. Prescribed burn would probably occur in late fall and fireline intensity would be moderated by firing pattern and fuel moisture content. Surface fuel load and depth are reduced by a factor of 2 in this treatment and areas originally assigned to NFFL fuel models 8, 9, 10 are re-assigned to custom models 14, 15, 16, respectively. Height to live crown base increased to 2 meters by burning.

3. Pile and Burn. Ladder fuels are mechanically cut by hand crews and / or machinery. Material is then piled and burned when original surface fuels will not combust, probably after first significant precipitation. Treatment removes ladder fuels but does not alter original surface fuels. Height to live crown base increased to 2 meters.

4. Cut and scatter. Ladder fuels are mechanically cut by hand crews and / or machinery. Fuels are lopped and scattered on site resulting in significantly higher surface fuel loads. Height to live crown base increased to 2 meters. Areas of NFFL fuel models 8, 9, 10 are assigned to custom fuel model 18 to simulate treatment effects on surface fuels.

5. Thinning and biomass. Ladder fuels and intermediate sized trees are mechanically cut by hand crews and / or machinery. Small material is biomassed (chipped) and larger material could be transported to a sawmill to produce wood products. Harvested material is taken off site, original surface fuels unchanged. In most cases biomassing and thinning would crush the surface fuels, but in this simulation surface fuel depth and load remain unchanged. Height to live crown base increased to 2 meters and crown density is reduced by a factor of 2 due to removal of trees.

6. Thinning and biomass followed by prescribed burn. Ladder fuels and intermediate sized trees are mechanically cut by hand crews and / or machinery as in treatment #5. Surface fuel load and depth are reduced by a factor of 2 by burning in this treatment and areas originally assigned to NFFL fuel models 8, 9, 10 are re-assigned to custom models 14, 15, 16, respectively. Height to live crown base increased to 2 meters and crown density is reduced by a factor of 2 due to removal of trees.

**TABLE 15**

Custom fuel models used in fire simulations.

| Fuel Model | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|
| 1 Hour Fuel Load (tons/acre) | 1 | 1 | 1.5 | 0.4 | 2.5 |
| 10 Hour Fuel Load (tons/acre) | 0.6 | 0.6 | 1 | 2 | 4.5 |
| 100 Hour Fuel Load (tons/acre) | 1.5 | 1 | 2.5 | 0 | 5.5 |
| Live Fuel Load (tons/acre) | 0 | 0 | 1 | 0.5 | 0 |
| 1 Hour Surface Area to Volume Ratio | 2200 | 2200 | 2200 | 2000 | 2000 |
| Live Fuel Surface Area to Volume Ratio | 1500 | 1500 | 1500 | 1500 | 1500 |
| Fuel Depth (ft) | 0.15 | 0.15 | 0.5 | 0.6 | 1.5 |
| Extinction Moisture Content (%) | 30 | 30 | 30 | 20 | 20 |
| Dead Fuel Heat Content (BTU/lb) | 8000 | 8000 | 8000 | 8000 | 8000 |
| Live Fuel Heat Content (BTU/lb) | 9000 | 9000 | 9000 | 9000 | 9000 |
| Fuel Adjustment Factor | 0.5 | 0.5 | 0.5 | 0.25 | 0.5 |

7. Salvage harvest operation without slash or landscape level fuel treatment. This treatment simulates a salvage logging operation that removes standing dead trees and leaves the resulting logging slash on site. Surface fuel load will be dramatically increased in the area of the salvage operation and the remaining landscape will be untreated. The simulation uses an opening with a diameter of 34 meters to represent the area covered by a salvage operation. In most cases, a relatively small group of bark beetle killed trees are removed by such salvage operations and this opening is representative of such a treatment. 600 of these openings were randomly placed inside the $16km^2$ simulation area and summed together, they cover 2% of the area. Surface fuels in areas outside the salvage operation consist of unmodified NFFL models. Height to live crown base set to 1 meter to simulate extensive ladder fuels and areas with untreated salvage slash are simulated by NFFL 12.

8. Salvage harvest operation with slash treatment but without landscape level fuel treatment. This treatment simulates a salvage logging operation that removes standing dead trees and treats the resulting slash by pile and burning. Surface fuel load will be reduced in the area of the salvage but the remaining landscape will be untreated. The simulation uses the same opening configuration as in treatment #7. Surface fuels in areas outside the salvage operation consist of unmodified NFFL models. Height to live crown base set to 1 meter to simulate extensive ladder fuels and the salvage opening is simulated by NFFL 0 which represents bare ground.

9. Salvage harvest operation with slash and landscape level fuel treatment. This treatment simulates a salvage logging operation that removes standing dead trees, treats the slash by pile and burning and treats the remaining landscape with prescribed fire or thinning and biomass followed by prescribed fire treatments. Surface fuel load will be reduced in the area of the salvage and on the adjoining landscape. The simulation uses the same opening configuration as in treatment #7. Surface fuels in areas outside the salvage operation consist of modified NFFL models 14, 15, and 16. Height to live crown base set to 2 meters to simulate a reduction in ladder fuels and the salvage opening is simulated by NFFL 0 which represents bare ground.

10. Group selection harvest operation without slash or landscape level fuel treatment. This treatment simulates a uneven-aged group selection silvicultural operation that removes all trees within the group and leaves the resulting logging slash on site. Surface fuel load will be dramatically increased in the area of the harvesting and the remaining landscape will be untreated. The simulation uses an opening with diameter of 72 meters to represent the area covered by a .4 Ha (1 acre) group selection unit. This opening size is consistent with ecosystem management objectives covered earlier in this report. 600 of these openings were randomly placed inside the $16km^2$ simulation area and summed together, they cover 10% of the area. Surface fuels in areas outside the salvage operation consist of unmodified NFFL models. Height to live crown base set to 1 meter to simulate extensive ladder fuels and areas with slash are simulated by NFFL 12.

11. Group selection harvest operation with slash treatment but without landscape level fuel treatment. This treatment simulates a uneven-aged group selection silvicultural operation that removes all trees within the group and treats the slash by pile and burning. Surface fuel load will be reduced in the group, however, the remaining landscape will be untreated. The simulation uses the same opening configuration as in treatment #10. Surface fuels in areas outside the salvage operation consist of unmodified NFFL models. Height to live crown base set to 1 meter to simulate extensive ladder fuels in these area and the group selection opening is simulated by NFFL 0 which represents bare ground.

12. Group selection harvest operation with slash treatment and landscape level fuel treatment. This treatment simulates a uneven-aged group selection silvicultural operation that removes all trees within the group, treats the slash by pile and burning and treats the remaining landscape with prescribed fire or thinning and biomass followed by prescribed fire treatments. Surface fuel load will be reduced in the group and surrounding landscape. The simulation uses the same opening configuration as in treatment #10. Surface fuels outside the group selection operation consist of modified NFFL models 14, 15, and 16. Height to live crown base set to 2 m to simulate a reduction in ladder fuels in these areas and the salvage opening is simulated by NFFL 0 which represents bare ground.

All new models were created and tested using newmodel and testmodel BEHAVE applications. Ray Hermit of the USFS California Spotted Owl Center assisted in the development of the custom fuel models. Table 16 specifies which models were used in each treatment and also gives overstory parameters used in the simulations. Initial fuel moisture contents required for the fire simulations are summarized in table 17 and are representative of fuel moisture contents during prescribed burns (Stephens 1995).

## Results and Discussion

The prescribed burning, thinning and biomassing followed by prescribed burning, and salvage or group selection with slash and landscape fuel treatments resulted in the lowest average fireline intensities, heat per unit area, rate of spread, and area burned in 24 hours for both the 75th and 95th per-

**TABLE 16**

Fuel and canopy characteristics for each treatment.

| Treatment | Fuel Models Used (also depicts ) when custom models were used | Crown Density ($kg/m^3$) | Height to (meters) Live Crown Base |
|---|---|---|---|
| None | 2, 4, 8, 9, 10 | 0.3 | 1 |
| Prescribed Burn | 2, 4=17, 8=14, 9=15, 10=16 | 0.3 | 2 |
| Pile and Burn | 2, 4, 8, 9, 10 | 0.3 | 2 |
| Cut and Scatter | 2, 4=17, 8=18, 9=18, 10=18 | 0.3 | 2 |
| Thinning and Biomass | 2, 4, 8, 9, 10 | 0.15 | 2 |
| Thinning and biomass followed by Prescribed Burn | 2, 4=17, 8=14, 9=15, 10=16 | 0.15 | 2 |
| Salvage without slash or landscape fuel treatment | 2, 4, 8, 9, 10, 12 | 0.3 | 1 |
| Salvage with slash treatment but without landscape fuel treatment | 0, 2, 4, 8, 9, 10 | 0.3 | 1 |
| Salvage with slash and landscape fuel treatment. | 0, 2, 4=17, 8=14, 9=15, 10=16 | 0.15 | 2 |
| Group selection without slash or landscape fuel treatment | 2, 4, 8, 9, 10, 12 | 0.3 | 1 |
| Group selection with slash treatment but without landscape fuel treatment | 0, 2, 4, 8, 9, 10 | 0.3 | 1 |
| Group selection with slash and landscape fuel treatment | 0, 2, 4=17, 8=14, 9=15, 10=16 | 0.15 | 2 |

**TABLE 17**

Initial fuel moisture values used in the simulations.

| | 75th Percentile | 95th Percentile |
|---|---|---|
| 1 Hour Fuel Moisture (%) | 6 | 4 |
| 10 Hour Fuel Moisture (%) | 8 | 6 |
| 100 Hour Fuel Moisture (%) | 10 | 8 |
| Live Woody Fuel Moisture (%) | 110 | 90 |
| Live Herbaceous Fuel Moisture (%) | 110 | 90 |

centile weather conditions (tables 18 and 19). Figures 3 and 4 summarize fireline intensity and heat per unit area at 95th percentile weather conditions for all treatments.

Torching only occurred at the 75th percentile weather conditions when slash from salvage, thinning or harvesting operations is untreated and the maximum fire size in 24 hours was 33 Ha. The cut and scatter treatment and group selection / salvage operations without slash or landscape fuel treatment produced the highest fireline intensity, heat per unit area and rate of spread since these treatments increased surface fuel load substantially. None of the fires simulated under the 75th percentile weather conditions would pose much of a risk to the surrounding ecosystems due to their moderate behavior.

Torching and spotting occurred in most of the simulations using the 95th percentile weather conditions with the exception of the prescribed burn, thinning and biomass followed by prescribed fire, and salvage or group selection with slash and landscape fuel treatments. These treatments all produced similar values for fireline intensity, heat per unit area, rate of spread and area burned in 24 hours. These treatments resulted in fire behavior that was relatively moderate and fires burning under these conditions would not pose a significant threat to giant sequoia / mixed conifer ecosystems.

This is in contrast to the no treatment option, thinning and biomass, and salvage or group selection options that do not

**TABLE 18**

Average results of fire simulations with 75th percentile weather.

| Treatment | Fireline Intensity (kW/m) | Heat/Area ($kJ/m^2$) | Fire Rate of Spread (m/min) | Area Burned in 24 Hours (Ha) | Spotting and Torching (y/n) |
|---|---|---|---|---|---|
| None | 72.8 | 3241.79 | 0.64 | 7 | no |
| Prescribed Burn | 7.94 | 1750.74 | 0.25 | 6 | no |
| Pile and Burn | 65.29 | 4613.31 | 0.72 | 24 | no |
| Cut and Scatter | 84.47 | 7975.95 | 0.66 | 33 | yes |
| Thinning and Biomass | 44.41 | 3805.71 | 0.61 | 20 | no |
| Thinning and Biomass followed by Prescribed Burn | 6.61 | 1712.88 | 0.23 | 6 | no |
| Salvage without slash or landscape fuel treatment | 87.59 | 5389.29 | 0.91 | 24 | yes |
| Salvage with slash treatment but without landscape fuel treatment | 22.75 | 3294.54 | 0.85 | 20 | yes |
| Salvage with slash and landscape fuel treatment | 8.23 | 1797.45 | 0.30 | 9 | no |
| Group selection without slash or landscape fuel treatment | 114.36 | 8382.84 | 0.49 | 26 | yes |
| Group selection with slash treatment but without landscape fuel treatment | 85.96 | 4467.26 | 1.01 | 23 | yes |
| Group selection with slash and landscape fuel treatment | 8.34 | 1721.45 | 0.31 | 8 | no |

**TABLE 19**

Average results of fire simulations with 95th percentile weather.

| Treatment | Fireline Intensity (kW/m) | Heat/Area ($kJ/m^2$) | Fire Rate of Spread (m/min) | Area Burned in 24 Hours (Ha) | Spotting and Torching (y/n) |
|---|---|---|---|---|---|
| None | 481.67 | 6204.9 | 1.42 | 330 | yes |
| Prescribed Burn | 38.94 | 2740.93 | 0.59 | 25 | no |
| Pile and Burn | 164.15 | 4529.19 | 1.2 | 120 | yes |
| Cut and Scatter | 1070.82 | 8699.56 | 1.43 | 620 | yes |
| Thinning and Biomass | 111.58 | 4132.52 | 1.31 | 100 | yes |
| Thinning and Biomass followed by Prescribed Burn | 37.93 | 2796.65 | 0.57 | 20 | no |
| Salvage without slash or landscape fuel treatment | 621.37 | 7824.89 | 1.64 | 280 | yes |
| Salvage with slash treatment but without landscape fuel treatment | 457.53 | 6869.00 | 1.23 | 170 | yes |
| Salvage with slash and landscape fuel treatment | 34.19 | 2991.67 | 0.46 | 20 | no |
| Group selection without slash or landscape fuel treatment | 1040.12 | 14141.37 | 2.42 | 320 | yes |
| Group selection with slash treatment but without landscape fuel treatment | 425.45 | 8336.16 | 1.23 | 180 | yes |
| Group selection with slash and landscape fuel treatment | 33.21 | 2885.78 | 0.44 | 16 | no |

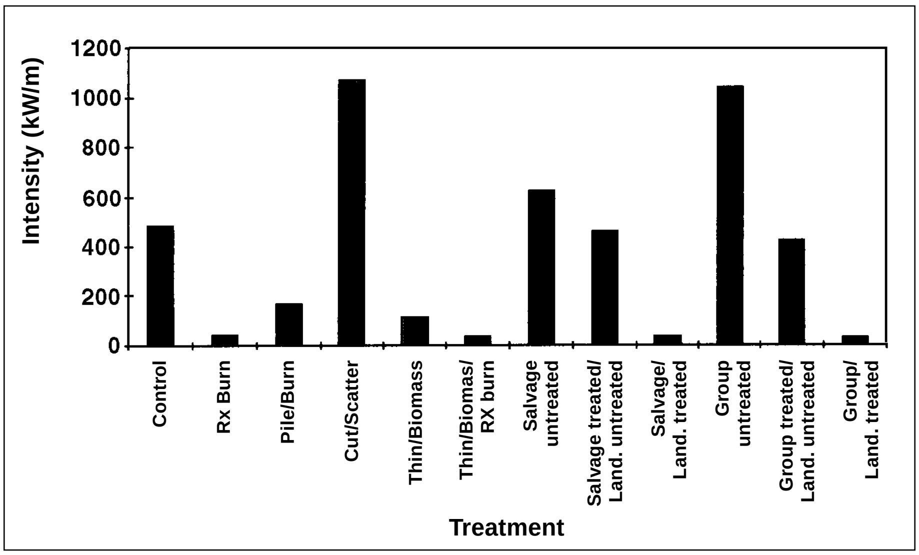



**FIGURE 3**

Average fireline intensity of simulations with 95th percentile weather conditions.

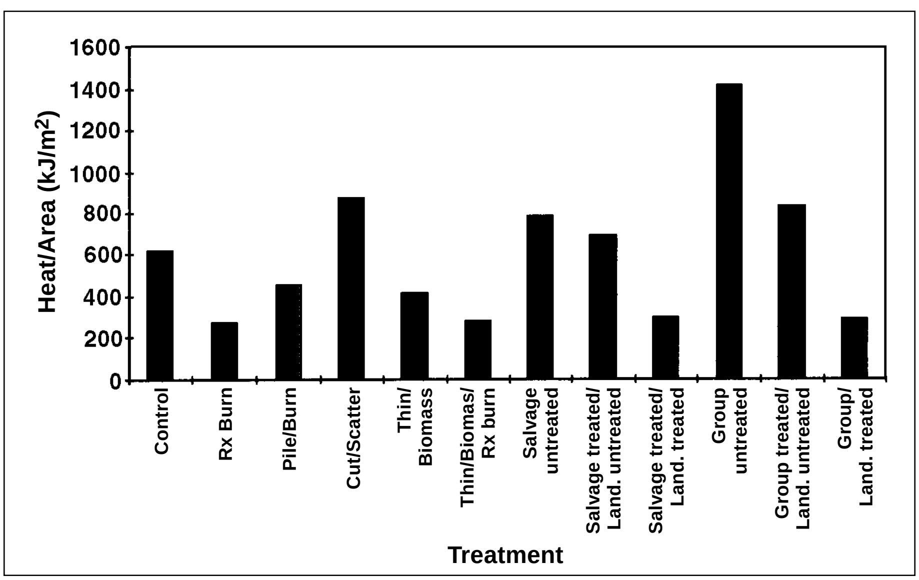



**FIGURE 4**

Average heat per unit area of simulations with 95th percentile weather conditions.

treat the adjoining slash and adjacent landscape which produced fireline intensities over 10 times greater than the prescribed burn, thinning and biomass followed by prescribed burn or salvage or group selection operations that include slash and landscape fuel treatments at 95th percentile weather conditions. These fires burned into the Tuolumne giant sequoia grove during the 24 hour simulation period, a distance of approximately 6 km, and would have damaged the grove extensively. Fire behavior was extreme and torching and spotting were common.

The cut and scatter and salvage / group selection treatments that do not treat the adjoining landscapes resulted in more extreme fire behavior when compared to the control treatment. This occurred because surface fuel load was increased significantly. Removing large, standing dead trees will not reduce fire hazard in these ecosystems.

The thinning / biomass and pile and burn treatments produced similar results. Both produced moderate fire behavior but both still produced spotting and torching. The resulting fuel structures are an improvement over the control in terms of potential fire behavior at 95th percentile weather conditions but still produce sufficient fireline intensity to kill many large trees. Neither of these treatments burned into the Tuolumne giant sequoia grove within the 24 hour period.

The most effective treatments are prescribed burn, thinning and biomass followed by prescribed fire, and salvage or group selection with slash and landscape fuel treatments. These treatments produce ecosystem structures that will not produce extreme fire behavior at 95th percentile weather conditions. These systems are dynamic and fuel will continue to accumulate after treatments. A comprehensive fuel treatment program is therefore required to keep fuel loads low and most mixed conifer / giant sequoia ecosystems should be re-burned every 7–15 years.

This study supports the conclusions reached by other researchers (van Wagtendonk 1996, SNEP report; Weatherspoon and Skinner 1996, SNEP report). van Wagtendonk used FARSITE on a simulated landscape to test the effectiveness of different fuel treatments. The results indicate prescribed burning is the most effective treatment followed by biomass / burn treatments in reducing fire behavior at 95th percentile weather conditions. This study also examined the effectiveness of fuel breaks in the Sierra Nevada and found them to be ineffective at extreme weather conditions.

Weatherspoon and Skinner recommend a landscape level strategy for fuels management in the Sierra Nevada. Defensible fuel profiles would be created on the landscape in this approach and prescribed fire would be used to restore natural processes where appropriate. Individual land management goals would also be used to create the fuel profiles since no one prescription is appropriate for the diverse ecosystems and ownership's of the Sierra Nevada.

## Summary

The simulations demonstrate a landscape perspective should be used in managing giant sequoia-mixed conifer ecosystems. Areas below giant sequoia groves should be managed to reduce fuel load and fuel continuity.

The costs of implementing a large scale fuel treatment plan will have to be investigated. Areas with high fire risk and hazard could be given higher priority (McKelvey and Busse 1996, SNEP report) in a fuel reduction program. Mechanical treatmens such as group selection and salvage operations with landscape level fuel treatments can be applied to reduce fuel loads in giant sequoia / mixed conifer ecosystems. In other areas, prescribed fire may be the only appropriate tool and it can be applied to simulate the dynamics of the giant sequoia / mixed conifer ecosystem.

A comprehensive management program is required to reduce fire hazard in the giant sequoia / mixed conifer ecosystems. Integration of independent assessments of fire hazard (fuel load, fuel continuity, topography), fire risk (ignitions from lightning, accidents, arson), and ecosystem values ("old-growth" forests, wildlife habitat, structures, watersheds) can be used to prioritize areas for fuel treatments. If this program is properly designed, it will produce ecosystems that are sustainable and it will also have the important benefit of employing many people in the Sierra Nevada.

# CASE STUDY: MANAGEMENT OF MOUNTAIN HOME DEMONSTRATION STATE FOREST

Information on stand growth under uneven aged management in the Sierra Nevada is limited. The main sources of information are at the University of California Blodgett Forest Research Station, the U.S. Forest Service PSW Redding Silviculture lab, and Mountain Home State Demonstration Forest. Information from the Blodgett Forest has been summarized (Helms and Tappeiner, 1995 SNEP report).

Mountain Home State Demonstration Forest is located in the southern Sierra Nevada, approximately 20 miles east of Springville, California. The size of the forest is 4,800 ac with an elevation range from 4,800–7,600 ft. Tree species found on the forest include white fir (*Abies concolor*), sugar pine (*Pinus lambertiana*), ponderosa pine (*Pinus ponderosa*), incense cedar (*Calocedrus decurrens*), giant sequoia (*Sequoiadendron giganteum*), red fir (*Abies magnifica*), and black oak (*Quercus kelloggii*). The land was purchased by the State of California in 1946 from the Michigan Trust Company. The forest was first logged in the 1870s, and by the late 19th century, twelve logging camps were in operation in the area. Early logging operations primarily concentrated on large giant sequoia and sugar pine.

Mountain Home is managed by foresters from the California Department of Forestry and Fire Protection. The land is managed for multiple use. The highest priority of Mountain Home is recreation with its seven campgrounds and ninety-six campsites. The annual number of overnight visitors is 40,000, and another 40,000 visitors come to the forest each year for day use. Many species of wildlife are found on the forest including deer, black bear, fisher, marten, grouse, quail and pigeons. Hunting on the forest is allowed during the appropriate season. Firewood cutting is allowed on the forest from existing dead and down logs when a firewood stamp is purchased. Many archeological sites have been found on the forest and a Native American site which was used for 8,000 years is currently being turned into an interpretive site for visitors.

The forest had a timber inventory of 100 million board ft when the state took over management in 1946. Large giant sequoia trees are not included in this inventory since they are not managed for timber production. Since 1946, the State has harvested approximately 100 million board ft of timber from the forest. Currently the forest has a standing inventory of 100 million board ft with an annual growth rate of two million board ft per yr. Growth rate data come from permanent plots located in the forest that are measured every five years.

What is believed to be the seventh largest giant sequoia is found on the forest: the Genesis tree. Many large giant sequoia are found and silvicultural prescriptions are designed to produce old-growth giant sequoia habitat for future generations. Several giant sequoia groves have been managed to produce relatively open stands which allow visitors to view the monarchs without obstructions. The open stands also break up the horizontal and vertical fuel continuity making these stands less susceptible to intense crown fires. Regeneration of giant sequoia at Mountain Home has been relatively successful due to past disturbance regimes (e.g., fire and logging).

A large program to identify and protect sugar pine trees resistant to white pine blister rust is being conducted on the forest. Seeds are collected from resistant trees and grown at State nurseries. Forest managers at Mountain Home are concerned about the low density of sugar pine on the forest from past logging operations and blister rust infestation.

### Silviculture at Mountain Home

The forest has been primarily managed using uneven-aged systems since 1946. Early logging operations (around 1900) used some clear-cutting, particularly in the harvesting of giant sequoia. Group selection is used on the forest to harvest timber and to provide the disturbance necessary for regeneration of shade intolerant species. The majority of timber sales on Mountain Home are dominated by white fir. The second most common tree harvested is sugar pine, followed by incense cedar and ponderosa pine.

At Mountain Home, current information on the growth of young growth giant sequoia stands is estimated from individual tree measurements (Dulitz 1985). Early work on growth of mature giant sequoia in the Mariposa Grove of Yosemite National Park yielded an annual average increment of .04 inches / year (Hartesveldt 1962). Uneven-aged management of young growth giant sequoia at Mountain Home has resulted in an annual increment of 0.13–0.31 in per yr (Dulitz 1985). Natural young growth giant sequoia stands at Mountain Home produced a mean annual growth rate of 629 board ft per ac at age 86 (Dulitz 1985).

Current research being done at Mountain Home will identify how large a group selection opening is required to successfully regenerate giant sequoia and sugar pine (Stephens 1995). In 1993, 840,000 board ft of timber was harvested from 60 groups varying in size between 0.25–2.5 ac. The groups have been harvested in an old-growth mixed conifer forest with mature giant sequoia. Three different slash treatments were prescribed: pile and burn, broadcast burn and lopped and scattered (no burn). The group selection cuts will be monitored to determine how the establishment and growth of each species will be affected by the different opening sizes and slash treatments.

Another research project is investigating the response of young growth giant sequoia stands to single tree selection. This experiment was started in the summer of 1989 and the principal investigators are Robert E. Martin and Donald P. Gasser of the University of California, Berkeley.

## SUMMARY

Due to variations in grove environments, grove age structures, and grove management histories, no singular "correct" management regime to "preserve, protect and restore giant sequoia groves" (Sequoia National Forest, 1990, Mediated Settlement Agreement) exists.

Data collected to date suggests that the majority of giant sequoia ecosystems have changed structurally with fire suppression and logging the last century, with some also differing in their composition and functionality. Of the approximately 75 giant sequoia groves in the western Sierra Nevada, about 30 are in essentially wildlands (e.g., wilderness, protected, unlogged). Many giant sequoia ecosystems appear to be in need of fuel reduction and the opening of canopy gaps, as natural regeneration of giant sequoia within the majority of unlogged groves has been very low this last century, shifting demographics. Human activities such as logging, road and housing construction, and recreation have changed the ecology of parts of groves, and in rare instances, entire groves, and appropriate restocking activities may be useful in some cases. Funds must be made available to allow implementation of needed management activities.

Due to variations in grove environments, grove age structures, and grove management histories, no single "correct" management regime to preserve, protect and restore giant sequoia groves is needed. A review of past and current giant sequoia management practices suggests that it would be useful for the SNEP to provide managers with a palette of grove assessment and management tools, and the workgroup is doing this. It is important for giant sequoia managers to work closely with scientists and the public to design goals or desired conditions for their giant sequoia ecosystems. Then, appropriate adaptive management techniques to restore groves to near-natural and other desired conditions can be chosen and carefully implemented, monitored, and modified as needed. Restoration tools to be considered should include prescribed fire, removal of individual trees using low-impact techniques, removal of various types of fuels, removal of roads and other human construction where appropriate, and replanting of juveniles from local seed sources.

Management of giant sequoia as a long-lived, massive tree with a shallow root system, and of the species with its geographically restricted distribution, narrow genetic variability, fire adaptations, and high public values as the Sierra Nevada's most "charismatic mega-floral component", suggests that public agencies (with over 90% of the approximately 40,000 acres of giant sequoia grove-based ecosystems in public ownership) should consider coupling local planning efforts with regional, ecosystem planning for giant sequoia such that a variety of human needs can be incorporated into grove use (e.g., recreation, spiritual, aesthetic) and management while insuring and improving the ecological status of the species. The species does not appear to be in danger of extinction, as well over 200,000 individual trees greater than 1 ft dbh exist, with the species responsive to management. There is an obvious need to better inform and educate the pubic about giant sequoia ecosystems, and incorporate the public into ecosystem management.

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## SILVICS, YIELD AND WOOD PROPERTIES OF GIANT SEQUOIA

Given the correct growing conditions (full sunlight, soil moisture availability throughout the year, and deep, fertile soils) giant sequoia will grow faster than any native or exotic tree species in the mixed conifer zone of the Sierra Nevada. Research conducted at the University of California Blodgett Research Station in the early 1960s has indicated giant sequoia's planted in selectively cut as well as clear-cut stands have out-grown other species (Gasser 1994).

Recent measurements of a clear-cut planted in 1981 at

Blodgett have shown giant sequoia height growth to be 20% greater than its nearest competitor (ponderosa pine), while it averages nearly double that of the other native species. Giant sequoia diameter growth in the same compartment is over 20% greater than ponderosa pine and nearly triple that of Douglas-fir, sugar pine and white fir (Gasser 1994). Young giant sequoia in Mountain Home Experimental State Forest have also out grown all other native species in the southern Sierra Nevada (Dulitz 1988).

Measurements of growth in a group selection system at Blodgett planted in 1982 has also shown giant sequoia is the fastest growing tree. Group size was approximately 1 acre. Average height growth is 50% greater than the nearest competitors (ponderosa and sugar pines), while its growth triples or even quadruples the other mixed conifer natives. Diameter growth in the same unit is over 60% greater than the nearest competitor and four to seven times that of other coniferous species (Heald 1989).

In the best plantations in the Sierra Nevada, giant sequoia averages 0.5 to 0.7 m (1.6 to 2.3 ft.) per year in height growth, and 1.3 to 2 cm (0.5 to 0.8 in.) in diameter growth per year (Finns 1979). Growth of young growth giant sequoia stands is reported to be 9 $m^3$/ year (126 $ft^3$/ year) at a mean annual increment age of 86 (Cook and Dulitz 1978) and estimated average productivity of giant sequoia groves is reported to be 11 $m^3$/ year (Libby 1994).

In old-growth groves, rapid height growth continues on better sites for at least 100 years. At 400 years, trees range in height from about 34 to 73 m (110 to 240 ft.) (Weatherspoon 1991). Analysis of a large old growth populations resulted in an average dbh of 48 cm (18.9 in) at 100 years, 132 cm (52 in) at 400 years, 219 cm (86.1 in) at 800 years and 427 cm (168 in) at 2,000 years (Harvey et al. 1980). Care must be taken in using these values of average growth since large variances will occur depending on individual site characteristics.

In some areas, giant sequoia growth has declined over time. In Foresthill, a plantation was installed in 1981 on site 1A land with good rainfall. On this site, giant sequoia in mixed plantings were initially the fastest growers but have since fallen off and ponderosa pine has surpassed them (Gasser 1994). Ponderosa pine is more adapted to a summer drought period and can out grow giant sequoia on drier sites. Giant sequoia growth in a plantation installed in 1966 in the same general area has also declined. Initially growth was rapid but it has declined over time and the trees color after five years of drought is chlorotic (Gasser 1994). Giant sequoia seedlings and saplings may not release quickly when the overstory is removed (Schubert 1962). Giant sequoia environmental requirements are not completely understood but the differences in growth rate may be related to light requirements and soil moisture availability during the summer.

Giant sequoia is rarely found in pure stands but is a component of the mixed conifer ecosystem. In a study where almost all of the giant sequoia's were inventoried in the national parks of California, giant sequoia occupies approximately 200 square feet of basal area per acre. On average, these trees are large since over half of the basal area per acre is composed of giant sequoia even though it only makes up 5% of stand density (trees / acre) (Stohlgren 1991).

Young growth giant sequoia has excellent wood quality when proper silvicultural treatments are applied. Proper treatments include early lower branch pruning to produce clear lumber and planting relatively high density stands to reduce trunk taper. When compared to young growth coast redwood (S*equoia sempervirens*), giant sequoia has qualities that meets or exceeds coast redwood in the important properties of specific gravity, most mechanical properties, extractive content and decay resistance (Gasser 1994). Studies have also shown that young growth giant sequoia is both stronger and heavier than old growth giant sequoia (Piirto and Wilcox 1981).

Giant sequoia has excellent characteristics such as growth rate and wood quality making it an excellent candidate for commercial operations. Silvicultural systems such as group selection that plant multiple species (giant sequoia, sugar and ponderosa pines, incense cedar, and white fir) can be used to produce wood products when this is a land management objective.

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**APPENDIX 8.1**

# Chronological Review of the Literature on Giant Sequoia

The early literature on giant sequoia (1853–1920s) mainly dealt with tales of the discovery of the trees, locations of new groves, measurements of size and age, general tree descriptions, comparisons to the coast redwood (*Sequoia sempervirens*), and the potential value for logging. Many myths were generated from incorrect tree measurements, hasty assumptions, and the general excitement about such a large and visually appealing tree. The Yosemite and Calaveras parks groves were early topics, as the discovery claims revolved mainly around these areas (e.g., Barton 1885; Hutchings 1886; Muir 1878; Vischer 1862).

One of the first issues to gain attention was the botanical classification (i.e., systematics) of the species. Arguments began initially when this California taxa was named *Wellingtonia gigantea* after an Englishman (Lindley 1853a, 1853b). The name and taxonomic affinities of giant sequoia have changed several times, and evolved to the species current taxonomic identification as *Sequoiadendron giganteum* (Lindley) Buchholz in the Taxodiaceae family; however, alternate ideas still remain (Hart and Price 1990; Piirto 1994; St. John and Krause 1954).

Cultivation of giant sequoia in other countries began quickly, as seed from the monarchs was gathered and sent away (Ewan 1973; Hartesveldt 1969; Knigge 1994). In addition, several railroad companies performed early surveys of sequoia groves for their own commercial purposes (e.g., commercial logging, timbers for railroad construction, etc.) (Sierra Railway Company 1909; Southern-Pacific Company 1901; Wells 1906, 1907), and their activity may have triggered early conservation efforts to preserve the big trees (Dilsaver and Tweed 1990).

Starting in the 1930s, more truly historical investigations reviewed the details of the discovery of giant sequoia (e.g., Ellsworth 1933), with some of these books becoming major popular references, such as the 1930 book by Fry and White which had many later additions published. Research was published on the basic biology of the species as well (e.g., Buchholz 1937, 1938). A large amount of Douglass' groundbreaking work on giant sequoia tree-rings, climate and growth was published in the 1940s (e.g. Douglass 1945a, 1945b), and in the 1950s Axelrod began publishing ideas from his paleobotanical research on the evolution of the giant sequoia (e.g., Axelrod 1959, 1962). DeLeon also made a strong statement in his 1952 findings that at least twenty species of insects did inhabit giant sequoia trees, in contrast to earlier misconceptions that giant sequoia was an insect repellent tree. Grove inventories were also published throughout these years, as individuals searched for the "biggest" trees.

In the late 1960s, more intensive studies of the ecology and distribution of giant sequoia emerged. Agee's studies of fire, survival and grove communities (e.g., Agee 1967, 1968, 1969) and Rundel's distribution, fire and water relations work (e.g., Rundel 1967a, 1969b) began a line of investigation focused on the giant sequoia ecosystem, not simply on the tree itself.

Hartesveldt became a major author on giant sequoia through his extensive research program, which began in the 1960s, and he published several books and papers with his San Jose State colleagues through the early 1980s (e.g., Hartesveldt et al. 1975; Harvey et al. 1980). Giant sequoia studies now focused on more detailed fire, pathogen, insect and neighboring tree interactions within specific sections of groves (e.g., David and Wood 1982a; Parsons 1978; Piirto et al. 1977; Tarasova 1977), and grove management was becoming a larger issue (e.g., Bonnicksen and Stone 1978; Christensen et al. 1987; Hawksworth 1977; U. S. Forest Service 1985 Workshop on Management of Giant Sequoia). Genetic differentiation within and between groves also began to be investigated more thoroughly (e.g., Du and Fins 1989; Libby 1985). The most recent work on birds in giant sequoia groves (Snyder et al. 1986; Marshall 1988) has built upon earlier studies (e.g., Koford 1953; Kilgore 1978), but remain as studies focused on a particular grove area (i.e. Redwood Mountain) or species (i.e. the condor).

Several research topics have received a lot of focus in the literature since 1990. Paleoecological studies using dendrochronology as a tool for fire and climate reconstructions and pollen analyses to reconstruct past plant communities and climatic changes have dominated the refereed scientific literature (e.g., Anderson and Smith 1994; Brown 1992; Caprio et al. 1994; Hughes and Brown 1992; Koehler and Anderson 1994; Mutch 1994; Swetnam 1993). Ecophysiology studies assessing the effects of air pollution on giant sequoia, and in particular ozone, have also gained attention (e.g., Evans 1991; Grulke and Miller 1994; Miller et al. 1994).

The role of fire in the ecosystem continues as an important research focus, with studies investigating fire as both a natural process and a risk or hazard of management concern (e.g., K. Anderson 1993; Christensen 1991; Franco 1993; Parsons 1993; Stephenson et al. 1991). The 1992 U.S. Forest Service Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, showed that topics such as genetics, wood properties, insects and pathogens, cultivation, and human interactions and values remain areas of current investigation.

Data on plant communities in giant sequoia groves can be obtained from several sources. Kilgore did a specific survey of a section of Whitaker's Forest during his bird studies (Kilgore 1968, 1971a). Rundel looked in detail at Muir grove and in general at several other sites during his dissertation work (Rundel 1969b). Harvey et al. (1980) surveyed areas of giant forest in their large study. In recent years, D. Graber and N. Stephenson (personal communication) have gathered vegetation data for Sequoia and Kings Canyon National Parks, as has Don Potter of the USFS for the Sierra and Sequoia National Forests (unpublished data, personal communication). Other areas have standard species checklists and other data sets depending upon research performed at each grove.

There is a need for research on a broader set of topics to inform ecosystem management For example, no detailed studies on reptiles or amphibians were found, which leaves a gap in the story of grove wildlife and plant-animal interactions. Grazing, noted by many as a cause of altered vegetation distributions in the Sierra Nevada, only can be found referencing the giant sequoia groves in historical books and two reports (Dilsaver and Tweed 1990; Otter 1963; Sudworth 1900a; Vankat 1968). One study on rock chemistry comprises the only direct geologic work in the groves (Sherwood 1994). Soils are studied in reference to human effects by Hartesveldt (Hartesveldt 1964b), with fire impacts by Rundel and St. John (e.g., Rundel and St. John 1975; St. John 1976), and for general soil properties as described by Zinke and colleagues (Zinke and Crocker 1962; Zinke and Stangenberger 1994), but much further research on soils and subsoils is needed. Some detailed soil mapping has been done for select areas. Aside from a few basic descriptions and symbiont / pathogen studies (e.g., Mejstrik and Kelley 1979; Miller 1987), work on roots has focused on biochemistry (e.g., the studies of Berthon and colleagues published from 1987–1991), with Wolford investigating the rooting of propagates (e.g., Wolford and Libby 1976). Decomposition, a long-term ecological process, has only been investigated by a few scientists (e.g., Stohlgren 1988a, 1988b; Harmon et al. 1987).

In addition, human dimensions of giant sequoia ecosystems have been incompletely addressed, although various popular press and a few scientific articles and books address the various human values we give the individual monarch trees (Dilsaver and Tweed 1990; Tweed 1994), our use of the understory components of the ecosystem (under Native American and other management) (Berland 1963; Franco 1994; K. Anderson 1993), the conservation movement and the role of giant sequoia in it (Vale 1975; Cloer 1994), grove aesthetics (Dilsaver and Tweed 1990), visitor perceptions (Dawson and Greco 1994), and commodity values and grove management (Dulitz 1994; Duysen 1994; Rueger 1994).

# Biogeography of Giant Sequoia: A Context for Management

The fundamental question concerning the biogeography of giant sequoia (*Sequoiadendron giganteum* ) is "Why are the trees are found where they are and not elsewhere?". Why is a species that is so adaptive (as witnessed in plantations and horticultural use) so naturally restricted in its distribtion? To answer this involves not only analysis of the factors presently controlling the distribution of giant sequoia, but interpretation of the paleoecology and prehistoric distribution of the species from fossil records.

Compared to other conifers in the Sierra Nevada, giant sequoia has a unique and highly localized distribution. A few other Sierra Nevada conifers have unusual, restricted distributions, such as Washoe pine (*Pinus washoensis*) and foxtail pine (*P. balfouriana*), but they have very different ecologies than giant sequoia. Giant sequoia occurs in approximately seventy-three groves as a local dominant in the mixed conifer zone on the western slope of the range. Northerly groves are more spatially disjunct. Giant sequoia's natural range is across a narrow north-south trending belt on the west slope of the Sierra Nevada approximately 15 mi wide by 260 mi long (between 35° 50' N - 39 °00' N). Giant sequoia elevational distribution ranges between approximately 4,500 and 7,500 ft, with no obvious north to south changes along an elevational gradient.

Although giant sequoia can be found growing under a range of physical environmental conditions, it tends to be most commonly associated with sites which are high in soil moisture and have a northerly aspect. The climate is montane, Mediterranean with wet winters and dry summers. Precipitation, mostly snow, exceeds 60 in at the northern limit of its distribution, decreasing to approximately 35-40 in in the south. Summers are mild with temperatures rarely exceeding 85°F, and winter temperatures only occasionally falling below 0°F.

## PREHISTORIC DISTRIBUTION AND MIGRATION

Most of the research into the ancient environments of giant sequoia and its ancestors is derived from the work of Axelrod (1956, 1959, 1962, 1976, 1986). Ornduff (1994) also provides a thorough summary as does Millar (1996, SNEP report). Fossils attributed to *Sequoiadendron* date as far back as the Jurassic (145–205 mya) and have been found in several locations, including the Western and Eastern United States, Greenland, Spitzbergen, mainland Europe, the British Isles, and eastern Asia (Florin 1963; Axelrod 1986). The most recent fossil evidence of an Old World distribution dates to the late Oligocene, approximately 30 mya (Florin 1963). This evidence suggests local extinction around this period, although more recent fossils may yet be found.

Giant sequoia is thought to have made the transition to a near modern distribution in the Sierra Nevada during the late Miocene and Pliocene, approximately 2.5–10 mya (Axelrod 1959). Fossils of the close ancestor *S. chaneyi* are listed in late Miocene and Pliocene collections from several locations in Western Nevada. It is hypothesized that the increasing continentality of interior Western North America with the orogeny of the Sierra Nevada, with subsequent development of a rainshadow to the east of the range crest and creation of a mosaic of topoclimates on the western slopes, is responsible for the range restriction and speciation. The increasingly inhospitable climate (with an increased temperature range and drying) of its former interior range likely caused local extinction and encouraged migration to the mesic and milder conditions of the western Sierra Nevada, probably around 6–7 mya. It is interesting to note that the fossils show the gross morphology of the species to be little changed over the last 20–30 million years (Fins and Libby 1994).

In a review of the Tertiary history of the Sierra Nevada, Millar (1996, SNEP report) summarizes the trends and changes in the biophysical environmen and associated floras and plant associations during the time period between 2.5–65 and mya. Her primary focus is on reviewing and analysing thirty-eight

Tertiary fossil floras collected at sites within or near the present day Sierra Nevada. The information pertaining directly to *Sequoiadendron giganteum* is briefly summarized below.

There is currently no Paleogene (pre-Miocene) fossil record of *Sequoiadendron* for the greater Sierra Nevada region. Fossils of *Sequoiadendron chaneyi* first appear in the Miocene. Complete species lists of the Miocene fossil assemblages containing *Sequoiadendron chaneyi* are provided in Millar's tables 5 (Aldrich Station), 8 (Chalk Hills), 12 (Fallon),19 (Middlegate), 26 (Purple Mtn.), and 29 (Stewart Springs). The modern taxa *Sequoiadendron giganteum* first appears in fossil assemblages from the Pliocene, summarized in Millar's tables 11 (Darwin Summit - Coso), 16 (Haiwee - Coso), 21 (Mt. Reba), and 24 (Owens Gorge). General information on the age, location, and elevation of the sample sites, and primary references are given in Millar's tables 2 and 3, while her figure 16 is a map showing precise locations of the collection sites for *S. giganteum*.

Very little information is available on the Pleistocene distribution of giant sequoia, as fossiliferous deposits are lacking or undated. Various accounts of "redwood" being encountered in well logs of Pleistocene alluvial deposits along the fans of the San Joaquin Valley and from Pleistocene Lake Tulare have been made (Anderson 1994), but dating of these materials has not been done. O. Davis (unpublished pollen diagram) has recorded small amounts of giant sequoia pollen from a nearshore core at Mono Lake (elevation ca. 1943 m asl) dating 10,000–12,000 year B.P. on the eastern side of the Sierra Nevada, well beyond the current range limit of the species. Davis and Moratto (1988) also record giant sequoia pollen at ca. 10,500 year B.P. in Exchequer meadow sediments at the 2219 m elevation of Sierra Nevada Forest, above the current elevational distribution of the species in this region. Cole (1983) also discusses the occurrence of giant sequoia in the late Pleistocene based on plant macrofossils and pollen from packrat middens collected from Kings Canyon, where giant sequoia pollen is found in middens ranging from 14,000–>>45,000 year B.P. in middens largely within the current elevational range of the species (with middens from 920–1,230 m elevation; see also Kohler and Anderson 1994). However, the best most interesting research on the latest Pleistocene–Holocene occurrence of giant sequoia comes from the work of Koehler and Anderson (1994) at Nichols Meadow (elevation 1,509 m asl) near the Nelder Grove (and within its administrative boundaries) on the Sierra National Forest. Meadow sediments here date to the last 18,500 years B.P., with this site below the elevational extension of the Sierra Nevada valley glaciers. Buried and surficial giant sequoia logs are present in the meadow, including two logs which date ca. 10,000 year B.P. Changes in the stream system following deglaciation and in the local groundwater table seem to account for the invasion of giant sequoia after 11,500 year B.P. Koehler and Anderson (1994) state that giant sequoia was excluded from the meadow and the Nelder Grove site during the full glacial, and largely restricted to riparian sites, probably migrating upslope with the termination of the glacial, with range restriction with the onset of early Holocene aridity ca. 9,000 year B.P.

Pollen data from Exchequer Meadow (elevation 2,219 m asl), about 5 miles north of the McKinley Grove on the Sierra National Forest, suggest that the early Holocene was warm (with temperatures not much lower than today) and dry (Davis and Moratto 1988), and that giant sequoia was expanding its range at this time. *Sequoiadendron* pollen is found here in meadow sediments dating to ca. 9,000–11,000 year B.P., with no macrofossils of *Sequoiadendron* found, suggesting that trees were not found immediately adjacent or upstream of the Meadow. This expansion of giant sequoia regionally occurred with warming conditions and the local demise of alpine grassland vegetation. As *Sequoiadendron* pollen levels drop to near zero following this event, giant sequoia trees must have either rapidly migrated through the region or major, or a rapid changes in local storm tracks occured, with storms from the south and southeast allowing wind deposition from the McKinley Grove or the Converse Basin grove complex. Regardless, the record suggest that giant sequoia were locally present around the 2,000 m elevation at this time.

John Muir (1877) was one of the first to speculate on controls of the modern distribution of giant sequoia, suggesting that Pleistocene glaciations were the driving force in shaping the current pattern of giant sequoia dispersion on the landscape. Additionaly, Axelrod (1986) points to a warm climatic regime during the Holocene, between 8,000–4,000 years ago, as a driving force which has restricted the current distribution. Anderson's (1994) study of pollen and plant macrofossils from Log Meadow (elevation 2,048 m asl), Sequoia National Park, treats this subject in greater detail, largely focusing on the last 4,000 years of the Neoglacial, and is summarized herein.

The record from Log Meadow in the Giant Forest grove (Anderson 1994) is divided into three distinct periods. From 9,000–10,500 year B.P., giant sequoia was locally absent, indicated by negligible amounts of giant sequoia pollen and a complete absence of macrofossils. The period between 4,500–9,000 year B.P. contains the first appearance of macrofossils and only slightly higher concentrations of pollen, indicating minimal local expansion of the giant sequoia population. From 4,500 year B.P. to the present pollen and plant macrofossils show a marked increase, indicating localized expansion approaching the contemporary occurrence of the grove. Additionally, the complete plant assemblages constructed from this record indicate a general trend toward moister conditions. In summary, the data strongly indicate the development and expansion of a giant sequoia grove at this site, with expansion being most vigorous during the most recent period from 4,500 year B.P. to the present. Anderson and Smith's (1994) summary of meadow sediment, pollen and plant macrofossil stratigraphies from the southern and central Sierra Nevada show that giant sequoia were rare in association with these meadows prior to 6,000 year B.P., expanding between ca. 4,000–6,000 year B.P. and continuing to increase thereafter. They infer that this range change may reflect both changing moisture regimes and the development of organic rich meadow sediments. Although still unclear, it is also suggested from the pollen stratigraphy that Sierra Nevada giant sequoia groves may have been expanding at the time of EuroAmerican settlement in California during the cooler Little Ice Age.

Further information on Holocene climatic change and fire frequency is also available from tree-ring studies. In the early 1900s, Ellsworth Huntington became interested in Andrew Ellicott Douglass' work with tree-rings of ponderosa pine in the American Southwest. Douglass was the founder of the Laboratory of Tree-Ring Research at the University of Arizona and was attempting to correlate rainfall records with tree-rings. Huntington began tree-ring ring studies in the Sierra Nevada examining the growth rings of giant sequoia in an effort to evaluate long-term changes in climate. In 1915, he showed Douglass the trees that had been sampled, and in that year Douglass began collecting his own samples for cross-dating purposes in the cutover areas of Converse Basin. Douglass continued to make trips to the Sierra Nevada and formed a 3,200 year-long chronology with each annual ring assigned to a calendar year, but could not precisely link his data to temperature and precipitation records from the time, due to a scarcity of meteorological data (Douglass 1919, 1928). Antevs (1925) and Huntington (1914) also were unsuccessful in comparing climatic records to the tree-ring data. Douglass eventually published a summary of his field sampling trips on giant sequoia and resulting studies in the *Tree-Ring Bulletin* (Douglass 1945a,1945b, 1946). Much of this work formed the basis for modern dendrochronology.

Chronologies developed by Brown et al. (1992) confirmed the dating chronology originally developed by Douglass (1919). Additional studies (Brown et al. 1992; Hughes and Brown 1992; Swetnam et al. 1992) yielded chronologies that could be linked to specific years and demonstrated a strong relationship between vary narrow rings in giant sequoia and extreme drought events in the San Joaquin River drainage (Hughes et al. 1990). Hughes and Brown used the number of times low-growth years (indicated by small ring-width indices) were present in samples from the Giant Forest Grove, Mountain Home Grove, and Camp Six complex to infer the number of extreme droughts from 101 BC to 1988 AD. They found the twentieth century so far to have had a below-average frequency of droughts, and the period from 1850-1950 AD to have had one of the lowest frequencies of drought of any one hundred year period.

## FIRE HISTORY

The presence of fire scars on tree trunks, logs, stumps and snags in giant sequoia-mixed conifer forests allows researchers to determine very detailed fire histories for these forests. Some of the noise encountered in the chronologies was thought to be growth responses to fire events, which was shown to be the case in further study (Brown et al. 1992; Swetnam 1992; Caprio et al. 1994; Mutch 1994). Fires were found to occur mostly in late summer and early fall, and vary in frequency, size and severity from a maximum of three to four per decade to a low of one to two per decade (Swetnam 1992). Swetnam's fire scar data showed that frequent, small fires occurred during a warm period from 1000–1300 AD, and infrequent, more widespread fires occurred in cooler periods of 500–1000 AD and since 1300 AD, all in relationship to regional climate (Swetnam 1993). These results showed that fire and climate records go hand-in-hand, as regional climate effected fuel accumulation, fire frequency, fire severity, and tree growth rings.

In addition, tree rings have provided information on fire intensity. Some scars suggest that large, high intensity fires burned through giant sequoia groves, but that these wer rare occurrences. For a high severity fire which occurred in the year 1297 AD in the Mountain Home forest (sampling area), Caprio et al. (1994) were able to study fire intensity and the post-fire growth release. The large growth release, lasting 30–100 years in some trees, is hypothesized to be due to release of competition, as neighbors were killed and therefore more light, water and nutrients were available to the surviving trees (Caprio et al. 1994).

Future work gathering data from earlier time periods and other groves is in progress, with wood density, cell size and wood chemistry under analysis as well. A thorough understanding of fire regime and fire-climate interactions in giant sequoia groves is critical to understanding the population dynamics of the groves. Data also will help with analyses of potential reactions of the groves to future climate change.

Fire in the giant sequoia mixed-conifer ecosystem has been written about often. It will be only briefly discussed here with regard to the potential role that forest fire has played in shaping the local pattern of giant sequoia dispersion during the late Holocene. In investigating the link between fire and maintenance of giant sequoia populations, Stephenson (1994) presents three lines of evidence supporting the strong role that locally intense fires play in successful seedling recruitment and establishment. First, intense, local crown fires did occur prior to substantial European disturbance of grove structure and fuel loads. Second, the highest levels of giant sequoia seed dispersal and the highest levels of establishment, growth and survival of seedlings are evident where fires have burned most intensely. Lastly, the present mosaic of locally even-aged clumps of living giant sequoias conforms well to patterns of localized destruction of the forest canopy from past fires. In other words, it is strongly suggested that the pioneering ability of giant sequoia in burned forest clearings is largely responsible for the patterns of establishment seen today.

## BIOLOGICAL HIERARCHIES

From a biological perspective, giant sequoia can be studied at the genetic level, at the whole organism level from a physiological and structural perspective, in its metapopulations that make up the giant sequoia groves and the species, in its association with other plants and animals in biotic communities, and at the ecosystem level in its association with the functionally integrated biophysical system.

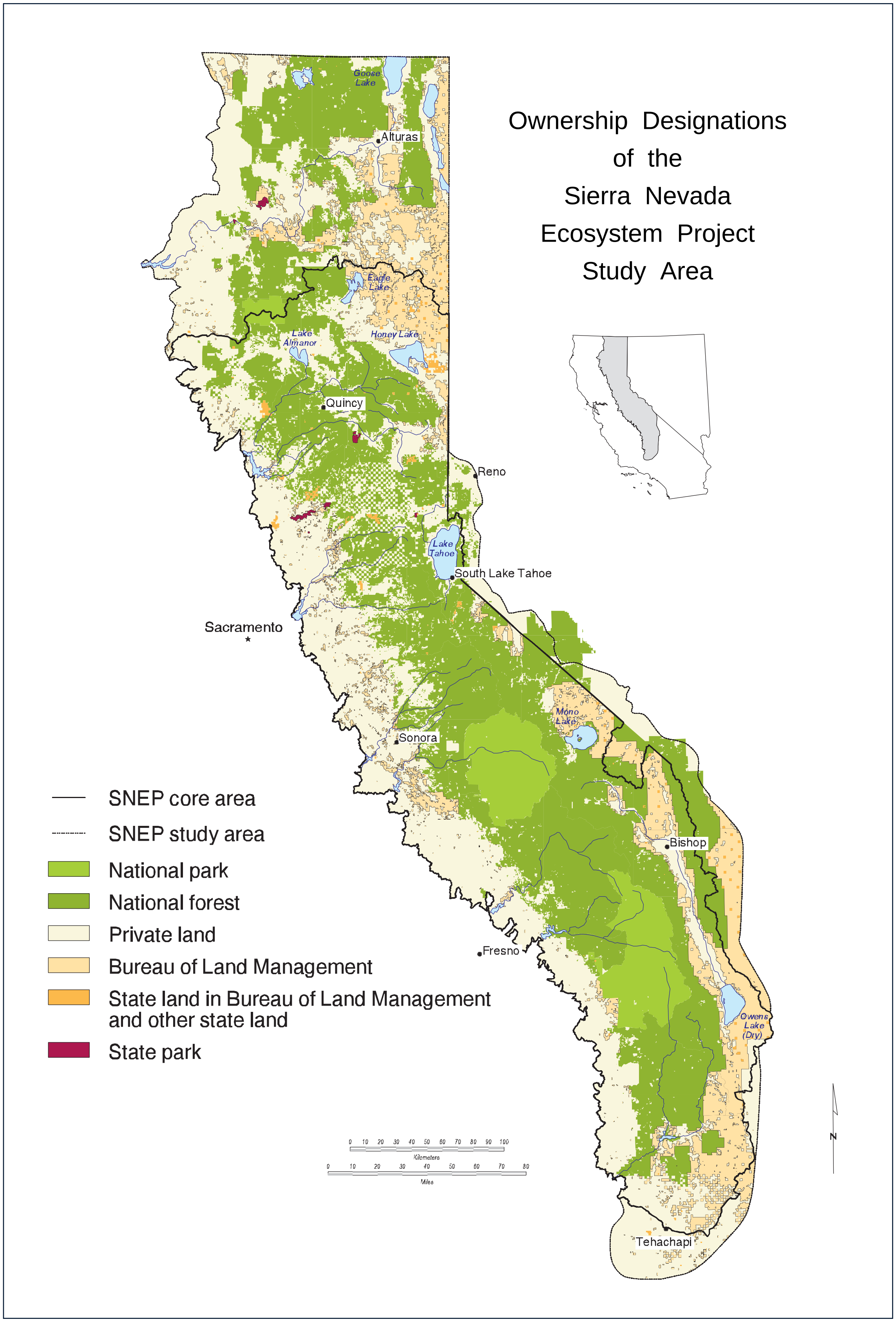
In reference to these hierarchies, the most complete work has been done at the population level, in reference to the distribution of the species and the number of trees in various size classes in the metapopulations. The most detailed demographic data is available for the groves of Sequoia and Kings Canyon National Parks. The life history of the species is also well know, as are its ecophysiological tolerances.

Select information exists on the genetic diversity of the species within and between populations across its natural range. Approximately thirty of the seventy-three giant sequoia groves had been sampled for genetic study, with seeds from various groves planted in common garden provenance studies both in California and elsewhere (Fins and Libby 1994). The most recent summary of this research is provided in Fins and Libby (1994) (citing Fins 1979; Fins and Libby 1982; Mahalovich 1985; Du and Fins 1989). The work of Fins and Libby (1994) and Rogers et al. (1996, SNEP report) suggests that the species genetic diversity is relatively low compared to other Sierra Nevada conifers, but the species does exhibit variability in its biochemical, morphological and growth traits. Isozyme analyses have shown the species to be low in genetic variation (Fins and Libby 1982), with 90% of the isozyme variability occuring within the groves, with the remaining 10% distributed among the groves. The northern groves (especially the Placer County Grove on the Tahoe National Forest) have the lowest within-grove genetic diversity (Fins and Libby 1982), which may be a function of the southern groves either serving as refugia during the Pleistocene (with the Deer Creek southerly grove not supporting this concept due to its similarly low within population genetic variation), or the northerly groves originating from a smaller gene pool as trees migrated to the north from the more southerly drainages following deglacation (Rogers et al. 1996, SNEP report) ca. 12,000–18,000 years B.P. Isozyme analyses also indicate that some inbreeding occurs in natural metapopulations (Fins and Libby 1994).

This is especially true of the Placer County Grove, which exhibits genetic rarity and it thus significant from a biodiversity conservation perspective (Rogers et al. 1996, SNEP report). Rare elements like the Placer County Grove are also threathened, as tree death due to timber harvest (although unlikely due to Botanic Area status of grove) or crown fire (possible due to heavy loading of surface and ladder fuels) would deplete the small gene pools (here, six mature giant sequoia trees). An additional serious threat is the presence of fifty-some in-planted giant sequoia trees from the Mountain Home grove; these trees were planted by the Lion's Club in 1951 and are reaching sexual maturity, and as such cross-breeding is a true threat. These trees should be removed by the Forest Service as soon as possible.

The possible consequences of artificial regeneration (e.g., replanting) in other groves, with the introduction of propagules from outside the grove following timber harvest, fire, or other disturbance events threatens the inherent and not fully understood genetic architecture of this species (Rogers et al. 1996, SNEP report). Furthermore, the Forest Service commonly plants giant sequoia as a fast-growing species in various timber cuts outside the species natural range and between the existing groves. This practice should be curtailed until there is a more complete understanding of the species' genetic architecture using sophisticated analytical techniques. Genetic investigations will also help us resolve the question as to whether "groves" have inherent properties making them a meaningful unit of biological study.

In reference to biotic communities and ecosystems, scattered information exists on associated plant and animal species, and on associated soil and rock types, but little comparable, comprehensive work has been done such that we may understand the variation in giant sequoia communities or ecosystems. A comprehensive study of plant communities and soils for the southern giant sequoia groves is in process by Don Potter, regional ecologist for the Stanislaus, Sierra and Sequoia National Forests. The Giant Forest grove probably has the most complete set of ecosystem data, as Sequoia National Park has funded various studies of this grove through their global climate change research program. Other groves which have been studied from a demographic and productivity perspective over decades includes the North Calaveras Grove, the Mariposa Grove, Redwood Mountain, and Mountain Home.

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