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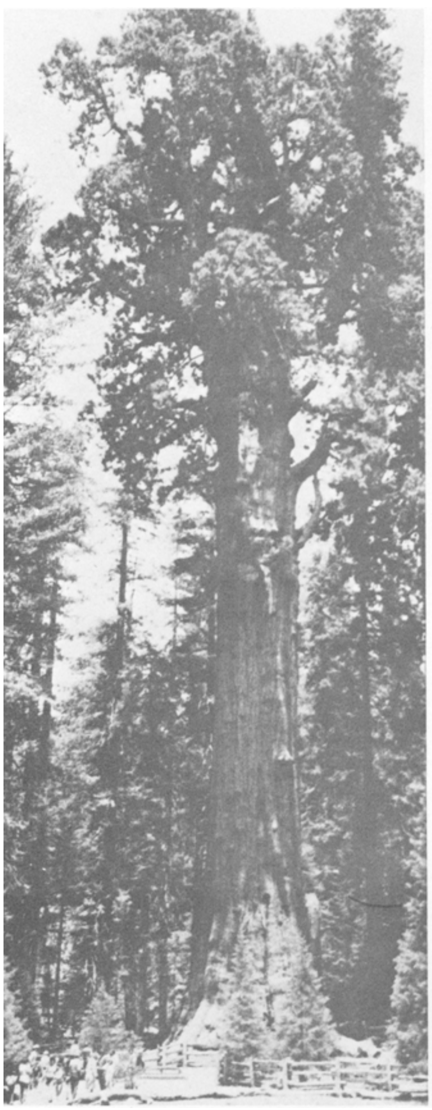
Proceedings of the Workshop on

Management of Giant Sequoia

May 24-25, 1985, Reedley, California



Cover: Management objectives for giant sequoia include restoring and maintaining natural ecosystem processes, protecting "showcase" areas or "specimen" trees, and producing timber. Photos show, clockwise from left: General Sherman Tree, Sequoia and Kings Canyon National Parks; prescribed burning for site preparation after whitewood removal, Bearskin Grove, Sequoia National Forest; and young giant sequoias, Sequoia National Forest.

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Technical Coordinators

C. Phillip Weatherspoon **Y. Robert Iwamoto** **Douglas D. Piirto**

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PREFACE

Since its discovery in the mid-nineteenth century, giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) has been noted for its enormous size and age, and its rugged, awe-inspiring beauty. Because the species has broad public appeal and a restricted natural range, most groves of giant sequoia have been accorded protected status. In some groves, however, and increasingly outside the natural range of the species---both in the United States and in many other countries---giant sequoia is being utilized for timber production. Many foresters consider its rapid growth and favorable wood characteristics to indicate a substantial potential for it to become a major timber-producing species. Giant sequoia also is widely planted and highly regarded as an ornamental.

The first-ever workshop designed to bring together the state-of-knowledge on giant sequoia and its management---"Management of Giant Sequoia"---was held at Kings River Community College in Reedley, California, May 24 and 25, 1985. It was sponsored by the University of California Cooperative Extension---Forestry and the Northern California Society of American Foresters. The intent of the workshop was to address the history, silvics, genetics, growth and yield, wood properties and products, insect and disease relationships, appropriate management strategies by different agencies and landowners, and recommendations for future management of giant sequoia.

The second day of the workshop included a field trip to view first-hand and to discuss management activities in Sequoia National Forest, and Sequoia and Kings Canyon National Parks. A short summary and handouts from the field trip are in the appendix.

Because of the considerable public and professional interest in giant sequoia, the Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, agreed to publish the proceedings of the workshop to make the information available to a larger audience. These proceedings are a useful reference for resource managers, foresters, naturalists, ecologists, and the interested public.

The views expressed in each paper are those of the author(s) and not necessarily those of the sponsoring organizations. Trade names and commercial enterprises are mentioned solely for information and do not imply the endorsement of the sponsoring organizations. The tree names currently accepted for use by the Forest Service are *Sequoiadendron giganteum* and giant sequoia. Other names, however, are also used in these proceedings.

We thank the many people who assisted in the workshop and field trip---Linda Parham, Robert Cannell, Paul Roche, Tom Nichols, and the staff from Kings River Community College, Sequoia National Forest, and Sequoia and Kings Canyon National Parks. We appreciate the excellent work done by Roberta Burzynski, Pacific Southwest Forest and Range Experiment Station, in editing these proceedings. Most importantly, we thank the speakers and field trip leaders and coordinators for willingly devoting their time and efforts in preparing the workshop papers, and their organizations for making their time available. Finally, special thanks go to the participants who contributed to the discussion and to the sharing of ideas that made the workshop a success.

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Evolution and History of Giant Sequoia[1]

H. Thomas Harvey[2]

Abstract: Ancient ancestors of the giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) were widespread throughout much of the Northern Hemisphere during the late Mesozoic Period. Climatic conditions changed, forcing the more recent ancestors of present giant sequoia into the southwestern United States. The native range is now restricted to the west slope of the Sierra Nevada. Although seen in 1833 the effective date of discovery by the Europeans was 1852. Soon after that specimen trees were cut, and then extensive logging removed about a third of the big trees. Preservation of groves started in 1864 and gained momentum in 1890 with creation of Sequoia and Yosemite National Parks. Numerous scientific studies have been conducted during the last century from paleobotany to genetics of these great trees, but much is still unknown.

EVOLUTION

The earliest close relatives of the giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) were present in the Cretaceous Period (late Mesozoic) throughout much of the Northern Hemisphere (Chaney 1951). Because they appear to differ significantly from the present giant sequoia, they are not considered their immediate ancestors (Axelrod 1959). The oldest sequoia *fossil (Sequoiadendron chaneyi*) that is probably the lineal ancestor of the present giant sequoia is from the Miocene Epoch about 10 to 20 million years ago. The sequoia fossil not only resembles the modern giant sequoia, but the plants associated with the fossil are similar to those in present sequoia communities (Axelrod 1964).

During the late Miocene Epoch, the giant sequoia's ancestors were in what is now western Nevada. As conditions became cooler and drier, along with the rise of the Sierra Nevada, the survivors managed to prosper at the southwestern edge of the mountain range. Eventually they migrated to the western slope of the relatively low incipient Sierra Nevada and may have existed as isolated groves or as a continuous belt about 300 miles (482.2 km) long (Harvey and others 1981). Although the disjunct groves at present are genetically distinct, no firm conclusions can be drawn regarding the duration of genetic isolation (Fins and Libby 1982). And thus it remains unknown whether the giant sequoia followed isolated routes across the mountains or if it advanced on one broad front to be dissected into widely separated groves in the northern part of its present range.

[1]Presented at the Workshop on Management of Giant Sequoia, May 24-25, 1985, Reedley, California.

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DISCOVERY

The earliest human encounters with giant sequoia probably occurred shortly after the first Native Americans arrived in North America tens of thousands of years ago. According to Hartesveldt (1975), in 1877 Powers recorded "that the people of the Mokelumne Tribe referred to the sequoia as 'woh-woh-nau,' which in the Miwok tongue was a word supposedly in the imitation of the hoot of an owl, the guardian spirit of the great and ancient trees." The interactions between people and the giant sequoia were thus benign for millennia.

When Europeans arrived on the scene things changed. In the mid 1800's the giant sequoia were first discovered by Europeans, even though colonization of the West had begun a century earlier and explorers had visited California two centuries before that. Two dates---1833 and 1852---are noted by Hartesveldt (1975) as landmarks. The Walker Party in late autumn 1833 crossed the Sierra Nevada and described "trees of the Redwood species, incredibly large---some of which would measure from 16 to 18 fathoms round the trunk at the height of a large man's head from the ground" (Hartesveldt 1975). In other words, at about 6 feet (1.8 m) up the trunk the diameter was estimated at over 30 feet (9.1 m). Probably it was crudely measured by counting people with outstretched arms as each equal to a fathom, and being on a slope possibly would account for such large estimates.

In the summer of 1852 Dowd, a hunter of meat for a water company, discovered giant sequoias in the vicinity of a lumber camp in the Sierra Nevada. As the story goes he returned to camp and told his incredulous tale of gigantic trees. But no one accepted his story, so he made one up that he needed help to bring back a giant grizzly bear that he had shot. The lumberjacks responded to that, and followed him to what is now known as the North Calaveras Grove (Harvey 1978). In June 1852 the *Sonora Herald* reported Dowd's discovery and the news travelled fast throughout the world (Harvey and others 1981). Then followed two reactions-one benign, the other malignant.

Several people claimed to have discovered the trees at an earlier date than did Dowd. But a mystery still unresolved is why no one from the Walker Party recalled their apparently valid earlier claim to fame. All those that did step forward claiming earlier discovery were suspect, for they reported dates later than 1852.

The other reaction was more dramatic and more significant in the history of the giant sequoia. To show the world that California really did have such huge trees, selected trees were stripped or cut down. The first to go was augered down in the North Calaveras Grove in 1852. It took a crew of 25 men working 10 days to drill enough holes to send it crashing down. The next tree to go in the North Calaveras Grove was one called "Mother of the Forest." It was stripped of its bark to about 120 feet (36.5 m) up from the ground and died several years later. This whole procedure upset John Muir who was reported to remark that it was "   as sensible a scheme as skinning our great men would be to prove their greatness" (Hartesveldt and others 1975). In 1891 the Mark Twain tree, a fine specimen, was cut down and sections sent to the American Museum of Natural History in New York City and to the British Museum in London where they are still on view (Harvey and others 1981). At least some interest in natural history was generated by the exhibition of portions of these great trees, but the destruction of individual trees soon expanded into logging.

LOGGING

Logging of giant sequoias was begun in 1856 and continued intermittently until the 1950's (Hartesveldt and others 1975). Some modest use of large downed trees and the clearing of a few smaller ones continues to date. The logging of Whitakers Forest from 1873 to 1879 produced devastating conditions that at first were deplored, but second-growth sequoias eventually provided comparative stands with old growth. Not all mature sequoias were logged so that esthetically the Forest was not as devastated as later was Converse Basin (Biswell and others 1966).

The Converse Basin Grove was once one of the largest groves of giant sequoias known in the Sierra Nevada. About 3 miles north of Grant Grove thousands of mature giant sequoias grew in a basin covering several square miles. During its 20 years of operation (1888-1908) the Sanger Lumber Co. cut an estimated 8,000 giant sequoias in the basin (Johnston 1973). Two ironic features of the logging were that not one cent of profit was realized, and that the largest tree was left and named after the logging supervisor Frank Boule.

The reasons for the lack of profit were numerous but paramount was the loss of timber shattered beyond salvaging on falling (Johnston 1973). In addition, trees over 8 feet (2.4 m) in diameter were augered and then sometimes blasted in two. Also, the lumber and time needed to build the over 30 miles (48.3 km) of flume from Millwood in the Sierra Nevada to Sanger in the Central Valley ate into the hoped-for profits. The flume, when extended to Hume Lake, was reputably the longest in the world (Johnston 1973).

Knowledge of several fascinating sequoia attributes was salvaged from the devastation at Converse Basin. Douglass counted rings on several cut sequoia stumps of which one (D-21, about 50 yd. north of the Chicago stump) had 3,200 rings and thus is to date, the oldest known giant sequoia. (The snag that John Muir claimed was about 4,000 years old is only about a mile northeast of D-21.) Less than a quarter of a mile north of D-21 is a stump from which a section was removed by Libby to serve as a yardstick for carbon-14 dating. Shortly after the logging the rings of about 100 giant sequoia stumps were counted by E. Huntington and his graduate students. Those data have been used to correlate diameter with age (Harvey 1980).

Logging moved from Converse Basin to the east when the Hume-Bennett Lumber Co. took over. They operated from 1908 to 1926 cutting giant sequoias in groves near Hume Lake where the mill was located and from which the flume ran to Sanger. Although Mather, the first Director of the National Park Service, attempted to include these sequoia lands in an enlarged park, his efforts fell short.

The impact of the destruction of specimen trees and logging of giant sequoias produced backlash of conservation and preservation. As early as 1873 a State law was enacted that no tree over 16 feet (4.9 m) in diameter could be cut in Fresno, Tulare, or Kern Counties. There is no evidence of the law being enforced (Johnston 1973).

PRESERVATION AND RESEARCH HISTORY

The first outright preservation of sequoia land had begun almost a decade before the State law was enacted, when in 1864 the Federal government deeded the Mariposa Grove to the State of California (Hartesveldt and others 1975). In 1890 Sequoia, General Grant and Yosemite National Parks were created thus protecting considerable sequoia acreage. Over a million signatures on a petition to President Roosevelt spurred a bill in 1909 creating Calaveras Bigtree National Forest including the North and South Calaveras Groves. They later became part of the State park system: the North Grove in 1931 and the South Grove in 1954. Most of the largest sequoia grove, Redwood Mountain Grove, was finally added to Kings Canyon National Park in 1940. On the basis of acreage, giant sequoia lands are presently largely in public ownership with almost 70 percent in National Parks and an additional almost 25 percent under other public agencies. With the protection afforded the giant sequoia, attention was directed toward managing this great natural resource. The history of managing giant sequoia is described in other papers in these proceedings (Benson 1986, Parsons and Nichols 1986, Rogers 1986).

The history of the scientific inquiry into giant sequoia grades into its natural history as well. It is difficult to separate the two and indeed it's probably not worth attempting to do so in the first place. The interest and effort put into investigating the many aspects of these unique trees vary, and the time spent ranges from a few days to several years. Due to restrictions of time and space only a few of those studies best known to the author are mentioned here with apologies for those overlooked. One may also consult the literature cited in works by Axelrod, Biswell, Fins, Hartesveldt, Harvey, Kilgore, Piirto, Rundel, and Stark (nee Beetham).

Among the first to write extensively about the giant sequoia was John Muir. He devoted a chapter to the big trees in his book on Yosemite (Muir 1912), and wrote articles on giant sequoia as early as 1876. In the 1920's Fry and White (1930) studied the natural history of giant sequoias.

In the 1930's Buchholz studied cone development in the sequoias, and though there are some questions about his work, the scientific name (*Sequoiadendron giganteum*) proposed by him is currently widely accepted. From the 1940's to 1960's Axelrod provided considerable information on the paleobotany of the giant sequoia. Also starting in the 1940's Meyer expressed concern for the survival of the giant sequoia. Hartesveldt began studies in 1956 that eventually led to further investigations on giant sequoia ecology (Hartesveldt 1962). Hartesveldt, Harvey, Shellhammer, and Stecker studied sequoia reproductive responses to fire and predation over a decade (Harvey 1980). In the 1960's and 1970's, Biswell along with several fine graduate students contributed to further understanding of fire and the giant sequoia (Biswell 1961), and Rundel contributed basic information on the distribution and ecology of the giant sequoia (Rundel 1969, 1971, 1972). The extensive work of Stark (1968a, 1968b) on seed germination and seedling . tolerances has enlightened many "students" of the sequoias ever since. Also starting in the 1960's Kilgore studied breeding bird populations in giant sequoia forests. In the 1970's he continued work on the role of fire (Kilgore 1972, 1975, 1976).

A significant investigation during the 1970's by Piirto (1977) did much to clarify the role of fungi in association with tree failure in giant sequoias. Also in the 1970's spatial patterns and succession in the giant sequoia ecosystem was studied by Bonnicksen (1975). Genetic patterns of variation were investigated by Fins (1981).

Although much has been learned about the giant sequoia in its natural ecosystem, much still remains to be discovered. For example, little is known about the role of fungi during seedling development under natural forest conditions. Almost all the research mentioned above led to more questions than they started with, and perhaps that's the way it ought to be.

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Silvics of Giant Sequoia[1]

C. Phillip Weatherspoon[2]

Abstract: Ecological relationships-including habitat and life history---of giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) in natural stands are summarized. Such silvical information provides an important foundation for sound management of the species.

Silvics is defined by the Society of American Foresters (Ford-Robertson 1971, p. 240) as "the study of the life history and general characteristics of forest trees and stands, with particular reference to locality factors, as a basis for the practice of silviculture." Silvics deals primarily with ecological relationships of trees in natural stands. Consequently, the degree to which some specific subject areas of silvics apply directly to management of a species depends on the type of management-i.e., how far the management practice departs from natural stand processes.

Management of giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) covers a wide spectrum. Because the species has broad public appeal and a restricted natural range, most groves of giant sequoia have been accorded protected status. In these groves, which generally are managed to maintain the functioning of natural processes, the silvical characteristics summarized in this paper are in large part directly applicable to management. Elsewhere, both within and outside the natural range of the species, giant sequoia is managed for other purposes, such as timber production. Where intensive timber management is practiced, for example, a manager might have limited interest in the characteristics of older trees, associated vegetation occurring in natural stands, and some aspects of natural regeneration (if regeneration is to be achieved through planting). Nevertheless, many aspects of the silvics of giant sequoia comprise an essential foundation for any form of sound management of the species and, as a bonus, tell the ecological story of a fascinating species.

HABITAT

Native Range

The natural range of giant sequoia is restricted to about 75 groves scattered over a 260-mi (420-km) belt, nowhere more than about 15 mi (24 km) wide, extending along the west slope of the Sierra Nevada in central California (Hartesveldt and others 1975). The northern two-thirds of the range, from the American River in Placer County southward to the Kings River, takes in only eight widely disjunct groves. The remaining groves, including all the large ones, are concentrated between the Kings River and the Deer Creek Grove in southern Tulare County (Rundel 1971). Varying in size from 1 to 4000 acres (less than 1 to 1619 ha), the groves occupy a total area of 35,607 acres (14,410 ha) (Harvey and others 1980).

Climate

Giant sequoia is found in a humid climate characterized by dry summers. Mean annual precipitation in the groves varies from about 35 to 55 inches (900 to 1400 mm), with high year-to-year variation. Less than 1.2 inches (30 mm) usually falls between June 1 and September 30. Most of the precipitation falls in the form of snow, between October and April. Mean annual snowfall ranges from 144 to 197 inches (367 to 500 cm), and snow depths of 6.6 ft (2 m) or greater are common in midwinter (Rundel 1969).

Mean daily maximum temperatures for July for typical groves are 75 to 84 ° F (24 to 29 ° C). Mean minimum temperatures for January vary from 34 to 21 ° F (+1 to -6 °Q. Extremes are about -12 and 104 ° F (-24 and 40 ° C) (Rundel 1969, Stark 1968a).

Low temperatures seem to be a limiting factor for giant sequoia at the upper elevational limits of its range, as well as in areas with severe winters where the species has been introduced. Distribution of the species at low elevations is limited mainly by deficient soil moisture during the growing season (Rundel 1972).

Soils and Topography

Soils are derived from a variety of rock types. Most groves are on granitic-based residual and alluvial soils, and three are on glacial outwash from granite. Schistose, dioritic, and andesitic rocks also are common parent materials (Hartesveldt and others 1975, Schubert and Beetham 1962).

Typical soil series are Dome, Shaver, Holland, and Chaix. Characteristic soil families are coarse-loamy, mixed, mesic, Dystric Xerochrepts; coarse-loamy, mixed, mesic Entic (and Typic) Xerumbrepts; and fine-loamy, mixed, mesic Ultic Haploxeralfs. The natural range of the species lies mostly within the mesic temperature regime, extending only a short distance into the frigid regime, and wholly within the xeric moisture regime (Mallory 1981).

Giant sequoia grows best in deep, well-drained sandy loams. Its density also is much greater in the more mesic sites, such as drainage bottoms and meadow edges, than in other

[1]Presented at the Workshop on Management of Giant Sequoia, May 24-25, 1985, Reedley, California. This paper is adapted from Weatherspoon (In press).

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habitats within a grove. Total acreage of these productive sites is small, however. Relatively shallow and rocky soils support vigorous individuals, some quite large, wherever the trees can become established and where underground water is available to maintain them (Hartesveldt and others 1975, Rundel 1969).

Soil pH ranges mostly from 5.5 to 7.5, with an average of about 6.5 (Mallory 1981). Long-term site occupancy by giant sequoia appears to develop a soil of high fertility, good base status, and low bulk density (Zinke and Crocker 1962).

Adequate soil moisture throughout the dry growing season is critical for successful establishment of giant sequoia regeneration, although seedlings do not survive in wet soils (Schubert and Beetham 1962). One study has shown more available soil moisture within a grove, possibly associated with subterranean flow from higher elevations, than in adjacent forested areas (Rundel 1972). Except for its moisture content, soil apparently plays only a minor role in influencing the distribution of the species, as evidenced by the considerable variability in parent material among groves and the fact that giant sequoia grows vigorously when planted in diverse soils around the world (Hartesveldt and others 1975).

Elevations of the groves generally range from 4600 to 6600 ft (1400 to 2000 m) in the north, and 5600 to 7050 ft (1700 to 2150 m) in the south. The lowest natural occurrence of the species is 2720 ft (830 m) and the highest is 8860 ft (2700 m). The eight northern groves are all on slopes of a generally southern aspect. Between the Kings River and the southern boundary of Sequoia National Park, groves appear on north and south slopes with about equal frequency. Farther south, aspects are predominantly northerly (Rundel 1969).

Associated Forest Cover

Giant sequoia groves lie wholly within the Sierra Nevada mixed conifer type---SAF (Society of American Foresters) forest cover type 243 (Eyre 1980). A grove is distinguished from similar mesic habitats in this type only by the presence of giant sequoia itself: no other species is restricted to the groves (Rundel 1971). Nowhere does giant sequoia grow in a pure stand, although in a few small areas it approaches this condition (Hartesveldt and others 1975).

Based on density or canopy coverage, groves typically are dominated strongly by California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.), despite the presence of emergent individuals of giant sequoia that overtop the canopy. Sugar pine (*Pinus lambertiana* Dougl.) is a characteristic associate. Incense-cedar (*Libocedrus decurrens* Torr.) at low elevations and California red fir (*Abies magnifica A.* Murr.) at high elevations may rival California white fir for dominance. Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and California black oak (*Quercus kelloggii* Newb.) often occupy drier sites within the grove boundaries. Trees less commonly associated with giant sequoia include Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), Pacific yew (*Taxus brevifolia* Nutt.), Pacific dogwood (*Cornus nuttallii* Audubon), California hazel (*Corylus cornuta* var. *californica* [A. DC.] Sharp), white alder (*Alnus rhombifolia* Nutt.), Scouler willow (*Salix scoulerana* Barratt ex Hook.), bigleaf maple (*Acer macrophyllum* Pursh), bitter cherry (*Prunus emarginata* Dougl. ex Eaton), and canyon live oak (*Quercus chrysolepis* Liebm.).

Shrub species most often found in giant sequoia groves are bush chinquapin (*Castanopsis sempervirens* [Kell.] Dudl.), mountain misery (*Chamaebatia foliolosa* Benth.), mountain whitethorn (*Ceanothus cordulatus* Kell.), littleleaf ceanothus (*C. parvifolius* [Wats.] Trel.), deerbrush (*C. integerrimus* H. & A.), snowbrush (*C. velutinus* Dougl. ex Hook.), greenleaf manzanita (*Arctostaphylos patula* Greene), western azalea (*Rhododendron occidentale* [T. & G.] Gray), *Ribes* spp., *Rosa* spp., and *Rubus* spp. (Hartesveldt and others 1975, Harvey and others 1980, Rundel 1971, Schubert and Beetham 1962).

Stand structure and species frequency vary substantially with elevation, latitude, exposure, soil moisture, and time since fire or other disturbance. In general, protection of groves from fire has resulted in increased prevalence of white fir, reduced regeneration of giant sequoia and pines, and reduced density of shrubs. The age-class distribution of giant sequoia also varies widely among groves. Most groves today, however, appear to lack sufficient young giant sequoias to maintain the present density of mature trees in the future. In these groves, giant sequoia regeneration evidently has been declining over a period of 100 to 500 years or more (Rundel 1971).

LIFE HISTORY

Reproduction and Early Growth

Flowering and Fruiting

Male and female cone buds form on the same tree during late summer. Pollination takes place between the middle of April and the middle of May when the female conelets are only two or three times as large it, diameter as the twigs bearing them. Fertilization usually occurs in August, by which time cones are almost full-size. Embryos develop rapidly during the next summer, and reach maturity at the end of the second growing season. The egg-shaped mature cones, 2 to 3.5 inches (5 to 9 cm) in length, yield an average of 200 seeds each (Hartesveldt and others 1975, Harvey and others 1980, Schubert and Beetham 1962).

Seed Production and Dissemination

Cones bearing fertile seeds have been observed on trees as young as 10 years of age, but the large cone crops associated with reproductive maturity usually do not appear before about 150 or 200 years. Unlike most other organisms, giant sequoia seems to continue its reproductive ability unabated into old age. The largest specimens (not necessarily the oldest) bear heavy crops of cones containing viable seeds (Hartesveldt and others 1975, Schubert and Beetham 1962).

Giant sequoias have serotinous cones which, at maturity, may remain attached to the stems without commencing seed dissemination. For 20 years or more, cones may retain viable seeds and continue to photosynthesize and grow, their peduncles producing annual rings which can be used to determine cone age (Hartesveldt and others 1975, Schubert and Beetham 1962).

A typical mature giant sequoia produces an average of 1500 new cones each year, although variability among trees and from year to year is great. Cones produced during years with ample soil moisture are more numerous (more than 20,000 cones on one large tree in an exceptional year) and yield seeds of greater viability than those produced in dry years. The upper third of the crown generally bears at least two-thirds of the cone crop. Because of extended cone retention, a mature tree may have 10,000 to 30,000 cones at any given time, two-thirds of which may be green and closed, and the remainder opened, brown, and largely seedless (Hartesveldt and others 1975, Harvey and others 1980).

Estimates of percent germination of seeds removed from green cones range from about 20 to 40 percent (Fins 1981, Harvey and others 1980, Stark 1968b). A number of variables, however, account for departures from these average values. Trees growing on rocky sites yield seeds with substantially higher germinability than those on bottom lands with deeper soils. Larger seeds germinate in higher percentages than small ones. In tests of cone age, germination increased from 20 percent for seeds from 2-year-old cones to 52 percent for 5-year-old cones, then dropped to 27 percent for cones 8 years of age. Germinability also varies with cone location in the crown, seed position within the cones, and among groves (Hartesveldt and others 1975). Artificial stratification of seeds for 60 days or more resulted in faster germination, but not in higher germination percent (Fins 1981).

Browning of drying of cones, with subsequent shrinkage of scales and dispersal of seeds, is brought about largely by three agents, two of which are animals. The more effective of the two is *Phymatodes nitidus* LeConte, a long-horned wood-boring beetle. The larvae of the beetle mine the fleshy cone scales and cone shafts, damaging occasional seeds only incidentally. As vascular connections are severed, scales successively dry and shrink, allowing the seeds to fall. Cones damaged during the summer will open several scales at a time, beginning during late summer and fall, and continuing for 6 months to 1 year. Cone and seed insects other than *Phymatodes* have only a minor impact on seed production (Harvey and others 1980).

The second animal having a significant role in giant sequoia regeneration is the chickaree or Douglas squirrel *(Tamiasciurus douglasii).* The fleshy green scales of younger sequoia cones are a major food source for the squirrel. The seeds, too small to have much food value, are dislodged as the scales are eaten. During years of high squirrel densities, the animals tend to cut large numbers of cones and store and eat them at caches. When squirrels are few, most of the cone consumption is in tree crowns---a habit more conducive to effective seed dispersal. The squirrels are active all year (Harvey and others 1980).

The chickaree prefers cones 2 to 5 years old, whereas *Phymatodes is* most prevalent in cones at least 4 years old. The combined activities of these animals help to ensure that seeds of all age classes are shed, and that rate of seedfall is roughly constant throughout the year and from year to year, despite variability in new cone production. An average rate is about 400,000 seeds per acre (1,000,000/ ha) per year (Harvey and others 1980).

The third and perhaps most important agent of seed release is fire. Hot air produced by locally intense fire and convected high into the canopy can dry cones, resulting in release of enormous quantities of seed over small areas ---for example, 8,000,000 per acre (20,000,000/ ha) (Harvey and others 1980). This increased seedfall coincides both spatially and temporally with fire-related seedbed conditions favorable for seed germination and seedling survival.

Giant sequoia seeds are well adapted for wind dispersal. They are light (average 91,000/lb [200,000/kgD and winged, and fall in still air at a rate of 4 to 6 ft (1.2 to 1.8 m) per second. Winds common in late summer and winter storms in the Sierra Nevada can disperse seeds more than 0.25 mi (0.4 km) from the tall crowns of mature trees (Hartesveldt and others 1975, Schubert and Beetham 1962).

Birds and mammals exert a negligible effect on giant sequoia seeds on the ground. Because they are small and contain little energy, sequoia seeds consistently rank at or near the bottom in food preference tests that include seeds of associated species (Harvey and others 1980, Stark 1968b).

Seedling Development

Natural reproduction in giant sequoia is an unusually tenuous process. Of the enormous numbers of seeds shed each year, few encounter the combination of conditions necessary for seedling establishment.

In contrast with most coniferous seeds, a large majority of seeds of giant sequoia die from desiccation and solar radiation soon after reaching the forest floor, especially during the summer. In one study, viability of seeds removed from fresh cones and placed on the ground dropped from 45 percent to zero in 20 days. Seeds collected from the forest floor showed an average viability of 1 percent (Harvey and others 1980).

Seed dormancy is not evident in giant sequoia, so surviving seeds germinate as soon as conditions are favorable (Harvey and others 1980). The most significant requirement for germination is an adequate supply of moisture and protection of the seed from desiccation. This is best provided by moist, friable mineral soil that covers the seed to a depth of about 0.4 inch (1 cm), and that is partially shaded to reduce surface drying. A wide range of temperatures is acceptable for germination. The generally sandy soils of the groves normally provide the additional requirement of adequate aeration and the optimum pH range of 6 to 7 (Stark 1968b). Because of rapid percolation, however, moisture retention for germination and initial root development is often marginal.

Seeds dropped just before the first snow or just as the snow melts may have the best chance of germinating and becoming successfully established. Seedlings that produce roots early in the season during favorable soil moisture conditions are more likely to survive the dry summer. The first stage of germination -extension of the radicle -sometimes takes place beneath the snow (Hartesveldt and others 1975).

Thick litter usually dries too quickly for seeds to germinate, and virtually all seedlings that do get started die before their roots can penetrate to mineral soil (Harvey and others 1980, Schubert and Beetham 1962). Only in exceptionally wet years do significant numbers of seedlings become established on undisturbed forest floor. The role of damping-off fungi in the mortality of natural giant sequoia seedlings is not well known (Bega 1981), but they are almost certainly a greater problem on thick litter than on mineral soil. After seedlings are established on more favorable seedbeds, a light covering of litter can moderate soil surface temperatures and retard drying (Stark 1968a).

Seedlings rarely become established in dense grass cover, probably because moisture is depleted in the surface soil early in the season (Schubert and Beetham 1962).

Soil disturbance, along with increased availability of light and moisture, resulting from early logging in some of the groves has led to establishment of several fine young-growth stands dominated by giant sequoia. Mechanical seedbed preparation is currently a legitimate regeneration option in some groves, although such treatment is inconsistent with management direction in most of the natural range of the species.

Of the various types of natural disturbances that may remove litter and bare mineral soil, fire is undoubtedly the most significant. Locally intense or highly consumptive fires are more effective than light surface fires or physical disturbance in promoting germination and subsequent seedling survival and early growth (Harvey and others 1980). The resulting short-lived friable soil condition facilitates seed penetration beneath the surface and root penetration after germination. Increased wettability in the surface soil layers resulting from high temperatures appears to improve water penetration and retention in the zones important for seeds and young seedlings. Fire also may kill some understory trees, thereby providing more light to speed the development (especially root penetration) of the shade-intolerant giant sequoia seedlings. Additional benefits include providing a surge of available nutrients, reducing populations of fungi potentially pathogenic to seedlings, and killing seeds and rootstocks of competing vegetation (Harvey and others 1980).

On the other hand, the dark surface and possibly increased insolation resulting from fire may cause more desiccation and heat killing of giant sequoia seeds and seedlings at the surface. Also, populations of endomycorrhizal fungi may be severely reduced temporarily (Harvey and others 1980). And low-consumption fires, rather than reducing competing vegetation, may instead greatly stimulate germination and sprouting of shrubs. Partially burned litter, in terms of its suitability for successful seedling establishment, ranks between undisturbed forest floor and areas subjected to hot fires (Stark 1968b).

First year giant sequoia seedlings established on treated---bulldozed or burned or both---areas were 30 to 150 times more numerous than those on undisturbed forest floor (Harvey and others 1980). Mortality of first-year seedlings during the 3 summer months on one treated area averaged 39 percent, with an additional 25 percent dying during the next 9 months. Desiccation was the primary cause of mortality in the summer. During a year of increased seasonal precipitation, mortality attributable to desiccation decreased, whereas that caused by insects increased to 25 percent of total mortality. Heat canker, damage by birds and mammals, and fungal attacks were of minor importance.

In the same study, direct mortality of first-year seedlings due to insect predation ranged from 3 to 18 percent of all seedlings present. Some of the significant additional insect damage probably caused delayed mortality. Largest seedling losses were in areas recently disturbed, especially by fire, probably because alternative food sources were reduced temporarily. Insects responsible for the damage were early instars of *Pristocauthophilus pacificus* Thomas, a camel cricket, and larvae of the geometrids *Sabulodes caberata* Gn. and *Pero behrensaria* Packard.

Survival of sequoia seedlings for a 7- to 9-year period was 27 percent on areas subjected to a hot burn as opposed to 3.5 percent on other treated substrates. No seedlings survived in undisturbed areas. In another instance, only 1.4 percent of seedlings established following light surface burning were alive after two summers. Mortality slows substantially after the first 2 or 3 years. At the end of 3 years, surviving seedlings usually have root systems that penetrate the soil to depths that supply adequate moisture through the summer, or to about 14 inches (36 cm).

Height growth of giant sequoia seedlings in the groves is relatively slow during the first few years, presumably due to competition for light and moisture from the larger trees. Seedlings 7 to 10 years old grew at an average rate of about 1.6 inches (4 cm) per year. Periodic annual height increment from 10 to 20 years was only 2 inches (5 cm). Seedlings grew significantly faster on areas subjected to hot burns than they did elsewhere (Harvey and others 1980). In contrast, giant sequoia seedlings in the open grow rapidly, and, given an even start, can outgrow any associated tree species. Height growth up to 24 inches (60 cm) per year is not uncommon (Fins 1979).

Up to 2 or 3 years of age, seedlings growing in dense shade (less than 25 percent of full sunlight) survive about as well as others, but grow poorly and develop abnormally (Stark 1968a). At higher light levels, one study found moderate reduction in height growth compared with seedlings in full sunlight (Stark 1968a), whereas another study found no significant effect of reduced light on height growth (Harvey and others 1980). The adverse effects of shade on older giant sequoias are more conspicuous with respect to both mortality and growth reduction.

Vegetative Reproduction

Giant sequoias up to about 20 years of age may produce stump sprouts after injury (Libby 1981). Unlike redwood (*Sequoia sempervirens [D.* Don] Endl.), older trees normally do not sprout from stumps or roots. Piirto and others (1986), however, reported sprouts on two small stumps from suppressed trees about 85 years old. Giant sequoias of all ages may sprout from the bole when old branches are lost by fire or breakage (Harvey and others 1980, Schubert and Beetham 1962).

Cuttings from juvenile donors root quickly and in high percentages (94 percent average) (Fins 1982).

Sapling and Pole Stage to Maturity

Growth and Yield

One tree species has a greater diameter than giant sequoia, three grow taller, and one lives longer (Hartesveldt and others 1975). In terms of volume, however, the giant sequoia is undisputedly the world's largest tree. The most massive specimen, the General Sherman tree, located in Sequoia National Park, has an estimated bole volume of 52,500 ft^3 (1490 M^3) (Flint 1981). The greatest known height for the species is 310 ft (94.5 m), and the greatest mean diameter at breast height (d.b.h.)---for the General Grant tree, in Kings Canyon National Park---is 28.9 ft (8.8 m). The indicated mean d.b.h. includes a large abnormal buttress. Excluding this abnormality gives a more realistic estimate of the maximum mean d.b.h. for the species---approximately 27.0 ft (8.2 m) (Flint 1981). Mature specimens commonly reach a diameter of 10 to 20 ft (3 to 6 m) above the butt swell and average about 250 ft (76 m) in height (Hartesveldt and others 1975).

A notable characteristic of mature giant sequoias that contributes substantially to their great volume is the slight taper of the bole---a feature more prominent in this species than in any other Sierra Nevada conifer (Hartesveldt and others 1975). In contrast, young open-grown giant sequoias taper markedly.

The greatest known age of a giant sequoia is 3200 years, determined from a stump count of rings (Hartesveldt and others 1975). Calculations based on increment borings yield age estimates of 2000 to 3000 years for many living trees.

Beyond the seedling stage, giant sequoia unhindered by an overstory continues to grow at least as well as associated species of the same age. In a survey of California plantations up to 50 years old in which giant sequoia had been planted, it outgrew other conifers (mostly ponderosa pine) in most instances in which species differed significantly in height or diameter growth. In the best plantations, giant sequoia averaged 1.6 to 2.3 ft (0.5 to 0.7 m) per year in height growth, and 0.5 to 0.8 inch (1.3 to 2.0 cm) in diameter growth per year (Fins 1979).

The growth and yield and wood properties of young-growth giant sequoia are discussed in detail in other papers in these proceedings (Dulitz 1986, Piirto 1986). Suffice it to say here that the species has been planted widely and often successfully in many parts of the world. Not only is it highly regarded as an ornamental, but many foresters see considerable potential for giant sequoia as a major timber-producing species of the world (Libby 1982).

In old-growth groves, rapid height growth continues on better sites for at least 100 years, producing dense conical crowns. At 400 years, trees range in height from about 110 to 240 ft (34 to 73 m). The rate of height growth declines beyond 400 years, and the typical tree levels off near 250 ft (76 m) at an age of 800 years to 1500 years (Harvey and others 1980).

Analysis of a large old-growth population showed average d. b. h. of 1.6 ft (0.5 m) at 100 years, 4.3 ft (1.3 m) at 400 years, 7.2 ft (2.2 m) at 800 years, and 14.0 ft (4.3 m) at 2000 years (Harvey and others 1980).

Although radial growth gradually decreases with age, volume increment generally is sustained into old age. The General Sherman tree, at an approximate age of 2500 years, has a current radial growth rate at breast height of about 0.04 inch (1 mm) per year (Hartesveldt and others 1975). Average volume increment for this tree since 1931 has been estimated by different methods at 40 ft^3 (1.13 m^3) per year (Hartesveldt and others 1975) and 51 ft^3 (1.44 m^3) per year (Flint 1981). Therefore, the world's largest tree also may be, in terms of volume increment, the world's fastest-growing tree. A related conclusion can be applied to the species: the enormous size attained by giant sequoia results not only from its longevity, but also---despite the apparent decadence of most veterans ---from its continued rapid growth into old age (Hartesveldt and others 1975).

Rooting Habit

During the first few years, the root system of giant sequoia seedlings consists of a taproot with few laterals---a habit that facilitates survival during dry summers (Schubert and Beetham 1962). The ratio of root length to shoot height during this period is about 2 to 2.5, with drier sites having higher ratios (Harvey and others 1980). After 6 to 8 years, lateral root growth predominates, and elongation of the taproot practically stops (Schubert and Beetham 1962).

Roots of a mature tree commonly extend 100 ft (30 m) or more from the bole in well-drained soils, and occupy an area of 0.7 acre (0.3 ha) or more. Along drainage bottoms or edges of meadows, the radial extent of the root system may be no more than 40 to 50 ft (12 to 15 m). The largest lateral roots are usually no more than 1 ft (0.3 m) in diameter. Few roots extend deeper than 3 ft (1 m) and even less in areas with a high water table. Most of the abundant feeder roots are within the upper 2 ft (0.6 m) of soil. Concentrations of feeder roots often are high at the mineral soil surface (Hartesveldt and others 1975).

Immature trees, both in the groves and in older plantings, are notably windfirm (Libby 1982). Considering the shallowness of the root system and the great above-ground mass of large mature giant sequoias, however, it is remarkable that so many of them---especially leaners---remain standing for so long (Hartesveldt and others 1975).

Root grafting is common in giant sequoia (Hartesveldt and others 1975, Schubert and Beetham 1962).

Reaction to Competition

Giant sequoia is shade-intolerant throughout its life. Of its common coniferous associates, ponderosa pine also is intolerant, sugar pine is intermediate in tolerance, incense-cedar is intermediate to tolerant, and California white fir is tolerant (Harvey and others 1980).

Fires or other disturbances that bare mineral soil and open the canopy characteristically benefit intolerant species, including giant sequoia, and move plant communities to earlier successional stages. In contrast, successful regeneration of giant sequoia in shade and in the absence of disturbance is less likely than that of any associated conifer (Harvey and others 1980). Also, young seedlings cannot tolerate low soil moisture, including that induced by competing vegetation.

Once established and with adequate light, young giant sequoias maintain dominance over competitors through rapid growth, and at maturity are the tallest trees in the forest. In dense thickets, however, young trees stagnate and recover slowly if released (Schubert and Beetham 1962).

Although conspicuous in late successional communities dominated by California white fir, giant sequoia is not a true climax-stage species, because it fails to reproduce itself successfully in an undisturbed forest. Instead, mature trees are successional relicts because they live for many centuries while continuing to meet their light requirements by virtue of their emergent crowns (Hartesveldt and others 1975).

If various natural agents of disturbance---especially fire---operated freely, giant sequoia groves would consist of a roughly steady-state mosaic of even-aged groups of trees and shrubs in various stages of succession. The patchy nature of vegetational units would correspond to the pattern of disturbances. In the absence of disturbance, however, successional pathways converge toward a multilayered climax forest of pure California white fir (Bonnicksen and Stone 1981). Since the advent of fire suppression, density of California white fir has in fact increased markedly, while densities of early successional stage species have decreased (Parsons and DeBenedetti 1979).

Damaging Agents

Fire is the most universal and probably most serious damaging agent of giant sequoia in its natural range (Schubert and Beetham 1962). Seedlings and saplings of giant sequoia, like those of most other tree species, are highly susceptible to mortality or serious injury by fire. However, in those locations most favorable for successful establishment and early growth-that is, mineral soil seedbeds and well-lighted openings -fuels tend to be sparser and to accumulate more slowly than in adjacent forested areas. The more vigorous seedlings and saplings thus may be large enough to survive a light fire by the time one occurs.

Larger giant sequoias, because of their thick nonresinous bark and elevated crowns, are more resistant to fire damage than are associated species. Nevertheless, repeated fires over the centuries sear through the bark at a tree's base, kill the cambium, and produce an ever-enlarging scar. Almost all of the larger trees have fire scars, many of which encompass much of the basal circumference (Hartesveldt and others 1975). Few veterans have been killed by fire alone, but conesquent reduction in supporting wood predisposes a tree to falling. Furthermore, fire scars provide entry for fungi responsible for root disease and heartrot (Piirto and others 1984). Decayed wood, in turn, is more easily consumed by subsequent fires. The net result is further structural weakening of the tree. In addition, fire scars have been cited as the main cause of dead tops, so common in older trees (Rundel 1973).

Lightning strikes, besides starting ground fires, sometimes knock out large portions of crowns or ignite dead tops. Mature trees seldom are killed by lightning, however (Hartesveldt and others 1975).

Old giant sequoias most commonly die by toppling. Weakening of the roots and lower bole by fire and decay is primarily responsible (Hartesveldt and others 1975, Piirto and others 1984). The extreme weight of the trees coupled with their shallow roots increases the effects of this weakening, especially in leaning trees. Other causative factors include wind, water-softened soils, undercutting by streams, and heavy snow loads (Hartesveldt and others 1975).

Disease and insect relationships are discussed by Parmeter (1986).

Of various types of human impact on giant sequoia in the groves (Hartesveldt and others 1975, Harvey and others 1980, Piirto and others 1984), the most significant has been fire exclusion. The damage caused by fire is outweighed by its benefits in perpetuating the species. As indicated earlier, fire is necessary to create and maintain conditions favorable for regeneration (Harvey and others 1980). Furthermore, the infrequency of fires has permitted a large buildup of both dead and live fuels and an associated increase in the potential for catastrophic crown fires. Agencies responsible for managing most of the groves have programs designed to reintroduce fire into giant sequoia ecosystems. An important part of these proceedings consists of descriptions by agency representatives of such fire management activities and other aspects of their overall management strategy for giant sequoia (Benson 1986, Harrison 1986, Heald 1986, Parsons and Nichols 1986, Rogers 1986).

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Diseases and Insects of Giant Sequoia[1]

John R. Parmeter, Jr.[2]

Abstract: Giant sequoias (*Sequoiadendron giganteum* [Lindl.] Buchholz) are susceptible to a number of diseases and insects at each state of development from seeds to overmature trees. We presently have little more than a catalog of occurrences. The impacts and the management implications of disease and insect losses have scarcely been investigated or evaluated, and much study is needed to provide data for sound management and protection of giant sequoia stands.

Management implications of disease and insect impacts in stands of giant sequoias (*Sequoiadendron giganteum* [Lindl.] Buchholz) are largely speculative, and available information is mainly descriptive or anecdotal. Review of standard lists of pathogens (Anon. 1960, Bega 1978, Hepting 1971, Peace 1962) or insects (Furniss and Carolin 1977, Keen 1952) of forest trees indicates that few pests of giant sequoia have been described. Giant sequoia is not even mentioned in Boyce's (1948) classic text on forest pathology. Pathogens (Bega 1964), fungi (Piirto and others 1984a), and insects (Stecker 1980a) on sequoia have been listed, and a few nematodes have been described (Cid del Prado and Lownsbery 1984, Maggenti and Viglierchio 1975). Knowledge of sequoia pests is gradually increasing, but---in general-their management implications are assessed mainly by extrapolation from what is known about similar pests of other species.

I have not attempted an exhaustive listing of references to diseases and insects of giant sequoia. I have, rather, selected references that provide good literature lists or that provide information bearing directly on evaluation of pest potentials in managed stands.

Pests become problems when they adversely affect the realization of management goals to an unacceptable degree. Pests do this by interfering with stand regeneration, development, and productivity. In stands managed for recreation or preservation, tree longevity and visitor safety may also be important.

REGENERATION

Factors affecting regeneration of giant sequoia were reviewed by Harvey and others (1980). They indicated that sequoias annually produce large numbers of seeds, the release of which is due in part to the activity of the cone beetle (*Phymatodes nitidus*). Seedling survival is rare in undisturbed duff and litter. Where mineral soil is exposed by fire or scarification, seedlings can become established, but not without considerable loss.

Seedling losses on suitable beds were attributed mainly to insect grazing and to desiccation, of which desiccation was by far the most important (Harvey 1980, Stecker 1980b). Insects variously injured large numbers of seedlings. Final mortality attributed to insects varied on study plots, with averages of about 6-25 percent in different years (Harvey 1980) but almost 30 percent on one plot (Stecker 1980b). Most insect damage occurred on first-year seedlings and was heavier on recent burns than on areas burned 2 or more years before seeding, presumably because in the first year or two after burning, sequoia seedlings were about the only plants available. The camel cricket (*Pristocauthophilus pacifcus*) and two geometrids (*Sabuloides caberata* and *Pero behresarius*) were prominent among seedling grazers (Stecker 1980b). Cutworms (*Noctuidae* spp.) have also been reported to destroy giant sequoia seedlings (Metcalf 1948). Any general grazers apparently can kill seedlings.

In closely related coast redwood (*Sequoia sempervirens* [D. Don] Endl.), cone and seed molds are associated with reduced seed viability. Damping-off and rootrot fungi are major factors in preventing seedling establishment in undisturbed duff and litter (Davidson 1971, Muelder and Hansen 1961). Research will likely show a similar situation in giant sequoia, especially since the effects of desiccation and disease can be difficult to separate.

Regeneration by planting requires nursery seedlings, and several pathogens can cause heavy losses of giant sequoia seedlings in nurseries, especially charcoal root disease caused by *Macrophomina phaseoli* and grey mold caused by *Botrytis cinerea* (Peterson and Smith 1975). Cultural and chemical methods are available to control nursery diseases, and care should be taken to see that healthy seedlings are planted.

STAND DEVELOPMENT

Little is known about how diseases and insects might affect developing, young-growth stands, especially those within the native range. Trees planted outside the native range in California (Bega 1964) or abroad (Libby 1981) can be severely damaged by a canker fungus (*Botryosphaeria* sp.) or by *Armillaria mellea*. Stumps of coast redwood are susceptible to colonization by *F annosus;* therefore, giant sequoia stumps probably would also be colonized (Cobb and Barber 1968). Because *F. annosus* attacks sequoia roots (Piirto and others 1974), managers should recognize the possibility that this pathogen could cause problems in thinned stands or stands established after cutting.

Because a number of insects have been recorded on giant sequoia, some probably could become problems in managed stands. The wood borer (*Trachykele opulenta*) reportedly kills trees stressed by road or stream cuts (Hartesveldt and others

[1]Presented at the Workshop on Management of Giant Sequoia, May 24-25, 1985, Reedley, California.

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1975), but killing by other insects is virtually unknown. In fact, Fowells (1965) stated: "None of the insects or diseases reported on giant sequoia has caused the death of a single tree." Giant sequoia is also one of the trees most resistant to "smog" damage (Miller 1978).

MATURITY

Maturity and decline of giant sequoia stands have been studied in some detail because of the recreational and specimen values of large, old trees. Historical, popular, and scientific accounts generally agree that mature giant sequoias seldom---if ever---are killed by insects or diseases. Excluding lethal fire, lightning, or other environmental damage, death of large trees generally results from uprooting or from stem breaking. Of 33 failures of big trees, 7 (21 percent) apparently fell mainly because of poor footing (wet soil, stream undercutting, etc.), 22 (67 percent) because of the failure of decayed roots, and 4 (12 percent) because of stem breaks (Piirto and others 1984b). All but 2 trees (both fell because of poor footing) had decay in either the stem or roots. Carpenter ants were found in 16 trees but appeared to contribute to failure of only 6. Fire scars were present in 27 trees and 26 fell to the fire-scarred side. Hartesveldt and others (1975) reported that 90 percent of the scarred trees fell to the scarred side.

Early beliefs held by Muir and others (see Piirto 1977 for discussion) that giant sequoias have no insect or disease problems are not tenable. While trees in native stands obviously resist much disease and insect attack, they eventually succumb to the sorts of decays and insects that limit the ages of other species of trees. Most records suggest that these effects of diseases and insects occur mainly in very old trees and would be a factor only in the management of "specimen" trees in park and recreational settings. However, because we lack knowledge of the losses that might have occurred in younger trees during grove development, we cannot be comfortable with the assumption that only very old trees will be injured or killed by insects and diseases.

Full assessment of pest impacts in mature sequoias will require additional study, but existing data (Piirto 1977, Piirto and others 1984b) suggest two important management implications:

1. Decay and carpenter ant activity were usually associated with fire scars. This may mean that protection of trees from fire scarring could increase longevity and decrease hazard to visitors. Such protection would involve mainly the removal of fuels from around the bases of specimen trees.

2. White firs serve as "pasture" for the aphids tended by carpenter ants (Tilles and Wood 1982, David and Wood 1980) and are highly susceptible to decay fungi that also attack giant sequoia roots. This may mean that white fir encroachment in giant sequoia stands might lead to increased insect and disease activity. Therefore, prescribed burning to reduce fir encroachment may also reduce the disease inoculum and the support for carpenter ant populations. Contrary to earlier reports (Hartesveldt and others 1975), food left by visitors does not appear to increase carpenter ant populations.

Intensive forest management often leads to increased pest problems, and it would be surprising if this were not the case with giant sequoia. It would certainly be prudent to learn as much as we can as fast as we can if we are to undertake large-scale planting of giant sequoia.

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Growth and Yield of Giant Sequoia[1]

David J. Dulitz [2]

Abstract: Very little information exists concerning growth and yield of giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz). For old-growth trees, diameter growth is the single factor adding increment since maximum height has been obtained. Diameter growth averages 0.04 inches per year in normal old-growth trees but will fluctuate with changes in the surrounding environment. Growth plots in natural California young-growth stands indicate stand yields of 629 board feet per acre mean annual increment at age 86. Planted European stands 76 to 122 years old have shown yields of between 285 and 601 cubic feet per acre mean annual increment. Growth of giant sequoia has far surpassed the volume production from other North American conifers grown in West Germany or Belgium.

Available information on growth and yield of giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) is limited, partly due to its restricted natural range and its relative unimportance as a commercial timber species. Giant sequoia has been established in plantations both inside and outside of its natural range. Natural and artificial stands are being considered for timber management in some areas. With this added emphasis on management of the species, along with the maturing of artificially regenerated stands, information on growth and yield has gained importance.

Giant sequoia rarely grows naturally in pure stands. It is most often a minor component in the mixed conifer type in the Sierra Nevada. Estimates of stand growth must be inferred from individual tree growth information, rarely occurring pure natural stands, or from plantations.

Growth of giant sequoia is dependent on site quality. In natural stands giant sequoia tends to dominate high quality sites, Dunnings' site I and II (Dunning 1942). This, in a way, tends to expand the applicability of local yield information over a broad range of natural stands because they occur on similar sites.

OLD GROWTH

Maximum heights of individual old growth trees tend to be site dependent, averaging 250-275 feet (Hartesveldt 1975). Maximum heights tend to decrease towards the south in the tree's natural range. Because maximum height has been obtained in almost all old growth trees, diameter growth is the single factor adding increment to the tree's volume.

Studies in the Mariposa Grove within Yosemite National Park show that in normal undisturbed old-growth trees, radial growth is fairly constant, averaging 0.04 inch per year (Hartesveldt 1962). Fluctuations in diameter growth can occur after a disturbance such as road building, paving, soil trampling, or a change in soil moisture in the vicinity of a tree. In many cases these types of disturbances resulted in an increase in diameter growth. This was mainly due to an increase in soil moisture from a reduction in competing vegetation.

Visual observations of historical diameter growth on windfallen trees in Mountain Home State Forest, Tulare County, show a cyclical growth fluctuation in some cases, which may be due to crown damage from wind, snow, or lightning. This damage would result in a reduction in the photosynthetic potential of the tree's crown. Changes in the surrounding stand may also cause a cyclical diameter-growth pattern due to a change in competition for light or water.

A release study on Mountain Home State Forest showed an increase in diameter growth of individual trees after removal of the surrounding stand in a logging operation. Twelve trees, 24 to 62 inches in diameter, averaged 0.13 inch of diameter growth per year before logging of the surrounding stand. After logging, the trees averaged 0.31 inch of diameter growth per year. These trees in general appearance resembled old growth giant sequoia more than they did young growth, but their sizes, forms, scarcity of fire scars, and their relatively fast growth before logging indicated that they were younger than the typical fire-scarred veteran. These results showed that the diameter growth of individual trees will respond positively to a decrease in competition from the surrounding stand.

YOUNG GROWTH

Growth and mortality plots were established during 1952-1953 on the Mountain Home State Forest, Tulare County, two of which contained a substantial amount of giant sequoia. These plots were selected to represent the typical cutover condition on the State Forest for determining growth and yield of the second-growth stand.

Plot 3 was established at 6,160 feet elevation on a south-facing slope that had been heavily logged in 1945. As a result of soil disturbance during the logging, the site became crowded with reproduction. There were 5,420 seedlings per acre on the plot when it was established. Current analysis of stand composition indicates that 45 percent of merchantable trees on the plot are giant sequoia.

Plot No. 4 was established at 6,250 feet elevation on a south-facing slope. The stand resulted from logging in the area in 1890. The plot was considered to be even-aged, containing 90 percent redwood, when measured in 1976.

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Table 1-*Combined growth data for Mountain Home giant sequoia plots 3 and 4*

Plot and stand age (years)	Total volume	Ingrowth	Mortality	Periodic annual increment	Mean annual increment
	Scribner board foot volumes per acre				
Plot 3					
7	0	0	0		0
13	0	0	0	0	0
18	188	188	0	38	10
22	743	291	0	139	34
31	5,938	2,966	0	577	192
Plot 4					
63	24,237	0	0	572	385
73	35,801	641	0	1,156	490
77	40,320	69	22	1,130	524
83	49,714	295	24	1,566	599
86	54,077	204	0	1,454	629

Because of the similarity of these two plots, the data were combined to provide yield information for a longer range of stand age classes. All trees in growth plot 3 became established after the 1945 logging; stand information exists for ages 7 through 31 years for the trees on that plot. Similarly, for growth plot 4, stand information is available for year 63 through year 86. Volumes for young growth giant sequoia are from local volume tables for Mountain Home State Forest (Wensel and Schoenheide 1971). Results of these 86 years of growth on typical cutover giant sequoia stands on the Mountain Home State Forest are shown in *table 1* and *figure 1* (Cook and Dulitz 1978).

On a ¼-acre, 102-year-old, growth plot of pure giant sequoia on the University of California's Whitakers Forest in Tulare County, the largest trees are 26 to 28 inches in diameter. Maximum height of the trees in the stand was 125-135 feet. Some .trees on the plot have grown only 1-2 inches in diameter in 67 years.

Some information is available for young growth giant sequoia plantations in Europe. A 0.62-acre plantation in Belgium, planted in 1906, had an average annual growth of 529 cubic feet per acre in 1951. In 1982, the same stand averaged 628 cubic feet per acre of annual growth (Kleinschmit 1984). A 3.71-acre German plantation, planted in 1862, had a volume of 17,871 cubic feet per acre at an age of 122 years. Maximum heights were 154 feet with mean heights of 127 feet. Maximum diameters were 48 inches at breast height with a mean diameter of 33 inches. Although not fully stocked, this plantation is growing at the rate of 285 cubic feet per acre per year (Kleinschmit 1984). Seven other small plantations in Germany and Belgium exhibited an average annual growth of between 515 and 601 cubic feet per acre per year (Guinon and others 1983, Knigge and others 1983).

Some general observations of the European stands show that the growth of giant sequoia far surpassed the known volume production of other North American softwood species grown in West Germany and Belgium. Investigations of diameter growth, taper, annual ring width, and specific gravity of stands in California were the same as those of European plantings (Knigge and Lewark 1984).

Some of these European yields are greater than those reported from natural stands in California. This difference may be due to the limited natural stand yield data available. Also, it is unknown what volume tables or equations were used to estimate individual tree volumes in Europe. Direct comparisons with other stand data may not be valid.

Giant sequoia will undoubtedly continue to gain importance as a commercial species. More growth information is needed from natural stands to accurately predict yields from the maturing young-growth stands that became established after the extensive logging 80-100 years ago in the Sierra Nevada. Giant sequoia will also continue to be an important plantation tree outside of its natural range. As these plantations develop, growth and yield information will be needed. Current volume tables for this species should be studied and refined to accurately estimate individual tree volume. These research needs will continue to present themselves as challenges in management of giant sequoia.

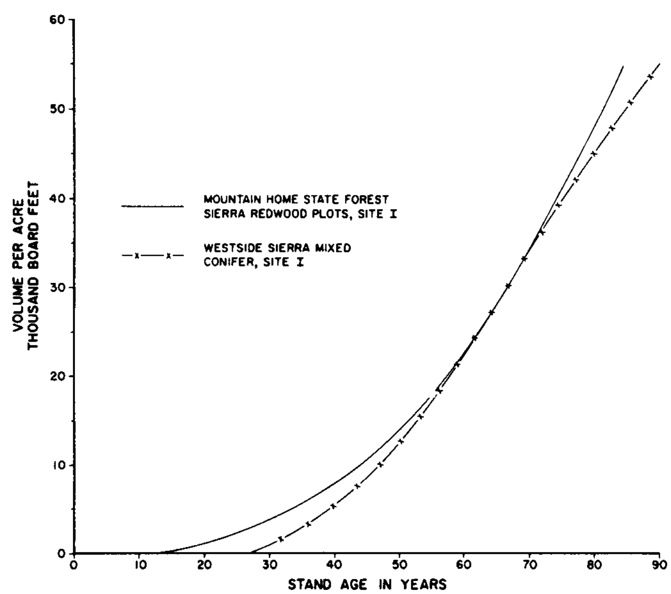

Figure 1-Comparative yield in thousands of board feet (Scribner Log Rule) of giant sequoia growing in a typical cutover stand on Mountain Home State Forest and on a mixed conifer site in the westside Sierra Nevada.

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Genetic Variation and Early Performance of Giant Sequoia in Plantations[1]

W. J. Libby[2]

Abstract: Giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) is genetically less variable than expected; furthermore, it is less variable and its populations are less structured than are several associated or related conifers. Giant sequoia seedlings from open-pollinated seeds of isolated trees or from small outlier groves do not survive and grow as well as those from large groves, and cold susceptibility is related to elevation of origin. On the basis of these observations and other considerations, planting strategies for within and outside the native range are recommended. More information is needed to develop guidelines for nursery and planting practices and for identifying appropriate sites for giant sequoia.

GENETIC VARIATION

Many species of animals such as fruit flies, mice, and humans maintain a great deal of genetic variation within their populations. Unlike most animals, most annual plants cannot escape or modify unfavorable elements of their environments, and perhaps that is why such plants maintain even more genetic variation than do animals. Trees, which must endure all of the physical and biotic variations of their environments for decades and even centuries, on average maintain even more genetic variation than do annual plants (Hamrick and others 1979). One might thus expect that giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz), which often endures for millennia, would be among the most genetically variable species.

My graduate students and I first studied the genetic variability of giant sequoia using enzyme variation as a measure of variation in the genes that code for those enzymes (Fins and Libby 1982). To our surprise, giant sequoia's genetic variation as measured at this enzyme level is distinctly subdued, compared with that of other Sierra Nevada conifers and of other trees in general. This result is supported by a recent study of giant sequoia's early survival, growth, and form (Mahalovich 1985). Trees from 21 of the 23 sampled groves on average survived and grew similarly. The relationship of elevation, latitude, and longitude of the sampled groves to performance of their offspring in the experiment was slight, if present at all. Although giant sequoias differ in such characteristics as foliage color, crown shape, and stem taper, and occasional trees have such deviations as variegated foliage or drooping branches, giant sequoia generally has a more predictable form than is typical of most other conifers.

Cloned giant sequoias were included in our recent study (Mahalovich 1985), and thus we were able to investigate whether genetic differences in growth and form exist between individual trees. Such tree-to-tree differences do exist, and they are biologically, statistically, and (perhaps) economically significant. But, consistent with earlier observations on form and enzymes, they are of much smaller magnitudes than have been found in associated and related conifers, for example, ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.), sugar pine (*Pinus lambertiana* Dougl.), or coast redwood (*Sequoia sempervirens* [D. Don] Endl.).

At the population (grove) level, there are two exceptions to the above generalization that are worth special note. First, trees from the northernmost (Placer) and southernmost (Deer Creek) groves grew substantially and significantly slower than, and differed in other respects from, trees of the other 21 sampled groves (Fins and Libby 1982, Mahalovich 1985). The Placer Grove has only 6 trees, and the Deer Creek Grove has about 30. Seedlings from isolated trees have also done poorly (Guinon and others 1982). Small population sizes probably result in inbreeding, which typically results in poor offspring performance.

Second, in tests on some European and New Zealand sites, particularly where many giant sequoias were injured by cold, trees from the Atwell Mill Grove (the southern grove in Sequoia-Kings Canyon National Park and one of the highest of the native groves) usually survived and grew relatively well (Kleinschmit 1982, Thulin 1982). In experiments where such cold damage occurred, it was significantly related to the elevation of the origin groves (Guinon and others 1982).

The above observations lead to a few recommendations for planting giant sequoia:

For planting outside native groves---Plants from isolated parents or of Placer Grove or Deer Creek Grove origins will probably not do as well as other giant sequoias. On a potentially good site for giant sequoia, plants from any of the other groves are, to the best of our current knowledge, equally likely to do well. On sites where cold damage may occur, plants from the Atwell Mill Grove or from other high-elevation populations may be more successful than those from lower elevations.

For planting in or near native groves---Just as designated "specimen" trees in native groves should be protected from human-caused destruction, so should the genetic integrity of these native groves be protected. While subdued, there is

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genetic variation within the giant sequoia species. Groves other than Placer, Deer Creek, and Atwell Mill may contain genetic variation that is interesting or valuable or both, and that is also unusual or even unique. Natural regeneration (probably following fire) is thus preferable to planting. If planting is done in or near native groves, it should be done with seeds or seedlings from that grove. The seeds should be collected from 20 or more representative trees in the grove to ensure an adequate sample of the grove's genetic variation.[3]

ARTIFICIAL REGENERATION

Planted giant sequoias may be placed in four performance classes: (1) they soon die; (2) they grow slowly and never grow well; (3) they grow slowly for about a decade, and then grow rapidly and well for a very long time; (4) they grow rapidly and well, commencing within 2 years of planting. Analyses of these four classes suggest the following:

For class 1, most likely something was wrong with nursery or planting practice, although in some cases the site or weather may have caused the mortality.

For class 2, the site is probably inappropriate for good growth of giant sequoia. Such planting experiences will accumulate, be increasingly understood, and provide guidelines for appropriate sites and conditions for giant sequoia.

For class 3, nursery practice or planting practice or elements of both were likely the problem. This pattern of growth has been commonly observed. It might be considered normal for sites appropriate for giant sequoia, were it not for occasional class 4 performance.

For class 4, nursery, planting and post-planting practices, and site apparently were all correct. As we learn more about these essential components of good plantation performance in reference to giant sequoia, this class will increasingly become the norm for giant sequoia plantations.

[3] If inadequate numbers of seeds are available, cloned material may be available from source-identified clone donors maintained at the Forest Service's Tree-Improvement Center at Chico, phone (916) 895-1176.

MIXED SPECIES PLANTINGS

Given good nursery stock and good planting technique on a site where giant sequoia grows well, giant sequoia will outgrow conifers native to Europe or to the Sierra Nevada--Cascade Mountains of western North America. The differences in growth are frequently large. The only exception frequently observed is European larch (*Larix decidua* Mill.), which may grow faster than giant sequoia during the first decade or so. Observations in Europe (Libby 1981) and in California (Fins 1979, Mahalovich 1985) are consistent with this generalization.

A common practice is planting about 15 percent giant sequoia mixed with one or more other conifer species on about 3-meter (10-ft) centers. One usually has confidence that the other species will successfully grow on the site. If giant sequoia fails, it usually fails early, and an early loss on the order of 15 percent can usually be accepted. If giant sequoia grows well, subsequent silviculture can adjust the developing stand to any percentage of giant sequoia desired.

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Wood of Giant Sequoia: Properties and Unique Characteristics[1]

Douglas D. Piirto[2]

Abstract: Wood properties of giant sequoia (*Sequoia gigantea* [Lindl.] Decne.) were compared with those for other coniferous tree species. Wood properties such as specific gravity, various mechanical properties, extractive content, and decay resistance of young-growth giant sequoia are comparable to or more favorable than those of coast redwood (*Sequoia sempervirens* [D. Don] Endl.). It is recommended that giant sequoia be considered for planting stock in managed production forests to increase future supplies of wood having the characteristics so highly valued in coast redwood and other decay-resistant species.

Giant sequoia (*Sequoia gigantea* [Lindl.] Decne.) is one of the oldest and certainly the largest living organism on earth. I have been studying giant sequoia and coast redwood (*Sequoia sempervirens* [D. Don] Endl.) since 1970. Although knowledge of both species is steadily improving, the focus has been on coast redwood, primarily because of its commercial importance. For this reason, correcting the many misleading generalizations about giant sequoia has been a slow and sometimes agonizing process. The wood from giant sequoia trees has had the reputation of being very brash (brittle) and of little use for lumber products. This belief fails to distinguish differences between old- and young-growth trees, and it fails to recognize the wide range of wood products obtainable from forest trees besides lumber, e.g., particleboard, plywood, and paper (Piirto and Wilcox 1981).

This paper has two objectives: First, to compare the wood properties of native grown giant sequoia to coast redwood, incense cedar (*Libocedrus decurrens* Torn), white fir (*Abies concolor* [Gord. and Glend.] Lindl. ex Hildebr.) and western redcedar (*Thuja plicata* Donn). And, second, to emphasize the value of giant sequoia in both National Parks and in production forestry (e.g., plantations containing giant sequoia). It also highlights key points in the following subject areas: (1) general characteristics and minute anatomy (2) physical and mechanical properties (3) chemical composition (4) natural decay resistance, and (5) utilization.

Several excellent studies on the wood properties of giant sequoia grown outside of its native range have been and are being conducted in several foreign countries (Finogeev and Kuznecov 1969, Liubimirescu and others 1972, Knigge 1983, Knigge and Wenzel 1982, Knigge and others 1983).

[1]Presented at the Workshop on Management of Giant Sequoia, May 24-25, 1985, Reedley, California.

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GENERAL CHARACTERISTICS AND MINUTE ANATOMY

The wood of giant sequoia closely resembles that of coast redwood (Panshin and deZeeuw 1970). The wood of both species is light in weight, rather soft, considered strong for its weight, and moderately coarse to coarse in texture (Mitchell 1935, 1936). Key points and differences between giant sequoia and coast redwood are these:

- The heartwood of both species is characteristically reddish-brown, but the wood of giant sequoia is darker and has a purplish cast (Panshin and deZeeuw 1970).
- On the average, the corresponding anatomical features of coast redwood are larger than those of giant sequoia (Mitchell 1935, 1936).
- Bands of latewood (one to four tracheids in width) are generally narrower in giant sequoia than in redwood (Panshin and deZeeuw 1970) *(fig. 1)*.
- Giant sequoia has 75 percent more ray tissue than does coast redwood (Mitchell 1935, 1936). This is a key diagnostic feature used to separate the wood of the two species.
- Tracheid length (4 to 4.5 mm) for giant sequoia wood is slightly longer than the average length for conifers but significantly shorter than for coast redwood (Cockrell and others 1971, Barman 1966) *(fig. 2)*.

Compression wood, wood formed on the lower side of branches and inclined trunks of softwoods, has been reported in young-growth giant sequoia (Cockrell 1974, Cockrell and Knudson).

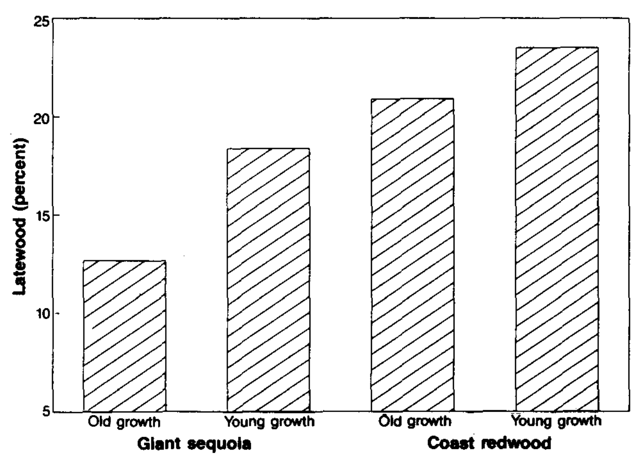

Figure 1-Percentage of latewood in giant sequoia and coast redwood. Values are from Cockrell and others (1971), Piirto and Wilcox (1981), and Resch and Arganbright (1968).

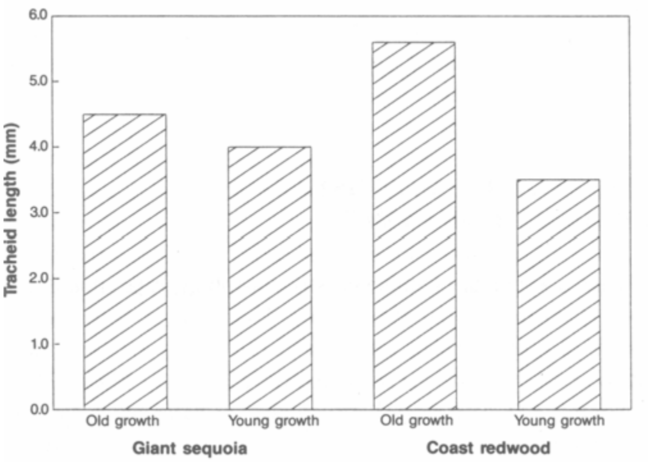

Figure 2-Anatomical characteristics of giant sequoia and coast redwood. Values are from Cockrell and others (1971), and Resch and Arganbright (1968).

PHYSICAL AND MECHANICAL PROPERTIES

The conclusions in the following paragraphs were reached by Piirto and Wilcox (1981) regarding the physical and mechanical properties of giant sequoia.

The average specific gravity (the ratio of the oven-dry weight sample to the weight of a volume of water equal to the volume of the sample at a specified moisture content-e.g., oven-dry weight/green volume) tends to be higher in young-growth (0.35) than in old-growth giant sequoia-0.30 (Cockrell and others 1971, Keylwerth 1954). Young-growth giant sequoia specific gravity is comparable to young-growth coast redwood *(fig. 3).*

Young-growth giant sequoia is heavier and stronger than old-growth giant sequoia (the reverse is true in coast redwood). Old-growth giant sequoia heartwood exhibits a characteristic brash-type failure in static bending and has very low toughness (resistance to sudden shock) values, thus it can be considered very

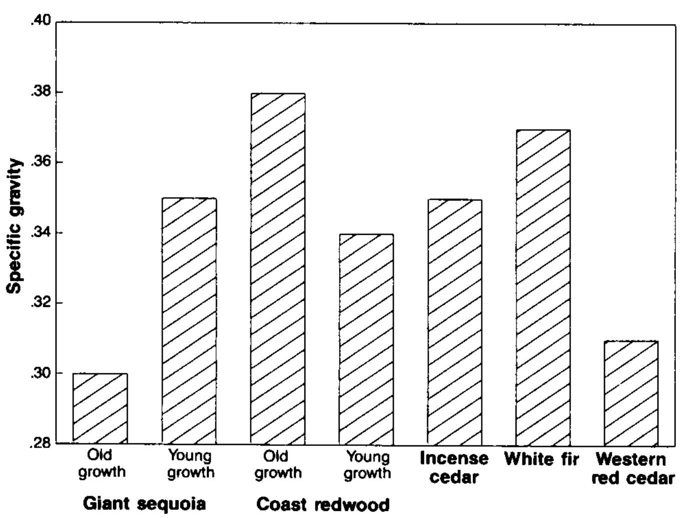

Figure 3-Specific gravity of several woods, based on oven-dry weight and green volume.

brittle. Koehler (1933) provided a good discussion of causes for brashness in wood; however, the mechanisms that cause wood to be brash are not completely understood *(figs. 4 and 5).*

Mechanical properties of young-growth giant sequoia are equal to, or somewhat superior to, white fir, incense cedar, western redcedar and young-growth coast redwood in most of its mechanical properties. Wood from young-growth giant sequoia is acceptable for dimension lumber in light construction (Cockrell and others 1971).

Heartwood of old- and young-growth giant sequoia and old- and young-growth coast redwood shows appreciably lower tangential, radial, and volumetric shrinkage than sapwood (old-growth heartwood decidedly lower than young-growth). Old-growth and young-growth giant sequoia have comparable shrinkage properties to similar categories of coast redwood (Cockrell and others 1971). Tarkow and Krueger (1961) attributed the relatively low shrinkage properties of coast redwood heartwood to the presence of extractives in the cell wall. This basic principle applies equally as well to the heartwood of giant sequoia. Deposition of extractives within the cell walls makes wood more resistant to decay and the compounds more resistant to leaching (Scheffer and Cowling 1966).

CHEMICAL COMPOSITION OF EXTRACTIVES

In addition to its principle cell-wall components (cellulose, hemicellulose, and lignin), wood may contain a great variety of chemical compounds extractable with water and neutral organic solvents such as alcohol, benzene, and ethyl ether. These compounds are called extractives and are not an integral part of the cell wall structure. Color, decay, and insect resistance (Anderson 1961), density and modulus of elasticity (Arganbright 1971), pulping properties (Institute of Paper Chemistry 1945, Hillis 1962, Martin and others 1960), and dimensional stability (Tarkow and Krueger 1961) as well as other wood properties of giant sequoia and coast redwood are specifically related to the quantity and nature of the extractives present. Most of the research on extractive chemistry has focused on coast redwood. However, it is reasonable to assume that giant sequoia would share many of the following key points:

• Amounts of extractives range from 15 to 30 percent of the wood's original oven-dry weight (Anderson and others 1962).

• Extractive compounds vary depending upon their location within the tree and age of the wood (Sherrard and Kurth 1933a). Extractive content of old-growth coast redwood decreases with height in the tree and towards the center of the lower trunk, with extractive content being highest in the outer heartwood of the butt log (Sherrard and Kurth 1933a, Isenberg 1951, Institute of Paper Chemistry 1945, Anderson 1961, Resch and Arganbright 1968). Contrary to this gradient pattern of extractive content in old-growth coast redwood, young-growth shows a tendency for a more uniform distribution of extractives throughout the heartwood (Anderson 1961, Resch and Arganbright 1968). Extractive concentration is significantly greater in the center of young-growth coast redwood than in old-growth. This difference suggests that the extractive gradient pattern in old-growth coast

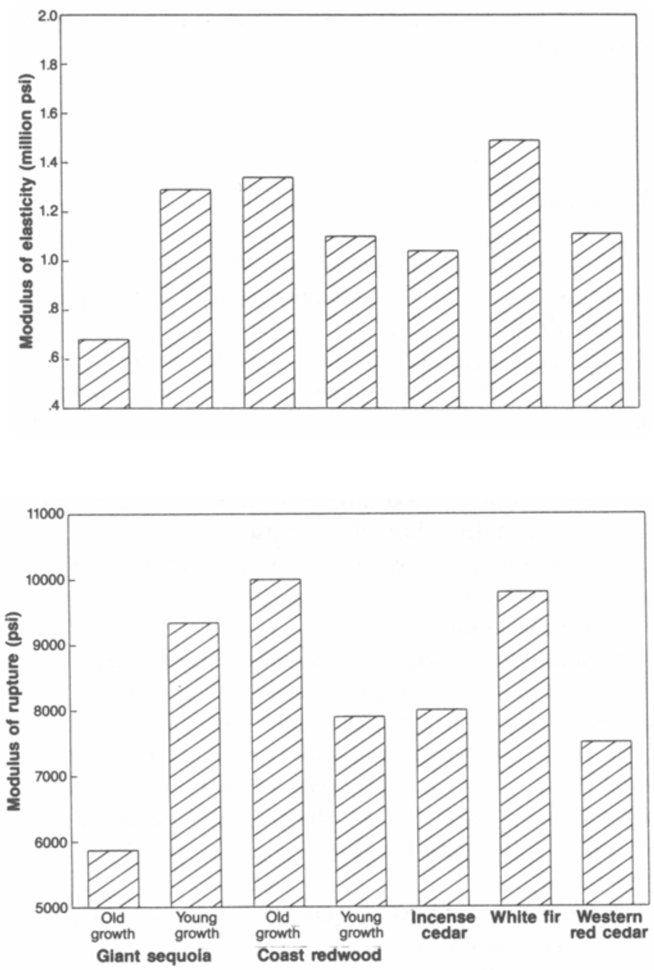

Figure 4-Modulus of rupture and of elasticity for several woods (air-dry condition). Values are based on data from Cockrell and others (1971), and USDA (1974).

redwood may be the result of decomposition, change in solubility, or change in extractive distribution with age (Resch and Arganbright 1968).

• Early reports indicated that these extractives were largely found in the cell lumina of ray and longitudinal parenchymal cells (Institute of Paper Chemistry 1945). However, more recent studies (Kuo 1977) have shown that 77 percent of the total extractive content is present within the cell wall.

• The greatest portion of coast redwood extractives are hot-water soluble (Anderson 1961) and include tannin, cyclitols, polyphenolics, polysaccharides, free sugars, color matter, and other unknown compounds *(fig. 6)*. Cyclitols have been reported as having some taxonomic significance (Anderson and others 1968a,b).

• The water insoluble extractives of coast redwood heartwood include phlobaphenes, polymerized tannin, native lignin, phenols, fatty acids, wax, and other compounds (Anderson 1961) *(fig. 7)*. These are soluble in hot ethanol.

• There is little ether-soluble material (less than 1 percent) in coast redwood indicating the absence of fats, waxes, oils, and resinous substances. However, terpenoids (e.g., alpha pinene and various resin acids) have been reported (Anderson and others

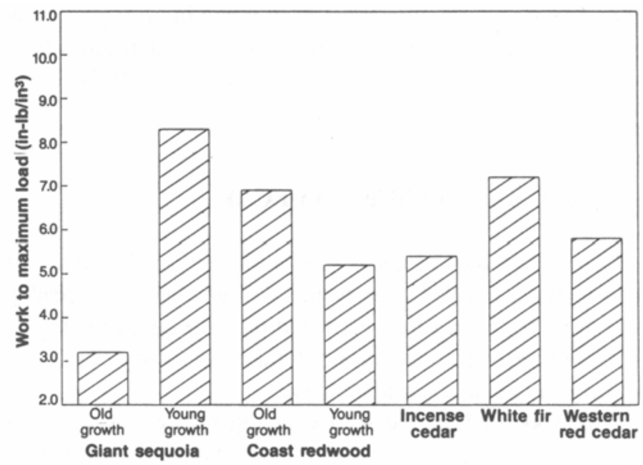

Figure 5-Work to maximum load for several woods (air-dry condition). Values are from Cockrell and others (1971) and USDA (1974).

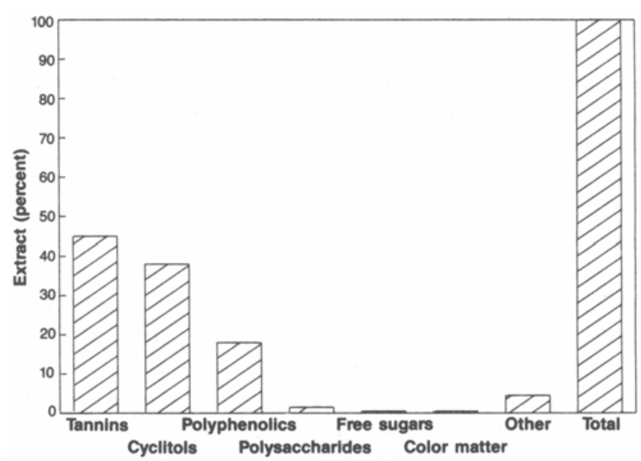

Figure 6-Water-soluble extractives of coast redwood heartwood. Values are from Anderson (1961).

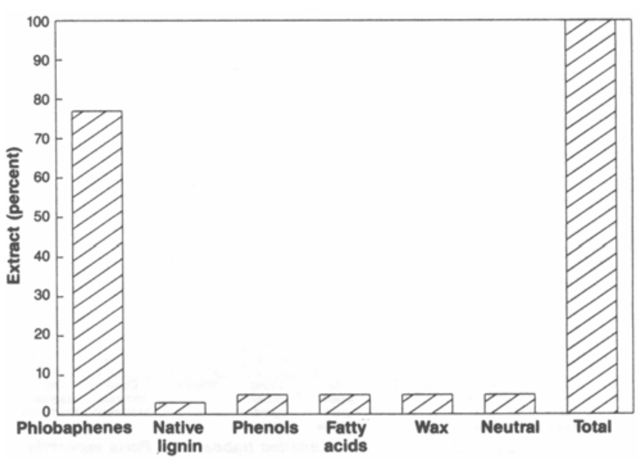

Figure 7-Ethanol-soluble extractives of coast redwood heartwood. Values are from Anderson (1961).

1968a,b) within a sticky viscous resin found in open pockets of coast redwood. Similarly, a resinous, sticky material has been observed on the fire scars of giant sequoia (Piirto 1977).

NATURAL RESISTANCE TO DECAY

Natural resistance to decay can be defined as the ability of wood to resist attack by decay fungi. The sapwood is readily decayed by fungi, but the heartwood of some species is highly resistant to decay. Key points on natural decay resistance of coast redwood and giant sequoia are these:

• The wood of both old- and young-growth giant sequoia is classified as resistant to *Poria monticola* and highly resistant to *Lenzites trabea.* However, giant sequoia shows lower decay resistance than does coast redwood, a highly decay-resistant species *(fig. 8).*

• Extractives have been reported as the principal contributors to decay resistance. The variation in extractive content within individual coast redwood trees has been found to be directly related to the variation in decay resistance within these same trees (Sherrard and Kurth 1933a, Anderson 1961). The durability of coast redwood and giant sequoia would therefore be highest in the butt log heartwood nearest the sapwood, and the susceptibility to decay would increase towards the pith of the tree and towards the top.

• The unstable labile nature of coast redwood and giant sequoia extractives makes it difficult to determine which component is responsible for the decay resistance. Tannins have been reported as being weak fungicides in laboratory tests. Phlobaphenes have been reported as being nontoxic (Anderson 1961).

Possible explanations for the high decay resistance of coast redwood and giant sequoia are these three: (1) several extractive components (water- and alcohol-soluble) may work together to produce fungi toxicity; (2) extractives may be basically nontoxic and merely operate as bulking agents preventing fungal enzymes from penetrating and subsequently decomposing cell walls; or, (3) some very toxic components may exist but have not been documented.

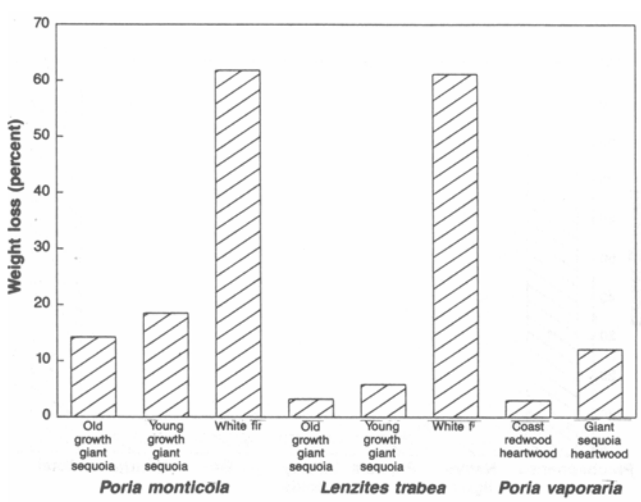

Figure 8-Decay resistance of several woods exposed to various decay fungi. Values are from Piirto and Wilcox (1981) and Rennerfeldt (1956).

UTILIZATION

Old-growth coast redwood is valued for its durability, low shrinkage and texture. It is commonly used for these purposes (USDA 1974):

• Building, particularly in areas of modest decay hazard.

• Siding, sashes, doors, blinds, and finish, and similar products.

• Cooling towers, wood stove pipe, tanks, silos, and outdoor furniture where decay hazard may exist.

• Split products such as fence posts and fence material.

• Decorative plywood.

• Paper manufacture.

Presumably giant sequoia could occupy these same markets, but the use of old-growth giant sequoia is limited by the brittle nature of the wood and the very small supply because the majority of giant sequoia groves have been incorporated into National Parks. Old-growth giant sequoia has been used for fence posts, vineyard stakes, shakes, shingles, and occasionally lumber where decay hazard is high (Panshin and deZeeuw 1970, Meyer 1952).

Young-growth giant sequoia, on the other hand, has favorable wood properties in comparison to white fir and young-growth coast redwood. It is acceptable for use as dimension lumber in light construction (Cockrell and others 1971). Young-growth giant sequoia has veneer properties comparable to coast redwood, which was rated as excellent for decorative siding and intermediate where strength is the primary concern to the plywood consumer (Lutz 1972). Finogeev and Kuznecov (1969) reported similar veneer quality of Russian-grown giant sequoia trees.

I suspected for sometime, and Knigge and others (1983) confirmed that heartwood formation begins early in young-growth giant sequoia and continues steadily following the shape of the stem. Knottiness is one of the biggest problems for all types of utilization of young-growth giant sequoia. As such, early pruning is recommended to produce any appreciable volume of clear lumber within short to medium rotation periods. A more cylindrical stem results from pruning.

Fiber studies by Cockrell and others (1971) and Barman (1966) indicated that giant sequoia promises to make acceptable pulp.

CONCLUSIONS

Wood properties of young-growth giant sequoia are comparable to or more favorable than those of coast redwood. It seems reasonable, therefore, to consider giant sequoia for planting stock in managed production forests to increase future supplies of wood having the same characteristics that are so highly valued in redwood.

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Recommendations from the Sierra Club for Managing Giant Sequoia[1]

Joseph Fontaine[2]

Abstract: The giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) groves in their natural setting are one of the outstanding scenic features of the southern Sierra Nevada. These groves where they have survived should be managed to protect their natural values and to restore former natural conditions wherever possible. Groves that are essentially intact should have the whitewoods removed that have encroached as a result of over-protection from fire. Pines and firs should be carefully removed to avoid damage to giant sequoias. Once natural conditions are restored, prescribed burning should be the primary technique used to maintain these conditions. Groves that have only a few specimen trees left or only second growth should be inventoried and a large percentage of them selected for restoration, a goal that may not be reached for several decades. The giant sequoia species should be investigated for its timber value, and if feasible, planted and harvested for commercial purposes in the general forest zone.

The scattered pockets of giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) groves provide some of the most attractive settings for visitors to the southern Sierra Nevada who seek the magnificence of a primeval forest. The mixture of very large old trees, scattered firs and pines, dogwoods, and fern-carpeted forest floor is unique and rivals the beauty of any forested area in the world.

One cannot help but contemplate what these giant trees have endured in the thousands of years some of them have been alive and what fate awaits them. The huge size and age of these giants is humbling and awe-inspiring as one wanders among them. In a philosophical sense, they are a link to the past---a link we should not break.

I make these remarks about the giant sequoia to emphasize the fact that these trees and their associated ecosystems have a value to the public far beyond their commodity value. With pressure on land managers and foresters to maximize the cut, it would be easy to overlook or minimize these values. But a forest is not just standing sawtimber. The giant sequoia groves have become symbolic to those of us who seek the esthetic and philosophical values to be found in the forest.

The Sierra Club's position is that wherever these groves are found, the basic land management policy ought to be restoring and managing them in as natural a condition as possible. Insofar as they can be identified, the conditions that created these groves in the first place should be perpetuated.

The individual big trees should not be treated as museum pieces without regard for the dynamic natural processes going on around them. A forest is a system of various plant species---in this case with giant sequoia among them---and various other conditions necessary for the plant associations to endure. To perpetuate the sequoia groves an entire ecosystem must be considered and not just the big trees themselves. Natural processes must be allowed to operate insofar as practical without human interference.

The giant sequoia ecosystem requires special soil and water conditions. Fire is also a necessary component. Roadbuilding and skid trails contribute to erosion and soil compaction. Road cuts can interrupt the natural flow of shallow water. These activities will occur in the groves if they are managed as part of the timber base of the forest. If normal logging activities occur around large specimen trees, they will in effect become museum specimens subject to the eventual mortality of all living things. Once these isolated large trees are gone, what then will show there was once a grove of giant sequoia at that location?

Perhaps the biggest threat to some of the groves today is fire. Accumulated fuel and dense stands of fir and pine are a disaster waiting to happen. The Sierra Club has advocated a one-time timber harvest in some groves where whitewoods are too dense. They should be harvested with great care using equipment such as rubber-tired vehicles and techniques such as end lining, that minimize disturbance.

Great care should be taken to avoid damage to standing young trees. Once a natural mix of sequoia and other species has been reestablished, methods such as prescribed burning could be used to maintain natural conditions. In other groves, such as those in the national parks, fire alone might be the proper tool to reestablish natural conditions.

On the national forests the groves range from those where no logging or roadbuilding has occurred to those that were completely cut over with only second-growth to be found. Obviously, all groves of giant sequoia cannot be treated the same.

Those that are untouched, save for overprotection from fire, could be treated in the manner I have already discussed.

Other groves have a few specimens in hard-to-reach places that were passed over, with the rest of the grove cutover and perhaps with a considerable amount of second growth. The temptation to protect the large trees as museum pieces and designate the major portion of the groves as part of the general forest zone would be greatest in these groves. I believe most of the public would regard such a policy as tokenism. When the large old trees die there would be nothing different about that part of the forest. It would be like the rest of the forest---dedicated to normal timber harvest.

Most of the groves that have been completely cut over have heavy second growth. Before these groves are "written off' and become part of the normal timber base they should be examined carefully for any unique characteristics that remain. The giant

[1]Presented at the Workshop on Management of Giant Sequoia, May 24-25, 1985, Reedley, California.

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sequoias are only one part, albeit the most spectacular part, of specialized ecosystems that persisted for thousands of years before the advent of the saw and axe. Who among us can say with certainty that there is nothing unique or important left in these ecosystems without further study now that the largest trees are gone?

Giant sequoias are fast-growing trees that are well suited to the conditions of the southern Sierra Nevada. The Sierra Club has no objection to the cultivation of the species for timber harvest. The characteristics of the wood make it useful for many purposes, and the harvest of cultivated giant sequoias could provide a valuable economic commodity. However, the Sierra Club does not believe the management goals of any of the untouched or partially cutover groves should include timber harvest on a permanent basis. Timber harvest might be advisable to restore natural conditions, but then should not be subsequently conducted within the boundaries of the groves. The Club advocates leaving the remains of fallen trees. These giant old logs are an important part of the esthetics of the groves.

The Sierra Club suggests consideration be given to making a start in restoring some of the totally cutover groves. If those trees were standing today, there would be no question about protecting them. It would be a tribute to this generation to begin the process of correcting the mistakes made when these groves were cut. Could not some of the more outstanding sites be selected and managed so that ultimately the second growth would replace the large old trees that were once there? No one alive today would live to see the outcome, but our generation would have the satisfaction of setting the process in motion.

I think that too often people are unable or unwilling to look beyond the pressures and concerns of daily life. These trees have been in the Sierra Nevada for probably millions of years. At one time they must have been one of the predominant species in the forest. Today they are found only in isolated pockets where they escaped the rigors of the Pleistocene. A long-term view is needed to consider what these groves represent from the past and to assure their future.

There is more to trees than allowable cut and boardfeet. The giant sequoias symbolize the beauty of Sierra Nevada forests. In a way the value put on these trees and the groves where they are found is an indicator of the quality of our culture. It will be interesting to see where the line is drawn between the intangible value placed upon beauty and philosophical experiences and the commodity value of the forest. How the giant sequoia groves are treated will, in a way, be a statement about the values of this generation.

Management of Giant Sequoia in the National Parks of the Sierra Nevada, California[1]

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Abstract: Management of giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) in Sequoia, Kings Canyon, and Yosemite National Parks focuses on the need for maintaining and, where necessary, restoring natural ecosystem processes. Such a program includes restoration of natural fire regimes, mitigation of impacts from visitor use, support for basic research and monitoring, and careful evaluation. Research includes studying the effects of air pollution. Interpretation translates information on the ecology and management of giant sequoia for the public.

Management of national parks has long been guided by the philosophy of preserving examples of ecosystems unaffected by human activities. In those areas where heroic or otherwise special species grow, placing the value of the total ecosystem above that of individual species often becomes difficult. The giant sequoia or Sierra redwood (*Sequoiadendron giganteum* [Lindl.] Buchholz) is an example. If the long-term survival of a "natural" giant sequoia community is to be assured, managing for a healthy ecosystem is needed and not just protecting individual trees.

Because they are limited to localized groves in the central and southern Sierra Nevada of California, giant sequoias are the focus of public interest and concern (Vale 1975). The giant sequoia represents only one part of a complex ecosystem (Harvey and others 1980). This complexity makes the task of preserving the natural state of the sequoia-mixed conifer forest a difficult one. Management of giant sequoia in national parks must aim at perpetuating the processes that make the environment suitable to the species' regeneration, growth, and survival. Faced with impacts from visitor use, fire suppression, and air pollution, park managers must devise policies that emulate natural ecological conditions despite a limited understanding of the ecosystem processes.

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HISTORY

Early Protection

The first European settlers to view giant sequoias were awed by their imposing dimensions (Hartesveldt and others 1975, Strong 1975). Recognition of the uniqueness of these giants led to placing the Mariposa Grove---in the area that was to become Yosemite National Park---under State protection in 1864. Concern over threats of exploitation by the timber industry and a desire to protect many prime sequoia groves spurred the creation of Sequoia, General Grant (incorporated into Kings Canyon National Park in 1940), and Yosemite National Parks in 1890. In succeeding decades, giant sequoias were strictly protected by the U.S. Cavalry and later by the National Park Service (after its creation in 1916). In those early years the big trees were specifically protected from logging or fire, but little attention was given to preserving the processes upon which the health of the sequoias depends. National Park Service management focused on the protection of natural objects and the pleasure of visitors (Graber 1983).

Evolution of Policy

The 1963 Report of the Special Advisory Commission on National Parks (Leopold and other 1963) stressed the importance of managing entire ecosystems to preserve examples of natural communities. The report specifically discussed the effects of fire suppression in shifting species composition and increasing hazardous fuels in Sierran coniferous forests. Report recommenddations, which were incorporated into National Parks Service policy in 1968 (Bonnicksen and Stone 1982b), provided a unifying direction for management of natural areas in national parks (Graber 1985, Kenner 1985, Lemons and Stout 1984). However, inconsistencies and ambiguities left certain aspects of management policy open to creative interpretation (Bonnicksen and Stone 1982b, Graber 1983).

To preserve natural ecosystem processes, it is necessary to understand the ecological relationships of the communities to be managed. The lack of such information for most presettlement ecosystems presents a serious problem for park managers. Leopold and others (1963, p. 63) recognized this need in advocating a "greatly expanded research program, oriented to management needs." Much of the basic biology of giant sequoia is now understood (Hartesveldt and others 1975, Harvey and others 1980, Kilgore 1973, Rundel 1971, Stark 1968). A continually expanding prescribed burning program (Bancroft and others 1985) has helped to identify additional research needs. These include basic community ecology, expanded monitoring of fire effects, evaluation of impacts of different intensity, seasonality and frequency of burns, and resolution of questions regarding interpretation of National Park Service policy (Parsons and others

Gen. Tech. Rep. PSW-95. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1986.

1986). Concern over the potential impacts of visitor use and air pollution on giant sequoias has led to the identification of additional information needs.

CURRENT POLICY

The principal aim of National Park Service resource management in giant sequoia groves, as in other natural areas, is the unimpeded interaction of native ecosystem processes and structural elements. Such a policy requires management intervention only when necessary to (1) reverse or mitigate the effects of human activities (e.g., suppression of wildfire), (2) protect a featured resource (such as a "showcase" or historical area), or (3) to protect life or property. Thus, while the overall goal is to minimize human intervention, such unnatural activities as fire suppression, prescribed burning, and selective cutting or mechanical fuel removal may be desirable under certain conditions (Parsons and others 1986).

Policy concerns, such as the definition of "natural," the precision with which management objectives must be achieved, the methods by which an area is selected to be a featured resource, and the relative importance of "ecosystem" versus "esthetic" values, continue to be the subject of spirited debate (Bonnicksen and Stone 1985, Graber 1985, Parsons and others 1986). One compromise that has resulted in part from such exchange is the concept of showcase areas. Unlike the major area of the Parks, showcase areas are managed primarily for esthetic objectives, and natural processes are not always permitted to operate fully.

The overall giant sequoia management program in the National Park Service includes research, management, monitoring, and interpretation.

1. Research. The research program is designed to provide basic information on giant sequoia ecology and the effects of different management practices. Studies have included fire history; effects of trampling, fire, fire suppression, and air pollution on forest structure and composition; fuel accumulation and decomposition; nutrient cycling; and associated fauna. Research has been designed primarily to understand ecosystem structure and processes and how these have been affected by human activities. The results help to direct the management program.

2. Management. The management program is designed to mitigate the effects of human activities. Management actions include prescribed burning to reduce fuel accumulation resulting from fire suppression, and the removal of roads, buildings, and water and sewer lines from affected areas. For the most part, these programs are designed to reverse the effects of years of misguided management activity, and to allow natural processes to influence ecosystems as fully as possible in the future.

3. Monitoring. Monitoring provides a means of measuring the effects of the management program and of evaluating its success in achieving objectives. Monitoring generally consists of field measurement before, during, and after management actions, and follow-up analysis and evaluation of data. It provides feedbacks to management strategy and tactics (Parsons and others 1985).

4. Interpretation. Interpretation plays the important role of informing park visitors on basic sequoia ecology as well as the reasons behind management actions. Translation of information from research and monitoring programs into a form understandable to both managers and the public is an essential part of the overall program. It helps to build support for, and thus assure, the long-term success of all National Park Service activities.

Fire Management

Research on the importance of periodic fire in maintaining natural giant sequoia forests has justified the need to restore a natural fire regime in those areas where fire suppression has been most effective. The first experimental prescribed burns were carried out in the Redwood Mountain Grove of Kings Canyon National Park in 1964. Research on the effects of these early burns documented the importance of fire in giant sequoia regeneration and in creating a mosaic of vegetation types (Harvey and others 1980)

In the late 1960's and early 1970's, additional prescribed burning was carried out in the Redwood Mountain Grove. Objectives at that time typically called for removal of 100 percent of the dead and downed fuel and removal of 70-100 percent of sapling and small pole trees (Bancroft and others 1985). Small (30-50 acres or 12-20 ha) blocks were burned uniformly with strip headfires. Objectives were met, although occasional foliage scorch over 100-200 feet (30.5-70.0 m) high occurred. These hottest fires interestingly produced the greatest number of sequoia seedlings. In contrast, in the Mariposa Grove of Yosemite National Park, young white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.) were manually cut and burned. This labor-intensive approach mimicked some of the effects of fire, but avoided unappealing effects such as dead trees and charred trunks.

A growing recognition of the natural role of fire in creating and maintaining mosaics of different ages and species (Bonnicksen and Stone 1981, 1982a), cycling nutrients (St. John and Rundel 1976), and controlling disease organisms (Piirto and others 1984) led to reevaluation of the fire management program. Today the principal goal of fire management in the giant sequoia groves of Sequoia, Kings Canyon, and Yosemite National Parks is to restore or maintain the natural fire regime to the maximum extent possible so that natural ecosystems can operate essentially unimpaired by human interference (see field trip handout in *appendix*). Prescribed burns are now conducted by igniting fires in a spot pattern, and allowing fuels, weather, and topography to produce a mosaic of fire behaviors and effects. Compared with the early Redwood Mountain burns and the extensive thinning of the Mariposa Grove, both ground and standing fuels are removed less completely. Crown scorch height averages about 30 feet (9.1m), although small areas that contained much deadwood have scorch heights of 60-100 feet (18.3-30.5 m). This mosaic of intensities and fire effects may well approximate the poorly documented historic role of natural fire in the giant sequoia-mixed conifer zone of these parks.

Objectives of individual prescribed burns are carefully designed to reduce fuels to the point where natural (lightning) ignitions can again be allowed to burn. Identifying areas where natural ecosystems have been most altered by fire suppression helps managers to place priorities on prescribed burning of areas to reduce unacceptably high fuel loading. Computer models such as FYRCYCL (van Wagtendonk 1985) can also help managers determine if and when a prescribed burn is needed by identifying the "natural" range or variability of fuel accumulation for a given area. Once fuels have been reduced to more acceptable levels, lightning ignitions will again largely be permitted to determine the fire regime. We anticipate that some natural ignitions will have to be replaced by prescribed burns where natural fires must be suppressed for safety or political reasons. The success of such a fire management program will depend upon the ability to predict fire spread and intensity under varying conditions, the number and size of natural fires allowed to burn, and public acceptance of the program.

Recently, burning prescriptions have been refined to the point where prescribed fire can be successfully used to modify forest structure. However, rather than dictate a given forest structure as desirable, the National Park Service has established the goal of restoring the natural role of fire to the forest and then allowing the structure and function to return to equilibrium. Realizing that the 60 years of successful fire suppression are merely a flash in the ecological time scale of giant sequoia, we consider allowing natural fire after prescribed reduction of fuels to be a conserve-ative approach that minimizes subjective judgment of which trees are good and which are bad.

The use of prescribed fire in Sierra Nevada National Parks can best be viewed as an evolving program. As is the case with many natural processes, it is impossible to know exactly what the long-term impacts of the program will be. For this reason, the program must be carefully monitored and frequently reevaluated. The study of unburned controls as well as areas burned with different intensities will help evaluate the long-term effect-tiveness of the program in restoring natural fire regimes. At the same time, additional research on fire history, fuel dynamics, fire spread rates, and fire effects is needed to make the conceptual and computer models upon which the management program is based as realistic as possible.

Showcase areas, where evidence of fire is minimized, have been designated in a few high visitation areas. Such areas are limited in size and used either to portray how an area appeared at a given point in time, or to present an esthetically and subjectively pleasing forest where the effects of fire or other disturbance are minimized. Managing to preserve natural processes and managing for an unburned appearance are inherently contradictory. The maintenance of showcase areas is achieved only at a severe biological cost. Even in such areas, the forest depends on fire for nutrient cycling and reproduction. To date, showcase areas are limited to a few heavily visited zones, such as around the General Sherman Tree in Sequoia National Park and around the General Grant Tree in Kings Canyon National Park.

Visitor Use

Early concern over the impacts of human use on giant sequoia groves focused on the fear that soil compaction from foot and vehicular traffic would lead to root damage and the eventual demise of the trees. However, soil compaction actually increased sequoia growth due to decreased evapotranspiration and competition from young trees and herbaceous plants (Hartesveldt 1964). This was an unnatural influence that could have long-term negative impacts, particularly through the exposure of surface roots. Additional impacts from the development of visitor facilities have included cutting roots and covering soil by buildings and asphalt (Vale 1975). Piirto and others (1984) suggested that soil and root disturbance associated with roads, trails, and other construction may initiate premature failure of giant sequoias.

The need to replace water and sewage facilities as well as dilapidated structures in the Giant Forest in Sequoia National Park raised the question of whether such development could continue to be tolerated. Concern over such impacts resulted in moving campgrounds out of the Giant Forest during the 1960's. Proposals and associated environmental assessments to move remaining structures were approved in 1979. The National Park Service and Guest Services Incorporated (the Park concessioner) are building new facilities at Clover Creek and Lodgepole, a few miles to the north, and out of the grove.

Air Pollution

Air pollution recently has been recognized as a potential threat to the health of the coniferous forests of the western United States (Miller 1980, 1985; Roth and others 1985). Ozone, in particular, has been implicated in forest damage in southern California (Williams and others 1971).

While mature giant sequoias are generally considered to be relatively tolerant of ozone, seedlings may be sensitive. Research funded by the National Park Service is investigating the sensitivity of sequoia seedlings to varying levels of atmospheric ozone. This work includes artificial fumigation of sequoia seedlings. Additional comprehensive studies of the potential effects of acid deposition as well as the use of remote sensing to detect changes in forest health are also underway in Sequoia National Park (Parsons and Graber 1985). Such information is critical to the long-term preservation of the giant sequoia ecosystem.

CONCLUSIONS

While an active---but conservative---management program continues, much remains to be learned about the ecology and fire history of giant sequoia ecosystems. The management programs in Sequoia, Kings Canyon, and Yosemite National Parks must still be looked on as partially experimental. It is, and will continue to be, impossible to accurately predict all of the ramifications of management activities. However, while the optimum level of fuel reduction or scorch height during prescribed burns can be debated, one fact remains: the exclusion of fire is unnatural.

All living organisms must eventually die. Giant sequoias are no exception. The fact that sequoia trees may fail due to root disease or fire scars should not in itself be cause for alarm. These are part of the natural ecological process and must be allowed to continue if natural ecosystems are to be preserved. However, it is when changes in these processes result from human activities that managers must be concerned.

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Management of Giant Sequoia on Mountain Home Demonstration State Forest[1]

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Abstract: Established in 1946, the Mountain Home Demonstration State Forest, Tulare County, California, is managed by the California Department of Forestry. It is a multiple-use forest with recreation as its primary focus, although timber management has always played an important role. Giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) occurs in isolated groves in the Sierra Nevada and grows on about half the acreage of the Mountain Home Forest. Old-growth specimens are protected, and selected young-growth trees are encouraged to grow to old-growth. Young sequoias are a valuable resource and are managed for timber production. A long-term study indicates that logging encourages sequoia reproduction by providing a suitable seedbed.

The California Department of Forestry manages seven State Forests to demonstrate continuous forest production practices, with due regard for conservation of soil, watershed, scenic, wildlife, and recreation values. Four of the seven State Forests are large enough to warrant a full-time staff. One of these---the Mountain Home Forest---occupies 4,562 acres (1846 ha) and has an extensive recreation program with 96 campsites in Tulare County in central California. A unique characteristic of the Forest is an extensive stand of giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz), which occurs only in isolated groves in the Sierra Nevada from Placer County south to Tulare County. Logging on what is now the Mountain Home Demonstration State Forest began in 1880, and most of the area has been cut over at least once. Public outcry against large-scale destruction of old-growth giant sequoias prompted the State Legislature to appropriate $550,000 to purchase the land in 1946 from the Michigan Trust Company.

This paper describes the history, physical characteristics, and management objectives of the Mountain Home Demonstration State Forest, with emphasis on management of giant sequoia. It also describes a study begun in 1966 to determine the benefits of logging on reproduction -and survival of giant sequoia seedlings. Seedlings were only produced on the logged plot and not on the unlogged plot, but subsequent brush competition may have reduced survival of seedlings on the logged plot.

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MOUNTAIN HOME STATE FOREST

Elevations on the Forest range from 5500 to 7500 feet (1680-2290 m), with mostly moderate slopes. Site quality is high, mostly I and IA. Climate is characterized by cool, wet winters and warm, dry summers. Average annual precipitation, primarily snow, is 40 inches (102 cm).

In contrast to the other six State Forests, which emphasize timber management, the Mountain Home Forest is managed primarily for public recreation. This objective, however, does not exclude timber production. Rather, timber management enhances and complements recreational values. The annual allowable cut is about 1.5 million board feet (Mfbm). Since 1946, the Forest has harvested 57 Mfbm of all tree species---including young-growth sequoia---without depleting the timber inventory. During this time annual recreation use has increased from 1,000 to 51,000 visitor-days.

Practices governing management of giant sequoia on the Forest are:

- Old-growth sequoia are protected during all management activities.
- Young-growth sequoias are considered a valuable and marketable resource.
- Selected young-growth sequoias are encouraged to grow into specimen trees.
- Campgrounds are located away from old-growth sequoias.

Old-growth giant sequoia is characterized by a rounded top with large limbs in the upper part of the bole and with the lower one-third of the bole free of branches. Growth is slow, with annual rings often only a few millimeters wide. The wood is brittle and not suitable for use in construction. Young-growth sequoia is characterized by a pointed top and branches persisting on the entire bole. Growth is rapid, with annual rings often one-half inch (1.3 cm) wide. The wood is considered better than white fir for construction uses.

Continuous Forest Inventory (CFI) data, which include trees over 5 inches (12.7 cm) in diameter at breast height (d.b.h.) indicate that the Forest has 7.8 (19.3/ha) young growth and 0.9 (2.2/ha) old-growth giant sequoias per acre. Old-growth sequoia volume was estimated at 138 Mfbm in 1907 by the James D. Lacy Company of Portland, Oregon (Goldsmith 1945). No estimate of volume for old-growth giant sequoia is available today. There are 5.72 Mfbm of young-growth sequoia. Basal area for old-growth sequoia is 61 ft^2/acre (14 m^2/ha) and for young-growth is 14 ft^2/acre (3.2 m^2/ha), which together make up 39 percent of the total basal area on the Forest.

METHODS

A study was begun at Moses Mountain in 1966 to investigate the long-term effects of logging on the establishment and sur-

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Table 1-*Merchantable trees on one unlogged and one logged 5-acre plot before (1966) and after (1968) logging, Moses Mountain, Mountain Home State Forest, California*

Species	Trees/acres		Volume		Basal area	
	1966	1968	1966	1968	1966	1968
			Tfbm/acre[1]		*Ft^2/acre*	
White fir:						
Unlogged	39.4	[2]---	39.8	---	143.9	---
Logged	31.0	--- 15.6	39.7	7.0	129.3	35.3
Sugar pine:						
Unlogged	6.2	---	20.9	---	52.2	---
Logged	8.6	5.0	28.6	11.5	72.3	32.6
Giant sequoia:						
Unlogged	9.8	---	125.0	---	295.6	---
Logged	4.2	3.6	151.4	144.3	299.4	282.9
Total						
Unlogged	55.6	---	185.7	---	492.1	---
Logged	43.8	24.2	219.7		501.0	350.8

[1]Thousand board feet per acre.
[2]Unlogged plot was not measured in 1968.

vival of giant sequoia seedlings (Schoenheide 1971). Two similar 5-acre (2-ha) plots 0.01 miles (0.016 km) apart were selected in an area where no fire or logging had occurred for more than 60 years. Both plots were inventoried *(table 1)* as follows:

•All trees over 11 inches (28 cm) d.b.h. were measured and labelled with numbered tags.

•Pole-size trees 5 to 11 inches (12.7 to 28.0 cm) d.b.h. were tallied.

•Reproduction was sampled and placed into one of two categories: less than 1 foot (30 cm) tall or 1 foot tall to 5 inches (12.7 cm) d.b.h.

•Other vegetation was sampled and identified.

One of the plots received only custodial care. The other plot was logged in 1968 as part of a timber sale. Over 70 percent of the softwood volume (not counting old-growth sequoia volume) was harvested, to remove the acreage from the tax rolls. This plot was then reinventoried in 1968 (*table 1*). Giant sequoia seedlings were sampled on both plots starting in 1967 using mil-acre strips. The unlogged plot was burned in summer 1985 removing much of the duff and preparing an excellent seedbed. The State Forest staff plans to compare seedling survival on this plot with survival on the logged plot.

RESULTS AND CONCLUSIONS

The unlogged plot has had no sequoia reproduction, but the logged plot had a high number of seedlings immediately after logging, followed by a dramatic decline:

Year	Seedlings/acre
1967	0
1969	332
1971	87
1973	28
1976	17
1981	8

This decline in the number of seedlings was probably due to increasing brush competition. These results indicate that sequoia reproduction can be enhanced by disturbance of the soil during logging, but brush competition can subsequently reduce seedling survival.

The Mountain Home Forest is unique among the public forests in California, because it is managed primarily for public recreation and the other Forests are managed primarily for timber production or multiple use. It is also the only State Forest with giant sequoias, which are managed to perpetuate old-growth specimens and to provide a sustained harvest of young-growth trees.

The State Forest staff plans to conduct further studies on the effects of logging on growth and yield, and to determine optimum stocking levels.

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Management of Giant Sequoia in the National Forests of the Sierra Nevada, California[1]

Robert R. Rogers[2]

Abstract: The Forest Service avoided positive management activities within giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) groves after heavy early logging on private lands caused adverse public reaction. However, since 1975 timber sales and prescribed burning have been conducted to encourage giant sequoia regeneration and increase tree vigor. General management direction is contained in supplements to the Forest Service Manual. Management strategies for individual groves will be finalized through the Land Management Planning process, now underway.

In the mid 1960's many people within the Forest Service began to recognize the need for positive management in stands containing giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) trees. This need was indicated by two different observations on National Forest lands:

1. The "groves" were being overtaken by white fir (*Abies concolor* [Gord. and Glend.] Lindl.), and did not appear to be reproducing naturally with giant sequoia.
2. Giant sequoia typically occupied the better timber growing sites, and there were opportunities for increasing timber productivity on National Forest land.

The first observation led to the altruistic decision that the Forest Service should not stand by and watch the giant sequoias, especially spectacular individuals, just pass out of the picture. The second led to a strictly pragmatic decision to manage the groves for timber production. As discussed below, the Forest Service management policy for giant sequoia now accommodates both of these decisions.

About 5 years lapsed between the first serious consideration of management needs and the first specific Forest Service Manual direction (U.S. Dep. Agric., Forest Serv., 1970). Another 5 years lapsed before any projects designed specifically for giant sequoia management were initiated. Even though it is not uncommon to find a delay of 10 years between concept and execution of any new idea, there was some justification for the delay on this issue. In the first place there was a lingering memory of adverse public reaction to heavy logging around the turn of the century, and a desire to avoid reawakening that controversy. Related to the potential for public reaction was a reluctance to begin artificial regeneration of giant sequoias outside of the naturally occurring groves for two reasons: (1) Planted trees might grow into controversial groves where further management would be curtailed; and (2) the wood of older trees was known to be brittle and not much good for lumber---investments from a strictly financial point of view did not make much sense. Thus the Forest Service was aware of the need to manage giant sequoia but unsure about how to begin.

Finally, in 1975 the Forest Service initiated a prescribed burn designed to reduce fuel loading and provide seedbed for giant sequoia regeneration in the Bearskin Grove (a stopping point on the field trip for this workshop. See handout in *appendix*). This particular project was undoubtedly influenced by observations on the prescribed fire research and project work conducted by the National Park Service on nearby Redwood Mountain. Encouraged by the success of the Bearskin burn, the Forest Service then decided to make a modest attempt at logging within the same grove.

Since then, four timber sales that included 60 acres (24 ha) within four groves on the Sequoia National Forest have been completed. All silviculture prescriptions have been directed towards the general goals of preserving existing "specimen" trees and perpetuating the species. Specific prescriptions were for seed tree harvesting with underplanting. In some cases the seed trees were sequoias only, in others mixed conifer species were left as well. At the time this workshop was held, four timber sales were under contract with 250 acres (100 ha) of harvest within four more groves. Prescriptions included seed tree, shelterwood, sanitation and thinning. Five timber sales in the planning stage propose harvests within giant sequoia groves.

Future management of giant sequoia depends on the outcome of the National Forest Land Management Planning effort. The Land and Resource Management Plan for the Sequoia National Forest is expected to be finalized in May 1987. However, of the approximately 14,000 acres (5700 ha) of forest land classified as giant sequoia type, a significant share probably will be managed to stress continuation of natural processes. The obvious candidates for this "preservation" category are groves located within wilderness areas, those that are unique geographically---such as Placer Grove in the extreme north end of the range, and those that deserve special administrative recognition---such as the Calaveras Big Tree National Forest established by act of Congress in 1909. Most of the 14,000 acres probably will be assigned to a management objective that stresses protection of large old trees and perpetuation of the species, but allows positive management actions to emphasize selected resource values. This category of management is defined as "non-intensive" in the Forest Service Manual supplement shown in the Exhibit attached. It accommodates the need for recreational developments in areas such as the Belknap Grove in the Tule River drainage of the Sequoia National Forest. It also allows for vegetation manipulation, including cutting trees and use of herbicides, to open up views of "specimen" trees or to prepare sites for regeneration. The key to non-intensive management action, then, is the selection of resource values to be emphasized.

[1]Presented at the Workshop on Management of Giant Sequoia, May 24-25, 1985, Reedley, California.

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Gen. Tech. Rep. PSW-95. Berkeley, CA. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1986.

Finally there are tens of thousands of acres of National Forest land on the west slope of the Sierra Nevada that would surely support good growth of giant sequoia if the species were planted there. The Forest Service has already begun introducing giant sequoia onto these sites as a component of the mixed conifer forest, and will manage most of it like any other species---primarily for timber production. This "intensive" category of management also applies to all or portions of about 1,000 acres (400 ha) where all of the large old trees were removed in early logging; although reconstructing natural conditions on some of this area may prove desirable.

Most of the philosophy and activities described above pertain to the Sequoia National Forest. It contains about 90 percent of the naturally occurring groves on National Forest land and more than 90 percent of the area they occupy. However, the unique characteristics of the species have also been recognized in other places. On all National Forests in the Sierra Nevada giant sequoias have been planted from time to time, as they have on several other forests in California. In fact, if interest in the species were measured by the amount of seed stored in the Forest Service seed bank at Placerville, then the San Bernardino National Forest runs a close second to the Sequoia. On the San Bernardino about 5,000 to 10,000 seedlings are planted each year, and at least one instance of natural regeneration from some of the early plantings has been observed.

On all National Forests within the natural range of giant sequoia it is generally considered to be a legitimate species for management in the mixed conifer forest type. The Forest Service is clearly committed to the management of giant sequoia. Now it is a question of precisely how and where it should be managed.

REFERENCE

U.S. Department of Agriculture, Forest Service. Supplement No. 91 to Forest Service Manual; Title 2400, Timber Management, Chapter 2405, Multiple Use Coordination. San Francisco, CA: Pacific Southwest Region; 1970.

TITLE 2400 - TIMBER MANAGEMENT

2471 - HARVEST CUTTING

Giant Sequoia Groves. The giant sequoia (Sequoiadendron giganteum) is remarkable for its great size and long life. Due to the limited occurrence of old, large giant sequoia trees and the aesthetic value of the species, they warrant special treatment.

The management objectives for stands of giant sequoias shall be established by Management Category. The general objectives shall be the perpetuation of the species, the maintenance and preservation of "specimen" trees, and sequoia, live or dead, that has mature characteristics such as: columnar form of stem, deeply furrowed bark, lower stem free of limbs, red bark, etc. In addition, it must be *-older than 150 years and larger than eight feet in diameter at six feet above ground level. To effectively meet the above objectives, the -* compatible practices are recognized by Management Category:

1. Preservation. This Management Category will be reserved for those stands or groves of present or potential high aesthetic or scientific values. Although this designation is generally restricted to large prominent groves, it may also apply to one, or a few, "specimen" trees, the protection of which is desirable because of unique size or location. It may also apply to Research Natural Areas or Botanical Areas.

Groves or stands selected for Preservation management shall have their exterior boundaries posted. No major activities that would be potentially harmful to the giant sequoia trees, such as campground or road construction, or timber cutting, will be permitted. Activities shall be limited to those needed to perpetuate the "specimen" trees and the natural conditions of the associated trees and ground cover, or to improvement such as foot trails to provide for public access. Dead and down giant sequoias shall be left in place. Deviation from these restrictions may be made only with the written approval of the Forest Supervisor.

2. Non-intensive. Mixed conifer stands which contain large, old growth (older than 150 years) giant sequoias as a component and which have not been designated and approved for Preservation will be given special treatment to preserve the old growth giant sequoias in the stand.

The objectives of management shall be to perpetuate the species, improve stand vigor, and develop replacement "specimen" trees. Management flexibility is allowed so that selected values may be emphasized, provided these objectives are met. Values selected for emphasis may vary between groves, and between stands within the same grove.

Silvicultural prescriptions shall be prepared for each stand to meet the objectives of non-intensive management as qualified by management emphasis. Any silvicultural system, even-aged or uneven-aged, may be used which will meet the objectives and the appropriate emphasis. Clearcutting of whitewoods to promote mixed species reproduction and thinning of giant sequoias to improve vigor and size are approved practices. Use of prescribed fire and all techniques for manipulating vegetation are also approved practices in these stands.

No "specimen" giant sequoia is to be cut or damaged. Management activities shall be conducted in a manner to insure protection of these trees from root damage, undue exposure to windthrow, or unacceptable damage which might occur from other trees felled into or against them. Deviation from these constraints shall be allowed only upon the approval of the Forest Supervisor.

3. Intensive. These are areas of National Forest land (primarily those acquired after logging) that support either pure stands of giant sequoia saplings, poles or large young trees, or mixtures of young giant sequoias and other species. In addition, there are areas that are outside of the present natural range of the species which, due to site quality or location, are capable of growing giant sequoias. There are no restrictions on management activities in these stands other than to promote expansion of the giant sequoia range where possible.

*-Giant Sequoia Grove Management.

1. Policy:

a.) A giant sequoia grove will be analyzed in its entirety prior to planning any timber sale or other activity that will affect the given grove.

b.) The need for a separate Grove Management Environmental Assessment (E.A.) will be determined at the time of scoping for the Position Statement. If no significant public issues are identified, the Grove Management Analysis may be included in the Compartment or Timber Sale E.A.

2. Grove Management Analysis:

The Grove Management Analysis will identify areas suitable for:

a. Preservation Management
b. Non-Intensive Management
c. Intensive Management

The rational for the allocation into each category will be documented. Also, the proposed management emphasis for Non-Intensive areas will be noted along with the reasons for the emphasis.

Detailed prescriptions will be developed by the project E.A.'s; i.e., Timber Sale or Compartment E.A.

The following criteria are established for determining the management direction in giant sequoia groves, or portions thereof.

1. Preservation:

All groves in wilderness areas are in this category. Groves outside of wildernesses should have at least one of the following attributes:

a. Comprised of unique specimens, groups, or eco-systems.

b. Offer outstanding recreational opportunities.

c. High public use or interest.

d. Adjacent to developed Recreation Sites or Wilderness Areas.

e. Unique features such as tallest, etc.

f. Second growth stand designated as replacement preservation grove.

Since the theme of preservation management is to allow natural environmental processes to operate, this management category is not necessarily limited to isolated or pristine groves.

2. Non-Intensive Management:

All grove areas not classed as Preservation or Intensive Management will fit into this category. The management emphasis will be identified; e.g., recreation, timber management, etc.

3. Intensive Management:

Lands meeting the following criteria may be considered for intensive management:

a. Second growth giant sequoia stands that have resulted from previous harvest; or

b. Planted giant sequoia stands.

Second growth and planted giant sequoia stands are <u>not</u> precluded from being considered for Preservation Management or Non-intensive Management. -*

Management of Giant Sequoia at Blodgett Forest Research Station[1]

Robert C. Heald[2]

Abstract: Researchers at Blodgett Forest Research Station, University of California, are studying giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) growth under both even-age and selection management in relationship to the presence of several shrub species and five native conifers. The sequoias are also being studied under several types of site preparation, vegetation control techniques, and stand densities. Seven management units are described. In virtually all situations, early (first 18 years) height and diameter growth patterns of sequoia equal or exceed those of native conifers.

FOREST DESCRIPTION

Blodgett Forest Research Station is a 2961-acre (1199 ha) field research station owned by the University of California, Berkeley, and operated by its Department of Forestry and Resource Management. The station provides a location for wildland resource research and demonstrates forest management principles and practices. Most of the property was given to the University by the Michigan-California Lumber Company in 1933 for timber management research. The forest is named in honor of John W Blodgett, who was then president of the lumber company.

The forest is located in the American River watershed on the western slope of the Sierra Nevada in El Dorado County. All of the property is located between 3900 and 4800 feet (1200 and 1500 m) in elevation on the Georgetown divide. The topography is moderate. Most slopes average less than 30 percent and few are greater than 50 percent.

Blodgett provides excellent examples of the Sierra mixed conifer/oak forest type. More than 400 species of plants are found on the forest. Common tree species include ponderosa pine, sugar pine, California black oak, white fir, Douglas-fir, incense-cedar, and tanoak. Some of the most common brush species are manzanita, deerbrush, whitethorn, bear clover and western azalea. Over 150 species of animals have been seen on the forest including mountain lions, coyotes, rattlesnakes, squirrels, porcupines, hawks, chickadees, and deer.

Four major soil types are found on the forest. All are loams or sandy loams, which are generally well drained, fairly deep, and reasonably resistant to erosion---except when they are on steep exposed slopes. The Holland, Pilliken-Variant, and Musick soils are all developed from granodiorite parent materials. The Cohassett soil type is developed from andesitic lahar. These soils support conifers capable of growing 90 to 110 (35 m) feet tall and 18 to 26 inches (46-66 cm) in diameter at age 50 to 60 years. The average acre can produce 200-250 cubic feet (14-17.5 M^3/ha) or 1000-1250 board feet of wood per year.

Blodgett Forest receives an average of 66 inches (168 cm) of precipitation per year with a 22-year range of 23 to 108 inches (58-274 cm). About 85 percent of the precipitation falls between October and March while less than 5 percent falls during the summer months. Snow is common from November to April, averaging about 100 inches (250 cm) per year. Average daily maximum temperatures range from 48 °F (9 °C) in the winter to 80 °F (27 °C) in the summer. Average daily minimums range from 32 °F (0 °C) in the winter to 57 °F (14 °C) in the summer. Frosts are common from October through May.

There are no native giant sequoias (*Sequoiadendron giganteum* [Lindl.] Buchholz) in the area. The nearest native groves are in Placer County about 10 air miles north across the Middle Fork of the American River and in Calaveras County about 50 air miles southeast. Most of the plantings described below are from seed sources at Whitakers Forest, another University of California field station, located on the west edge of Kings Canyon National Park.

FOREST MANAGEMENT

To provide future opportunities for research, portions of the forest are managed utilizing even-and uneven-aged silviculture. Since the mid 1960's, sequoia has been gradually introduced under both systems. Since virtually all the forest was heavily cut-over in the first two decades of this century, all the sequoias planted at Blodgett Forest have been in areas where either young growth mixed-conifer-oak (50- to 70-year-old) forests or brushfields were cleared.

Uneven-Aged Management

Sequoia in uneven-aged management was introduced initially alone and most recently mixed with other native conifers in group selection cuts. These openings have ranged from ¼ to 2 acres (< 1 ha). Most such openings also have natural regeneration of native conifers about the same age as the planted sequoias.

One planting is a 10-year-old ½-acre (¼ ha) group selection cut on Holland soil located on a ridgetop at about 4600 feet (1400 m) elevation and a 10 percent east slope. The surrounding canopy is about 70 years old and 120 feet tall.[3] Sequoias range from less than 3 feet tall near the edge of the cut to about 20 feet tall near the center. Competing natural ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.) regeneration at the same age range from 3 to 15 feet tall. Shrub competition is principally deerbrush (*Ceanothus integerrimus*), and is over 6 feet tall despite having been cut to ground level 5 years earlier.

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[3]1 ft =0.305 m

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Another unit is a 13-year-old group selection cut of about ¾ acre (⅓ ha) on the same type of site. Sequoia heights range from 10 feet on the group cut edge to 26 feet at the group's center. Diameter at breast height ranges up to 10 inches (25 cm) for the largest trees. Live crown ratios (LCR) are all over 90 percent despite the close spacing of about 6 to 8 feet within the group. Branch diameters are all less than 1 inch (2.5 cm) regardless of tree position in the group. Natural ponderosa pine and white fir regeneration of the same age ranges is up to 18 feet in height. The Northern California Forest Yield Cooperative (NCFYC) site for the surrounding 70-year-old natural stand averages (breast height age 50) about 100 (Bigging and Wensel 1984). Dominant ponderosa pine in the group cut also average about site 100 using Oliver's (1972) pine site classification. Dominant sequoia appear to have an equivalent site index (although no real site index for sequoia exists) of about 130, or 30 percent taller at this age than ponderosa pine.

The oldest group selection planting at Blodgett Forest is 18 years old in a less than ¼-acre (1/10 ha) opening. Dominant sequoias are over 30 feet tall with 60 LCR despite the 120-foot tall surrounding conifer stand. Interestingly, the opening was apparently created by harvesting of a pocket *Fomes annosus*-infected white fir. Several white fir stumps among the planted sequoia have numerous *Fomes annosus* fruiting bodies. The sequoia showed no signs of disease at this writing.

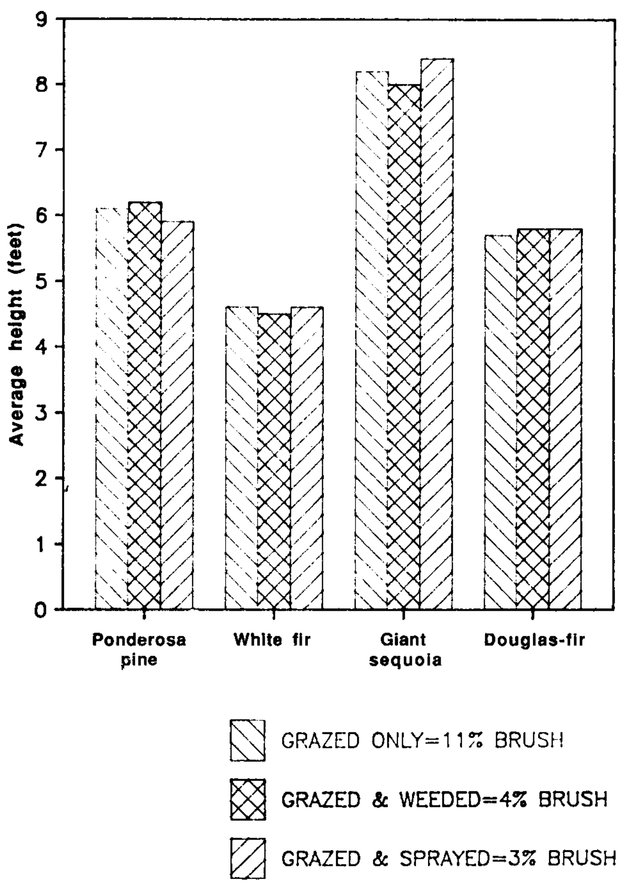

Figure 1-At age 5, planted giant sequoias averaged 8 feet in height on Unit 321-E.

Even-Aged Management

Sequoia has been fully integrated into Blodgett Forest even-aged management regeneration efforts only since 1981. Sequoia is currently included in each clearcut planted at a 10 to 20 percent rate. Unit 321-E is a 15-acre (7 ha) clearcut located on north and east slopes, at 4400 feet (1340 m) elevation. Again it is a Holland soil. Slopes range from 5 to 40 percent. The site was prepared by a crawler tractor equipped with a brushrake. Ponderosa pine, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), white fir, and giant sequoia were planted on 8-foot (2.5 m) spacings in April 1981. Giant sequoias were container stock grown in 8-inch super cell leach tubes at the Simpson Nursery in Korbel, from Whitaker seed source. Sequoias were less than 8 inches (20 cm) tall at the time of planting. Sequoias averaged 12 inches (30 cm) in height at the end of the second growing season but had more than tripled their volume of foliage. By the start of their fifth growing season (May 1985), sequoias averaged 8 feet in height *(fig. 1)*. Most sequoia trees had full dense foliage throughout their crown despite average fourth year internodes in excess of 3 feet. Ponderosa pine averaged 6 feet with some individuals up to 8 feet. Douglas-fir averaged 5 feet with some individuals up to 7 feet. The tallest sequoias were nearly 10 feet tall at the beginning of their fifth growing season. On this clearcut competing vegetation is quite sparse. Shrub control is almost entirely the result of range cattle grazing. Inside cattle exclosures, deerbrush averaged 5 feet tall with over 80 percent crown cover on this site. Sequoia survival was greater than 80 percent. Despite heavy cattle and deer use, only one damaged sequoia was found. The damaging agent was not identified.

This pattern of sequoia growth is essentially duplicated on a 10-acre (4.5 ha) clearcut (Unit 200-E) planted at Blodgett in 1981. This second site is a steeper (30 to 50 percent) west-facing slope at 4100 feet (1250 m) elevation on Musick Series soil. The tallest sequoias were over 10 feet at the end of their fourth growing season *(fig. 2)*. This location does not have cattle grazing. Shrubs---deerbrush and tanoak *(Lithocarpus densiflorus)*---were controlled in a third of the site by hand grubbing, and in another third by herbicide; one third of the site had no shrub control at all. Deerbrush cover in the control area exceeds 60 percent with average height over 4 feet. Although all trees including sequoia exhibited less dense foliage in areas with heavy shrub competition, only a slight difference in total height of sequoia was evident at the end of the fourth growing season. Ponderosa pine, Douglas-fir, and white fir showed significant reductions in height at age 4, when grown in the untreated brushy area.

On an 11-acre (5 ha) clearcut planted with white fir in 1970, approximately a 1-acre (½ ha) area was planted with giant sequoia in spring 1971. A dense shrubfield of deerbrush and greenleaf manzanita *(Arctostaphylos patula)* over 6 feet in average height has developed since planting. White fir averages less than 3 feet in height with occasional natural ponderosa pine overtopping the brush. Sequoias, on the other hand, average nearly 30 feet in height, with several trees over 35 feet. Diameter at breast height ranges from 6 to 13 inches (15 - 33 cm), despite about 6-foot average spacing in this 14-year-old plantation. This is a

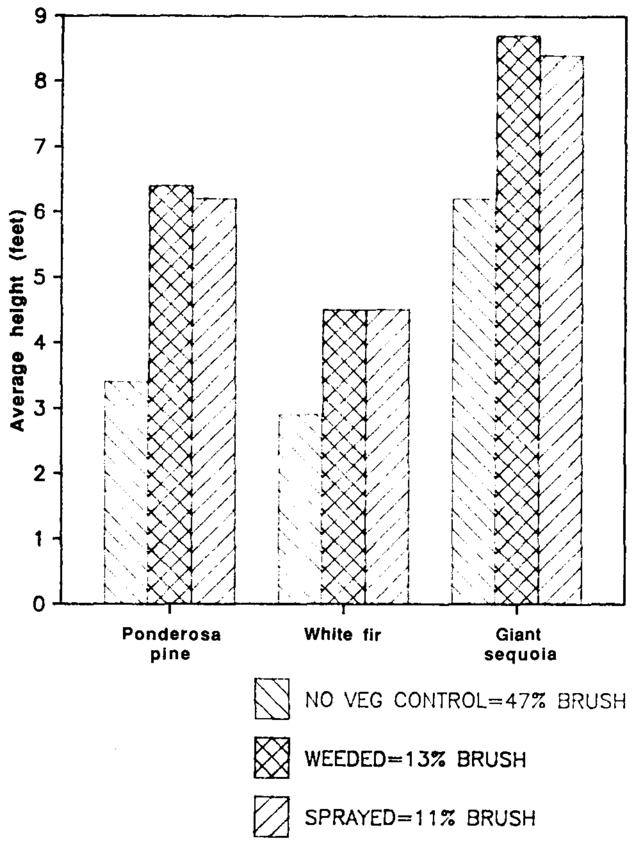

Figure 2-After four growing seasons, the tallest giant sequoias were over 10-feet high on Unit 200-E.

wet site on the edge of a spring. Nevertheless, the sequoias were able to suppress both grass, sedges, and deerbrush (as evidenced by skeletons inside the sequoia stand) that had a 2-year headstart on growth. Indeed, the sequoias on this wet site were actually about 20 percent shorter at age 5 than on the aforementioned 5-year-old plantation, which is on a well-drained hillside. Perhaps the extra moisture on this site partially compensated for early shrub competition. Some individual trees are truly impressive. One tree had a height of 38 feet and d.b.h. of 14.9 inches (38 cm) at age 14. Several trees have been pruned over the last 3 years. They exhibit virtually no epicormic branching. Some apparently minor sapsucker damage is visible.

Another plantation, which is about 16 years old, was originnally started as a density study. This site is a dry, eastfacing midslope area at 4200 feet (1280 m) in elevation on Pilliken-Variant soil. The area was a brushfield before clearing and planting with giant sequoia. A dense 6-foot tall greenleaf manzanita, bush chinquapin *(Castanopsis sempervirens),* and bear clover *(Chameabatea foliolosa)* shrubfield again occupied the site by the early 1980's. Natural pine regeneration is scattered throughout the area with heights ranging up to 16 feet. Pine trees and sequoias are taller where tree survival was higher, and tree spacing closer together. Many sequoias survive at or below the general brush canopy height. In 1983, the brush was cut with a chainsaw-powered cutter. Sprouting shrubs were sprayed in 1984. Released sequoias had already increased height growth and greatly increased in crown volume only 2 years after brush control. Typical giant sequoias were 7 to 10 feet tall with about 20 to 40 percent crown height above the brush in 1983.

At this early stage of research, adding sequoia to both even- and uneven-age managed young-growth stands seems quite compatible with existing wood production goals. Increased species diversity may be an additional benefit to wildlife habitat and visual quality. Early sequoia height and diameter growth appears less susceptible to growth reductions due to competition with ceanothus shrub species than are other native Sierra conifers.

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Management of Giant Sequoia at Calaveras Big Trees State Park[1]

Wayne Harrison[2]

Abstract: The California Department of Parks and Recreation manages two groves of giant sequoia (*Sequoiadendron giganteum* [Lindl] Buchholz) located in Calaveras Big Trees State Park. Since the 1970's prescribed burning has been an integral part of the management program for these groves, with early indications of successful results. Restrictions have been placed on the program to avoid scorching and charring the soft outer bark of the trees. As high levels of fuels that accumulated during decades of fire suppression are reduced, restricttions are being removed. Future plans call for manual thinning of stands in an attempt to reduce interspecies competition and restore presettlement conditions.

The California Department of Parks and Recreation (CDPR) manages two groves of giant sequoia or Sierra redwood (*Sequoiadendron giganteum* [Lindl.] Buchholz), located at Calaveras Big Trees State Park. Known as the North and South Calaveras Groves, these stands may represent the northern extent of the species' optimum range, because only the small Placer Grove is located at a higher latitude. The Park itself is located 77 road miles (123 km) east of Stockton and 36 road miles (58 km) west of Ebbetts Pass, and is bisected by the North Fork of the Stanislaus River, which also separates the two groves *(fig. 1)*.

NOMENCLATURE

Buchholz (1939) defined the morphological differences between *Sequoia gigantea,* as Sierra redwood was known at the time, and coast redwood *(Sequoia sempervirens).* He showed that-while taxonomically related-the two did not belong to the same genus. It was not until the 1960's, however, that this distinction was given formal recognition, and the binomial *Sequoiadendron giganteum* was adopted. As a result of the change, the State of California decided that the popular common name "giant sequoia" was technically inaccurate and its use inappropriate. The State formally recognized Sierra redwood as the common name, because it established both a distinction and a relationship with the other "redwood" species: coast redwood and dawn redwood *(Metasequoia glyptostroboides).*

DESCRIPTION OF THE GROVES

The Calaveras Groves have different overall characteristics. The South Grove is by far the larger, with nearly 1,000 specimens in 445 acres (180 ha). It is located in a basin formed by Big Trees Creek. The basin is uniformly sloped throughout, with only a few flat areas located along the stream. Sierra redwoods are typically found on these slopes.

The North Grove, on the other hand, has 158 specimens spaced over 60 acres (24 ha). It is also located in a stream basin, but one of generally low relief. One steep, north-facing slope exists along an edge of the grove, but only seven trees are found there. The rest of the mature specimens are found on the flat flood plain formed along the watercourse. A unique biological feature of the North Grove is the close association between Pacific yew *(Taxus brevifolia)* and Sierra redwood. The North Grove represents the southern limit of yews in the Sierra Nevada, and the occurrence is confined to the grove. This is the only known exclusive association involving the Sierra redwood and another plant species.

Histograms of the size frequency of specimens found in each grove are similar, particularly in that both indicate a depression in small- to mid-range frequencies (12-95 inches in diameter at 6 feet or 240-420 cm at 1.8 m) and a peak at mid-range diameter (96-168 inches or 240-420 cm) *(fig. 2)*. This could indicate a general decline in reproduction over the past centuries, or perhaps an extended period in the past during which exceedingly favorable conditions existed.

Cumulative frequency curves *(fig. 3)* further indicate the similarity between the two groves, although the significance of this cannot be determined without comparison with other groves.

At least one case shows evidence that the North Grove---despite its small size---provides an exceedingly favorable growing environment. The infamous "Big Stump," the remnant of the tree deliberately felled simply because it was there, clearly indicates the tree's growth record. Its age has been placed at only 1,300 years, although its girth (less bark) of 24 feet (7.2 m) would indicate a much more venerable tree. An average annual growth of 0.20 inches (5 mm) in diameter supports the notion that the North Grove provides a very favorable habitat.

PRESCRIBED BURNING PROGRAM

As is true of virtually all resource agencies, the California Department of Parks and Recreation has only recently foregone the strict, protectionist theory of resource management-recognizing that prudent stewardship requires more active (and in some cases remedial) measures. The centerpiece of this type of management is an ongoing program of prescribed burning begun in 1975 under the tutelage of Dr. Harold Biswell, Professor emeritus, School of Forestry, University of California, Berkeley. A

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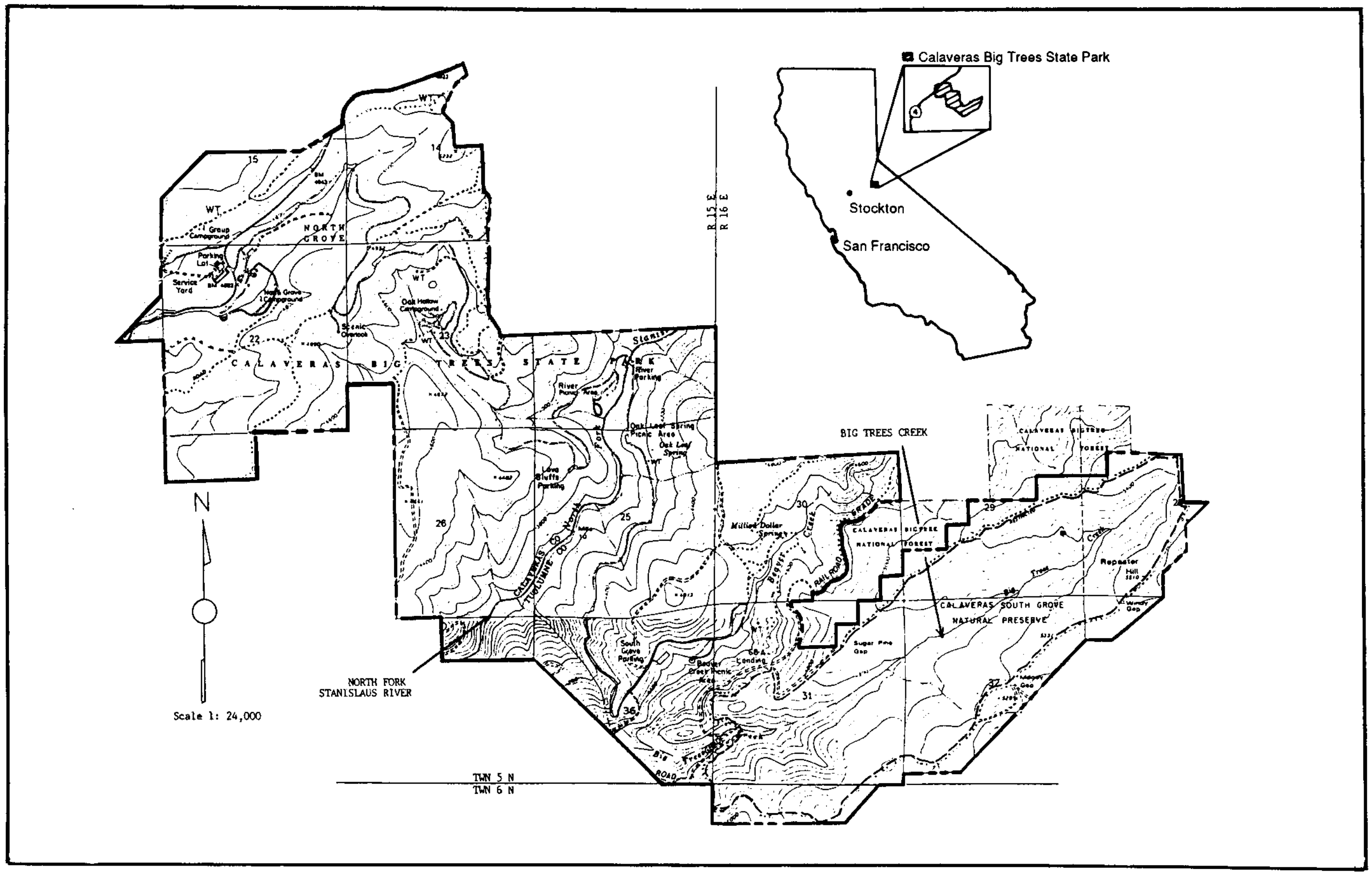

Figure 1-Calaveras Big Trees State Park is located between Stockton and Ebbetts Pass.

critical aspect of the burning program was that CDPR is not only a resource agency but a recreation agency as well. Moreover, the agency has an administratively close relationship with the public. For example, the CDPR has historically depended upon private organizations such as the Save-the-Redwoods League and the Sempervirens Club for the purchase of park property. In fact, the South Calaveras Grove was acquired in this manner. In a broader scope, a major portion of funding for CDPR comes from bond acts passed by the citizens of California. Therefore, the agency would be remiss if the views of the private sector were not considered in the planning processes. This public opinion has affected the evolution and management of the prescribed burning program.

When the issue of conducting burns in the South Grove was first raised, little concern was expressed over the desirability of such a program: The National Park Service (NPS), U.S. Department of the Interior, had already well established its efficacy. Rather, the public was more concerned over the potentially undesirable visual impact that burning might have on the soft and ignitable outer bark of the Sierra redwood. As a means of mitigation, CDPR cut a line to mineral soil around each of the nearly 1,000 big trees in the South Grove. Other efforts designed to reduce visual and environmental impacts included keeping fire away from riparian zones and stream channels, protecting snags and raking around mountain dogwoods *(Cornus nuttallii),* which are susceptible to cambium damage from fire.

To further complicate matters, unlike the NPS and the Forest Service, U.S. Department of Agriculture, CDPR is not its own fire control agency: all burns have to be conducted with the approval of the California Department of Forestry (CDF). In 1975, CDF was still divided over the question of prescribed burning. When CDPR requested a permit from CDF to start burning in the South Grove basin, the size of each burn was limited to only a few acres. Given the limited burning "windows" available in the spring and fall each year, burning the entire 1,250 acres (506 ha) of the Big Trees Creek basin would have been a monumental task. As CDPR showed that it could conduct burns safely, these acreage limitations were gradually eased, and finally removed.

Similarly, some of the other restrictions already mentioned were dropped when the CDPR began burning in the North Grove in 1984. Only the restriction on charring the Sierra redwoods remained, and each tree was again raked before burning. When the North Grove burn is completed, this final mitigation measure can probably be dropped, and future burns in both groves may be conducted without special protection for the Sierra redwoods. These efforts were always considered to be primarily a response to the unusually high levels of forest fuels resulting from decades of fire suppression. Fires conducted under such conditions could be unnaturally intense and damaging. Now that fuel levels have been lowered, prescribed burns should be possible without producing unacceptable charring of the trees.

When the CDPR began burning in the South Grove in 1975, it was with intense concern over the potential disaster that could result if an uncontrolled wildfire should enter the' basin before

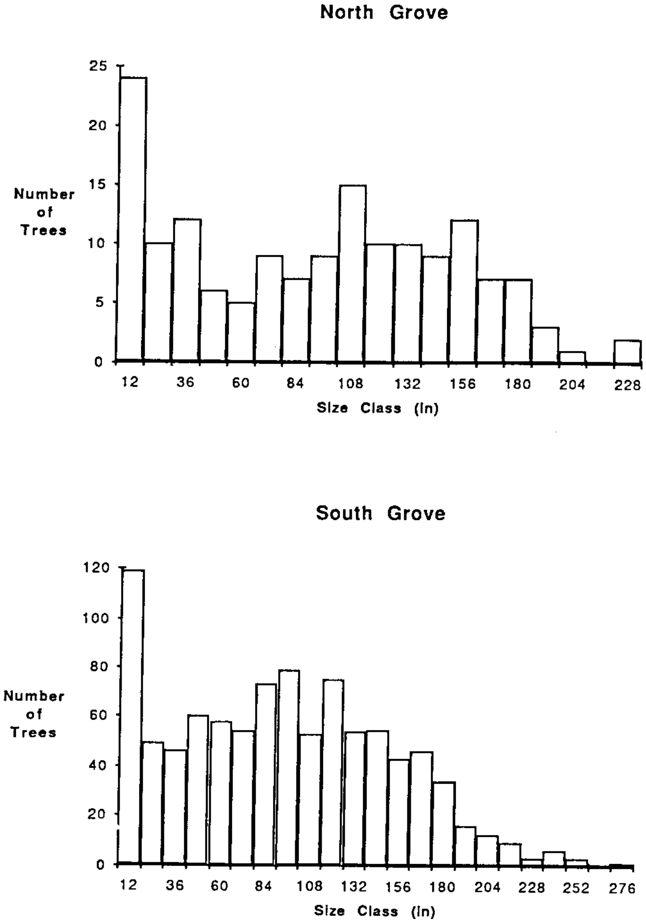

Figure 2-The frequency distribution of Sierra redwood is similar in the North and South Groves.

the unnaturally high fuel loadings could be reduced. Because measured loadings range from 27 to 115 tons per acre (Agee and Biswell 1977), a summer wildfire in such fuels would be cataclysmic. For this reason, conducting prescribed burns in the South Grove was given the highest priority, at the expense of conducting an extensive and detailed preburn monitoring program. Furthermore, during the 5 years that burns were conducted in the South Grove, whenever burning was not possible, crews manually thinned the understory throughout much of the grove. About 20,000 trees were removed in this manner. Once

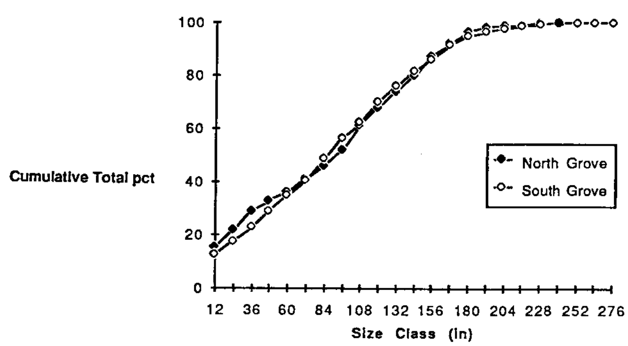

Figure 3-Cumulative frequency curves for Sierra redwood show that the North and South Grove apparently are similar.

again, no pretreatment studies were conducted. Consequently, little substantive data is available on the condition of the grove immediately before these activities and their results can not be measured.

BIOLOGICAL EVALUATION

To rectify this lack of data (albeit belatedly) the CDPR initiated in 1985 a biological evaluation of the South Calaveras Grove and the surrounding basin. This study was designed to provide baseline data on a number of parameters, including growth rates, top condition, tree defects, and population characteristics for the Sierra redwood, plus composition and size characteristics for all other tree species. Permanent reference points and plots have been established so that follow-up studies will have a basis for comparison. It is unknown if this study will result in any management decision, but-at the least-it may be of interest to those who wish to know more about the community dynamics of the grove.

The only previous systematic study of the South Grove population was conducted by the Forest Service in 1924. Oscar M. Evans mapped and measured each Sierra redwood with a diameter of 12 inches (30 cm) or more, in both groves. The histograms *(fig. 2)* and frequency curves *(fig. 3)* were derived from these data.[3] They are the best sources of information available about the North and South Groves but are over 60 years old.

This new study will at least identify changes over this period, although the methods and parameters are not similar to those of the Evans. The prime value of the biological evaluation will not be realized until the studies are replicated, or when other agencies conduct similar programs in the groves they manage. For instance, comparable information on growth rates between groves located at the northern, middle, and southern ranges would at least be interesting, and at the most could provide useful comparisons between different management schemes. I encourage such studies.

FUTURE PLANS

Finally, CDPR is planning an intensive management program in the North Grove. Using backward projection techniques developed by Bonnicksen and Stone (1978), we hope to develop a model of the presettlement characteristics of the grove, and manually thin the stand to reflect those conditions. This program is now in the planning stages, and work should begin during the 1986-87 fiscal year.

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Bonnicksen, Thomas M.; Stone, E.C. An analysis of vegetation management to restore the structure and function of presettlement giant sequoia-mixed conifer forest mosaics. 1978. Unpublished manuscript.

Buchholz, J.T. The generic segregation of the sequoias. Am. J. Bot. 26 (7): 535-538;1939.

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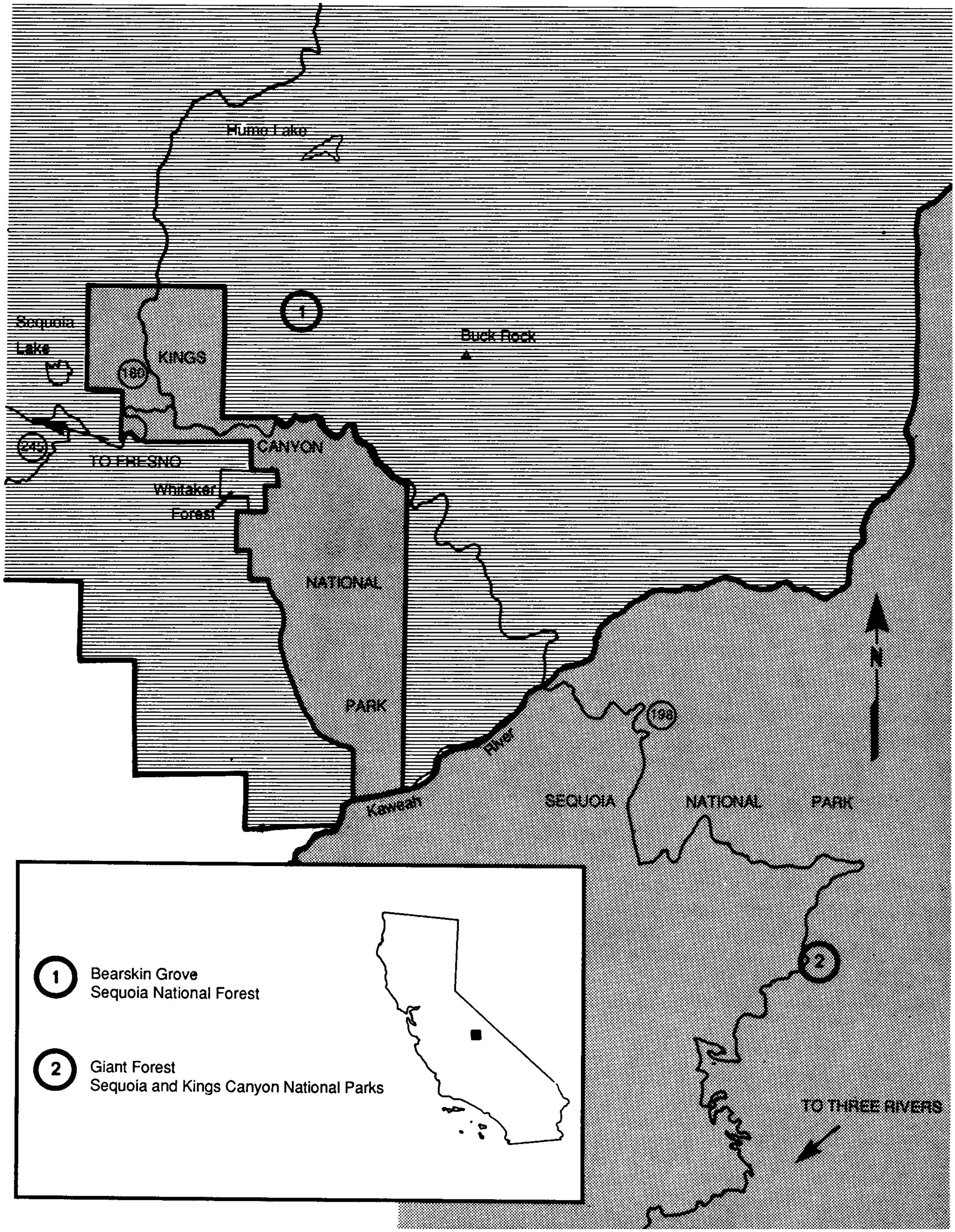
APPENDIX
Field Trip Summary and Handouts

The field trip held during the Workshop on Management of Giant Sequoia allowed participants to observe first-hand some of the appropriate management activities being practiced by the Forest Service and National Park Service, U.S. Department of the Interior. Two other objectives of the field trip were to stimulate discussion and to encourage the exchange of ideas among the workshop participants, and the research and resource experts in the field. The field trip met all three objectives, and stimulated further interest in the future research and management of the giant sequoia species.

At the Bearskin Grove in the Sequoia National Forest (1 on map), participants observed two seed tree shelterwood units in which all the whitewoods were removed, leaving the residual giant sequoias as a seed source. The two units also enabled comparing the effects of two site preparation methods, broadcast burning and mechanical piling/burning (see handout).

At the General Sherman Grove in Sequoia and Kings Canyon National Parks (2 on map), participants observed results of the prescribed underburning program designed to encourage natural stand structure and composition, and natural giant sequoia regeneration in the Grove. The other management scenario of preservation was also observed (see handout).


Hume Lake
Sequoia
Lake
KINGS
180
245
TO FRESNO
CANYON
Whitaker
Forest
Buck Rock
NATIONAL
PARK
N
198
River
Kaweah
SEQUOIA
NATIONAL
PARK
TO THREE RIVERS
1 Bearskin Grove
Sequoia National Forest
2 Giant Forest
Sequoia and Kings Canyon National Parks

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

MANAGEMENT PROJECTS WITHIN THE BEARSKIN GROVE
SEQUOIA NATIONAL FOREST--HUME LAKE RANGER DISTRICT

Paul Roche, Jr., Field Trip Leader

SPECIFIC INFORMATION:

Grove size - 60 acres.

Legal description - T.13S., R.28E., Sections 34 and 35, MDBM.

Mean elevation - 6,340 feet.

Aspect - Northeast.

Soil - Loamy sand and sandy loam in the A and B horizons, respectively. Granite parent material.

Annual precipitation - 43 inches, primarily snow.

MANAGEMENT PROJECTS:

Bearskin Grove Prescribed in 1975

The objective of this project was to reduce the fire hazard to the Grove and the surrounding areas, and to improve the regeneration capability of giant sequoias in the Grove.

This was to be accomplished through two controlled burns. The first burn was implemented in the spring of 1975 to reduce the ground fuels. The second burn was scheduled for the fall of 1976 to insure an increase in seed germination.

The first burn met the objective. The second burn was never implemented as giant sequoia seedlings were quite abundant the following spring. However, the seedlings did not survive.

Huckleberry Timber Sale in 1983

This timber sale harvested two units within the Bearskin Grove. The objective for these units was to obtain mixed conifer regeneration dominated by giant sequoias.

To achieve this, a seed tree cut was planned for each unit, leaving six to ten trees per acre. Different site preparation methods were selected for each unit so that a comparison of site preparation methods with regards to regeneration could be made. Unit 23, approximately 8 acres in size, was planned to have site preparation accomplished through broadcast burning, while Unit 24, approximately 9 acres, was planned for mechanical site preparation by tractor piling. Herbicide application was planned prior to planting.

Harvesting operations were completed during the summer of 1983. The following year, site preparation was completed in both units. The application of herbicides was deleted. Planting of giant sequoia stock is planned for the spring of 1986.

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL PARK SERVICE

THE FIRE MANAGEMENT PROGRAM IN SEQUOIA AND KINGS CANYON NATIONAL PARKS

H. Thomas Nichols, Field Trip Leader

The Congressional act which established the National Park Service provided that the purpose of parks is to "...conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations." The National Park Service, by its Congressional mandate, is concerned with the perpetuation of a natural environment and the natural processes functioning therein, a policy further enunciated in Management Policies of the National Park Service (Branch of Fire Management, Boise Interagency Fire Center. NPS-18; 1986).

Fire is part of the natural environment. The vegetation-wildlife complex which existed when the first pioneers came through this area developed in the presence of periodic fires. These originated from both Indian burning and from lightning activity. In the sequoia-mixed conifer forest, these fires occurred about every 10-20 years, frequent enough to keep fuel levels low. As a result, fires were generally mild.

In the sequoia-mixed conifer forest, fire performs several functions which include:

1. Removes accumulations of dead fuels on the forest floor, thus reducing the potential for conflagrations that could destroy entire forest communities.

2. Thins young trees, opens the forest canopy favoring the survival of non-shade tolerant sequoia and sugar pine seedlings over shade-tolerant white fir and incense cedar.

3. Removes forest litter and exposes the mineral soil necessary for the germination of sequoia and other species.

4. Provides the heat stimulation necessary to germinate the seeds of many chaparral species and to stimulate the sprouting of existing shrubs, thereby providing newer and higher quality wildlife browse.

5. Recycles nutrients locked up in dead wood and makes them more available to plants as fertilizing ash.

6. Creates a mosaic of vegetation types and age classes, thus creating more habitat types and a greater diversity of plant and animal species.

Following the establishment of the National Parks and National Forests in the Sierra Nevada, fire suppression activities began to have an effect on the forest communities. The suppression of human-caused fires such as those from logging, carelessness, or arson, and many of the lightning fires, was necessary for public safety. It was also believed that fires were a destructive force which should be eliminated from the environment. The suppression of these produced a vegetation-wildlife complex much different from what had existed previously in the presence of fire. Those species which did not require fire for reproduction, such as white fir, became much more prevalent, while species which were fire dependent, such as sequoia, displayed a drastic decrease in reproduction success.

In an effort to recreate fire's beneficial effects and to restore more natural conditions in Sequoia and Kings Canyon National Parks, a fire management program was developed. This program defines any fire as either a wildfire or a management fire, depending on the fire's ability to meet specified, or prescribed, conditions of fire behavior and effects, public safety, and legal considerations such as air quality, threatened or endangered species, and jurisdictional boundaries. All wildfires are promptly suppressed because they do not meet management objectives.

Management fires are either natural fires (started by lightning) or prescribed burns (started by trained National Park personnel). Eighty percent of the Park is in a natural fire management zone. This is primarily above 8,000 feet (2,400 m), where lightning fires are allowed to burn largely unimpeded, subject primarily to air quality considerations and public safety. This program has been active since 1968, and was based upon the knowledge that fire suppression activities had far less impact on the fuels and vegetation of the higher and more remote regions of the Park because of their relative inaccessibility. All such fires are under continual surveillance. These burns are also monitored to determine their effects on the environment and for information applicable elsewhere in national parks and other wildland areas.

Prescribed burns have been used since 1964 in low elevation areas, generally under 8,000 foot elevations, where vegetation and fuels are heavy and have built to dangerous proportions through past fire suppression efforts. Lightning fires could not be allowed to burn as in higher elevations. Here, fire is used under controlled conditions to remove these fuel accumulations and to restore more natural conditions. While these fires are burning, a temporary decrease in local visibility may occur.

Prescribed burning is done only under selected weather and fuel conditions to maximize the beneficial effects of fire upon the environment. Monitoring before, during, and following such burns assures that resources management objectives are being met. As natural conditions are approximated, natural fire will be allowed to play its role to the fullest extent possible. Forests in and near developed areas will be prescribed burned on a rotation simulating the natural frequency, since it would be difficult to allow natural fires, which tend to occur in July and August, to burn and to produce smoke in areas which are intensively used by the public during their busiest period. Therefore, the fire management program attempts to allow fire to be an important process in the dynamic Sierra Nevada ecosystems, while ensuring that the possibility of a destructive fire is kept to a minimum.

Weatherspoon, C. Phillip; Iwamoto, Y. Robert; Piirto, Douglas D., technical coordinators. **Proceedings of the workshop on management of giant sequoia; May 24-25, 1985; Reedley, California.** Gen. Tech. Rep. PSW-95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1986. 47 p.

Giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) has long been noted for its size and beauty. It is widely planted as an ornamental and increasingly is being utilized for timber production. The workshop was the first ever designed to bring together the state-of-knowledge on giant sequoia and its management. Presentations covered its history, silvics, genetics, growth and yield, wood properties and products, insect and disease relationships, and management strategies. The proceedings are a useful reference for resource managers, foresters, naturalists, ecologists, and the interested public.

Retrieval Terms: giant sequoia, Sequoiadendron giganteum, Sierra redwood, mixed conifer forest type, resource management, Sierra Nevada (California)