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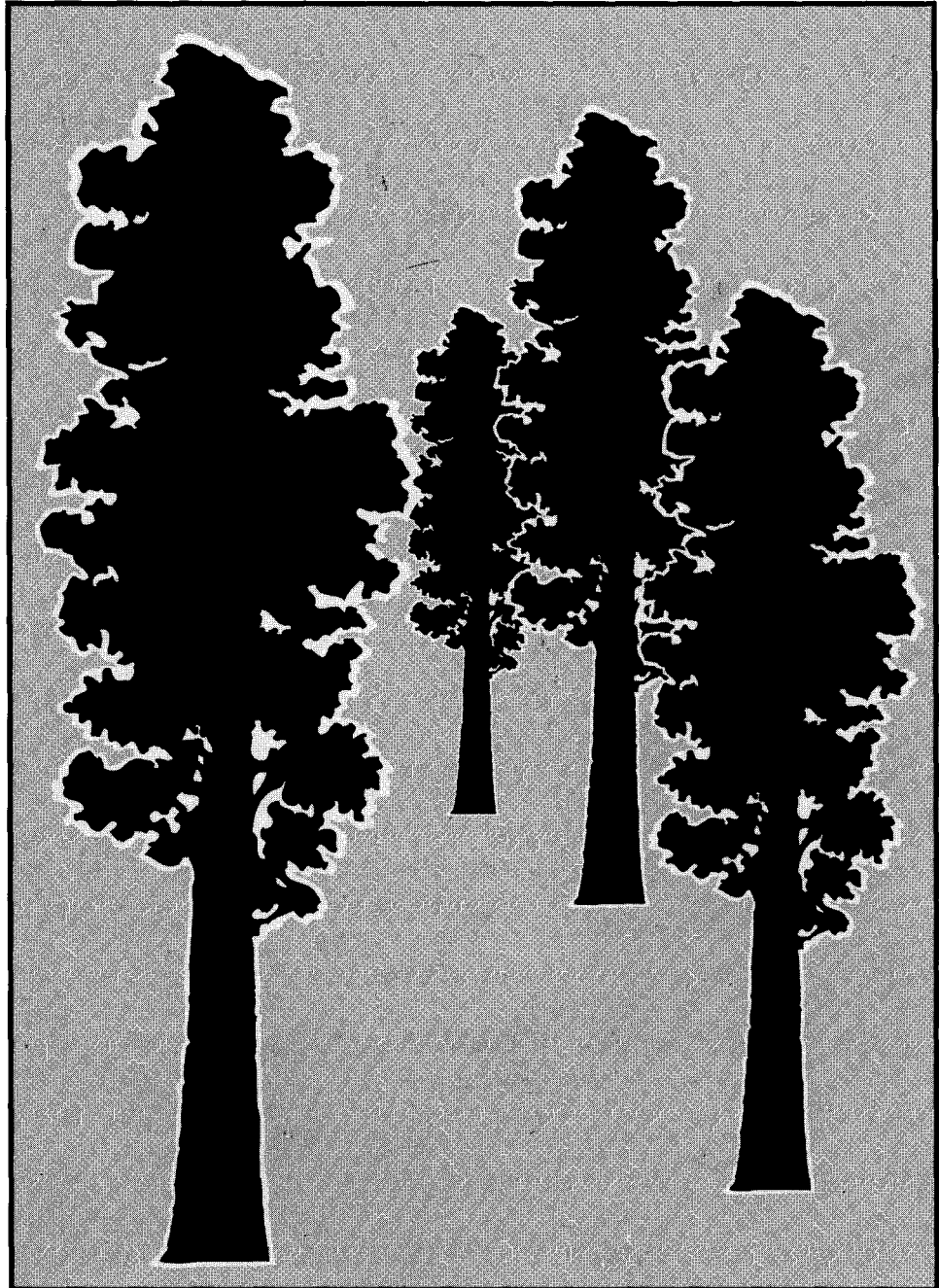
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Proceedings of the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society



June 23-25 1992

Visalia, California



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These proceedings summarize the results of a blending of public perceptions, management, and research presented at a symposium on Giant Sequoias (*Sequoiadendron giganteum*), held in Visalia, California. Twenty-eight papers are included, focusing on six major topics: public values and perceptions, natural perspectives, disturbance environments, grove development, management strategies, and views from agency leadership. These papers summarize the state of knowledge and perceptions of this magnificent species and their place in ecosystems and society.

Retrieval Terms: big trees, Giant Sequoia, Giant Sequoia management, Sequoia

Technical Coordinator:

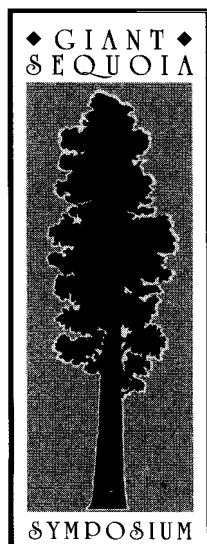
Philip S. Aune is Program Manager-Vegetation Management at the Station's Silviculture Laboratory, 2400 Washington Avenue, Redding, CA 96001.

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(Mailing address: P.O. Box 245, Berkeley, California 94701-0245
Telephone: 510 559-6300)

July 1994



Proceedings of the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society

June 23-25, 1992

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Philip S. Aune, *Technical Coordinator*

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In Brief...

Aune, Philip S., technical coordinator. 1994. **Proceedings of the symposium on Giant Sequoias: their place in the ecosystem and society; June 23-25, 1992; Visalia, CA.** Gen. Tech. Rep. PSW-GTR-151. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 170 p.

Retrieval Terms: big trees, Giant Sequoia, Giant Sequoia management, Sequoia

These proceedings contain 28 papers presented at a symposium on "Giant Sequoias (*Sequoiadendron giganteum*), Their Place in the Ecosystem and Society." The objective of this symposium was to provide the state of knowledge on Giant Sequoia by blending the results of research with human values and perceptions while reviewing agency policies and management directions. The symposium featured field trips to Sequoia National Forest, Mountain Home State Forest, and Sequoia National Park to allow participants to observe

first hand one of the three agency management strategies for Giant Sequoia. These field trips greatly enhanced the subjects and presentations offered during the formal presentations. The symposium was structured around the following general topics:

- Natural values, public values, and public perceptions;
- Genetic characteristics and ecological considerations;
- Giant Sequoia in a disturbance-driven environment;
- Management strategies;
- Influences on grove development;
- Native values and public agency management strategies;
- Reflections on management strategies;
- Views from agency leadership.

The results of this symposium can be used to address conservation and long-term strategies for sustaining the largest of all trees and the wonderful groves people have valued ever since they were first viewed by humans.

Preface

The Giant Sequoia (*Sequoiadendron giganteum*) is known worldwide as an awe-inspiring species of immense size, longevity, and attractive silhouette. The species spans a spectrum of values including natural beauty, ecological and scientific significance, adaptability for ornamental and horticultural use, and excellent wood properties. This graceful tree is found in groves in National Forests, national parks, state parks and forests, and other public and private lands in the Sierra Nevada range of California. Because of the unique range of values and adaptability of the species, Giant Sequoia has been planted beyond its native range successfully in northern and southern California, Oregon, New Zealand, and Europe. Thus the future of the species is of national and international concern.

Because of this "awe-inspiring" nature, Giant Sequoia has also developed as a focal point for many "awe-inspiring" debates over the proper care, use, and management of this magnificent species. Such was the case in 1991, when Congressional field hearings were held concerning the latest in a long line of intense debate over the management of giant sequoias. United States Forest Service Regional Forester Ronald E. Stewart suggested during his testimony at the field hearings that a formal symposium of researchers, managers, private interests, non-governmental organizations and interested citizens be conducted to establish the state of the art and science in managing and sustaining this internationally valuable species. Thus was the genesis of this symposium.

Approximately 200 researchers, managers, representatives, and individuals attended the symposium in Visalia, California. The symposium was divided into two days of technical presentations, with a field trip for participants in the middle. The two days of technical presentations were structured around major topics selected by a Steering Committee of agency, university, and non-governmental organizations. Each of the technical sessions was hosted by a moderator and included the following topics:

- Natural values, public values, and public perceptions (moderator-Bob Jaspersen, Save-the-Redwoods League);
- Genetic characteristics and ecological considerations (moderator-Bill Libby, University of California, Berkeley);
- Giant sequoia in a disturbance-driven environment (moderator-Dave Parsons, Sequoia National Park);
- Management strategies (moderator-Joseph Fontaine, Sierra Club);
- Influences on grove development (moderator-Julie Allen, Sequoia National Forest);

- Native values and public agency management strategies (moderator-Janet Wold, Stanislaus National Forest);
- Reflections on management strategies (moderator-Ken Delfino, California Department of Forestry and Fire Protection);
- Symposium Results: Views from agency leadership (moderator-Phil Aune, Pacific Southwest Research Station).

In addition to the technical sessions, the symposium featured a keynote address by Douglas Leisz, retired Associate Chief of the USDA Forest Service; an evening address on Giant Sequoia in Europe presented by Professor Dr. Wolfgang Knigge of the University of Göttingen, Germany; and an excellent dramatic interpretation of John Muir: Giant Sequoia in the Sierra Nevada by Lee Stetson. Other features included a wide-ranging poster session and closeout with audience responses on what the future should be.

Participants were provided a field experience in the middle of the symposium. They chose from one of the following three tours:

Tour 1. Sequoia and Kings Canyon national parks managed by the National Park Service. Participants examined post-disturbance phenomena in Big Stump Basin and fire and climatic history. They also discussed Park Service prescribed fire programs in Giant Forest as well as overall Giant Sequoia management strategies and philosophy.

Tour 2. Mountain Home Demonstration State Forest, managed by the California Department of Forestry and Fire Protection. Participants examined recreation impacts on Giant Sequoia groves, Giant Sequoia intensive management strategies, and the Department's grove management philosophy.

Tour 3. Sequoia National Forest Black Mountain Grove managed by the USDA Forest Service. Participants looked at the sites of highly controversial timber harvesting conducted in the mid 1980's and areas where timber was harvested in Giant Sequoia groves over 20 years ago. Regrowth of Giant Sequoia and other species on these sites will allow visitors to examine vegetation changes over time after logging.

Acknowledgments

We are especially grateful for the organizational role provided by the Extension Services of the University of California, Davis under the leadership of Dr. Dennis Pendleton. Dr. Pendleton and Debbie Roberts of his staff provided the overall leadership to make the symposium a great success. Thanks to all the authors during the long process of providing your manuscripts, editing and final completion. My personal

thanks also go out to our editors and publication staff at the Pacific Southwest Research Station under the direction of Vincent Y. Dong with excellent editing provided by Sandy Young and Laurie Dunn and publication support provided by Kathryn Stewart and Esther Kerkmann.

Initial financial support was enthusiastically provided by the Regional Office of the USDA Forest Service. Without this support, this symposium would not have occurred. We are also grateful for our other contributors whose support and commitment of personnel and finances made the symposium a success. The contributors included: California Department of Forestry and Fire Protection, Save-the-Redwoods League, USDI Bureau of Land Management, USDI National Park Service, National Audubon Society, Bureau of Indian Affairs, Tule River Tribal Council, and the Pacific Southwest Research Station of the USDA Forest Service.

Assisting the symposium organizers were invaluable sponsors who graciously extended their offices to support the symposium. Included in our thanks are: Bureau of Indian Affairs; USDI Bureau of Land Management; California Department of Forestry and Fire Protection; California Department of Parks and Recreation; Natural Resources

Management Department, California Polytechnic State University; National Audubon Society; National Park Service; Northern California Society of American Foresters; Save-the-Redwoods League; Tule River Tribal Council; University of California Department of Forestry and Resource Management; University Extension, University of California, Davis; and the USDA Forest Service.

A Final Note

These proceedings mirror the symposium and contain a mixture of high quality research papers, excellent management papers, personal observations, and opinions. Readers are encouraged to keep in mind that our overall objective was to develop a state of the science and art of managing and sustaining the Giant Sequoia resource. One inescapable conclusion is that achieving the long-term sustainability of Giant Sequoia will take some form of active management rather than a passive legislative solution. Active management is necessary to perpetuate and sustain the species, the groves, and the incredible biological diversity represented by the species and its environment.

Philip S. Aune
Technical Coordinator

Remarks for the Giant Sequoia Symposium¹

Douglas R. Leisz²

Abstract: Giant sequoia groves are part of a complex ecosystem which has evolved over thousands of years. European man's influence on the species began with the discovery over 140 years ago. Major discussion items are the species unique characteristics and habitat, natural enemies, the discovery of the species, early logging history, public grove acquisition, and various management strategies employed for perpetuating the groves. The sharp conflicts between the public agencies and preservation groups over the management practices are noted. Important issues are listed which require resolution to insure the perpetuation of giant sequoia groves, the specimen trees and the associated ecosystems.

California's rich diversity of forest trees provides an awesome resource base with an extraordinary range of values. Our Mediterranean climate, good soils and adequate moisture create very productive forest communities. With the involvement of a large population of people who are deeply dependent on forest resources and keenly interested in preservation, aesthetics, renewability and utility of the forest resources, forest managers face a demanding job. They must consider forest history and all of the ecosystem components and they must provide especially for endangered species, responding to both public sentiment and needs, and science and politics as they develop management strategies.

Old-growth giant sequoia (*Sequoiadendron giganteum*) is a unique component of the Sierra Nevada mixed-conifer type. The natural range is restricted to 75 groves scattered along the western slope of the Sierra Nevada, between the American River and southern Tulare County. The large groves are concentrated between the Kings River and the Deer Creek Grove. The 75 groves occupy about 36,000 acres, ranging in size from 1 acre to about 4,000 acres.

Characteristics and Habitat

The Sierra Redwood is noted world wide for its great longevity, enormous size, awe inspiring beauty, ruggedness, decay resistant wood properties and its adaptability to thrive as both an ornamental and a timber producing tree in many locations around the world.

Everything about the tree is intriguing from the tiny seeds (91,000/lb.) to the huge mass of the thousand (or more) year old giants and the beauty of the distinctive pyramid shaped crown of young giant sequoias. Seed production is very high, as many as 1,500 new cones per year from a mature tree, but viability is often as low as 1 percent with cones collected from the forest floor.

Successful natural giant sequoia regeneration requires soil disturbance that bares mineral soil and adequate soil moisture for the entire growing season. The giant sequoia is less likely than any of its associated conifers to become established without the required sunlight and soil disturbance. Established sequoia seedlings, growing out in the open with good soil and moisture, will equal or outgrow any of the associated species.

Giant sequoia is intolerant of shade throughout every stage of its life. Fires that cause enough disturbance to bare mineral soil and open the canopy to full sunlight benefit shade intolerant species such as giant sequoia and support earlier successional stages of plant communities. Sierra redwoods are but one part of a complex ecosystem. Perpetuation of old-growth redwoods is a difficult management job.

At maturity giant sequoias are the tallest trees in the forest, dwarfing other conifers so that other sizable trees may go unnoticed. The giant sequoia is not a true climax species, as it does not reproduce itself in an undisturbed forest. However, any tree persisting for three thousand years or more, exerts a major influence on the ecosystem vegetation. Mature trees are successional relicts, living for many years, continuing to meet their light requirements by their dominant height position in the forest.

If we were able to design the ideal conifer for our Sierra Nevada forests, it might look a lot like the giant sequoia. Examine some of the trees' attributes: highly adaptable to many changes in the environment, a fast grower with few natural enemies, extremely attractive as a young tree, able to reproduce by seed or by rooted cuttings, great longevity, good wood quality in young trees, and continued rapid growth even into old age. Giant sequoia has enormous potential for carbon storage and has demonstrated resistance to smog.

It has been reported that the General Sherman Tree, at approximately 2,500 years has an average volume growth increment of 40 to 51 cubic feet per year, which may be the world's fastest growing tree!

Natural Enemies

For many years it was thought that the giant sequoia was free of insect and disease problems and able to cope with the natural phenomenon of fire and flood. Instead, research shows that seedlings and saplings are highly susceptible to injury by fire; large sequoias may be damaged by repeated fires causing loss of supporting wood, which may result in the tree toppling or provide an entry for fungi responsible for root disease and heart rot. Mortality in old giant sequoias is usually by toppling from weakened boles, decay of roots, undercutting by streams or excessive snow loads. Diseases often contribute to root or stem failure. At least nine separate

¹ An abbreviated version of this paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

² Consulting Forester, 2399 Kingsgate Road, Placerville, CA 95667; Retired Associate Chief, USDA Forest Service.

fungi have been identified with decayed giant sequoia wood. Giant sequoias have proven to be wind firm in spite of their height and large crown exposure.

Discovery

In 1852 the Sonora Herald reported the discovery by Dowd of the giant sequoia while he was meat hunting for a water company. What an inspiring sight that must have been! Discovery triggered the need to provide evidence of the size and character of these trees to people in distant places. This need led to the destruction of specimen trees, as bark and cross sections were displayed in the eastern U.S. and Europe.

John Muir viewing the destruction at a specimen gathering site was greatly disturbed and was reported to have remarked that this was "as sensible a scheme as skinning our great men, to prove their greatness."

Logging

Logging began in 1856 and continued intermittently until the 1950s, although at a much reduced rate after 1935. One operation in Converse Basin cut an estimated 8,000 giant sequoias. Logging of the giants was enormously complicated. Flaws in the felling methodology employed in the rough terrain led to a great waste by breakage. Bucking the trees into logs, splitting the logs and moving the enormous log sections to the mill by chute was a challenging job. Milling logs sometimes required enlarging the mill's entrance. Transporting the rough sawn lumber by rail and chute was accompanied with never ending problems of maintenance of the chutes and trestles supporting them. Repeated losses of mill facilities due to fire, coupled with construction and high maintenance costs proved to be prohibitive. Reportedly no profit was realized from this operation and the largest tree, which remains standing, is named after logging superintendent Frank Boule.

Public Acquisition

In 1873, a State law was enacted, which prohibited the cutting of any tree over 16 feet in diameter in Fresno, Kern or Tulare Counties. There is no record, however, of this law ever being enforced.

The movement to place the giant sequoia groves in public ownership began in 1864 when the Federal government deeded the Mariposa Grove to the State of California. Sequoia, General Grant and Yosemite Parks were created in 1890, including considerable giant sequoia acreage. The Calaveras Big Trees National Forest was created in 1909. The Nelder Grove was added to the Sierra National Forest in 1928. The Redwood Mountain Grove became part of the Sequoia, Kings Canyon National Park in 1940. Between 1935 and 1975 all or portions of many groves in private ownership, within the Sequoia National Forest, were acquired by

the U.S.D.A. Forest Service. One of the most significant acquisitions occurred in 1935 when over 20,000 acres, including Hume Lake, the Converse Basin, 10 other groves and the surrounding lands, were sold to the Forest Service for less than \$15.00 an acre. The purchase included the remnants of 11 redwood groves, logging camps, lumber, chutes, trestles and abandoned machinery. One grove included trees which had been felled and abandoned when the mill at Sanger burned. Hume Lake was full of stumps and sinker logs. The Forest Service undertook a monumental cleanup job, which was to last for more than twenty years.

Public acquisition continued with the State of California acquiring Mountain Home in 1946. By 1962, the Black Mountain, Freeman Creek, Long Meadow and Peyrone Groves had been added to the Sequoia National Forest.

Acquisitions were not without problems. There was heavy competition for the small amount of purchase funds available. Periodically, strong political opposition restrained acquisitions. While I was on the Sequoia National Forest in the 1960s, the General Accounting Office challenged a grove appraisal, stating there was no commercial market for Sierra redwood. We overcame that problem and the acquisition was completed, once again trying the patience of the willing seller. Other acquisitions reserved to the previous owner the right to cut and remove selected white woods for a period following the transfer of ownership. In many cases, the private owners had to wait for long periods for the tedious acquisition process to be completed. A few are still waiting!

Today 90 percent of the giant sequoia groves are in public ownership. Public acquisition of groves that remain in private ownership continues today.

Research

Significant research has been done on giant sequoias. Various individuals have and are making major contributions to what we know about the species. Unfortunately, there has not been a focused, continuous research program adequate to support all needs. Many opinions exist, but very little is known with certainty of long-term effects of the various management strategies. The National Park Service, the Forest Service, the University of California and the California Department of Forestry and Fire Protection as well as others have made significant contributions.

The National Park Service appointed a committee in 1986 and charged them with reviewing the history, current status and scientific basis for the sequoia/mixed-conifer fire management program. Following their report, a joint funding effort was undertaken by the National Park Service, the Forest Service and the Sequoia Natural History Association to support a comprehensive research program.

We are indeed fortunate to have as speakers and moderators many of the people who have made significant contributions to our knowledge of giant sequoias and their place in the ecosystem.

Grove Ownership

Ten percent of the groves are in private ownership. Three of these private groves are being managed for the production of forest products; three others are residential sites.

Another 14 percent are managed by the State of California Departments of Forestry and Fire Protection and Parks and Recreation, Tulare County, Bureau of Land Management, the Tule Indian Reservation, and the University of California.

The National Park Service manages 34 percent in Sequoia, Kings Canyon, and Yosemite National Parks, and the Forest Service manages 42 percent in the Sierra, Sequoia, Stanislaus and Tahoe National Forests.

Grove Management

Much has been done by the Federal and State agencies toward protecting and enhancing the giant sequoias under their jurisdictions. None of the agencies have, or plan to harvest or injure any of the large specimen giant sequoia trees. All are concerned over the difficulty in recruiting new giant sequoia trees into the overstory.

Management of giant sequoia by the various public agencies and private owners provides an opportunity for observation and evaluation of results of the different management strategies. Different techniques have been used in response to the various goals and grove conditions, as well as the preferences of managers.

The California Department of Forestry and Fire Protection has employed a combination of forest harvesting and prescribed fire for the Mountain Home Demonstration Forest. Management goals for the area are multiple use, with emphasis on recreation and perpetuation of groves.

The USDI National Park Service has employed prescribed fire as the primary tool to reduce fuel and return groves to natural fire regimes with a goal of restoring natural ecosystem processes. Prescribed fire practices are modified where public use and visitation are in conflict.

The Forest Service has used a combination of silvicultural practices and prescribed fire to achieve management objectives for about 10 percent of their groves. Other groves, which had been logged of both white woods and most specimen redwoods before acquisition, have been thinned and planted with redwood seedlings. Still other groves have received only custodial protection. The Forest Service has created some of the largest disturbances and have successfully established many young giant sequoias through planting and natural seeding. As for the Forest Service's logging of white woods in and around the groves, (which has been severely criticized by the Sierra Club and the Audubon Society), Piirto (1991)³ reports, "There appears to be no evidence that the recent logging of the 1970's and 1980's has resulted in

any major detrimental effects. While there are a few recent tree failures of specimen old-growth giant sequoias in, or near recently logged areas, there are equally as many or more old-growth tree failures in the National and State Parks where custodial protection and prescribed burning occur."

The Forest Service multiple use management direction has been modified by the mediated settlement agreement reached in 1990. The agreement removed sustained yield timber management as a grove objective for all but a portion of the Converse Basin Grove. Other multiple uses will continue. This agreement will be discussed in depth later in the program.

The California Department of Parks and Recreation largely relies on prescribed fire in managing the Calaveras Big Trees State Park; some fuel reduction work has also been done through hand labor. The University of California has used prescribed fire on a continuing basis at Whitakers Forest to thin the stand and reduce the fire load. Some selection harvest has also been practiced.

Increasing management activities by the agencies has brought some criticism and unsubstantiated claims of impending grove destruction. Some groups have proposed elimination of all management activities and suggested the groves be given monument status. The role of fire as a management tool for groves remains controversial. All forms of silvicultural practices which include the harvesting of white wood trees and thinning of young redwoods has been assailed, by some, as leading to grove destruction. Unfortunately, some political activists have worked hard to create a public perception that giant sequoia groves managed by the Forest Service are being devastated and soon no big trees will remain. This fabrication could lead to government action precipitated by environmental scare tactics and media sensationalism, resulting in over-regulating which will likely work to the long-term disadvantage of the grove ecosystems. We can ill afford manipulation of fact, somehow justified by the noblest of causes.

Issues for Discussion

A number of issues are ripe for discussion and resolution during and following this symposium. These issues and points of differences must have resolution if this symposium is to be useful in charting the future management of giant sequoia groves. The following questions should be given consideration:

- What is the best method to reduce the fuels which have built up in the groves during the years of fire protection? Certainly the variable conditions of individual groves will require a variety of prescriptions.
- How can the giant sequoia fire controversy be resolved? Prescribed fire has both positive and negative effects on the giant sequoia groves. Under what circumstances and to what intensity and frequency should fire be used within the groves?

³ Douglas D. Piirto's witness statement before the U.S. House of Representatives Committee on Interior and Insular Affairs, September 14, 1991.

- Which silvicultural practices should be employed in management of groves? When should thinned trees be used for commercial purposes?
- What is the best method to recruit giant sequoias into the overstory to provide future large trees in the stands? Failure to recognize the need and provide for recruitment will eventually lead to the reduction or loss of the old-growth giant sequoia stand component.
- Much of our understanding of sequoia ecology is based on limited research. How can we best establish and support a program of coordinated research, involving all interested parties? Funding and maintaining a research program in these times of tight budgets will be difficult and require widespread support.
- What is the best method to identify the successes, findings and failures from past management of giant sequoia groves? Mountain Home State Forest, Sequoia, Kings Canyon and Yosemite National Parks, Whitakers and Blodgett Forests, Sequoia, Sierra, Stanislaus and Tahoe National Forests, and other groves in public and private ownership, all offer opportunities for increasing our knowledge with respect to sequoia groves and associated ecosystems.
- Giant sequoia has been planted along with other species following logging on many National Forests in California and on the University and State Forests. It is common for giant sequoia to make up from 3 to 20 percent of the planting mix in the general forest zone of the west side of the Sierra Nevada on the National Forests and at Blodgett Forest. What should be done to promote the understanding of giant sequoia as a part of the commercially harvested species in areas outside the old-growth groves?
- Do giant sequoia groves need special legislated protection? Is present criticism of grove management really driven by a background goal of creating a Range of Light National Park, or as part of the effort to eliminate all timber harvesting on the National Forests in California?
- Which process or combination of processes is best for the long-term survival, restoration and perpetuation of the groves? The 75 groves are quite variable in composition, largely due to past activities but also because of soils, moisture conditions, associated species, and other factors. For example, the Forest Service has responsibility for a great variety of groves; some were acquired with the old-growth and other components intact; others were heavily logged with only a few old-growth trees remaining and now contain young giant sequoias; still others were acquired after the desirable white woods were removed and specimen redwoods were left standing. The various groves, irrespective of ownership, will likely require quite different management practices due to the great variability in stand structure, composition, management objectives and past activities in the groves. The influences of visitor use and the need for public understanding cannot be overlooked.
- The role of science in natural ecosystem management must include full consideration of human values, as well as of policy and political practicality. What's the best forum for bringing these together, so the long-term benefits accrue for the giant sequoia groves?
- What is the best method to gain recognition and understanding for all interested parties of the variability and complexities of the successional processes associated with giant sequoia groves?
- What is the best method to establish monitoring systems so that short and long term ecosystem changes can be measured to provide the feedback to managers and interested parties? These systems would provide opportunities for an evaluation of management's success in attaining grove objectives, or a basis for the modification of practices.
- The current discussion and conflict seems to focus on how to best preserve naturally occurring giant sequoia groves. But an equally important question should focus on how to manage giant sequoia groves including the establishment and recruitment of young giant sequoia trees into the overstory to become the giants of the future.
- What is the best method to re-establish a relationship between the public agency professionals and the outspoken interested public? This is a serious problem and will not go away unless it is dealt with openly and honestly.
- Outright preservation of groves, especially those within designated wilderness will most likely result in recruitment failures. This issue needs full discussion and understanding.
- What is the best method to bring about public acquisition of the groves that remain in private ownership?

Dialog Required

Some participants at this symposium have devoted the majority of their lives working with giant sequoias. There are also many attending this symposium who have gained knowledge and expertise regarding giant sequoia who are not on the program. This symposium provides an opportunity to join in a dedicated effort to learn more about giant sequoia and its place in the ecosystem. The information gathered here can then be applied to future research and management activities which will perpetuate the groves, restore the full ecosystem and provide for the recruitment of new dominant trees into the forest canopy.

Our society can afford to spend the resources to provide for the perpetuation of the magnificent giant sequoia groves. Perhaps John Muir said it best, "The Big Tree is Nature's forest masterpiece and so far as I know, the greatest of living things. It belongs to an ancient stock-and has a strange air of other days about it, a thoroughbred look inherited from the long ago-the Auld Lang Syne of trees."

Public Perceptions of Giant Sequoia Over Time¹

William Tweed²

Abstract: Public perceptions of the giant sequoia (*Sequoiadendron giganteum*) differ significantly from those of land managers. Members of the public tend to perceive sequoias as unchanging, sacred objects, not as dynamic members of evolving ecosystems. These perceptions strongly color public expectations about how giant sequoias should be managed, and thus must be taken into account by successful land managers.

Public land managers who perceive giant sequoia trees only as biological objects to be managed like other trees are missing an important point. Giant sequoias are not only biological organisms but also, at least to human beings, sacred objects with substantial psychological context. Much of the recent controversy surrounding the management of Big Trees results from this fact. In recent years, we have all too often managed the trees from a strictly biological point of view, ignoring in the process the emotional context that controls much of the public's reactions to our actions. The result of this biological focus has been that significant portions of the public have objected strongly to our management of the groves. This criticism is not leveled at any single managing agency. Whether we are talking about the problems the Forest Service has had with its giant sequoia forestry program, or the criticisms the National Park Service has received for its prescribed burning within the groves, the cause is the same—managers have failed to understand or credit the strong emotional feelings many citizens hold for the Big Trees.

Foresters, natural resources managers, and others trained in the modern biological sciences tend to perceive that giant sequoias in most respects are simply conifer trees, similar in most respects to their many arboreal cousins. Biologically, this is true. That which is distinctive about the sequoias is really fairly minor compared to that which is shared with other trees. With the exception of the fact that they grow larger than their neighbors and live longer than most other Sierra Nevada species, the giant sequoias are not biologically all that distinctive.

But this is not at all how the general public views the Big Trees. In the popular mind, as compared to the biologically trained scientific mind, size and age are of critical importance. These two attributes are readily accessible to the human imagination and tend to capture our interest. Think of the popular literature about the sequoias. How often do key phrases or ideas repeat themselves? "This tree

was alive before Christ was born." "This tree weighs as much as a dozen blue whales." "The world's largest living thing."

Most citizens see the giant sequoias not as just another expression of coniferous biological diversity, but rather as a unique life form with very special significance. Visitors to the groves are fascinated by the trees' "immense" size, "amazing" age, and "astounding" vitality. And each of these attributes resonates within the human psyche. Because we prize our own limited time on this planet, we admire organisms which persevere on a scale which grossly exceeds our own.

Adding greatly to the public sense of the Big Trees' significance is their perceived rarity. Again biology and popular perceptions diverge. Most visitors perceive the giant sequoias as extremely rare. Giant sequoia literature traditionally has emphasized this point: The sequoias grow "only in 75 remnant groves"; they are found "only in the southern Sierra Nevada and naturally nowhere else on earth"; they are "living fossils," surviving "only in a tiny part of their past range." These statements are true, of course, but again, they do not describe a unique situation. Numerous Sierra Nevada plant species exist within smaller geographical ranges than the giant sequoia, and many have evolutionary histories every bit as interesting. But these other species are seldom showcased in the way the Big Trees are.

The reaction of persons of European descent to the sequoias has been amazingly consistent since the trees were first publicized in the early 1850's. From the very beginning the public was fascinated by the trees' distinctive characteristics, and from these perceptions of uniqueness came motivation to protect the groves. It can be argued that during the 19th century no other plant species in North America motivated so much public curiosity, so much preservation concern and activity. Within a year of Dowd's discovery of the Calaveras Grove, the first of numerous exhibit trees had been cut and laboriously hauled away to a city for display. Throughout the remainder of the 19th century, curiosity remained high enough to justify repeated cuttings for urban display. Hollowed giant sequoia stumps became an expected highlight of world's fairs and major museums. Big Trees were displayed at the fairs at Philadelphia in 1876 and Chicago in 1893, two of the nation's biggest public events between the end of the Civil War and the beginning of the 20th century. In 1893, the American Museum of Natural History cut the Mark Twain Tree from what is now Kings Canyon National Park and hauled a cross section to its new building facing Central Park in New York City. A full century later, the huge cross section remains on display, still fascinating new generations of urban residents.

Even more impressive, in historical hindsight, was the power of the sequoias to motivate American citizens to reject all the political norms of 19th century laissez-faire

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²Chief of Park Planning and Concessions Management, Sequoia and Kings Canyon National Parks, National Park Service, Three Rivers, CA 93271.

land management policy. In the mid-19th century, when the groves were first discovered by European-Americans, this nation was at the very height of its expansionist pioneer era. With the sole exception of lands needed for national defense, all government lands were for sale, usually for a minimal price. Regardless of political affiliation or orientation, nearly all Americans agreed on the necessity of the privatization of government land and of the unfettered right of land owners to utilize their holdings as they individually saw fit. Yet, within a dozen years of the discovery of the Big Trees, and in total contradiction of the nation's political culture, Congress saw fit to set aside the Mariposa Grove and give it to the State of California to be managed in perpetuity for preservation and recreation. In hindsight, few students of conservation history or public land management realize just how radical the 1864 Yosemite Grant was within the political context of its times. It directly contradicted the entire land management ethic of the nation. Yet such was the power of the giant sequoias to motivate action.

As the last third of the 19th century passed in an orgy of public land give-away under such often-abused statutes as the Timber and Stone Act and the Swamp and Overflow Act, the giant sequoias retained their ability to motivate Americans toward resource preservation. In 1880, the Surveyor General of California, responding to local demands, unilaterally set aside the Grant Grove from sale while all the land around it was made available for logging. And in the late 1880's, California residents began a campaign to protect major parts of the sequoia belt which resulted in the 1890 creation of Sequoia and General Grant National Parks. Sequoia National Park, in fact, ranks second in age in the entire American National Park System. The importance of the giant sequoias so motivated 19th century citizens and their politicians that the designation of a federal park to protect the trees followed only the protection of Yellowstone's thermal wonders.

Not surprisingly, early managers of the reserves set aside to protect giant sequoias stressed the very characteristics of the trees that had originally captured the public's interest. Books, museums, and ranger lectures endlessly emphasized the trees' age, size, and rarity. To these values were added corollary values that would later come to haunt the late-20th-century managers of the groves. The sequoias were "enduring," "timeless," and "unchanging." Because their individual antiquity so exceeded individual human life spans, the perception that the trees did not change was extended back over the entire life history of the species. Biologists should have known better, of course, but most went along with the assumption. As late as 1973, a well-reviewed new book about the giant sequoias was entitled *The Enduring Giants*.

During the past 30 years, radical and necessary changes have occurred in giant sequoia management. Beginning in the early 1960's, the National Park Service began to move away from its founding philosophy of preserving objects to a management strategy based on preserving ecosystems. In

few areas was this change more applicable than in the management of giant sequoias. Because early National Park managers had accepted the idea that giant sequoias were enduring and unchanging, it was easy to manage them as individual objects. Trees were fenced to protect them from visitors; fires were suppressed. Every attempt was made to provide a stable and unchanging visual scene.

The arrival of ecosystem management in the National Park Service's sequoia groves challenged all these old values. Studies that began under Richard Hartesveldt in the early 1960's and have continued through a long sequence of researchers to this day repeatedly pointed out the fallacies in the old position. Neither giant sequoia groves nor individual trees were particularly "enduring" or "unchanging." Actually, the groves and trees were every bit as prone to change as the rest of the natural world. Repeated intense natural disturbances, particularly fires, had played a major role in determining forest structure, and climates had changed so dramatically over recent millennia that some groves were probably not much older than their oldest individual living trees.

Eventually both Forest Service and Park Service managers modified their management strategies to take into account their increasing knowledge of grove dynamics and history. In Park Service groves this new knowledge expressed itself mostly in the form of a highly visible prescribed fire program which aimed to make major changes in existing forest structure and return the groves to a more "natural" state. In Forest Service groves, similar motivations expressed within a multiple-use management context resulted in active forestry programs to remove "whitewoods" from the groves.

Rather quickly, both of these programs ran into significant public opposition. Public perceptions of the trees had not evolved in concert with changing management philosophies. While scientists and managers had begun to appreciate and even value the dynamic, flexible nature of the giant sequoia groves, most citizens remained comfortably wedded to the concept of Big Trees as enduring, unchanging sacred objects, largely unconnected to the ecosystems in which they resided.

This perception gap between giant sequoia grove managers, who are responding to what they define as biological imperatives, and significant portions of the general public, who have been taught that giant sequoias are sacred objects which transcend the normal limits of life, continues to haunt and to confuse the current world of giant sequoia management. The point of this paper is not to argue that one perception or the other is inherently superior. Instead, it is to assert that most managers, pursuing an ecological logic, have lost touch with mainstream public perception. In a democratic society, this situation is not sustainable, since managing agencies are ultimately dependent upon the goodwill of the public if they are to accomplish their (often self-defined) tasks.

Successful giant sequoia managers must respond to a number of perceptions held by the general public:

- To many (perhaps most) citizens, giant sequoias are not living organisms within ecosystems, but rather sacred objects transcending the normal limits of human perception.
- To many (perhaps most) citizens, the sequoias represent a model of enduring, unchanging nature.
- “Sacred object” status means to most citizens that the trees are to be “left alone”; corollaries include:
 - Tree cutting is very suspect, regardless of rationale, and ecological management of any type which changes human experiences (perceptions) usually unacceptable.

- And finally, for many citizens, the preservation of the giant sequoias as sacred unchanging objects transcends the usual issues which guide their judgments about natural resources management.

As we gather together to discuss the present and future management of these fascinating trees, I challenge you all to keep in mind the limitations placed upon us by these aspects of popular culture. Managers who ignore these perceptions are fated to suffer further controversies within their programs. A public which does not see sequoias as we do will likely continue to resist even the best-intentioned of management programs.

Sequoia Grove Preservation: Natural or Humanistic?¹

William Croft²

Abstract: Management of giant sequoias in the National Parks and on the National Forests has changed over the years, with a recent emphasis on "naturalness," including natural processes such as fire. Some difficulties in implementing this goal of a "natural" ecosystem, include the current incomplete knowledge of the sequoia grove ecosystem before Europeans arrived and the permanently altered and fragmented character of the contemporary Sierra Nevada ecosystem. Nevertheless, the goals of sequoia preservation are ultimately ethical choices made by modern human society, and those choices are formed through the interaction of government, nongovernmental organizations, and concerned individuals.

The Death of a Great Tree

I will begin with a story about the other redwoods, the coast redwoods of Northern California. It's a sad story, but it will be familiar to any of you who have gotten to know the giant sequoias well, or any other great tree. I've tramped through almost every old-growth coast redwood grove and without a doubt my favorite tree was the Dyerville Giant, which stood in a grove that is deemed sacred by most redwood lovers: a tree so tall, so huge and so healthy it was simply stunning. But the Dyerville Giant leaned, and early in the morning of March 25, 1991, it fell in a tremendous storm. On my annual return to California in May 1991, my wife and I traveled up to Humboldt Redwoods State Park to pay our last respects to the fallen Giant. It was a cool, drizzly May day, peaceful and still; the mist damped the sounds of the forest and our footsteps (as well as the freeway). We walked on the loop trail towards the Giant. The first thing we saw was the hole in the sky where the Giant once stood. That really drove home to us that the Giant was gone. The trail turned, and we saw the crater in the ground and the Giant's body. It really looked like a body, especially since we had so recently seen the Giant alive. My wife said, "I'm sorry that he had to fall in our lifetimes." I replied, "Yes, especially as we'd only just gotten to know him."

Fortunately, I haven't yet experienced the loss of any of the giant sequoias I've come to know and love in my wanderings around the groves of Sequoia National Forest and Sequoia National Park. I'm sure that I'd feel some of the same emotions. But these emotions are uniquely human. The other trees in the forest don't mourn the fall of the Dyerville Giant, or of an ancient giant sequoia. For them, the hole in the sky is a new source of light, for new seedlings and new growth on their branches. The animals of the forest also view the fall of the Giant in the same way—just something that happened, an opportunity perhaps.

Human Response or 'Nature-Minus-People'

Only people see the loss of a tree like the Dyerville Giant or the Wawona tree as something tragic. It's not a "natural" response, in the sense of nature-minus-people. The response of nature is to satisfy basic needs, not to preserve natural beauty just for the sake of its beauty. Natural processes include for instance the boom-and-bust cycles of the caterpillars that feed on the oak trees of the Coast Range, or the moose and wolves of the Boundary Waters region of Minnesota. The predators (caterpillars, wolves) overkill the prey (oak leaves, moose), and then their populations "collapse"—in other words, they starve—after which the prey overexpands until the predator population rises again. This is entirely natural, and these cycles are a demonstration that ecosystems aren't in a static, perfect balance. But notice that the oak moth caterpillars do not pass laws regulating the consumption of oak leaves in order to prevent the exhaustion of the natural resource, nor do they designate certain oak trees, or even branches of trees, as being of such outstanding value that they should be preserved for future generations. They simply eat them all until they run out. This is an example of how humans are different from caterpillars.

Of course, people do also have the same sort of response. After clearing the forests of New England, they moved to Michigan; after they cleared the forests of Michigan, they moved to California and the Pacific Northwest; now that those forests are nearly cleared, they are talking of moving on to Siberia (not to mention the tropical rainforests). When we run out of forests and a few other things, the population will collapse. This has already happened twice in history, once at the end of the Classical era in the 5th century A.D. and again at the end of the Medieval era in the 14th century, when population growth exceeded the resources available by the technology of the time (McEvedy and Jones 1978). And this "natural" response is not just a consequence of advanced technological societies; the Maoris of Polynesia finished off the moa and other native species of New Zealand, and some believe that the large mammals of Ice Age North America were hunted to extinction by the prehistoric people of that time. And of course we saw it in the sequoia groves as well. One-third of the sequoia groves were clearcut, including Converse Basin, one of the very finest groves. In many other sequoia groves, all of the whitewoods, including the sugar pines, the noblest trees of the Sierra Nevada after the sequoias, were clearcut, as recently as five years ago. Free-for-all economic behavior—exploitation to the extent allowed by technological ability and dictated by human need—is the human equivalent of a "natural" response: people

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²Assistant Professor, Program in Linguistics, University of Michigan, Ann Arbor, MI 48109-1285.

acting "naturally," similar to plants, animals and other living things in the ecosystem.

This definition of "natural" isn't, of course, the use of the word "natural" among those who are concerned with preservation of the giant sequoia groves, in both the national parks and the national forests. Their concern is one of nature-minus-people (more accurately, nature-minus-Europeans), that is, the attempt to restore the "natural" ecosystem as it was. Specifically, the Leopold Committee report on Wildlife Management in the National Parks (1963) states that 'the goal of managing the national parks and monuments should be to preserve, or where necessary to recreate, the ecologic scene as viewed by the first European visitors' (Bonnicksen 1988). This has meant not just recreating the state of the giant sequoia groves in 1833 when Zenas Leonard became the first European to see them (Engbeck 1973). It has also meant recreating the dynamics of the ecosystem at that time, and in particular the re-creation of sequoia regeneration must be recreated. In fact, some of the groves do not seem to be regenerating, and may die out in a couple thousand years (quite a long-range management point of view, I might add; consider the Roman Empire 2000 years later). Thus, to 'preserve the ecologic scene' of the sequoia groves, the emphasis in management has been to encourage giant sequoia regeneration. The primary way to do this in the National Parks has been through fire-both prescribed burns and naturally-ignited burns. This has led to a lot of fire in the forest (too much according to some), which has started public debate and also professional debate focused on fire management implementation.

The Ethics of Sequoia Management

The Forest Service's solution to the problem of sequoia regeneration was more drastic: instead of using fire to thin the trees that have allegedly choked off sequoia reproduction, it opted to log them and sell the timber. In fact, a clearcutting policy was instituted, which removed the last 50 years of sequoia regeneration as well. Now, I think that there is no natural process that would lead to the complete removal of all vegetation except for adolescent and mature giant sequoias, which is what happened in Sequoia National Forest between 1982 and 1987 (except perhaps the Mountain Home fire of 1297); but that's not the point. Clearly, the management policies followed by the Forest Service during that period were not "natural"; they were not intended to be, since the Forest Service wants to sell timber, not just preserve forests. But there really is only a difference of degree between the management policies of the Forest Service and the National Park Service.

If I take off my Save-the-Redwoods League hat and put on my linguistics hat for a moment, I can state that the verbs 'preserve' and 'recreate' both require a volitional agent to carry out the action described. The decision not to let the allegedly moribund giant sequoia groves become extinct in a

couple thousand years or so is a human choice. One could argue that it might be more "natural" to let them die out. After all, they barely survived the ice ages, and fossils tell us that other members of the redwood family simply didn't make it. But that's the wrong argument too: it is a human choice to let the groves die out (if that's what might really happen), or to let fuel loads increase, as they did during the period of fire suppression, or to let naturally-ignited fires burn. We can tell it's a conscious human decision; it is a policy that was formulated after much effort, and is now implemented and regulated.

This example shows the real problem with the "natural" argument. For better or worse, people are now part of the Sierra Nevada ecosystem. The Sierra Nevada ecosystem consists not only of the mixed-conifer forest with its giant sequoia groves, but also vast acres of cutover land (not all of which is coming back as second-growth forest), paved roads, Giant Forest Lodge, Fresno, air pollution, hundreds of thousands of RV's, millions of human feet, and all of the other components of the modern Sierra Nevada. And while we can still try to recreate the image of a giant sequoia grove of 1833 (including prescribed fire), as if it were an island in time surrounded by the modern human ecosystem, we cannot really separate the two. This is true at the ecological level, of course-we can't put a bubble around the groves to keep out the pollution from the Central Valley, for example-but it's also true at the human level. I for one cannot think about how to manage Giant Forest without first thinking that it's the last reasonably pristine major sequoia grove, since Converse Basin has been clearcut and Mountain Home has been logged of many of its whitewoods. Nor can I think of the management of the mixed-conifer forest in and around it without thinking that it is part of only a tiny fraction of the original old-growth mixed-conifer belt remaining, with much of the rest probably to be logged.

These thoughts all pertain to ethical values. If I say, for example, that we shouldn't let a prescribed burn or a permitted natural burn kill a mature giant sequoia because there just aren't that many of them left, I'm making an ethical judgement. It is equally an ethical judgement to *let* such a burn kill a mature sequoia. It may look natural in the narrow view of what is happening on those few acres of land, but not in the larger context of what has happened to the Sierra Nevada in the last 150 years. Human agency is the dominant force over nature today, and determines how the sequoias are to live: as timber (as in Converse Basin Grove in the 1890s, and also in the 1990s); as relics in a tree plantation (as in Long Meadow Grove in Sequoia National Forest); as part of a summer home community (as in the private Alder Creek Grove, and parts of McIntyre Grove in Sequoia National Forest); as commercial tourist attractions (how Mariposa Grove was formerly managed, and how parts of Giant Forest still are); or as fragments of America's wild past, as the Leopold Commission recommended-or as some combination of all of these.

A 'Land Ethic' for the Future

Giant sequoia management is an ethical act, a decision based on human values. People are not simply part of the Sierra Nevada ecosystem; the surviving fragments of the Sierra Nevada ecosystem are part of modern American society, a part that American society chose to keep. Enough people valued the preservation of the sequoias, and the Sierra Nevada forests in general, that forest reserves and national parks were established at the end of the nineteenth century. Enough people valued the preservation of the sequoia groves in their 1833 state that the National Park Service's management policy was established. Enough people valued the sequoia groves that the National Park Service's fire policy has been challenged and questioned in public forums, and there was legal action against the Forest Service that led to the mediated settlement agreement for Sequoia National Forest. For many of those people, this expressed what Aldo Leopold called the "land ethic" in which we treat sequoias and other living things as we do people: belonging to the world in their own right. The land ethic is, as the name implies, an ethic: it is part of our humanistic heritage. This is not the only ethical value that has led to the preservation of the giant sequoias and other natural treasures, however. For example, the ethic that our children's lives should be as rich as ours also values the preservation of the sequoias, as does also the ethic described forcefully by Fyodor Dostoyevsky in *The Brothers Karamazov*: 'Mankind can live without learning, without bread; only beauty is indispensable.'

Of course, ethical goals can only be accomplished through scientific means. Our choices as to what characteristics and natural processes of the sequoia forest to preserve or recreate are only the first step; how those choices are achieved owes a great deal to the scientific study of forest ecosystems, the role of fire, etc. But the scientific knowledge is a means to an end which is dictated by society. The Leopold Commission report is a public policy statement, not a scientific research paper. Public policy and the ethical values that lead to its adoption are choices that a society makes. Our society must choose whether to preserve the giant sequoias and other aspects of the Sierra Nevada forests, how much of them to preserve, and how to go about preserving them. In a democratic society such as ours, all voices can and should be heard. Society is not just the government agencies and legislators charged with carrying out the wishes of society, but nongovernmental organizations and concerned citizens who voice ethical values that are not always expressed through government officials. Only in this way can we be assured of choosing the best policy for managing the giant sequoias.

References

- Bonnicksen, Thomas M. 1988. Restoration ecology: philosophy, goals and ethics. *The Environmental Professional* 10: 25-35.
- Engbeck, Joseph H., Jr. 1973. *The enduring giants*. 3rd ed. Sacramento: California Department of Parks and Recreation.
- Leopold, A.S.; Cain, A.S.; Cottam, C.M.; Gabrielson, I.N.; Kimball, T.L. 1963. Wildlife management in the national parks. *America Forests* 69: 32-35 and 61-63.
- McEvedy, Colin; Jones, Richard. 1978. *Atlas of world population history*. Harmondsworth: Penguin Books; 361 p.

A Botanist's View of the Big Tree¹

Robert Ornduff²

Abstract: Although assigned to *Sequoia* for most of its taxonomic life, there is general consensus that the Big Tree merits its own genus (*Sequoiadendron*). Recent taxonomists have suggested that its traditional family (Taxodiaceae) should be merged with the Cypress Family (Cupressaceae), to comprise the expanded Cupressaceae. Like its redwood relatives, the Big Tree has an extensive fossil record and once had a wider range than at present. Its current range appears to have been rather recently occupied, and to have been shaped by Pleistocene glaciations and an extensive Xerothermic period a few thousand years ago. The maximum height and maximum mass of the Big Trees have been a matter of dispute, but both are exceeded by other organisms. Botanists, foresters, and the public continue to be impressed by the majesty of the Big Trees.

The invitation to present a paper about the Big Tree came as a surprise to me, since my own botanical work has been devoted mostly to annual herbs whose life span is counted in weeks or months. I can claim to be a true innocent, then, and what I know about the Big Tree has been learned from others. My view encompasses a number of features, including the interesting ecological relationships of the Big Tree and its attenuated genetic structure. But since these will be described by experts, I will say little about them and confine myself to topics which have not been covered by other contributors.

Naming the Big Tree

In 1852, San Francisco botanist Dr. Albert Kellogg was the first botanist to possess specimens of the Big Tree. Kellogg had intended to name this new species as the sole member of a new genus *Washingtonia* but delayed doing so. In 1853 he showed his specimens to English plant collector William Lobb, who had been sent to California by the prominent English nursery, Veitch and Sons, to locate promising California plants for British horticulture. After seeing Kellogg's specimens of the Sierran giants, Lobb traveled to the Calaveras County populations, collected seeds, herbarium specimens, and living seedlings, and departed with them for England. Lobb's material was shown to English botanist John Lindley, who named and described *Wellingtonia gigantea* on Christmas Eve, 1853. He named the tree after the Duke of Wellington, who had died a year earlier. Lindley wrote "Wellington stands as high above his contemporaries as the Californian tree above all the surrounding foresters" (1853a, 1853b). That an Englishman snatched from Californians the opportunity to name this tree after an American hero led botanical historian Joseph Ewan (1973) to remark that Lindley's choice of a generic name

"unleashed American cross fire that was to consume hundreds of pages for decades to come." Even today, British horticulturists refer to our Giant Sequoia or Big Tree as "Wellingtonia."

Although the impression was given that American botanists believed that Lindley had pulled a fast one by his expeditious scientific naming of the Big Tree, I am not convinced that his rush into print reflected anything other than excitement over what he had learned of the tree. He wrote "What a tree is this! -of what portentous aspect and almost fabulous antiquity!" (Lindley 1853a). To Lindley (1853b), as a horticultural subject the Big Tree promised to be an "extraordinary tree... of almost imperial aspect." We will never know whether Lobb told Lindley of his meeting with Albert Kellogg; if this tale has a villain, it might well be William Lobb. According to Ewan (1973) southern California botanist C.C. Parry, "who was evidently with Lobb at Monterey just before (he) set out for the Calaveras Grove, and therefore should have firsthand information, places almost criminal shades on Lobb's actions." At the time of this chauvinistic furor, American, British, and European botanists apparently were unaware that the name *Wellingtonia* was invalidly applied to the Big Tree, since 13 years earlier Swiss botanist Carl Meisner had applied it to a genus of tropical hardwoods. In 1855, French botanist Decaisne transferred the Big Tree to the genus *Sequoia*, a genus that had been established to accommodate our Coast Redwood.

For many decades after its discovery our Coast Redwood had passed as a member of the bald cypress genus *Taxodium*, but in 1847 Viennese botanist Stephan Endlicher recognized its distinctiveness and assigned the tree to a new genus that he called *Sequoia*. While the name *Sequoia* is believed to commemorate a prominent member of the Cherokee nation, it was published without any explanation of its derivation. The mystery of a Viennese botanist who had never visited the United States naming a genus after Sequoyah (otherwise known as George Guess) has been explained by Cook (1955): Endlicher was not only a botanist but a linguistic student as well, and was probably aware that in 1821 the man Sequoyah had invented an 86-character alphabet to accommodate the Cherokee language. Cook wrote that this invention and its impact on the Cherokee nation are "considered one of the cultural masterpieces of modern times." Thus, Endlicher the botanist commemorated an American who was not a botanist, but who came to his attention because of his interest in linguistics.

Most botanists writing about the Big Tree from the time of its scientific naming until well into this century have referred to it as *Sequoia gigantea*. In 1939, John Buchholz, a professor of botany at the University of Illinois, studied various botanical features of our coastal and Sierran redwoods and concluded that the several differences

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²Professor Emeritus, Department of integrative Biology, University of California, Berkeley, CA 94720..

between the two species were sufficiently strong to merit placement of the Sierran species in a distinct, new genus which he called *Sequoiadendron* (Buchholz 1939). It was not until a few years later that the difference in chromosome number between the two redwoods was discovered and added to the intergeneric distinctions. Botanists in California, however, found it irksome that a midwesterner should meddle with the nomenclature of one of our most cherished endemics. In an amusing article (not intended to amuse, apparently, but nevertheless humorous today), forester W.A. Dayton published a poll of California botanists in 1943, asking their opinions on the correct generic placement of the Big Tree and what they considered to be its correct species name (Dayton 1943). Before describing the results of this poll, I should mention that in 1943, as today, there was in force an internationally accepted code of botanical nomenclature, which, among other things, provides the legalistic basis for determining the correct specific name for a species. Acceptance of *Sequoiadendron* or continuing to recognize the Big Tree as a species of *Sequoia* is a matter of botanical opinion, but the code leaves little room for opinion as to which species name must be used in either genus. In 1943, the terms of the code apparently specified that as *Sequoia*, the Big Tree must be called *S. wellingtonia*; at least that was the interpretation of Roxana Ferris of Stanford and Lincoln Constance of Berkeley. Constance, however, preferred the name *S. gigantea*, though he said "we are all quite aware that this is a specific violation of the International Rules." (Dayton 1943). Kelsey and Dayton (1942) stated that the name *S. wellingtonia* was "unpalatable to the American people... There is every reason for believing that, Rules or no Rules, *Sequoia gigantea* will continue to be the name in general use." Bay Area botanists David Keck and John Thomas Howell both rejected the new genus *Sequoiadendron*; Jens Clausen suggested both redwoods should be returned to *Taxodium*! Southern Californian botanists Lyman Benson and Carl Epling, on the other hand, accepted the new genus *Sequoiadendron*, with Benson writing that "there is ample support for the segregation of *Sequoiadendron*." (Dayton 1943). Emmanuel Fritz, another northerner, wrote dramatically "I beg of you, on bended knee, don't accept Buchholz's new genus." (Dayton 1943). Current opinion favors the Big Tree as a member of its own genus, fully called *Sequoiadendron giganteum*. This status apparently is accepted by the diverse sponsors of this symposium. A more extensive account of the nomenclatural history of the Big Tree is given by St. John and Krauss (1954).

Family Position of the Big Tree and Its Relatives

The family status of the bald cypress family (Taxodiaceae), to which redwoods are traditionally assigned, has been challenged from time to time. In 1976, a graduate student of mine, Jim Eckenwalder, although not working on redwoods or conifers for his dissertation, published a carefully reasoned

and fully documented analysis that proposed merging the Taxodiaceae with the cypress family (Cupressaceae), which single collective family would have to be called the Cupressaceae (Eckenwalder 1976). Eckenwalder argued that cypresses (*Cupressus*) and the southern hemisphere genus *Callitris* of the cypress family are as closely allied to the redwoods as the redwoods are to other members of the Taxodiaceae, and thus assigning these genera to two families is unsound. So far as I can tell, Eckenwalder's proposal was not accepted by subsequent taxonomists. A decade later, Harvard botanist Jeffrey Hart published a cladistic analysis of conifers and concluded that "if one chooses to recognize the Cupressaceae... at the family rank, then the Taxodiaceae cannot be recognized" (Hart 1987). Hart thus supported Eckenwalder's proposal. More recently, another graduate student of mine, Bob Price (whose doctoral dissertation dealt with wallflowers and not conifers), working with Jerold Lowenstein at the UC Medical Center in San Francisco and using immunological techniques, supported a merger of the two families. These workers pointed out that in a single family, members of the Cupressaceae and Taxodiaceae would be scattered, and that collectively the group represents a single evolutionary lineage (Price and Lowenstein 1989). All these researchers have suggested a very close relationship between *Sequoia* and *Sequoiadendron*, a pair of genera closely related to the Asian genus *Metasequoia*. Two years ago, Hart and Price (1990) merged the two families, saying that "the two families are held together by an impressive number of morphological characters" and that the Cupressaceae, taken in the broad sense to include the Taxodiaceae, are "a natural group quite distinct from other families of conifers." Since these views were published in an influential arboretum journal I suspect they will be taken seriously. You might be interested, however, to learn that in the newly revised Jepson's manual of California plants, the two families are kept apart (Hickman 1993). There is still much to be learned about our redwoods, and new ways for botanists to think about them.

Evolutionary History of the Big Tree

Redwoods are well represented in the fossil record, although the discovery of *Metasequoia*, named in 1941, and its earlier confusion with *Sequoia* in the fossil record necessitated a revision of ideas concerning the past history of the latter genus. At one time, the redwoods and their allies were conspicuous members of the forest vegetation of much of the northern hemisphere. In time, the distribution of most of these trees contracted considerably, leaving remnants in North America, represented by our two redwoods and the bald cypress (*Taxodium*) and in eastern Asia, represented by the Dawn Redwood (*Metasequoia glyptostroboides*) and a few other genera. Fossils attributed to *Sequoiadendron* are known from several localities in what are now the western and eastern United States, Greenland, Spitsbergen, Europe, the British Isles (Florin 1963) and eastern Asia (*vide* Axelrod 1986). The tree, or an ancestral species, persisted in the Old

World at least until the late Oligocene, about 30 million years ago (Florin 1963). In North America, Big Tree antecedents had a wider range than did those of the Coast Redwood, which appears always to have been restricted to the western portion of the continent.

Thanks to the extensive work of paleobotanist Daniel Axelrod (1956,1959,1976,1986) much has been written about the history of the Big Tree in western North America. Axelrod has studied fossil remains of *Sequoiadendron* and has found that prior to migrating to California, this genus grew in Nevada where an oak woodland/chaparral/conifer forest mosaic existed in a mild climate with year round precipitation between 25 and 35 inches. These Nevada populations occurred in ecological and floristic settings that can be more or less duplicated in parts of the lower margin of the current range of the species in the southern Sierra Nevada. The rainfall at the modern sites is much lower, however, than that postulated for the Nevada localities and the winters are much more severe. The higher rainfall in its former habitat may explain the current preference of the Big Tree for moister sites, where enhanced soil moisture conditions compensate for lower rainfall. Axelrod (1986) has suggested that with the increasing continentality of the climate of interior western North America and the gradual rise of the Sierra Nevada and the development of its spectrum of climates on the western slopes, the Big Tree disappeared from its former interior range and its increasingly inhospitable climate, and migrated westward to the young Sierra Nevada, where it had arrived by 7 million years ago. By 6 million years ago, the Big Tree community was termed "near modern" (Axelrod 1986). At that time there were a few plant associates growing with the Big Tree which have subsequently disappeared from the area, such as cypresses and an elm.

Although over a century ago John Muir (1876) suggested that the modern distribution of the Big Tree was shaped by the Pleistocene glaciations, Axelrod (1986) believes that the present discontinuities that characterize the range of the species were also strongly affected by a dry, warm climatic regime (a Xerothermic period) that occurred between 8,000 and 4,000 years ago. Gloomy about the future of the Big Tree, Axelrod wrote in 1986 that "the scattered stands of the Sierra redwood are certainly on the road to extinction. This is the result of continued fire suppression by the U.S. Forest Service and National Park Service... Unless the forest groves are opened by clearing, or controlled burning, these forest giants-some of which are over 3,000 years old, and whose ancestry reaches back fully 70 million years-will all be gone within a few hundred years, or possibly less."

Features of the Big Tree

Certainly the most impressive features of the Big Tree to both botanists and the public are the enormous mass and great age of the trees. Harvard botanist Asa Gray visited the Mariposa and Calaveras groves in 1872 and referred to the

Big Trees as the "wonder of the world" and commented on "their singular majesty" (Gray 1872). Gray's contemporary, botanist Sereno Watson, wrote in 1880 that both our redwoods are "remarkable and noted" (Watson 1880). And, early in this century, California botanist Willis Linn Jepson (1923) wrote of "standing in rhapsodical admiration" before a Big Tree. Even foresters such as Gifford Pinchot (1900) have expressed admiration for the Big Trees as "the grandest, the largest, the oldest, [and] the most majestically graceful of trees...". He pointed out that, at the time, "the majority of the Big Trees..., certainly the best of them, are owned by people who have every right, and in many cases every intention, to cut them into lumber." Based on second-hand information, Pinchot reported that a specimen called Starr King in the Calaveras Groves was 360 feet tall (Pinchot 1900). Jepson (1923) gave 331 feet as the maximum height, which he said is "a figure in excess of any measurements hitherto given which have been made by presumably accurate methods." Munz (1959) gave 100 meters (328 feet) as the maximum height. In any event, the tallest trees are or were taller than the Statue of Liberty or Berkeley's campanile.

The maximum volume of the largest trees is said to be about twice that of the largest individuals of the Coast Redwood. The total mass of a very large Big Tree has been estimated variously; the maximum figure I have found is somewhat over 6,000 tons (Engbeck 1973). The greatest age is about 3,300 years. When we speak of age, however, we must remember that no living cell in a Big Tree is over a few decades old, and that the living tissues of the tree form a shell over a dead, wooden interior of greater mass and age. There are plants in California that are older, depending on how age is described. An extreme example is a clone of Creosote Bush (*Larrea divaricata*), the so-called "King Clone," estimated to be about 12,000 years old (Vasek 1980). The individuals of this "specimen" are physically separated from each other, but are believed to represent the clonal descendants of a seedling that established itself in the desert about 12,000 years ago, the time at which the first Creosote Bushes may have invaded the North American continent from South America.

The Big Tree's mass also may be much exceeded by other organisms. Recently, in northern Michigan, a fungus was discovered whose "body" occupies an area of about 30 acres, and which weighs over 20,000 pounds (Smith and others 1992). Critics have pointed out, however, that Big Trees and Blue Whales have "relatively determinate growth within a defined boundary," whereas this gargantuan fungus does not (Brasier 1992), and thus "its status as a champion organism depends upon one's interpretation of the rules."

The history of the scientific discovery and naming of the Big Tree is a fascinating one. The present consensus of plant taxonomists is that *Sequoiadendron* merits generic distinction from *Sequoia*, although the proposed well-argued merger of the bald cypress family (Taxodiaceae) into an expanded cypress family (Cupressaceae) will doubtless meet continued resistance by botanists and foresters.

The Big Tree is a member of ancient evolutionary lineage and currently persists in a series of scattered groves along the western slopes of the Sierra Nevada. Its continued well-being will require intelligent vegetation management practices on the part of the Federal and state agencies that are custodians of this remarkable botanical relic. The size and age of the Big Trees, each exceeded by other species, continue to impress scientists and the public alike. I join W.L. Jepson in his "rhapsodical admiration" of these formidable giants.

References

- Axelrod, Daniel I. 1956. Mio-Pliocene floras from West-Central Nevada. University of California Publications in Geological Sciences 33: 1-322.
- Axelrod, Daniel I. 1959. Late Cenozoic evolution of the Sierran Bigtree forest. *Evolution* 13: 9-23.
- Axelrod, Daniel I. 1976. History of the coniferous forests, California and Nevada. University of California Publications in Botany 70: 1-62.
- Axelrod, Daniel I. 1986. The Sierra Redwood (*Sequoiadendron*) forest: end of a dynasty. *Geophytology* 16: 25-36.
- Brasier, Clive. 1992. A champion thallus. *Nature* 356: 382-383.
- Buchholz, John T. 1939. The generic segregation of the sequoias. *American Journal of Botany* 26: 248-256.
- Cook, Lawrence F. 1955. The giant sequoias of California. Washington: United States Government Printing Office; 28 p.
- Dayton, W.A. 1943. The names of the giant sequoia. *Leaflets of Western Botany* 3: 209-219.
- Eckenwalder, James E. 1976. A re-evaluation of Cupressaceae and Taxodiaceae: a proposed merger. *Madroño* 23: 237-256.
- Engbeck, Joseph H. 1973. The enduring giants. Berkeley: University California Extension; 113 p.
- Ewan, Joseph. 1973. William, Lobb, plant hunter for Veitch and messenger of the Big Tree. University of California Publications in Botany 67: 1-36.
- Florin, Rudolf. 1963. The distribution of conifer and taxad genera in time and space. *Acta Horti Bergiani* 20: 121-312.
- Gray, Asa. 1872. Sequoia and its history. The relations of North American to northeast Asian and to Tertiary vegetation. *Proceedings of the American Association for the Advancement of Science* 21: 1-31.
- Hart, Jeffrey A. 1987. A cladistic analysis of conifers. *Journal of the Arnold Arboretum* 68: 269-307.
- Hart, Jeffrey A.; Price, Robert A. 1990. The genera of Cupressaceae (including Taxodiaceae) in the southeastern United States. *Journal of the Arnold Arboretum* 71: 275-322.
- Hickman, James C., ed. 1993. The Jepson Manual: Higher Plants of California. Berkeley and Los Angeles: University of California Press; 1400 p.
- Jepson, Willis Linn. 1923. The trees of California, 2nd ed. Berkeley: Associated Students Store; 240 p.
- Kelsey, H.P.; Dayton, W.A., eds. 1942. Standardized plant names, 2nd edition. Harrisburg: J.H. McFarland Co.; 675 p.
- Lindley, John. 1853a. [Untitled]. *Gardeners' Chronicle* 52: 819-820.
- Lindley, John. 1853b. New plants. *Gardeners' Chronicle* 52: 823.
- Muir, John. 1876. On the post-glacial history of *Sequoia gigantea*. *American Association for the Advancement of Science Proceedings* 25: 242-253.
- Munz, Philip A. 1959. A California flora. Berkeley and Los Angeles: University of California Press; 1681 p.
- Pinchot, Gifford. 1900. A short account of the big trees of California. United States Department of Agriculture Division of Forestry Bulletin 28; 30 p.
- Price, Robert A.; Lowenstein, Jerold M. 1989. An immunological comparison of the Sciadopityaceae, Taxodiaceae, and Cupressaceae. *Systematic Botany* 14: 141-149.
- Smith, Myron L.; Bruhn, Johann N.; Anderson, James B. 1992. The fungus *Armillaria bulbosa* is among the largest and oldest living organisms. *Nature* 356: 428-431.
- St. John, Harold; Krauss, Robert W. 1954. The taxonomic position and the scientific name of the Big Tree known as *Sequoia gigantea*. *Pacific Science* 8: 341-358.
- Vasek, Frank. 1980. Ancient creosote bush rings in the Mojave desert. *Fremontia* 7: 10-13.
- Watson, Sereno. 1880. Botany of California, vol. 2. Cambridge: University Press; 559 p.

Selected Perspectives on the Giant Sequoia Groves¹

Dwight Willard²

Abstract. Several perspectives on the groves are briefly treated. Broader appreciation is needed of the giant sequoia groves which are not famous and easily accessible. The USDA Forest Service administers the largest single ownership of natural giant sequoia grove acreage. The giant sequoia groves have major resource values in addition to old-growth giant sequoias. Certain giant sequoias should be considered rare plants. Giant sequoia groves that suffered major sequoia logging retain sequoia values. Converse Basin Grove is globally significant. Manipulated widespread forest canopy destruction is not necessary to perpetuate giant sequoia groves. Much basic research regarding giant sequoia resources is lacking, and the giant sequoia literature contains a surprising amount of misleading information. Public participation is needed in giant sequoia management.

Aside from the usual perspectives of awe and fascination concerning old-growth sequoias (*Sequoiadendron giganteum*), my studies have given me several perspectives on sequoia resources and management options that are not commonly expressed in much of the sequoia literature. A cursory treatment of several of these perspectives is probably a more useful contribution to the proceedings of the Giant Sequoia Symposium than a single topic paper.

Everything that I have to contribute regarding the giant sequoias begins from my belief that they are an incredible, inspirational natural resource that is very uplifting to research and discuss. The great majority of the primeval old-growth sequoias survived the sequoia logging era. Where the sequoias and other grove old-growth were logged, the groves can regain their old-growth forest character. The sequoia groves are a marvelous, cheering exception to the often gloomy assessments of the world's deteriorating natural resources. With proper protection and management the groves can provide more public recreation and enjoyment than at present, without resource degradation. There is no more likely environmental issue on which to build a positive management consensus.

The groves cover such a small total geographic area they can be protected without the sort of controversy and economically painful trade-offs associated with issues such as how to preserve the northern spotted owl in millions of acres of Pacific Northwest forest. Total natural sequoia grove acreage is less than 40,000 acres. Supplementary unpublished sequoia location data which has become available since 1975 confirms the earlier findings of such limited sequoia acreage in Hartesveldt and others (1975) and Meyer and others (1952).

¹An abbreviated version of this paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

²Attorney and author of a reference book on giant sequoia groves.

Broader Appreciation of Sequoia Resources Is Needed

Despite the fame of the sequoia as a species, most of the sequoia groves are relatively unknown to the public. Visitors flock to several famous and easily accessible groves such as North Calaveras Grove (Calaveras Big Trees State Park), Mariposa Grove (Yosemite National Park), Grant Grove (Kings Canyon National Park), and Giant Forest (Sequoia National Park). These highly visited groves are wonderful, with their many named huge sequoias and the cultural heritage of providing recreation for thousands ever since they became easily accessible in the 19th century. But it is also wonderful to realize that they are only a small fraction of the sequoia resources. Unpublicized groves, unfrequented by tourists and generally ignored in past sequoia literature, have majestic old-growth sequoia resources that are comparable to those in some famous groves.

Most of the less publicized groves are in Sequoia National Forest. In part, their obscurity understandably results from tourists and researchers giving more attention to preeminent National Park groves. But the lack of publicity about Sequoia National Forest groves also largely results from past, de facto, unofficial Sequoia National Forest policy not to publicize their groves or encourage recreation in them. Strangely, one has to learn of the sequoia wonders of Sequoia National Forest by exploring like a 19th century pioneer, because written reference material, sequoia inventory information, useful grove maps, interpretive activities, and even detailed published access information on the Forest's groves are almost nonexistent (as of June 1992). Very few of the Forest's groves have any maintained trails. Sequoia National Forest groves were not even described in the current Sequoia National Forest management plan documentation (Sequoia National Forest 1985, 1988). Nonetheless, that so many of the sequoia groves are so little known is still surprising, considering their magnificent resources.

Some of the notable unpublicized sequoia resources of Sequoia National Forest are the following:

A. Freeman Creek Grove: This is the largest generally unlogged grove on National Forest land and one of the finest of all old-growth groves. Most of it is in wilderness condition.

B. Black Mountain Grove: This grove (which extends into the Tule River Indian Reservation) is one of the ten largest groves in the Sierra Nevada. Much of the grove has a very high density of surviving mature and old-growth sequoias, though it has lost an overall old-growth character from past logging.

C. Evans Grove: This large grove has dramatic Kings Canyon and peaks of the Monarch Divide and distant Sierra

Crest as scenic backdrops. The unlogged east section has a very high density of old-growth sequoias. Much of the western part of the grove was heavily logged before 1920 in a fascinating railroad logging episode. Old-growth stumps and vestiges of the early logging era give the grove unusual historical interest. Much of the logged section has recovered a scenic forest cover, including abundant young sequoias, mixed with scattered old-growth survivors.

D. McIntyre Grove: This is another large grove with a high density of surviving old-growth sequoias. It is part of the viewshed of Highway 190 east of Camp Nelson.

E. Packsaddle and Kennedy Groves: These are medium-sized, trailless, wilderness condition groves, which remarkably survive in old-growth condition adjacent to heavily logged non-grove timberland. These groves exemplify how even smaller groves can serve as impressive preserves of old-growth mixed-conifer forest, as well as sequoia preserves. Kennedy Grove has the ninth largest known sequoia (the Ishi Giant, discovered by the author in 1993, size ranking and volume computation by Wendell Flint) (*fig. 1*). Packsaddle Grove has numerous exceptionally large specimens, including the Packsaddle Giant, a sequoia with a larger base than the General Sherman Tree (Flint 1987).

Even within National Parks, many major grove resources are relatively unknown. In particular, the relative remoteness of many Sequoia National Park groves has discouraged visitation and study. About 15 of the Park's groves are accessible only by rugged, sometimes even hazardous, cross-country routes. Park groves without trail access include Eden Creek Grove, one of the largest Park groves, and smaller Oriole and

Suwanee Groves, which are known for having unusual concentrations of exceptionally large specimens.

It is important to emphasize that the USDA Forest Service has the largest single ownership of sequoia grove acreage (Author's calculations, confirming Meyer and others 1952) because some past academic authorities (e.g., Hartesveldt and others 1975) and outdated public agency interpretive materials (e.g., 1993 display at Sequoia-Kings Canyon National Parks' Grant Grove Visitor Center) have incorrectly maintained that most grove acreage was in National Parks. Such error fosters the mistaken impression that most grove acreage was protected by a legislative mandate that groves should be managed only for National Park purposes, which exclude commercial timber harvest. No such legislative protection exists for the National Forest groves, as illustrated by heavy logging of several Sequoia National Forest Groves for non-sequoia timber in the 1980's. In the absence of protective legislation, the only way to protect National Forest Groves is through the USDA Forest Service planning and land management process.

Non-Sequoia Resources within Groves

Sequoia groves have major resource values worthy of preservation aside from the old-growth sequoias. However obvious this perspective sounds, it has been lacking in much commentary on groves which focused preservation concerns solely on old-growth sequoias. A narrow view of grove resources has been expressed, for example, in disinterest or disdain for current resources of logged groves. In agency



Figure 1—Ishi Giant, Kennedy Grove. Though severely burned, this remote giant is 25.5 ft dbh counting buttresses, thicker than the General Sherman Tree. It was not definitively identified and measured until 1993, which suggests that other distinctive sequoia resources are yet to be discovered.

management, the narrow perspective resulted in heavy grove logging for non-sequoia conifers as recently as 1986.

Aside from their mature sequoias, many groves have some of the best remaining non-sequoia old-growth mixed-conifer forest in the Sierra Nevada and many of the largest individual pine, white fir, and incense cedar specimens. Old-growth groves also provide valuable wildlife habitat for southern spotted owl and other old-growth dependent species. This is particularly true in several grove areas (e.g., Long Meadow Grove) which are now small islands of old-growth surrounded by area in which logging has virtually eliminated old-growth habitat. Also, maturing young sequoia stands, most conspicuous in groves logged during the sequoia logging era, are a major resource not to be taken for granted. Some relatively "young" post-logging sequoia regeneration is now over a century old and larger than typical non-sequoia old-growth conifers.

The non-sequoia values within sequoia groves have been well publicized on occasion. For example, the need for protection of the exceptional old-growth sugar pines of the South Calaveras Grove area was stressed in the successful 1950's campaign for public acquisition of that grove. Non-sequoia values in groves are recognized in National Park and State Park protective management policies.

In contrast, 1980's grove management planning by Sequoia National Forest characteristically devalued non-sequoia grove resources, except as commercial timber. The apparent management assumption, permitted by applicable regulations, was that sequoia groves could be intensively logged, so long as old-growth sequoias were preserved. An example of the Forest's devaluation of non-sequoia resources was the heavy 1980's "whitewood" (non-sequoia conifers) logging in Black Mountain Grove. The logging fragmented a large block of old-growth forest wildlife habitat and cut some of the largest individual sugar pine specimens on the Forest, aside from scenic degradation and other drawbacks of clearcut logging. But the planning documents for that timber harvest did not even identify or discuss the issues of wildlife habitat fragmentation or elimination of rarely large conifer specimens (Sequoia National Forest 1983). Another example of past oversight of grove resources was Forest Service failure to discover that Starvation Creek Grove had an active California condor nest. Condors there were discovered only during 1984 logging operations.

The largest diameter southern Sierra Nevada sugar pine specimen that I am aware of (about 9 ft diameter at the cut) was harvested in the 1980's Black Mountain Grove logging. That may have been the largest sugar pine in Sequoia National Forest. Even if it was not, it was an extremely rare tree of scientific value. Nine-foot dbh (diameter at breast height, i.e. 4.5 ft above the high point of the ground) sugar pine in the southern Sierra, if any still exist, are almost certainly rarer than even 20 ft dbh sequoias. Such exceptional non-sequoia conifers in sequoia groves deserve to be inventoried and protected. They should not be categorized as nondescript commercial timber in Forest Service planning.

Such trees may also be of commercial forestry value as a seed source if they are blister rust resistant.

To my knowledge, no Sierra Nevada national forest identified preservation of exceptionally large non-sequoia conifer specimens as a general issue or goal in their Forest Plans prior to January 1993, when interim guidelines were issued by the California Regional office of the Forest Service in order to protect conifers at least 30 inches dbh from logging in certain southern spotted owl habitat. Current interim protective policy should not erase memory that the 1993 management imperative for protection of old-growth spotted owl habitat and large individual conifers was not yet an official posture at the 1992 Giant Sequoia Symposium, and hardly considered in Sequoia National Forest grove management planning less than a decade earlier.

Many sequoia groves have lost much or all of their overall old-growth forest character because of past logging of non-sequoia conifers. "Whitewood" logging has been far more extensive in groves than logging of sequoias themselves. The amount of sequoia grove acreage which is generally old-growth forest habitat is considerably less than the acreage in which the old-growth sequoias themselves survive. Beyond the groves, huge old-growth ponderosa and sugar pine specimens have been logged almost to extinction in every accessible, unprotected area of the Sierra Nevada west slope. The remaining non-sequoia old-growth pine, fir, and incense cedar growing with the sequoias should be treasured, just as the old-growth sequoias themselves. The sequoia groves where such large old-growth specimens remain provide some of the best remaining opportunities to preserve areas of high quality mixed-conifer old-growth forest.

Sequoias as Rare Individual Plants

Sequoias are not generally thought of as rare plants, in the sense of being extremely limited in total population. This is an oversight with respect to the exceptional, largest size specimens (e.g., >15-16 ft dbh). In my view, the total population of a few thousand sequoias in the largest size classes is so limited that each such specimen should be valued as an individual rare plant, rather than just as a generic example of a mature sequoia type.

It is not surprising that sequoias, considered as an undifferentiated species, have not been perceived as rare. Sequoias are abundant within many of their natural groves, and young planted sequoias thrive in many sites outside of the natural groves. However, sequoias should not be considered merely as a relatively undifferentiated species. Unfortunately, that has been a common practice. Except for recognition of famous, near-record size specimens (range-wide or locally), land managers and writers on sequoia subjects have tended to casually lump sequoia subpopulations into two broad categories, old and young. More specifically, reference is made to "mature" or "old-growth" sequoias, the focus of awe and conservation concerns, on the

one hand, and "young" sequoias (also commonly referred to in the context of logged lands as "regeneration" or "second growth") on the other hand. There is typically not much discussion of the differences within each of these two broad categorizations, with regard to the natural groves.

In particular, the sequoia literature and grove management documentation do not contain much discussion of the differentiation among types (or subpopulations) within the various size classes of the category of "mature" or "old-growth" sequoias. For example, 1980's National Forest regulations classified sequoias as either "specimen" trees (those at least 8 ft diameter 6 ft above ground, which were protected from cutting) or as smaller trees which could be cut. (See Sequoia National Forest 1985 Environmental Impact Statement glossary and Forest Service Manual Sec. 2471 as of 1985.) National Park and Forest Service regulations do not differentiate among the largest sizes of "specimen" sequoias (except possibly for a few famous named trees), either in terms of resource values or management prescriptions. Yet, in the field, who does not recognize the striking difference between a relatively common 8 or 9 ft dbh "specimen" (which in highly favorable circumstances could be as young as 200-300 years old) and a singular, wonder-of-the-world, 20+ ft dbh (and 1,500+ years old) specimen? The obvious difference in kind should be reflected in evaluations of sequoia resources and in management prescriptions.

Mature sequoias are not a homogenous group. When the sequoia population is considered in terms of its subpopulations within various size classes, it is clear that the exceptionally large sequoia specimens (e.g., >15 ft dbh), which most engender awe of the species and represent it in the public eye, are actually very unrepresentative of the total large sequoia population. In particular, the erratically scattered population of the few thousand largest individual sequoias is so limited that it is reasonable to consider each of them to be a rare plant.

Despite the largely incomplete state of available sequoia inventory data, enough data exist to support my conclusion that there are now fewer than 5,000 individual sequoias which are at least 15 ft dbh. More narrowly defined subpopulations of larger diameter sequoias (>16 ft dbh, >17 ft dbh, etc.) decline dramatically in absolute numbers compared to smaller diameter class subpopulations of mature trees (e.g., see sequoia inventory data for Sequoia and Kings Canyon National Parks, Hammon, Jensen, and Wallen Associates 1964, 1970, 1975, 1976, Western Timber Service, Inc. 1970.). By my calculations, fewer than 800 sequoias in the entire Sierra Nevada are now at least 19 ft dbh. Sequoias 20 ft dbh or larger are extremely rare. Fewer than 75 sequoias are now 22 ft dbh or more, scattered among less than a quarter of the groves.³

To better appreciate the rarity of the largest size classes of sequoias, one should consider that, even in an unlogged grove, sequoias at least 10 ft dbh, though common, are almost always a relatively small minority of the sequoias >1 ft dbh in the grove. They are usually also a minority of the large

(e.g., at least 5 ft dbh) sequoias in the grove. Such 10 ft dbh or larger sequoias, though common in unlogged groves, are not representative of the "average" or typical large sequoia.

Sequoias at least 10 ft dbh were found to be less than 20 percent of the sequoias at least 1 ft dbh in two very large old-growth groves in Sequoia-Kings Canyon National Parks (18.3 percent in the National Park section of Garfield-Dillonwood Grove and 16.9 percent in the National Park section of Redwood Mountain Grove). Sequoias at least 10 ft dbh are usually still less than 50 percent of the subpopulation of sequoias at least 5 ft dbh in unlogged old-growth groves (e.g., 48 percent in Giant Forest, 43.1 percent in the National Park section of Garfield-Dillonwood Grove, and 37.3 percent in Muir Grove). Sequoias at least 10 ft dbh were only about 19.1 percent of all sequoias at least 1 ft dbh, and only about 46.2 percent of those at least 5 ft dbh in the total sequoia inventory of the largest available sequoia inventory data base—that for all Sequoia and Kings Canyon National Parks' groves (inventoried 1964-76).⁴

By my calculations, the entire Sierra Nevada population of sequoias at least 10 ft dbh is certainly lower than 25,000 trees, and probably lower than 22,000. (The comprehensive Sequoia and Kings Canyon National Parks' sequoia inventory identified 10,184 sequoias as at least 10 ft dbh.) The total is almost certainly steadily increasing in recent times. At present, significantly more sequoias are growing to 10 ft dbh or larger than the number of sequoias that size that die, in the Parks and probably among almost all groves.

Sequoias at least 15 ft dbh are truly exceptionally large examples of the species. Relatively few mature sequoias that have attained literally "giant" proportions at least 10 ft dbh have grown to 15 ft dbh or larger. For example, the full Sequoia-Kings Canyon National Parks' sequoia inventory showed that only 2,463 specimens there were at least 15 ft dbh. This total was only about 24.1 percent of those at least 10 ft dbh, and only 11.2 percent of those at least 5 ft dbh.

³Present lack of comprehensive sequoia inventory data for more than 35 percent of the grove area (by my calculation) prevents exacting estimates of all sequoia size class subpopulation ranges. (Most Sequoia National Forest groves lack comprehensive inventory data.) But enough unpublished data cumulatively exists (from numerous sources) to support reasonable estimates of subpopulations within approximate ranges for the exceptionally large size classes of sequoias in the entire range.

All sequoia inventory statistical analysis in this paper concerning Sequoia-Kings Canyon National Parks' groves is derived from the inventory data in Hammon, Jensen, and Wallen Associates (1964, 1970, 1975, 1976) and Western Timber Service, Inc. (1970), and from unpublished summary data concerning those inventories which was prepared by National Park Service staff, and which is on file at Ash Mountain offices, Sequoia National Park. In those inventories, sequoia diameters larger than 1 ft dbh were rounded to the nearest foot. This rounding-off is reflected in my discussion of that inventory. I also relied on the summary data computations, from the Park Service staff, of individual and overall grove acreages. These reflected the area of actual sequoia occurrence, rather than all area within a grove perimeter, which is often larger.

⁴Inclusion of the inventory data for the small amount of the Parks' grove area that was historically logged only slightly skewed the total sequoia inventory towards smaller size classes.

Groves like Giant Forest and Redwood Mountain Grove each have hundreds of sequoias at least 15 ft dbh. But this relative local commonality of exceptionally large specimens should not obscure their overall rarity. By my calculations, nearly 80 percent of all sequoias at least 15 ft dbh occur in only 8 large groves. Several groves have no sequoias that large (e.g., unlogged Cahoon Creek, Surprise, and Placer County groves, and logged Cherry Gap and Indian Basin groves), or less than 4 specimens that reach that size (e.g., unlogged Coffeepot Canyon, Dennison, Horse Creek, New Oriole, Pine Ridge, and Sequoia Creek groves in Sequoia-Kings Canyon National Parks). Even sequoias less than 15 ft dbh can also be considered as rare, in a local sense (e.g., the relatively few largest mature and old-growth sequoias which survive in heavily logged Converse Basin Grove). It reinforces the perception of rarity to remember that each sequoia at least 15 ft dbh is larger in dbh than almost all non-sequoia trees in the world, including almost all old-growth coast redwoods.

Recognition of the rarity of some sequoia specimens has management implications. Special efforts should be made to protect the rare sequoias. At a minimum, management should abate unnaturally extreme fire hazards in the immediate vicinity of rare sequoias, even if more widespread fuel management in the grove is not yet a management priority. Such specimens, which usually have fire scars vulnerable to re-ignition, should be carefully protected during management controlled burns, and given some recognition in wildfire suppression plans. Currently there is no National Forest policy to take special precautions against fire risks to what I regard as rare sequoias.

Management recognition of rarity can also promote public appreciation and enjoyment. In many groves, a visitor has little chance of finding the grove's largest specimens without trails or guidance. Several opportunities exist for providing visitor access to now-ignored clusters of rare sequoia specimens with new construction of a few short trails.

Undervaluation of Groves Where Sequoias Were Logged

Though no one asserts that logging has literally eliminated a grove, the misleading sense that logging has permanently eliminated all of a grove's sequoia values has often been communicated. This descriptive pattern has diverted attention from the high sequoia values that remain in groves which have suffered heavy old-growth sequoia logging. Regret about past logging should not lead to the wrong conclusions that logged groves no longer have significant sequoia resources, that they cannot regain an old-growth for-est character, or that they no longer need careful stewardship.

Many discussions of Converse Basin Grove, where the most extensive early sequoia logging occurred, exemplify the common tendency to unreasonably devalue the present resources of logged groves. Some prominent authors erroneously described the grove as if there was nothing left there

by the early loggers. Walter Fry and John White, who served a total of more than 30 years as superintendents of Sequoia National Park, incorrectly asserted in printing after printing of their *Big Trees* book that every sequoia in Converse Basin Grove was logged except for the Boole Tree (e.g., Fry and White 1946). A prestigious National Park Service publication (Hartesveldt and others 1975) repeated that exaggeration. The error is puzzling, since surviving old-growth sequoias are readily apparent on the busiest grove road (to the Boole Tree trailhead) on the forest horizon only a few hundred yards west of the grove's famous "Stump Meadow" (fig. 2). A mundane example of the "past tense" type of thinking about logged groves is the 1993 Kings Canyon National Park interpretive sign at the Redwood Mountain Grove overlook on Highway 198, which states that Converse Basin was "once" the largest grove. Despite logging, Converse Basin Grove has not ceased to exist, nor significantly shrunk.

Some conservationists' priorities have also reinforced the attitude that logged groves are of far less concern than old-growth sequoia groves. In 1990, most conservationist appellants challenging the Sequoia National Forest management plan (Sequoia National Forest 1988) settled their appeals with an agreement (Sequoia National Forest 1990) which included provisions that barred commercial logging activities in all Forest groves during the current planning period, *except* in Converse Basin Grove. This signaled a uniquely lower level of concern with that grove.

The present and future sequoia values of logged grove areas should be recognized. First of all, most areas that suffered sequoia logging were not totally logged of old-growth. For example, heavily logged Nelder Grove retains 108 old-growth sequoias (Hawksworth 1979), including the Nelder Tree, the second largest known sequoia (in volume) in the eight groves north of the Kings River (See Flint 1987.). Nelder Grove probably has about 30 or more sequoias over 15 ft dbh (see Hawksworth 1979). Logged Nelder Grove has more surviving old-growth sequoias and more exceptionally large sequoia specimens than occur in several unlogged groves. Evans and Mountain Home Groves, and the University of California's Whitaker Forest section of Redwood Mountain Grove are other examples of groves with once heavily logged areas that retain many old-growth sequoias.

Second, sequoia stumps and logs which remain from early logging are highly interesting features. Many sequoia stumps provide the opportunity to review thousands of years of environmental history, reflected in tree rings. Available tree-ring studies indicate that in most areas where substantial old-growth sequoia logging occurred, there are commonly stumps of sequoias aged >1,000 years (Huntington and others, 1914).

In addition, many logged grove areas have sequoias that, while not old-growth, are significantly older than post-logging sequoia regeneration. These older types of relatively "young" sequoias, along with any residual old-growth,



Figure 2-Converse Basin Grove has scattered surviving mature sequoias. This old-growth cluster is west of Stump Meadow.

provide an older tree component of generally younger forest stands in logged areas. While most sequoias in logged grove areas regenerated after early logging, numerous surviving non-old-growth sequoias predate the early logging by decades, if not longer. While I am unaware of any systematic age studies of surviving large, but not old-growth, sequoias in logged grove areas, the size (in the range of 5 to 7 ft dbh) and/or rounded or rounding crown form of many present sequoias in such areas indicates that they are well over a century old. Many may be two centuries old or more.

This survival of pre-logging conifers in some logged grove areas like Converse Basin is not as surprising as it may sound. Historical photos and anecdotal reports show that much of the early grove logging was selective. Early loggers often ignored smaller trees (though many were destroyed in the process of harvesting the larger trees or in subsequent fires). My own limited, unsystematic tree ring studies of several pine and fir stumps cut in the 1980's in Converse Basin Grove (which were adjacent to old-growth sequoia stumps cut by the early loggers) showed that several were between 150 and 200 years of age when cut. This also indicates the early logging practice of sparing many small conifers.

Historical logging, however regrettable, has left vestiges aside from stumps which are interesting today. The human saga of the early logging era has an undeniable fascination. Resource destruction is an inescapable aspect of western Americana. The dirt roads to Cherry Gap Grove

from the west and in Evans Grove largely follow pre-1920 logging railroad routes.

Finally, because of the good growing sites in groves, generally excellent sequoia regeneration in areas logged before 1920, and the common rapidity of young sequoia growth, much of the logged grove areas have recovered a scenic appearance dominated by impressive medium-sized sequoias. Many of these trees are now 3 to 6 ft dbh, and many may grow to the dimensions of what the Forest Service has called "specimen" size within the next century. Many grove sites logged a century or so ago can soon recover many old-growth forest characteristics.

Logged grove areas should still be regarded as prime grove areas which deserve protection. Those areas typically also have a road system, facilitating public recreation.

Globally Significant Converse Basin Grove

Converse Basin Grove should be recognized and studied as one of the world's most fascinating forest heritage sites for numerous reasons. The grove is probably the second largest in area, after Redwood Mountain Grove. Subjectively, it once might have been considered the most impressive of all groves in its primeval condition (c. 1890). The grove's size and high density of sequoia stumps makes it reasonable to conclude that it had one of the very largest, if not the largest, primeval population of mature sequoias, of any grove. (Cf.

Converse Basin Grove is probably more than a third greater in acreage than Giant Forest, the most famous grove in Sequoia-Kings Canyon National Parks. Converse Basin Grove has not had a sequoia stump inventory, so there is no reliable basis to precisely estimate the primeval sequoia population there.) Only a few other large sequoia groves rivaled Converse Basin Grove in expansive majesty.

The grove retains numerous scattered mature sequoias, aside from the famous old-growth Boole Tree, the largest sequoia on National Forest land. These include an only lightly logged old-growth grove area along Cabin Creek in the Kings Canyon.

Many observers have anecdotally reported that Converse Basin Grove had an exceptional concentration of extremely large sequoias (e.g., Fry and White 1946, Johnston 1983). The General Noble Tree (which became "The Chicago Stump"), cut in 1892, was probably the largest sequoia ever cut (Flint 1992). The grove includes the type of well-watered, relatively gentle-sloped terrain where the greatest known concentrations of exceptionally large sequoias occur, as in Giant Forest and Mountain Home groves. Much of the grove has ideal sequoia growing conditions. My unsystematic comparisons of Converse Basin Grove and large Evans Grove to its east, for example, tend to confirm that primeval Converse Basin had a greater density of the larger size class sequoias. Abundant, durable old-growth sequoia stumps readily suggest the magnitude of the forest that was lost there, just as ancient ruins evoke lost civilizations.

The grove had numerous exceptionally old sequoias. A selective study of 220 grove stumps identified 53 that exceeded 2,000 years of age (Huntington and others 1914). The Muir Snag, which died before the logging era, is the oldest known sequoia. It was dated by Wendell Flint to be about 3,500 years. (Flint 1992, who determined approximate age from a partial ring count). The Muir Snag is also the remains of what might have been the largest sequoia ever. (Flint 1987) "D-21," the oldest-lived sequoia dated by a full ring count, achieved an age of 3,232 years in Converse Basin Grove before it was logged (dated by A.E. Douglas).

It is plausible that Converse Basin Grove had some of the most productive forest sites, in terms of standing large conifer wood volume, of any Sierra Nevada forest in the historic era. Prime sequoia grove areas comparable to primeval Converse Basin have had the highest known forest site productivity of any Sierra Nevada forests, measured in terms of standing timber volume (See, for example, Evans 1926.) In all probability, only California's highest volume coast redwood forest sites significantly surpassed the best Converse Basin growing sites in standing old-growth wood volumes.⁵

⁵This conclusion is based on comparative analysis of timber volumes for representative samples of old-growth coast redwood "flat" forests, which have the highest known timber volumes for small acreage sites of any timber type in North America if not the world, and the limited timber volume data available for dense old-growth sequoia (with mixed-conifer) forests (e.g., in Evans 1926). The Basin's heaviest volume sites were probably comparable to other high volume sites, such as in Giant Forest.

By my calculations, 1892-1907 Converse Basin Grove logging felled more mature and old-growth sequoias there than were cut in all other groves combined. A peerless aggregation of sequoia stumps is one obvious result. The logging also resulted in the most extensive and, in my opinion, most impressive (in aggregate) young sequoia (with mixed-conifer) stands that occur in any grove. Much of the post-logging Converse Basin forest has the appearance of forest older than the 85-100 years since early logging. This is due to the rapid growth of much post-logging sequoia regeneration and to the numerous scattered young mature sequoias that probably exceed 120 years in age. The grove has a very large number of apparently rapidly growing sequoias in the 5 to 7 ft dbh size class that can regain a literally "giant" appearance in another century or sooner. Much of the grove has the potential to be restored within a few centuries to "old-growth" condition (although it will still lack the once ubiquitous specimens aged >500 years).

The grove is large enough and vigorous enough to be regarded as an outstanding site in terms of its present resources and future resource potential, as well as a peerless memorial heritage site of lost old-growth. The grove's terrain, ample water, numerous meadows, and present network of decent quality dirt roads also make the grove well adapted to handle more public recreation at the same time that its resources are preserved and restored.

Grove Perpetuation and Manipulated Destruction of Large Blocks of Forest Canopy

Some have asserted that near-term logging of a scale and intensity that opens up large chunks of mature forest canopy (e.g., 2 to 40 acres) is appropriate or necessary for sequoia regeneration and "recruitment" (survival to maturity), i.e. that such manipulations are needed for "grove perpetuation." Similarly, some have asserted that human-implemented fire that destroys forest canopy on a similar scale is appropriate for grove perpetuation. The implication of these analyses is that the groves will shrink to non-existence over time without such manipulations. I reject that theory.

Theories that large-scale manipulated forest canopy destruction was necessary to grove perpetuation were used by managing agencies in the 1980's to justify large-scale "white-wood" clearcut logging in several Sequoia National Forest groves and controlled burns in Sequoia and Kings Canyon National Parks intense enough to do significant damage to the forest canopy. The urgency of the issues posed by those management actions has been alleviated by subsequent political developments. By the late 1980's, conservationist challenges effectively ended large-scale grove logging in National Forest groves and led to some moderation in the intensity of National Park controlled burning in groves. January 1993 California Region interim guidelines for protection of the southern spotted owl have reinforced the thrust of a prior agreement (Sequoia National Forest 1990) and Presi-

dential executive order (1992) protecting National Forest groves from controversial logging impacts. There is apparently no longer an imminent threat of manipulated actions which destroy large blocks of forest canopy. However, it is still important to critically examine the rationalizations for such management approaches, as past flawed management approaches might be proposed again in the future.

The following analysis of recent “grove perpetuation” debate is intended to debunk what I see as unscientific conclusions about grove perpetuation issues, and to encourage more meaningful discussion of grove management issues. Past “grove perpetuation” justifications for major forest canopy destruction in groves seem to me to be more reflective of conscious or unconscious biases than of objective scientific analysis. The foremost bias at work was the past National Forest System programmatic bias favoring old-growth timber harvest. In addition, my analysis is intended to advocate and justify management guidelines which maintain a general old-growth forest character in groves (which implies allowance of small-scale “disturbances” essential to perpetuation of the mixed-conifer/sequoia grove ecosystem).

Certainly, major “disturbance”⁶ can result in profuse sequoia reproduction. But intensely destructive, large-scale grove disturbances (e.g., larger than 10-acre “whitewood” clearcuts) which eliminate old-growth forest character, and which are very damaging in the short term to forest resources and to scenic and recreational values, are not necessary for grove perpetuation (*fig. 3*).

Certainly also, soil disturbance which creates a mineral soil seedbed is necessary for sequoia seedling germination, and some forest canopy opening appears to be necessary for young sequoia survival to maturity. Human-implemented disturbances with relatively little effect on the overall forest canopy, such as large-scale understory thinning and ground fuel reduction, certainly may promote sequoia regeneration and recruitment (while also accomplishing other management goals such as reducing unnatural hazards of catastrophic

⁶“Disturbance” has been used in recent grove management planning debates to refer to large-scale forest canopy changing impacts, typically from fire or logging, rather than in reference to the ubiquitous minor vegetation disturbances and constant natural dynamics which do not suddenly destroy large blocks of forest canopy.



Figure 3—1980's Sequoia National Forest clearcut in Black Mountain Grove. Such large-scale removal of forest canopy is not necessary for sequoia regeneration.

fire, maintaining natural tree population mixes including shade-intolerant pines, and improving recreation values). Small-scale disturbances are necessary for sequoia survival. They will always occur naturally, regardless of human management decisions.

The key grove management issue is not whether disturbances shall be naturally allowed or introduced, but rather what shall be the timing, scale, and intensity of the allowed or introduced disturbances. There is no management option of preventing "disturbance," which will always occur naturally sooner or later. In fact, a long-term policy of total prohibition of major "disturbance" (e.g., by long-term total fire suppression) will increase rather than reduce the probability of the most intense and large-scale foreseeable disturbance, a high-intensity crown fire that kills almost all forest trees over wide areas. Interests favoring large-scale old-growth canopy disturbances have irresponsibly attempted to vindicate their position by mischaracterizing conservationists as foolishly opposed to all grove disturbances, rather than responding to the true grove management issues of disturbance timing, scale, and intensity. Attempting to frame the debate in terms of "disturbance" itself avoids rather than stimulates meaningful debate on grove management options.

As I see it, there are now two main schools of thought on grove management strategies. One group wishes to implement large-scale disturbance, such as for commercial timber harvest motivations or out of a creed that intensely destructive fire is more "natural," desirable, and acceptable. The other group would allow, and under certain circumstances introduce, disturbances, but only in a manner which does not destroy large blocks of a grove's old-growth forest character.⁷ Debate is needed on various grove management options, but the debate should be based on facts and values, free of nonsense about threats to "grove perpetuation."

There is a compelling case for manipulated disturbance to many grove sites, in order to reduce unnaturally dense understory vegetation and down wood conditions arising from past practices of total fire suppression. But the argument that 20th-century disturbances such as clearcutting all non-sequoia conifers in 10- to 40-acre blocks is necessary to perpetuate the groves (as rationalized by Sequoia National Forest in the 1980's) is baseless. Similarly, grove perpetuation in areas where logging is restricted, such as in National Parks or legislated wilderness in National Forests, does not require fires intense enough to destroy much of the forest canopy in 5- to 20-acre blocks, as some assert. In fact, relatively shade-intolerant sequoia and pine reproduction can occur within what would be considered an old-growth mixed-conifer/sequoia forest ecosystem. This old-growth forest ecosystem allows for the sort of dynamic change, including a mosaic of small-scale disturbances and

canopy openings, which provide for sequoia regeneration and recruitment.

My conclusion that grove perpetuation is possible within the ecological mosaic of old-growth forest is based on facts such as the following, which have not been seriously disputed:

- a) The groves endured for thousands of years, before their first manipulations (grazing, logging, purposely ignited "shepherd fires") by Caucasians in the 19th century.
- b) The groves generally endured as old-growth forest ecosystems. Every sequoia grove had the perceived general character of old-growth conifer forest at the time of the groves' discovery by Caucasians in the 19th century, to my knowledge. (The groves also had some areas of younger forest as well as younger understory forest, creating the uneven-aged forest structure and mosaic dominated by large conifers which is characteristic of old-growth mixed-conifer/sequoia forest.)
- c) The groves endured without logging or a general pattern of large-scale, intense crown fires. Native Americans did not conduct any significant logging in the groves. Research indicates that the natural fire regime of the groves, including natural fires and any set by Native Americans, was generally one of relatively frequent fires, but of low intensity. For example, a pioneering fire history research study in Redwood Mountain and Bearskin Groves concluded that the grove study areas had a fire regime of frequent low-intensity fires during the period 1700-1875, and that no intense, widespread crown fires had occurred in the prior 2,000 years (Kilgore and Taylor 1979). Frequent low-intensity fires were also characteristic of the Giant Forest fire regime prior to the 1860's (Swetnam, this volume).

Available evidence indicates that general infernos are unusual exceptions to the natural fire regime of groves. Over millennia, intensely destructive, widespread grove fires apparently only occurred occasionally, such as on the Mountain Home plateau in 1297 (Swetnam, this volume), in Big Stump Grove in the 13th century (Stephenson 1991), and in part of the river canyon section of Mountain Home Grove in the 1870's (Keeler-Wolf 1990). Sequoia groves' natural fire regime is compatible with a stable old-growth forest type (which allows for a mosaic of small forest canopy disturbances). Even where general infernos are known to have occurred, available research indicates that the groves generally had an old-growth condition during the last millennium. For example, Big Stump and Mountain Home Groves each apparently had about four consecutive centuries of old-growth condition between

⁷I use "old growth" in a general sense to refer to a forest ecosystem dominated by large sequoia and non-sequoia conifers 150 years of age or more, and not in the more limited sense of a forest stand dominated by mature or older conifers that is also structurally characterized by heavy "decadence," numerous down logs, etc.

about 150 years after their 13th century infernos and the arrival of loggers in the late 19th century. Infernos did not recur in the interim.

- d) The active natural process of grove perpetuation without manipulated canopy destruction or frequent widespread canopy destruction by fire is apparent from sequoia inventory data. All unlogged groves (except anomalously tiny Placer County and Surprise Groves) contain numerous size classes of sequoias, sufficient to imply a range of age classes. (The wide range of mature sequoia ages within old-growth groves is readily apparent from tree rings displayed on stumps of logged sequoias. Sequoia age and size do not strictly correspond, but I do not believe it can be seriously disputed that the range of sequoia sizes among mature trees (as among sequoia stumps) significantly reflects different age classes.

For example, in Giant Forest, 20.7 percent of sequoias at least 1 ft dbh were only 1 to 2 ft dbh despite 50 prior years of near total fire suppression that some imply is prohibitive to the survival of such sequoias.⁸ And 21.5 percent were 4 to 6 ft dbh, having triumphed over early mortality threats, and grown above the young white fir understory, with promise of reaching the forest canopy. In the National Park section of Redwood Mountain Grove (recognized as having exceptional natural sequoia regeneration during the pre-management burn era by Aley 1963), 54.2 percent of sequoias at least 1 ft dbh were only 1 to 2 ft dbh; 9.6 percent were 4 to 6 ft dbh. In Muir Grove, which epitomized conditions of old-growth dominated canopy and a white fir dominated understory, 30 percent of sequoias at least 1 ft dbh were only 1 to 2 ft dbh, and 22.8 percent were 4 to 6 ft dbh. Some of these 1 to 6 ft dbh sequoias have the potential to reach the forest canopy and to live for a millennium or more after today's 1,000-year-old sequoias topple.

- e) Sequoias commonly live (with mature capacity for profuse production of viable seed) for ages exceeding 1,000 years and frequently for ages exceeding 2,000 years. Exceptional specimens can exceed 3,000 years (Huntington and others 1914).
- f) The recruitment of extremely few sequoias, relative to the hypothetical maximum regeneration potential of sequoias, can perpetuate the grove. Unlogged groves in Sequoia and Kings Canyon National Parks, many of which epitomize prime old-growth groves, had an average density of about 2 to 4 large sequoias (at least 5 ft dbh) per acre of actual sequoia occurrence. For example, Giant Forest and Redwood Mountain Grove (National

Park section only) averaged 2.8 such large sequoias per acre. (Some grove sites may have 10 or more large sequoias per acre, but that is more than the average density of mature sequoias in old-growth grove forest.) The natural range of large sequoia (at least 5 ft dbh) densities in old-growth groves is indicated by relatively very high density Muir Grove (avg. 3.8 sequoias per acre) and relatively low density Castle Creek Grove (avg. 1.9 sequoias per acre). To maintain an average density of 2 to 4 mature sequoias per acre in groves, it is sufficient that an average of 2 to 4 sequoias per acre that will survive to maturity regenerate in a comparable distribution pattern within every period of several centuries or even a millennium. It is not credible to assert that large-scale forest canopy destruction is necessary to maintain the average density of 2 to 4 large sequoias per acre which represent the National Park old-growth grove conditions that we hold in awe.

- g) Sequoia seedlings can germinate, survive, and grow rapidly with exposed mineral soil seedbed, and naturally occurring moisture, temperature, light, and lack of competing vegetation conditions. Though such a combination of favorable conditions rarely occurs in closed canopy old-growth forest, it nonetheless naturally occurs there over time, within the dynamic old-growth forest mosaic.
- h) Suitable bare mineral soil sequoia seedbeds naturally occur, or can be manipulatively created by land managers without altering a general old-growth forest type. This can occur with natural or managed low-intensity fire, natural erosion (particularly common along periodically flooded drainages), natural large tree falls, or by manual removal of ground level vegetation, woody litter, and duff.
- i) Full sun or moderately filtered sunlight sufficient to sustain survival and growth of young sequoias is available in relatively small openings in an old-growth forest canopy (perhaps openings as small as .3 acre), assuming that adequate moisture and other conditions for growth are present.

On the basis of the above facts, I conclude that the groves have naturally perpetuated themselves within relatively stable old-growth forest ecosystems. I reason from the known facts that they can continue to do so, absent prohibitive climatic change, lethal air pollution, or other unforeseen environmental constraint.

Aley (1963) and others perceived that regeneration of sequoia in the groves, as measured by lack of common sequoia seedlings and saplings, was at low levels in many groves, and that it was sometimes nonexistent in some sections of groves. These conditions are readily observable

⁸The Giant Forest sequoia inventory predated controlled burns there.

today in many grove areas. Relative lack of sequoia regeneration is commonly attributed to dense forest understory growth and buildup of ground level forest litter resulting from suppression of fire in most of the 20th century.

However, sequoia seedlings, saplings, and pole-sized trees are almost never absent from entire groves despite fire suppression effects. (For example, Sequoia and Kings Canyon National Parks' sequoia inventories following a long period of fire suppression policies showed that all groves in the Parks had significant regeneration of sequoias <12 inches dbh and significant subpopulations in the 1 to 5 ft dbh size class.) Even in groves where regeneration was observed to be low overall, observers like Aley noted significant levels of sequoia regeneration along drainages and in small areas of natural disturbance to forest canopy and soil, such as those created by tree falls or small lightning fires.

Observations of relatively few viable sequoia seedlings and saplings in studies such as Aley's, as compared with anthropocentric expectations, encouraged alarmist misassumptions. Somehow, observations of erratic and sparse sequoia regeneration in a period of perhaps 30 years (1/50 of the lifetime of a 1,500-year-old sequoia) generated an incorrect, often repeated new conventional wisdom that grove existence was thereby threatened. A more reasonable conclusion would have been that erratic, locally sparse sequoia regeneration was a curiosity, but irrelevant to long-term grove perpetuation.

The assumption that several decades of fire suppression or limitations on large-scale forest canopy disturbance threatens the groves is wrong for several reasons. Foremost, due to the longevity of sequoias, routinely successful regeneration and vigorous growth of young sequoias within every season, decade, or even (in theory) every several centuries is not necessary to perpetuate groves. A grove could be perpetuated quite well if adequate successful regeneration and recruitment occurred at several century intervals. In fact, such successful regeneration seems to almost always occur more frequently, even under unnatural fire suppression conditions, as described above.

Adherents to the theory that grove existence was threatened also apparently assumed that major fire could be permanently excluded (by human will and ability) from the groves. Incidents like the immense 1980's wildfires in Yellowstone National Park and Stanislaus National Forest demonstrate that humans cannot always control wildfires, regardless of modern fire-fighting resources. It is virtually certain that within time frames of centuries, major grove fires will occur. Humans can only influence their timing and intensity.

Just as lack of profuse sequoia regeneration was incorrectly interpreted as a threat to grove perpetuation, the profusion of sequoia seedlings that often follows major grove disturbances has been incorrectly regarded as highly meaningful, beneficial, or essential to grove perpetuation. There is no doubt that major disturbances, such as a 20-acre clearcut or crown-destroying fire, can greatly promote sequoia regeneration, and that some of that regeneration has potential to survive to maturity. But the profuse sequoia

regeneration that can follow large-scale intensive grove disturbances is largely irrelevant to grove perpetuation. The old-growth population of the grove which ultimately results from major destructive grove events might not differ significantly from that which ultimately results from grove management which preserves scenic and old-growth values.

Under natural conditions, few of the thousands of seedlings that germinate after a major disturbance will survive to become pole-size trees. Far fewer will survive to maturity. For example, a 1930 Tuolumne Grove inventory counted more than 1,000 young sequoias in an area of about 18 ft x 36 ft (Bellue 1930). Almost all of these young sequoias were gone, apparently from natural mortality, when the site was inventoried 36 years later (Dion 1966). (The area was not subject to any known logging or management-controlled burns in the interim period.) Similarly, in a controlled research project on two acres in Mountain Home Grove, sequoia seedlings declined from 332 per acre almost immediately after logging to 8 per acre in only 12 years (Benson 1985). This degree of extreme attrition among early sequoia regeneration can be informally observed by anyone who revisits sites of profuse sequoia seedling regeneration over several years. It is quite possible that regeneration of thousands of sequoia seedlings could suffer 100 percent early mortality. The advantages of profuse seedling regeneration should not be overemphasized.

Grove perpetuation depends much more on survival to maturity than it does on seedling regeneration. It is plausible that, despite natural attrition, a relatively few sequoia seedlings in favorable circumstances (that will probably occur within time frames of centuries) might have a comparable number survive to maturity as would survive from tens of thousands of sequoia seedlings that can regenerate following widespread canopy-destroying grove disturbances. Some might generalize the immense attrition rate of young sequoias in most sites to all sequoia regeneration, thereby reasoning that regular, profuse regeneration throughout the grove is essential to assure an adequate number of sequoias that will survive to maturity. I reason that rates of sequoia attrition vary immensely depending upon conditions, and that it is plausible that an adequate number of sequoias will survive to maturity from erratic, relatively non-profuse regeneration, as well as from the numerous local blooms of profuse regeneration that will inevitably occur in a grove within several century time-frames.

Using a natural succession model of recruitment and natural mortality and reasonable probabilities, various models of grove perpetuation could be hypothesized. Conservative model assumptions might include the following:

- a) An average mature sequoia life span of 800 years
- b) 0.5 to 0.75 acre of canopy clearing (with associated soil disturbance) is sufficient to allow sequoia regeneration and recruitment to maturity in suitable sites
- c) Sequoia regeneration is often hundreds or thousands to the acre in favorable situations

- d) Recruitment rates of an average of at least 2 to 4 sequoias to maturity per suitable acre during relevant time frames of multiple centuries
- e) Lack of prohibitive change in climate or other unforeseen mortality factors.

Different theoretical models could control for frequent, randomly distributed, small-scale disturbances, or intense, widespread disturbances once every 1,000 years, or other plausible combinations. I expect that all plausible models would demonstrate, in the absence of prohibitive new environmental constraints, that the grove could be perpetuated with a relatively consistent overall old-growth forest character (with dynamic microchanges and small-scale disturbances) for most of each millennium.

Grove management should not aim for maximum regeneration and recruitment of sequoia by manipulated destruction of large blocks of forest canopy. Aside from being contrary to values of perpetuating natural conditions, such a strategy can create a forest for the short-term that is more akin to an even-aged sequoia plantation than a perpetuated natural forest. In the long-term, such an unnatural, near-monoculture of even-aged sequoias may be vulnerable to unforeseen mortality factors that would not affect the sequoia in its naturally occurring, uneven-aged distributions. The factors responsible for natural mortality of sequoia are not fully understood (Piirto, this volume).

Clearly, even after severe early attrition, overdense stands of young sequoia (such as now exist in some formerly logged areas) will inevitably face further severe mortality in the longer term, regardless of human manipulations. The impressive population of 100 or more vigorous, 1 to 2 ft dbh sequoias that can grow on an acre cannot all mature. Current sequoia distribution data show that it is biologically impossible for even 40 mature sequoias to grow on an acre. Even the unequalled mature sequoia density of the famous Sugar Bowl group in Redwood Mountain Grove includes less than 30 sequoias at least 6 ft dbh on its densest single acre aggregation of mature sequoias (see Western Timber Service 1970 sequoia inventory map). The prodigious density in famous mature sequoia clusters such as the House, Senate, and Founders Groups in Giant Forest occurs in less than 0.5 acre, with far fewer mature sequoias in the balance of the acre (Hammon, Jensen, Wallen and Associates 1964 inventory map). In any event, these are sensational anomalies of extremely high mature sequoia density. Biological constraints have apparently limited mature sequoia densities to grove-wide average densities of less than 4 per acre (Hammon, Jensen, Wallen and Associates 1964, 1970, 1975, 1976, Western Timber Service, Inc. 1970).

Most of a highly dense stand of vigorous young sequoias, however worthy as a resource, are nonetheless irrelevant to grove perpetuation. It seems wiser and more "natural" to resist the anthropocentric, "more-is-better" appeal of the proven human ability to manipulatively create short-term (relative to sequoia life-span) lawns of sequoia seedlings and virtual

plantations of young sequoias. They are a poor substitute for the natural old-growth grove ecosystem.

In any event, sequoia regeneration can be manually fostered by activities which do not alter the general old-growth character and scenic quality of old-growth grove forest. These are methods which should be implemented to meet management goals of restoring natural forest understory conditions and eliminating unnatural fire hazards through low intensity controlled burns. Burns of generally low intensity allow for scattered, more intensely burned "hot spots" of <1 acre which can create small forest canopy openings, akin to the natural fire regime. Manual manipulation of vegetation and down fuels (cutting, raking, removal, pile and burn techniques, etc.) are also compatible with maintaining the general nature of an old-growth forest in groves.

The above critique should not be interpreted as a blanket objection to any significant human manipulation of grove vegetation. Site-specific management prescriptions should be planned after study of site conditions.

Research and Literature Needs

Much basic resource data concerning the sequoias is still lacking. For example, most groves in Sequoia National Forest have never had a comprehensive sequoia inventory. Many have not been reliably mapped. Because Sequoia National Forest groves are such a large percentage of the total sequoia resource, uncertainties about the Forest's groves create uncertainties about sequoia resources in general.

Most groves are not the subject of any published ecological surveys. The limited extent of research still leaves much to debate about what natural conditions were in the groves, and to what extent it is desirable, or possible, to attempt to perpetuate or restore them. Most research on Pacific Slope old-growth ecosystems of any type is very recent.

What is the total area of natural sequoia occurrence? How many sequoias are there in the natural groves? How many old-growth sequoias are there over 10 ft dbh, or over 15 ft, or over 20 ft dbh? How many old-growth sequoias were logged, and of what size or age classes? How many mature and old-growth sequoias were there before sequoia logging started? What sequoia and non-sequoia forest structure changes have occurred in grove areas logged in the early logging era? What is the inventory of non-sequoia forest resources within the sequoia groves? What are the volumes of standing forest in a broad range of grove sites? What is the tallest sequoia? What is the oldest sequoia? How many sequoias are in what age classes? Which grove originally had the most sequoias? What is the future of sugar pine in the groves, considering the white pine blister problem? What will the long-term effects of various management controlled fires be? Surprisingly, the answers to these questions are generally still uncertain. There is clearly much basic sequoia research to be done.

The usefulness of much past sequoia literature is also limited by a surprising amount of error and misleading

information. Much of the error is inconsequential, but some of it concerns fundamental facts concerning the sequoias. For example, as mentioned above, some prestigious sources have greatly overstated the percentage of grove acreage that was in National Parks. Fry and White (1938) severely understated sequoia resources of many groves, both inside and outside of the National Parks, sometimes describing major groves as if they were only a few mature sequoias. Sequoia National Forest draft land management plan documentation, the primary basis for public comment and participation in forest planning (Sequoia National Forest 1985), contained no descriptive information on individual sequoia groves and omitted disclosure that major logging operations were imminently planned and occurring in Forest groves at that time. These examples are symptomatic of a misleading tendency to devalue Sequoia National Forest groves relative to National Park Groves that permeates much of the pre-1990 sequoia literature. A more complete, more correct, and more comprehensively appreciative reference base is needed.

Public Participation

Informed public participation in grove planning is essential. History has shown that from the creation of Yosemite and Sequoia National Parks in the 1800's to grove logging and controlled burn controversies of the 1980's public participation is the best assurance of grove protection. Within a mandate of grove protection, there is still a wide range of grove management planning that will benefit from public scrutiny and comment. There is still no consensus among ecologists and land managers on an ideal method of grove management. Given the wide range of circumstances and terrain within the sequoia groves, a great deal of site-specific management planning is essential. Public agency planners should welcome citizen participation.

References

- Aley, T.J. 1963. Final report on the type mapping and regeneration studies in the giant sequoia groves of Kings Canyon and Sequoia National Parks. Unpublished report for the National Park Service on file at Ash Mountain offices, Sequoia National Park.
- Bellue, Alfred. 1930. A technical report on the Sequoia gigantea of Tuolumne Grove. Unpublished report on file at Yosemite National Park Research Library.
- Benson, Norman J. 1985. Management of giant sequoia on Mountain Home Demonstration State Forest. In: Proceedings of the workshop on management of giant sequoia; May 24-25, 1985; Reedley, California. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 30-31.
- Dion, Carl. 1966. Unpublished paper on Tuolumne Grove on file at Yosemite National Park Research Library.
- Evans, Oscar M. 1926. The Calaveras Grove of Big Trees. *West Coast Lumberman* 50:154-158.
- Flint, Wendell. 1987. To find the biggest tree. Three Rivers, CA: Sequoia Natural History Association; 116 p.
- Flint, Wendell. Writer and researcher regarding giant sequoias. [1992 conversations with Dwight Willard]
- Fry, Walter; White, John. 1938 and 1946 editions. *Big trees*. Palo Alto, CA: Stanford University Press.
- Hammon, Jensen, Wallen and Associates. 1964, 1970, 1975, 1976. Sequoia tree inventory. Hammon, Jensen and Wallen Mapping and Forestry Service, Oakland, CA. Report to the National Park Service. Unpublished reports and maps concerning giant sequoia inventories in Sequoia and Kings Canyon National Parks, on file at Ash Mountain offices, Sequoia National Park.
- Hawksworth, John; Hawksworth, Marjorie. 1979. Historic overview of the Nelder Grove. Unpublished contract report for Sierra National Forest.
- Hartesveldt, Richard; Harvey, Thomas H.; Shellhamer, Howard S.; Stecker, Ronald. 1975. The giant sequoia of the Sierra Nevada. Washington, DC: U.S. Dept. of the Interior, National Park Service.
- Huntington, Ellsworth; Schuchert, C.; Douglas A.E.; Kullmer, C.J. 1914. The climatic factor as illustrated in arid America. Publication No. 192. Washington, DC: Carnegie Institute of Washington.
- Johnston, Hank. 1983. They felled the redwoods. Glendale, CA: Trans-Anglo Books.
- Keeler-Wolf, Todd. 1990. An ecological survey of the Moses Mt. Candidate Research Natural Area, Tulare County, California. Unpublished manuscript on file at Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, California.
- Kilgore, B.M.; Taylor D. 1979. Fire history of a sequoia-mixed conifer forest. *Ecology* 60:129-142.
- Meyer, Frederick; Schlobohm, Dean. 1952. Status of Sequoia gigantea in the Sierra Nevada. Report of the State Park Commission and the State Forester to the State Legislature.
- Stephenson, Nathan. Ecologist, Sequoia-Kings Canyon National Parks. [1991 conversation with Dwight Willard]
- U.S. Department of Agriculture, Forest Service, Sequoia National Forest. 1983. Environmental Assessment Report, Project: Black Compartment. (Regarding Solo Timber Sale in the Black Mountain Grove)
- U.S. Department of Agriculture, Forest Service, Sequoia National Forest. 1985. Draft Sequoia National Forest Land and Resource Management Plan (with Environmental Impact Statement and appendices).
- U.S. Department of Agriculture, Forest Service, Sequoia National Forest. 1988. Final Sequoia National Forest Land and Resource Management Plan (with Environmental Impact Statement and appendices).
- U.S. Department of Agriculture, Forest Service, Sequoia National Forest. 1990. Final Mediated Settlement Agreement for the Sequoia National Forest. (Modification of the 1988 Final Forest Land and Resource Management Plan)
- Western Timber Service, Inc. 1970. Sequoia tree inventory. Western Timber Service, Inc., Arcata, CA. Report to the National Park Service. Unpublished reports and maps concerning giant sequoia inventories in Sequoia and Kings Canyon National Parks, on file at Ash Mountain offices, Sequoia National Park.

Giant Sequoia (*Sequoiadendron giganteum* (Lindl.) Buchholz) in Europe¹

Wolfgang Knigge²

Abstract: Since 1853, seeds of *Sequoiadendron giganteum* (Lindl.) Buchholz have found their way to Europe. Planted in botanical gardens, arboreta, and parks, Giant Sequoia survived to significant size in many countries of Western Europe. Today its growth surpasses that of all other softwoods known on the continent. The author analyzes its potential as a useful addition to forestry, stressing European experiences with geographic distribution, different climates, soils, genetic variability, increment, and yield. Other aspects described are Giant Sequoia's wood qualities, i.e., knottiness, width of annual rings, heartwood formation, fiber length, specific gravity, strength, durability, and the chance for adequate utilization by the forest products industry.

It is certainly a special privilege to talk here at Visalia, close to the western slope of California's Sierra Nevada, about a species of tree which is the botanical saurian of our world, the most massive living organism known and second only to bristlecone pine (*Pinus aristata* Engelmann) in verified longevity (Kleinschmit 1984, Dekker-Robertson and Svolba 1992). I remember very well my first visit to the Mariposa Grove in 1959 and the awe I felt facing trees exceeding a height of 80 m, a diameter at breast height of 10 m, and a volume of 1,000 m³ (fig. 1).

At the end of a 3-month tour of collecting samples of second-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) between British Columbia and Northern California, I had not the slightest idea that I would return one day caring for second-growth Giant Sequoia.

But already in the 1950's, C.A. Schenck (1953/54), a man who inspired modern forestry in the United States as in Europe, had finished a broad inventory of "exotic" trees investigated by the German Dendrological Society with the remark that the growth of Giant Sequoia planted in many parks and botanical gardens in Europe surpassed that of all other species controlled by the Society. Looking at the knottiness of the species, he asked on the same occasion, what we should do with the wood of a tree, which was shunned for exactly this reason even in California. In 1957/58 E. and I. Martin, a dentist couple and hobby dendrologists, stressed the potential of Giant Sequoia as a useful addition to forestry and started planting some younger stands in Western Germany, fascinated mainly by the growth rates of stands established at Weinheim and Heimerdingen (Germany) and Belle Etoile (Belgium).

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²Professor of Forestry and Director (emeritus) of the Forest Products Laboratory of the Georg-August-University of Göttingen, Büsgenweg 4, D-37077 Göttingen, Germany.

The Way to Europe

Hartesveldt (1969) traced not only the history of the tree's discovery by the white man about 1833, but also some of the seed's ways to Europe in 1853. He listed 591 locations in 25 European countries, where *Sequoiadendron* was planted and surviving to significant size. But it was Libby (1981), Fins (1979), and Wolford and Libby (1976) who mobilized the interest of Forestry and Forest Product's research in the species, which was well represented in Europe before the quaternary glacial periods as was Douglas-fir. Today I should like to present to you some results of cooperative research, prompted by W.J. Libby, done by the Department of Forest Tree Breeding of the Lower Saxony Forest Research Institute

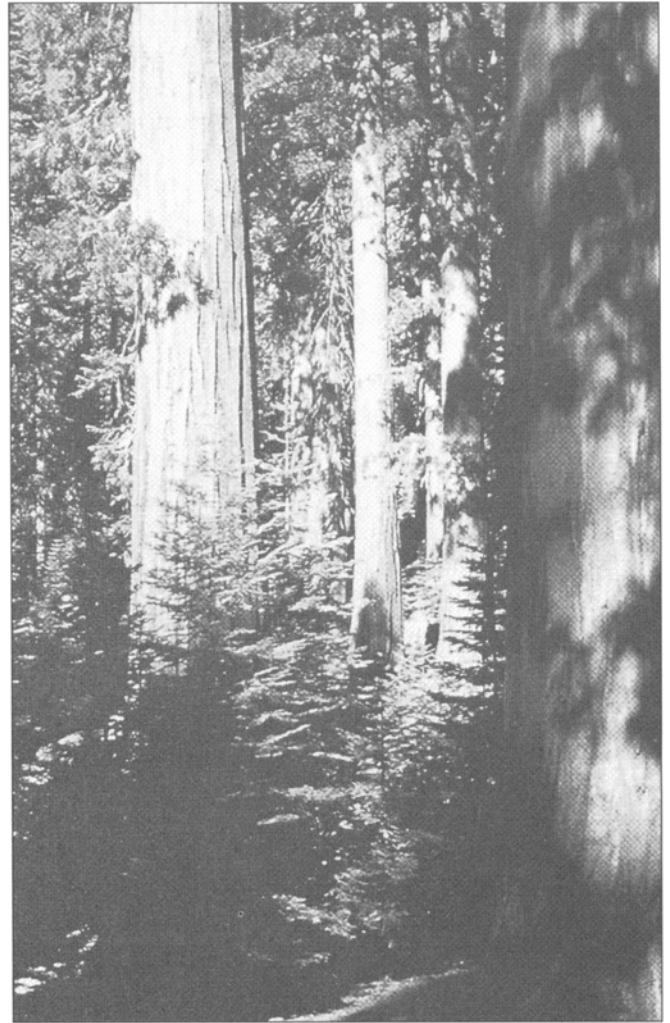


Figure 1-Giant Sequoias at the Mariposa Grove, California, 1959.

(Director Dr. J. Kleinschmit) and our Forest Products Laboratory of the University of Göttingen.

Where did we get the first seeds? It seems today that the parties who crossed the Sierra Nevada on their way west met the giant trees distributed along the western slope of California's Sierra Nevada mountains, in the most northern areas of a band nearly 400 km long. It may have been the Merced or Tuolumne, even the Calaveras groves, and eventually also the Mariposa grove which today is part of Yosemite National Park. It is quite certain that other groves in the Sierra Nevada may have been found within the 20 years which passed between the first encounters in 1833 and a first report in London's *Gardener's Chronicle* in 1853. Since the seeds were introduced to botanical gardens, arboreta, and parks, little is known about their origin. On the other hand, these seeds were very expensive (Hartesveldt 1969).

According to Löffler (1985), King William I of Württemberg, a typical Swabian-stingy, but forestry-minded-ordered in 1864 a considerable amount of seed, which partly went to the forestry stations. But also this "royal" gift ended up mostly in arboreta around these stations, partly near Heimerdingen (fig. 2). Until the early years of this century, only three true stands (according to a forester's understanding) had been planted in Europe, the first of them by Baron Christian von Berckheim at Weinheim, Germany (fig. 3), the second in Belle Etoile (Belgium) of the Groenendaal Experiment Station (now 91 years old), and finally one of the same age at "Tervuren" at the Domaine Royal, also located in Belgium (Kleinschmit 1984).

All the younger stands were established after World War II at a time when greater knowledge and experience were available from earlier plantations of stands and solitaires.

Climates and Soils

What were the lessons learned by Europeans exploring the results of more than 100 years of raising Giant Sequoias between Norway and the Black Sea, and between the Mediterranean and the Baltic Sea (fig. 4)?

Sequoiadendron has shown itself to be adaptable to a wide range of climates. While it occurs naturally only between northern latitudes of 35°5' and 39°3', it was successfully planted in Europe between latitudes of about 39° and 61°. In California it occurs between 1370 and 2300 m elevation where annual precipitation averages more than 1000 mm. Precipitation falls in the form of snow or rain almost entirely in the winter. Most of the European plantations are located further to the north and have colder, wetter weather. Elevations range from sea level up to 1000 m with rainfall amounts less than 1000 mm scattered all over the year. Guinon and others (1982) found resistance to frost to be one of the limiting factors regarding the growth of seedlings, but at the same time found significant and



Figure 2-Giant Sequoias at Heimerdingen near Calw, Germany, planted about 1865. (Courtesy of J. Kleinschmit, Escherode).

substantial differences in winter damage between 22 provenances representing the entire natural range of Giant Sequoia in California.

After the period of plantation and first thinnings, the warmth of the growing season seems to be of some importance (Libby 1981, Landesanstalt für Ökologie (LÖLF) 1982).

Many quite different soils proved to be a healthy basis for the growth of Sequoiadendron. Weak and moderate acidity seems to be a favorable quality, as are well aerated and well drained soils. Loose sediments and sedimentary rocks such as graywack and slate showed themselves to be very good as did silicate-rich areas. Since the roots of the species keep expanding quickly into the lower horizons of the soil profiles, they are capable of reaching the upper levels of groundwater, developing a somewhat heartlike form of the overall root (Wolford and Libby 1976). On the other hand, stagnating water proved to be the source of many disappointments (LÖLF 1982).



Figure 3—The famous stand of *Sequoiadendron giganteum* at Weinheim, towering over the central Rhine Valley near Heidelberg. (Courtesy of J. Kleinschmit, Escherode).



Figure 4—Plantations of Giant Sequoia in Western Europe according to Hartesveldt (1969) and Libby (1981).

Form of the Crown

Sequoiadendron is simply a beautiful tree, a fact that explains its rapid progress in the many parks and arboreta in Europe. This is true not only for nearly all stages of its life as a solitaire, but also in the companionship of its natural neighbors within its Californian environment (*Abies concolor*, *Pinus jeffreyi*, *Pinus ponderosa*, and *Calocedrus decurrens*). The form of the crown is highly variable, partly for genetic reasons (Martin 1957/58, Fins 1979), and partly for the pressure produced from other species within the same stand (figs. 5 and 6). Since Sequoiadendron suffers badly from all types of shade, it should be planted in distances of about 4 x 4 m. The other species in Europe, mainly Douglas-fir, European Larch, black pine, and white fir, should be mixed into the spaces left after Sequoiadendron has survived the first tests of its frost-hardiness.

With increasing age, the yellow-brown color, the strong texture of the bark, and the silvery or sometimes yellowish-golden shine of the leaves, a genetically fixed



Figure 5-Different forms of the crown of Giant Sequoia within an arboretum at Escherode, Germany. The 30-year-old trees were planted by Richard Kleinschmit, who grafted stocklings from frost-hardy specimens north of the Main River. (Courtesy of J. Kleinschmit, Escherode).

variability, will add to this impression (Hartesveldt 1969, Kleinschmit 1984). If R. J. Hartesveldt quotes Alan Mitchell of the Royal Forestry Commission, "that there is scarcely a hilltop or mountain top in all of Great Britain from which a Giant Sequoia cannot be seen," I should like to state that we expect the same tree to become one of the important landscape trees of the future, at least in Western and Central Europe.

Genetic Architecture

For reasons mentioned before, Europeans felt rather disappointed about their restricted knowledge of the differences in growth and quality of Giant Sequoia originating from variations in the genetic architecture of the species within the area of its natural distribution in California. R. Kleinschmit, the father of J. Kleinschmit, began a conservation program in 1955 for Sequoiadendron specimens older than 60 years, which had already proven to be frost hardy enough to survive under comparably harsh conditions, north of the

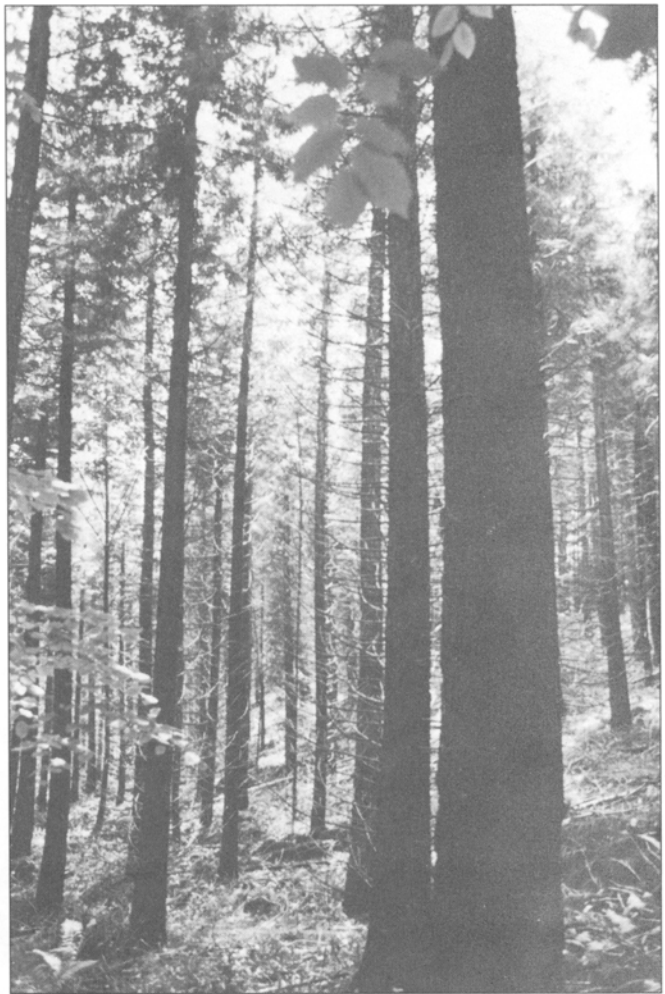


Figure 6-Also pressure from adjacent trees leads to variations of the form of the crown, for example, here in a 32-year-old plantation at Baden-Baden on the western slope of the Black Forest. (Courtesy of J. Kleinschmit, Escherode).

Main River. Seeds of these trees were grafted and planted in an orchard in Escherode. They showed that *Sequoiadendron* is by far the most productive conifer that can be grown in Europe (Kleinschmit 1984). Nevertheless, it was Lauren Fins who furnished seeds from 34 different provenances within the Sierra Nevada to the Lower Saxony Research Institute in 1976. The seeds constituted the basic material for

tests on three different sites in North Germany (Fins 1979) (fig. 7).

Recently, Decker-Robertson and Svolba (1993) reported the first results of their measurements on the three fields of the Experiment Station (fig. 8). Leaving aside many of the statistical problems and the uncertainty of inbreeding, I should like to mention that the tallest provenance overall was Whitaker's Forest, followed by Standard USA and Mountain Home. Mortality did not follow a generally geographic distribution, nor was it influenced by the elevation from which the provenance originated. Certain provenances appeared to be poor survivors and performers on most sites. But even this experiment exemplified our close dependence on all the research carried out here in California. On the other hand, Kleinschmit (1984) mentioned that he forwarded seedlings (plantable rooted cuttings) from 22 provenances to the French AFOCEL and received seeds from 11 stands from A. Franclet. Other investigations are under way in Hungary and Yugoslavia, all of them cooperating with the University of California. Therefore we expect to be increasingly informed about the giant tree's genetic diversity

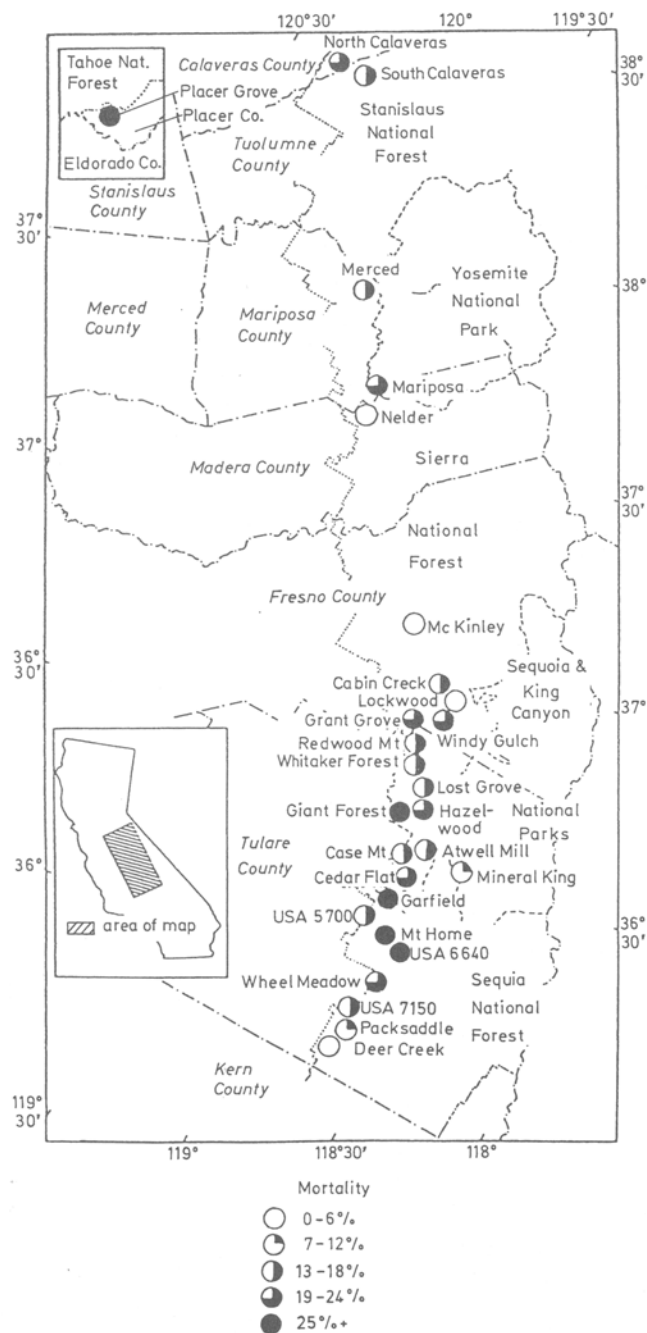


Figure 7-Mortality of provenances from different California Giant Sequoia groves planted by the Lower Saxony Forest Research Institute at Escherode at three different experimental fields in Lower Saxony (northern Germany). (Dekker-Robertson and Svolba 1992).

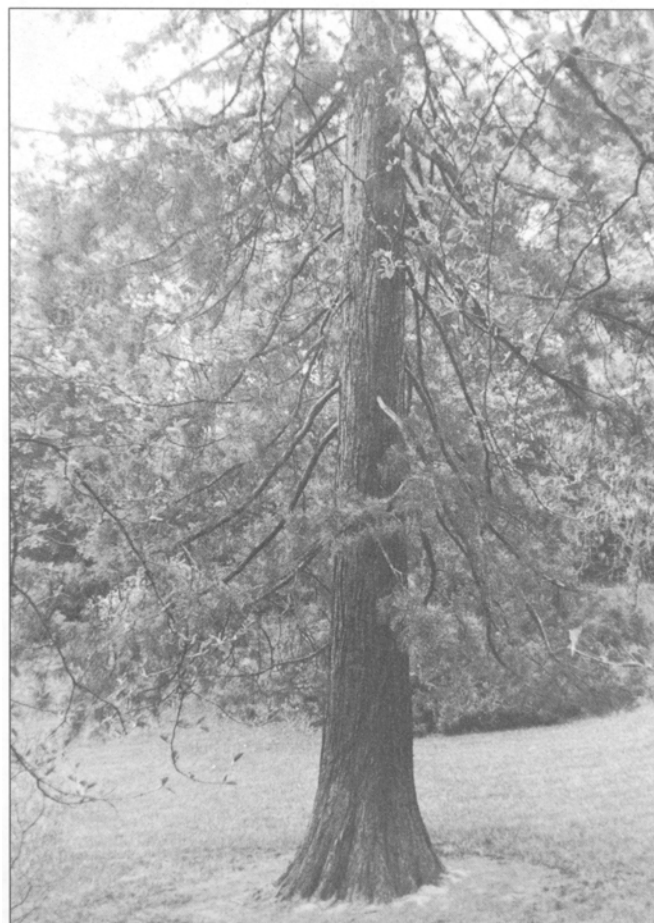


Figure 8-Typically tapered lower part of the trunk of one of the tallest solitaires of *Sequoiadendron giganteum* (Lindl.) Buchholz, planted in Germany. This tree was planted 121 years ago in the park of the former Grand Duke of Hessa-Darmstadt at Bensheim. Height 49 m, diameter at breast height 204 cm.

in the near future, especially if we continue cooperating in the way we have done during the past 15 years.

Growth and Yield

In our attempt to get more information about the qualities of *Sequoiadendron* as a forester's tree, its growth and yield required special consideration. We had learned much about the fantastic growth of solitaires in many parts of Europe, but solitary trees do not behave like trees in normal stands, and the number of real stands is very limited, as mentioned

before. The famous stand at Weinheim, by now 120 years old, still shows a current annual increment of 20 m^3 (fig. 9), the one at Belle Etoile shows a mean annual increment of more than 44 m^3 per ha (fig. 10). This is by far more than every European conifer can do in its highest yield classes (European silver-fir, yield class I, after heavy thinning 20 m^3 , at age 45. But these "stands" represented a size of only 1.4 or 0.25 ha (Kleinschmit 1984). Therefore, we decided to analyze growth as well as yield and wood quality by sampling two whole trees from 7 different stands. These trees were generally of the same age, while the age of the



Figure 9-Experimental stand of different Californian seeds provided by L. Fins and W. R. Libby at Escherode. The other control fields were established in comparable situations close to the Harz and Soiling Mountains.

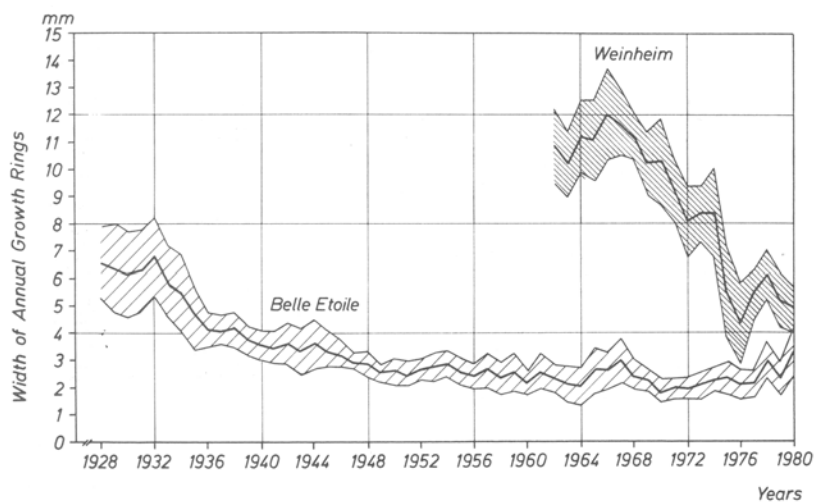


Figure 10-Variation of the width of the annual rings in young trees planted close to the well-known old stands at Belle Etoile (Belgium) and Weinheim (Germany) according to investigations of Guinon and others (1983).

stands varied between 11 and 98 years. At the same time Guinon and others collected two increment cores from 20 trees of every stand, choosing them from individuals in dominant or intermediate positions, representing KRAFT'S tree classes I-III. The Kraft-classification is used in Europe for the characterization of the social position of a tree within a stand. In this way we gained basic information from about 150 trees, nevertheless a minimum for any statistical calculation.

The width of the annual growth rings frequently exceeded 18 mm during the first and second decade of life, leading to diameters at breast height up to 45 cm (including bark) at an age of only 20 years. Stem analyses of these European trees indicated (figs. 11 and 12) that this period of fascinating growth is restricted, and as a result, most plantation trees produce a decidedly tapered form (0.36

versus 0.47 for European silver-fir). Only as the crown recedes does the maximum width of the growth rings shift upwards, resulting in a more cylindrical bole of the mature tree. Since we have no representative number of stands of Giant Sequoia, we have no yield tables for this species. Using the control data of different stands in Nordrhein-Westfalia and simulating the further development of height and breast-height diameter, the Forest Experiment Station of Nordrhein-Westfalia designed the future of both parameters to an age of 120 years (LÖLF 1982). I should like to compare these curves with those of the best site classes of Douglas-fir, Norway spruce, and Scots pine according to the tables of Bergel (1969), Wiedemann (1936/42), and Wiedemann (1943) to exemplify the potentials of Giant Sequoia in Western and Central Europe (figs. 13 and 14).

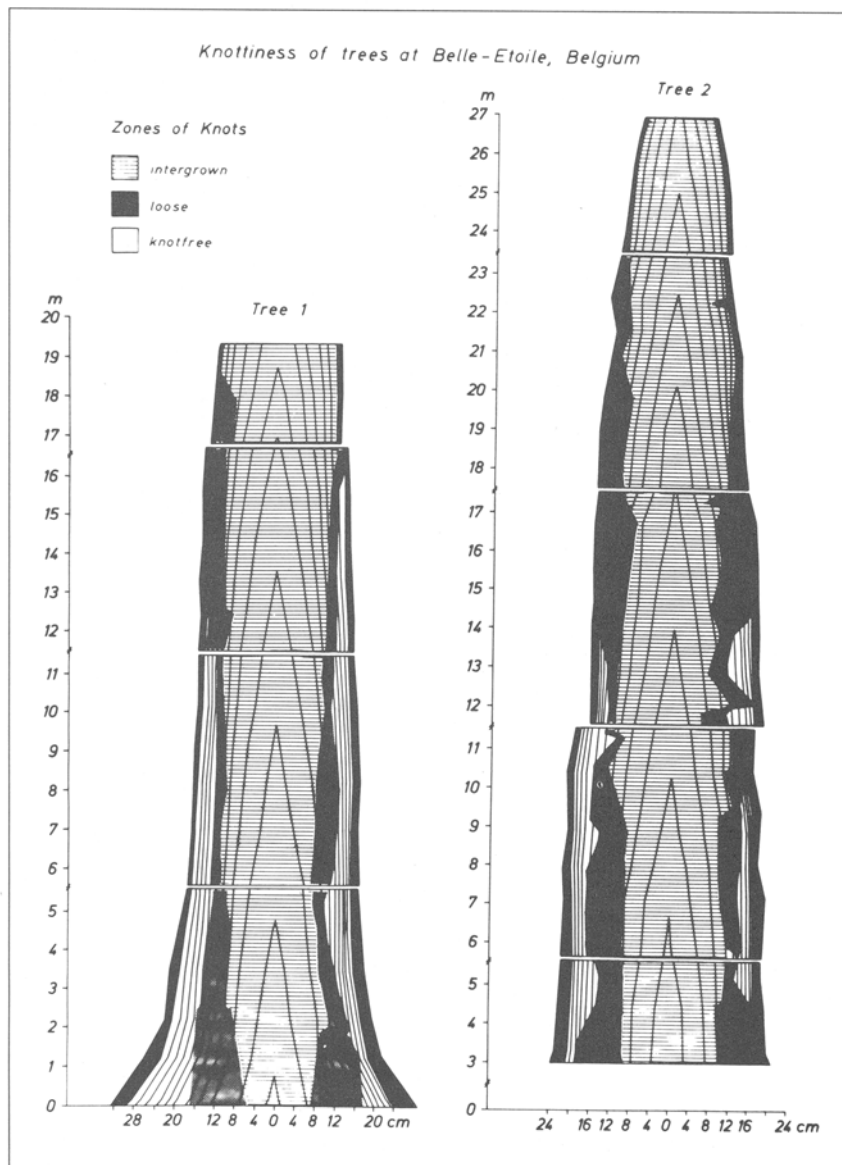


Figure 11—Stem analyses of two trees from Belle Etoile, Belgium, showing the decrease of the growth zones with age, at the same time also the variation of zones of intergrown and loose knots and a relatively small knot-free area covering the outer shell of the trunk of Giant Sequoia.

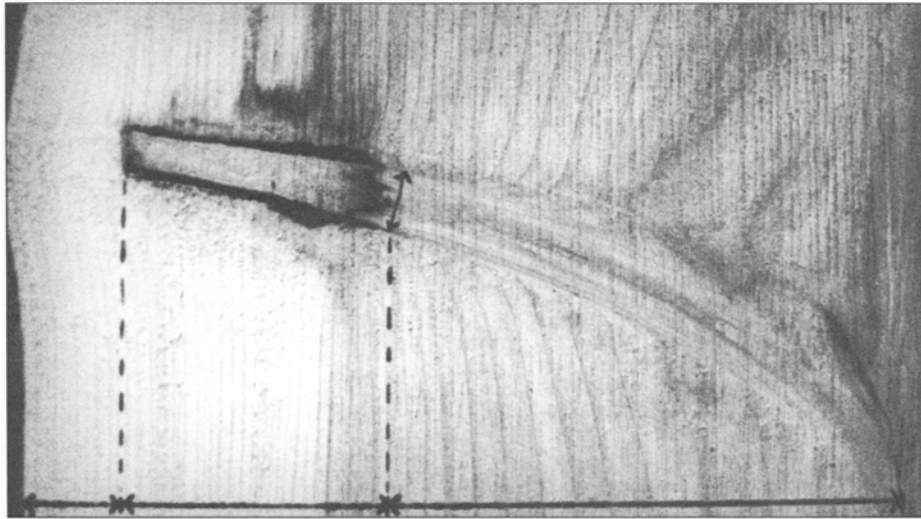


Figure 12-The fascinating growth of diameter is restricted at least in stands of normal standards of forestry.

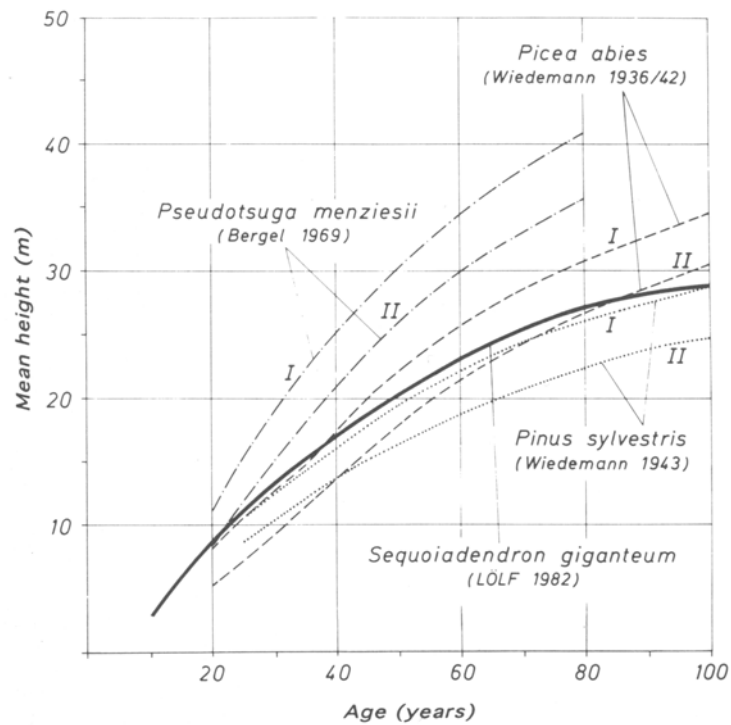


Figure 13-Average height growth of Giant Sequoias planted in Nordrhein-Westfalia, compared with site classes I and II of Douglas-fir, white fir, and Scots pine (data from LÖLF 1982).

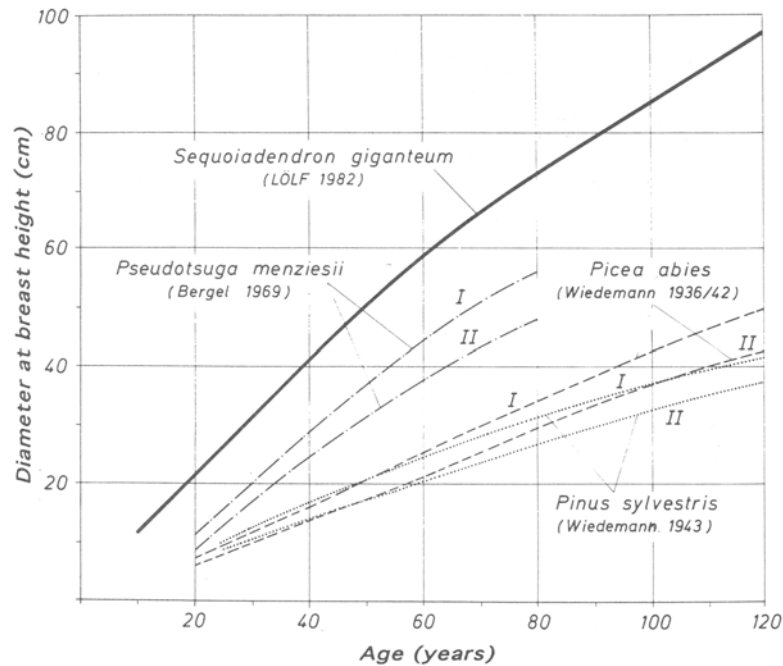


Figure 14—Average diameter growth at breast height of Giant Sequoias planted in Nordrhein-Westfalia compared with site classes I and II of Douglas-fir, white fir, [or European silver-fir?] and Scots pine (data from LÖLF 1982).

Wood Quality

Our drawing leads us to problem No. 1 regarding the use of the wood of our trees: its knottiness. From the lack of natural regeneration and the necessary wide spacing of most plantations, we get so many knots within and outside the trunk that it appears sometimes difficult even to take increment cores at breast height from younger or medium aged trees (figs. 15 and 16). Because of several factors, e.g., the early heartwood formation in stem and branch, the length of time the dead stubs remain on the tree exceeds the proportions known in other species. In addition, a two-dimensional drawing of distribution and size of knots on the surface of a younger stem from Belle Etoile shows that there are practically no internodes between the branch generations (fig. 17). Figure 18 exemplifies the borderline between loose and intergrown knots (Knigge and others 1983). Let me conclude that Giant Sequoia is so slow in shedding its branches that early pruning is a must in order to produce an appreciable volume of clear lumber within rotation periods of short or medium length. On the other hand, pruning apparently is the most effective means to achieve a more cylindrical form of the stem within reasonable time. At least the European market for Douglas-fir keeps honoring this modus. Therefore, we are planning for the same procedures on *Sequoiadendron*.

Heartwood Formation

If heartwood formation is a prerequisite for early pruning, its variation in *Sequoiadendron giganteum* deserves special

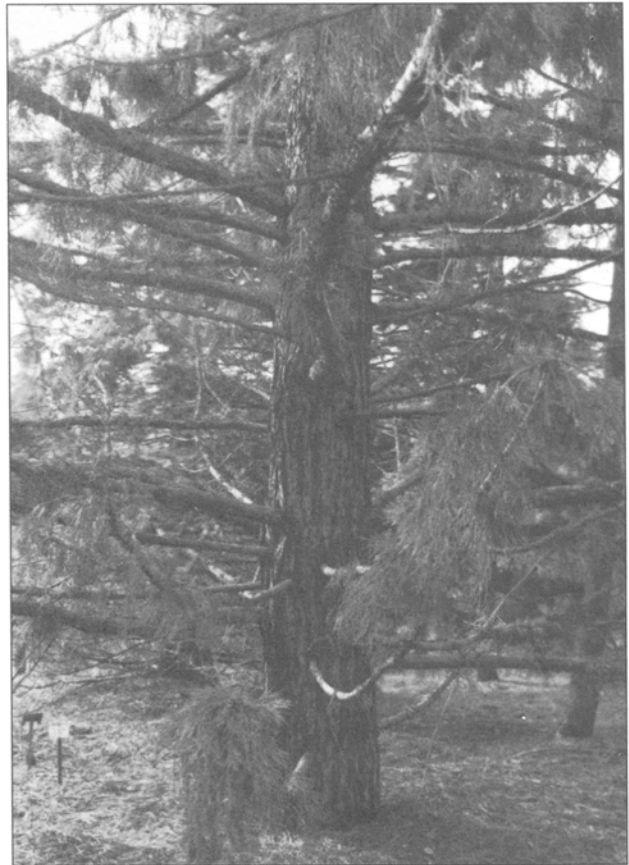


Figure 15—Lower part of the trunk of a 19-year-old Giant Sequoia in an arboretum at Göttingen showing the unusual longevity of living and dead branches.

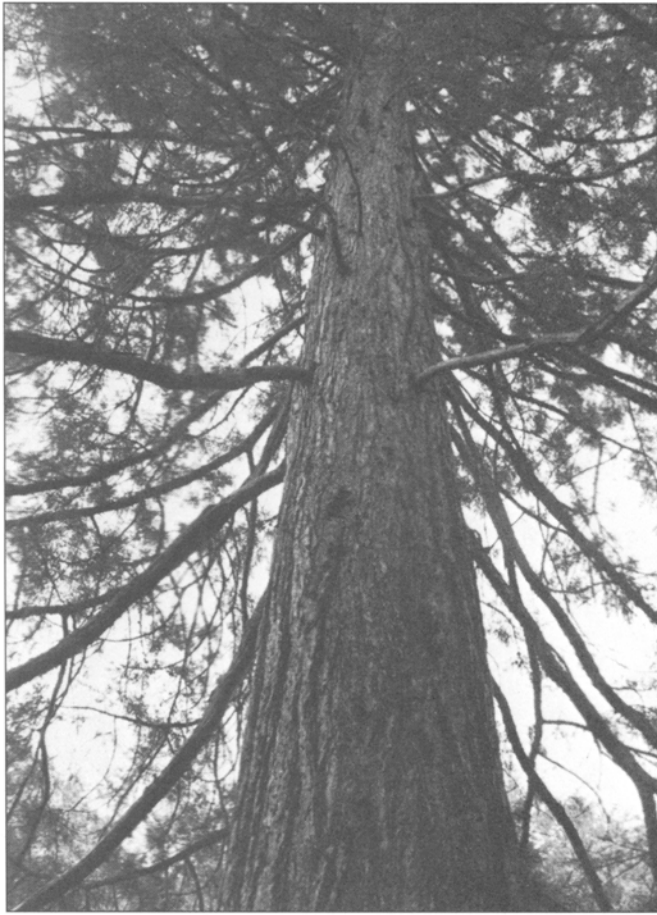


Figure 16-Even the bark of this Giant Sequoia at Bensheim with an estimated age of over 90 years shows traces of many intergrown and loose knots within the stem and a sufficient number of living branches too.

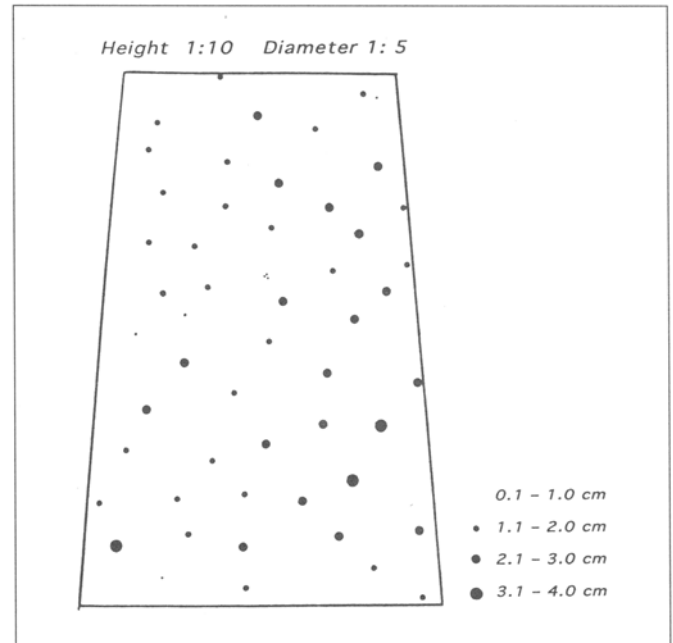


Figure 17-Scheme of distribution and size of knots found on the bark of a medium-aged Giant Sequoia from Belle Etoile.

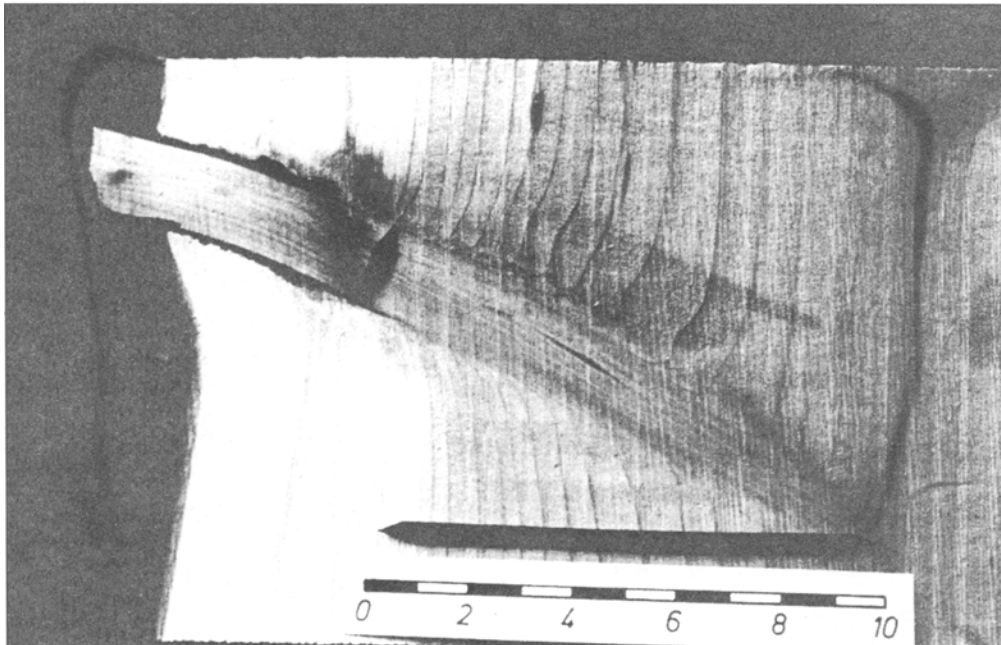


Figure 18- Heartwood and sapwood of a 29-year-old Giant Sequoia from Weinheim exemplifying the border between intergrown and loose knots in the stem.

attention. Piirto and Wilcox (1981) investigated the comparative properties of old-growth and second-growth heartwood in California. They found no distinctive differences. In Europe, we were surprised by variations within the different trees collected (Knigge and others 1983). While the transition of sapwood into heartwood starts as early as after the 5th to 9th growth ring, there is frequently a variety of colors within sapwood and heartwood (*fig. 19*). In our investigation we tried to differentiate between ordinary sapwood, blue stained sapwood, lighter and darker heartwood, and some

variations of decay within the heartwood. In some older trees, zones of unfinished transition into heartwood were observed (*fig. 20*). This was probably a result of incomplete formation of the various organic substances generally known as extractives. There were also different forms of decay close to the soil or in upper parts of the trunk following damage. Apparently, even the famous heartwood of Giant Sequoia seems to be the object of attacking bacteria and fungi, phenomena which deserve more exploration and examination (*fig. 21*).

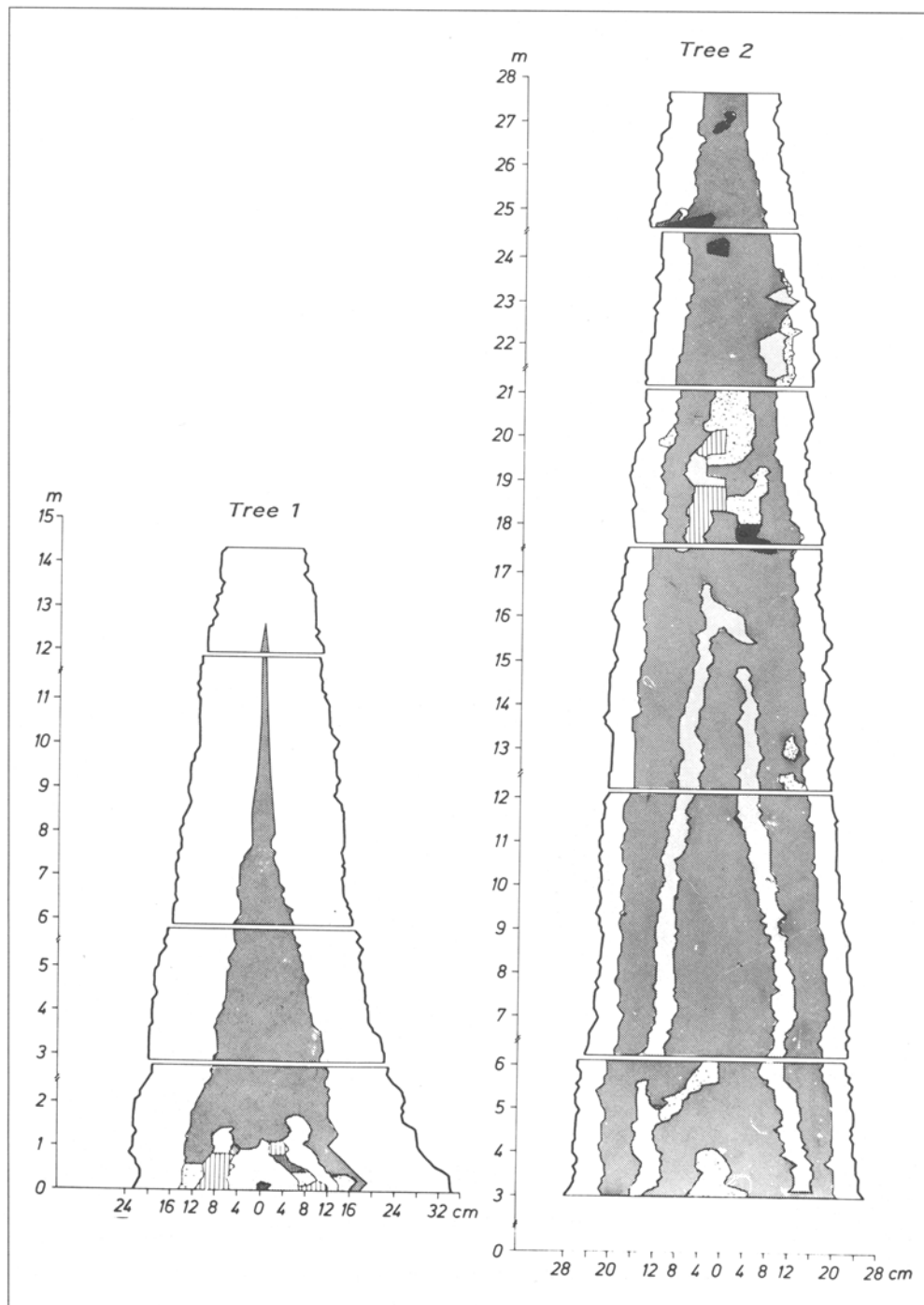


Figure 19-Formation of multicolored heartwood and moderate decay in two trees from Weinheim (Germany).

Fiber Length

A significant part of second-growth wood of *Sequoiadendron* will end up in pulp and board mills. This led us to the investigation of its fiber length. As in most softwoods, tracheid length within a stem cross section showed the typical increase from the pith to the bark. From 4,800 measurements in different heights of a 63-year-old tree from the Belle Etoile plantation the average tracheid length turned out to be 3.09 mm (fig.22) compared to 1.1-6.3 mm in

Norway spruce and 1.3-4.5 mm in Scots pine. As usual, the increase was also more distinct within the juvenile wood than within the more mature wood. The curves show continuous increase in cell length with neither a levelling of constant cell length nor a decrease after reaching a maximum. Apparently the tree investigated had not yet achieved its maximum tracheid length (Knigge and Wenzel 1982). Also no significant increase of fiber length between the foot and the top was observed, and only at two different heights could a distinctive negative correlation between the length of the

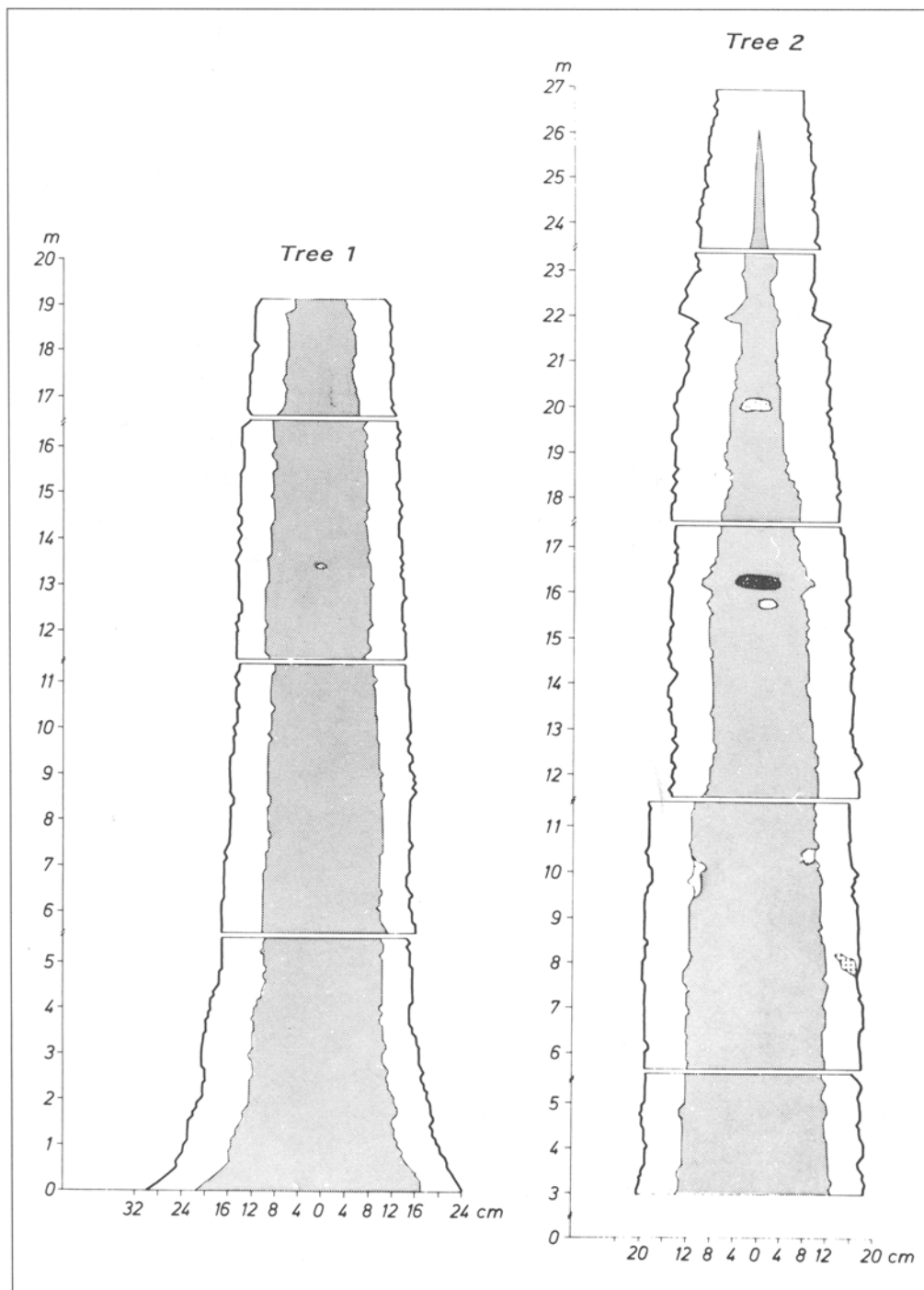


Figure 20-Nearly uncolored heartwood(?) in two trees from Belle Etoile (Belgium).

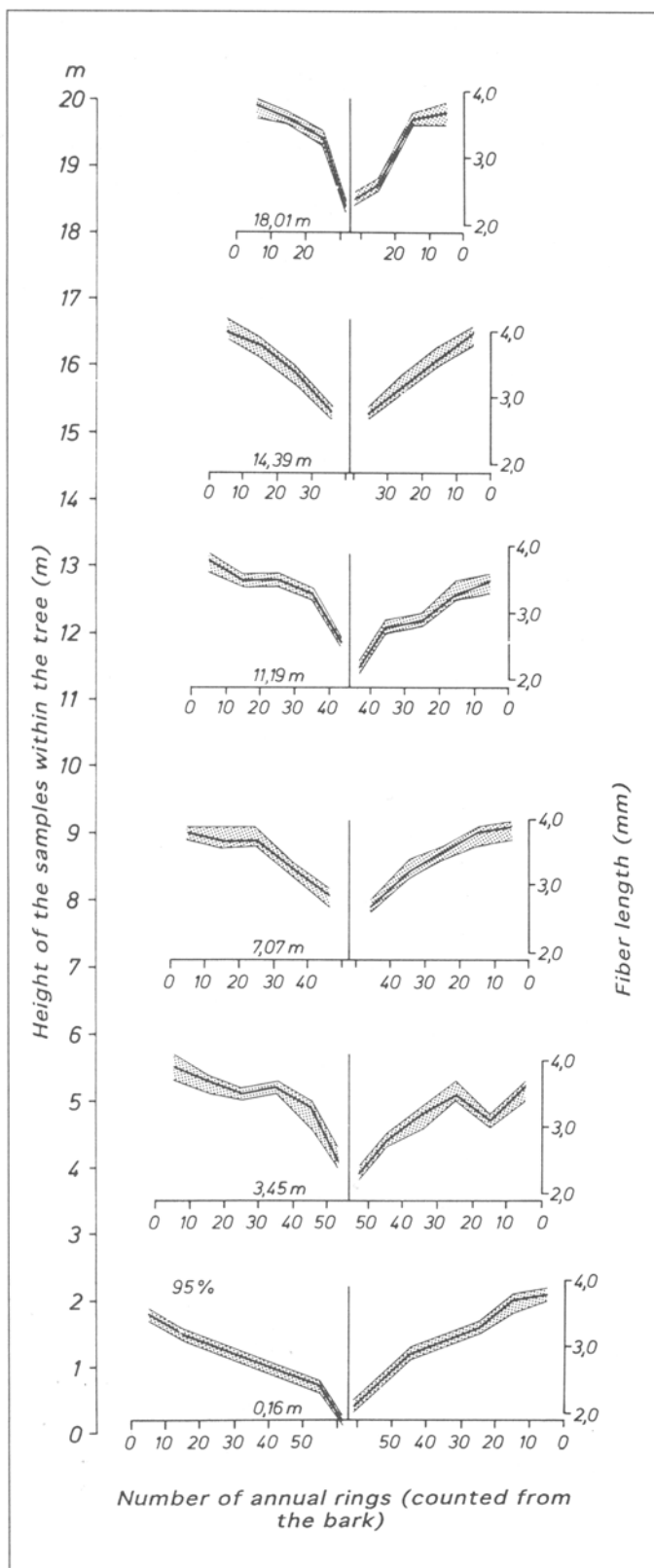


Figure 21-Increase of fiber length measured in different heights of a tree from Belle Etoile (Belgium).

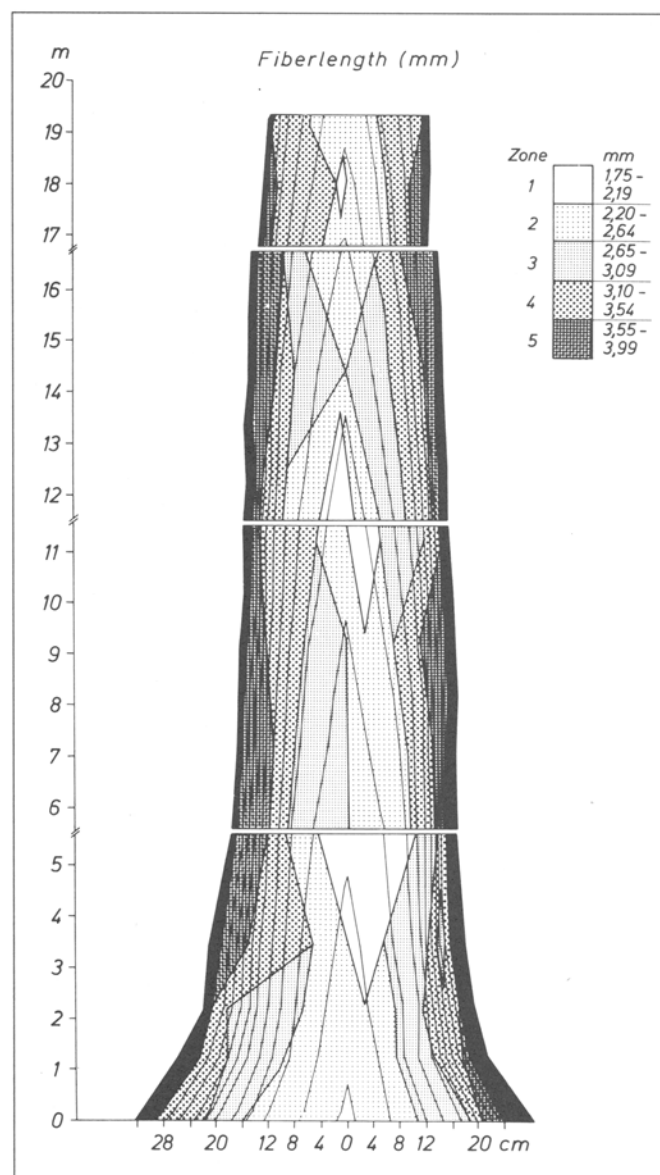


Figure 22-Variation of fiber length between pith and cambium in a 63-year-old tree from Belle Etoile (Belgium).

tracheids and the width of the annual growth ring be established. From all parameters considered there is no reason for separating this wood from the other softwoods sold to the industry.

Specific Gravity

Specific gravity = density of European Giant Sequoia was the next property to be examined on European trees. The measurements on 3,149 samples from 14 trees produced data that put this species in the class of ultra-light softwoods (fig. 23). We found a medium value of 0.345 g/cm^3 with a range from 0.180 to 0.600 g/cm^3 . I should like to compare this value with the density of the increment cores taken in 1981 with the help of Dr. Libby from 97 trees from more or less exactly this area in California. The densities averaged 0.369 g/cm^3 with extremes between 0.279 and 0.671 g/cm^3 . This permits the conclusion that in California, as in Europe, one has to expect that the new generation of Giant Sequoias will provide you with easily handled and utilized raw material. In spite of the fact that specific gravity usually is closely and positively correlated with all strength properties, it is exactly this low density which offers new forms of utilization for this softwood, as I will demonstrate later.

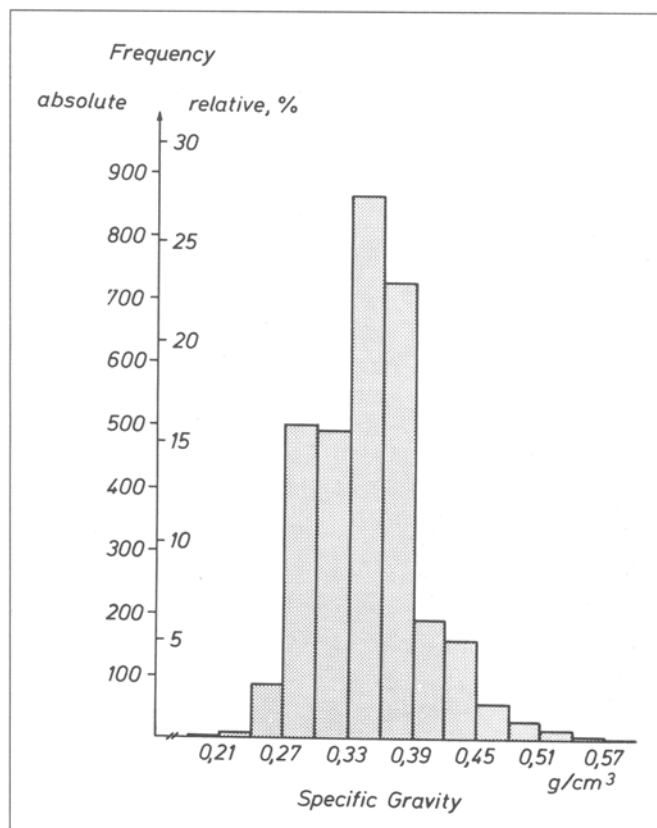


Figure 23-Specific gravity of 14 trees from seven different stands in Germany and Belgium averaged 0.346 (0.180 - 0.600) g/cm^3 classifying Giant Sequoia as an ultra-light softwood.

On the other hand, it is of more than academic interest that we found Giant Sequoia's specific gravity neither positively nor negatively correlated with the width of the annual growth rings, and that our models of the variation within the trees investigated showed a decrease between the pith and the bark (fig. 24). No significant correlation could be established between wood density and age, width of the annual rings, and the height of the samples within the tree. Certainly we do not have to be afraid of relatively wide spacings of new plantations as long as we care for the necessary job of artificial pruning, another reason for doing so.

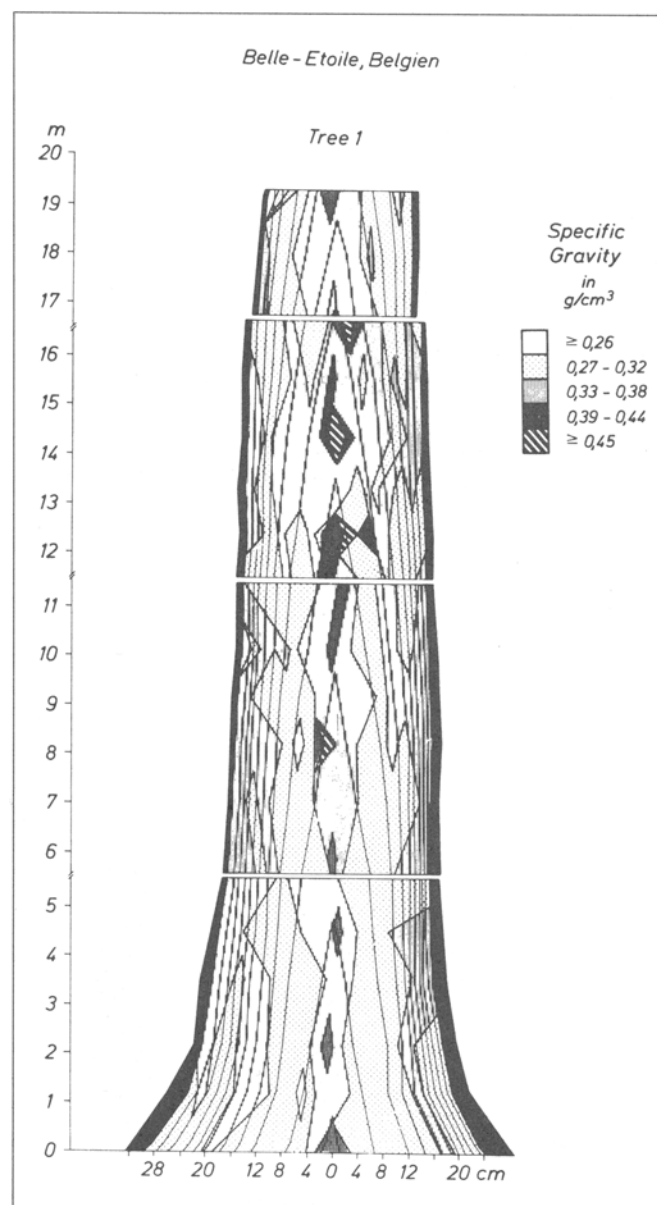


Figure 24-Variation of specific gravity within the same tree (63-years-old, from Belle Etoile, Belgium) investigated for its fiber length.

Strength

Regarding strength I am well aware of the fact that, in California, the strength of Giant Sequoias is generally considered to be inferior to that of the Coast Redwood. The carefully executed investigations of Cockrell and coworkers (1971, 1973) and of Piirto and Wilcox (1980), which were promising and encouraging, apparently did not impress foresters and industry too much with the generally higher level of second-growth strength. Our own tests based on trees mentioned earlier from plots in Belgium and Germany showed low values for compression strength and tensile strength parallel to grain (fig. 25). Also static bending strength turned out to be low in comparison with nearly all other softwoods of Europe and North America. On the other hand, shock resistance or toughness showed a medium of 4.21 J/cm³. Surprisingly, toughness of the sapwood zones proved to be significantly higher than those of the heartwood area, a phenomenon very likely connected with the usual variation of specific gravity. Puzzled by this result, we increased the number of samples examined, dividing the total 1,600 equally between heartwood and sapwood. But the result did not change significantly. Again the influence of anatomic and biologic composition on the strength properties was not easily recognized, leaving room for additional investigations also in the United States (Knigge and others 1983). A transformation of the American standards (ASTM) used by Cockrell and co-workers and the Yugoslavian (GOST) standards into the new European standards and a comparison

of all the data collected lead us to the still tentative statement, that while the static strength properties of second-growth Giant Sequoia are very modest, its toughness deserves recognition (Blank and others 1984).

Durability

Last but not least the durability of Giant Sequoia was largely considered as its most outstanding wood quality. We left this part of our investigation to the Fraunhofer Society for Applied Research at the Wilhelm-Klauditz-Institute in Braunschweig. While early growth was hampered in many areas of Europe by *Armillaria mellea* (Honey fungi) (fig. 26), *Botrytis cinerea* (Grey-mold) and several forms of the genus *Stereum* accompanied single trees until the age of maturity. At Braunschweig front- and backsides of sun- and rain-exposed samples within a general multi-year durability test did not show signs of fungal or bacterial attack during the first 18 months (fig. 27). According to personal communication with Dr. Böttcher from the Wilhelm-Klauditz-Institute, the color changed slightly from red to a grayish red in the heartwood zones, while sapwood demonstrated no more resistance than other European softwoods, i.e. Norway spruce and white fir. We were also a bit puzzled that later there was no indication of decay in the heartwood of some of the trees and increment cores when initially collected and investigated (fig. 28). In 1986 and by the end of this experiment of the Wilhelm-Klauditz-Institute, a few of the samples with fairer stripes within the heartwood indicating a possibly

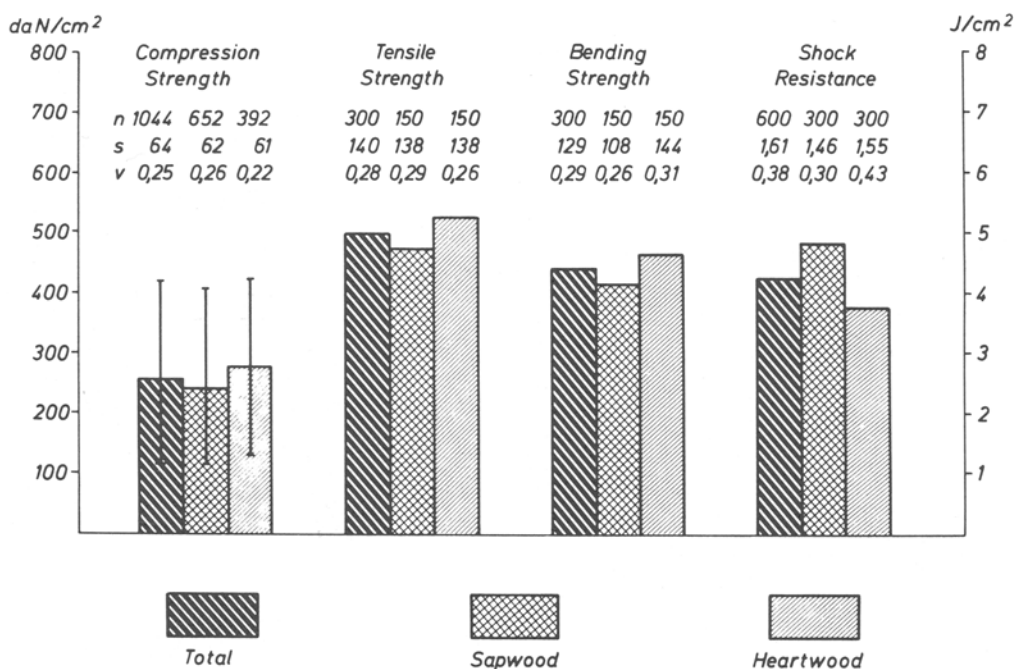


Figure 25-Static and dynamic strength properties of 14 Giant Sequoias from seven stands in Belgium and Germany. There were no significant differences between sapwood and heartwood. Static strength turned out to be low, dynamic strength comparatively high.

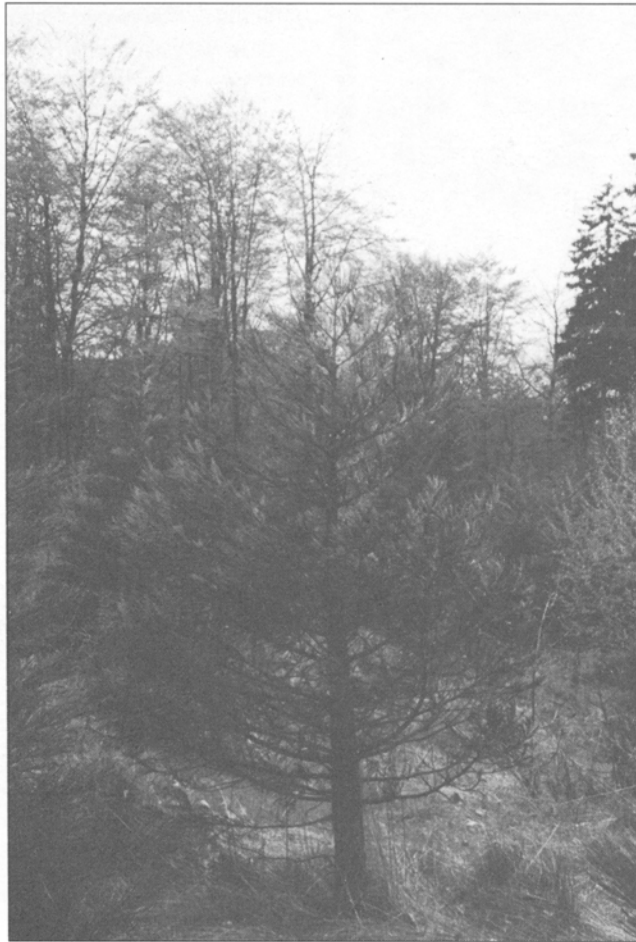


Figure 26-Dead trees in a plantation of 11-year-old Sequoias at Escherode resulting from attack by *Armillaria mellea*. The area was previously occupied by the hardwood *Fagus sylvatica* L. (Beech).



Figure 27-Durability test of different species at the Wilhelm Klauditz-Institute (Fraunhofer Society) at Braunschweig. (Courtesy of P. Böttcher)



Figure 28-Decay in the heartwood of a young stem of Giant Sequoia from Mettmann (Germany).

incomplete formation of fungitoxic extractives showed a slightly greenish surface originated by a modest bacterial attack. Generally the color on the sun- and rain-exposed sides became more discolored red than the backsides. Longitudinal cracks were frequent in sapwood as in heartwood. But no investigations of mycelial fans, rhizomorphs or sporophores were carried out. This basis is too small for any comparison of its durability with the famous one of Coast redwood. According to Dr. Böttcher, it did not significantly exceed the resistance showed by the heartwood of accompanying European larch and Scots pine.

A Reproducible Raw Material

Taking all aspects into account, a European is permitted to conclude that Giant Sequoia could and should add its qualities to the limited number of trees consistent with our intensive way of forest management. What we found is a fast-growing tree of unusual beauty and high durability. Its low density and accompanying low strength are not a special problem, since there will be a growing demand for softwood of this kind. Until now Eastern white pine from the East coast of the United States represented this special character, and we faced no difficulty in selling them. Of

course, a sufficient and continuous supply of roundwood will be necessary to establish a market for this species. However, we have experienced difficulties of this kind from other North American imports such as Douglas-fir, Grand fir, Eastern white pine, and Japanese larch. Since Central Europe produces only 50 percent of its own demand for roundwood, the other 50 percent has to be imported, mostly as wood equivalents like North American and Scandinavian pulp and paper, Russian and East European lumber, and African, Asian or Latin American veneers and plywood. Giant Sequoia could be one of the most important reproducible raw materials to be planted on the growing surplus of agricultural areas. These "reproducible materials" are more than only a popular topic in the European Community.

Sequoiadendron's Limits

Regarding the limits of frost-hardiness, we should like to leave this problem to further analysis by geneticists. The problem of diseases or decay are probably not greater than in all other species which became extinct during the Ice Age and which are currently under consideration for partial repatriation. Therefore, the possibilities of utilizing the wood of Giant Sequoia seem to hold the key for its propagation.

However, if we can handle the problems of fast-growing Monterey pine (*Pinus radiata* D. Don.) more or less the world over, we should be able to solve those originating from the particulars of Giant Sequoia. From the wood biologist's point of view, plantations of the future should consist of genetically controlled material. As we learned, Dr. Bill Libby and Dr. Lauren Fins with their co-workers at the Universities of California and Idaho, respectively, keep devoting much interest to the genetic peculiarities of this species. In Europe, several research groups joined them in exploring the variability of different clones. First thinnings could be combined with harvesting Christmas trees, which could easily be sold domestically and internationally (fig. 29). Early pruning, which is extremely necessary, should enable us to sell the green parts of the branches during October and November (All Souls, fig. 30). By increasing the ratio of the thinnings over the years, the usual decline of diameter growth should be slowed down to a certain extent (fig. 31).

On the other hand, we should not expect an annual yield of 20 m³ per hectare under every condition of soil and climate. But quite apparently the average growth of Monterey pine at the southern half of the Earth can at least be achieved. Therefore a rotation period of 30 to 40 years-according to the different site classes-would leave enough time for the necessary heartwood formation and diameter growth at breast height to at least 45 cm.

Utilization

Regarding the utilization of Giant Sequoia, Europeans understandably lack the experience gained in the United



Figure 29-Young Giant Sequoias ready to be sold as Christmas trees.
(Courtesy of J. Kleinschmit, Escherode)

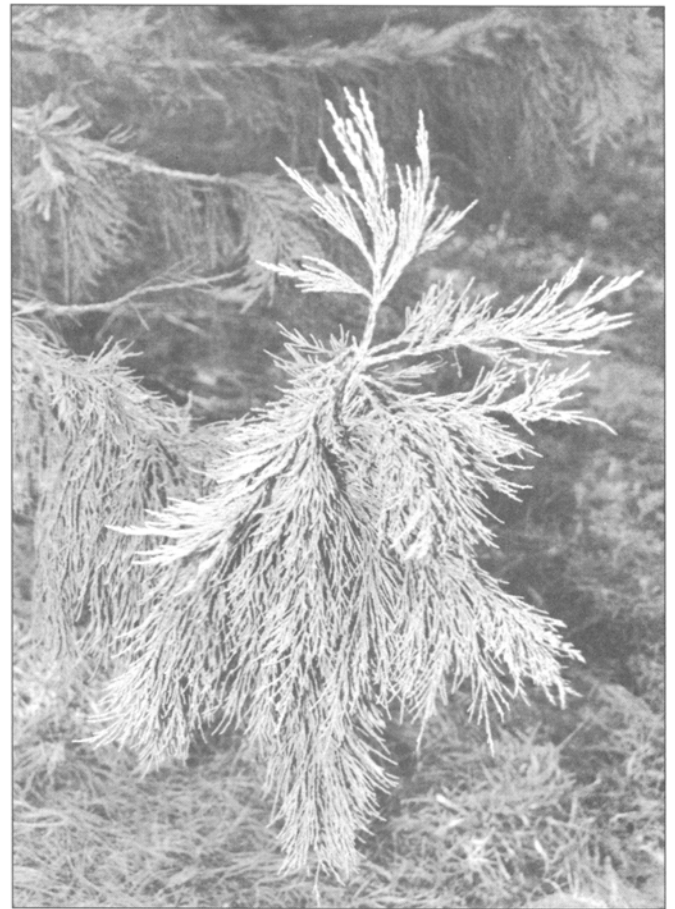


Figure 30-Sequoia branches to be pruned with tips to be harvested and sold during the winter season (All Souls).

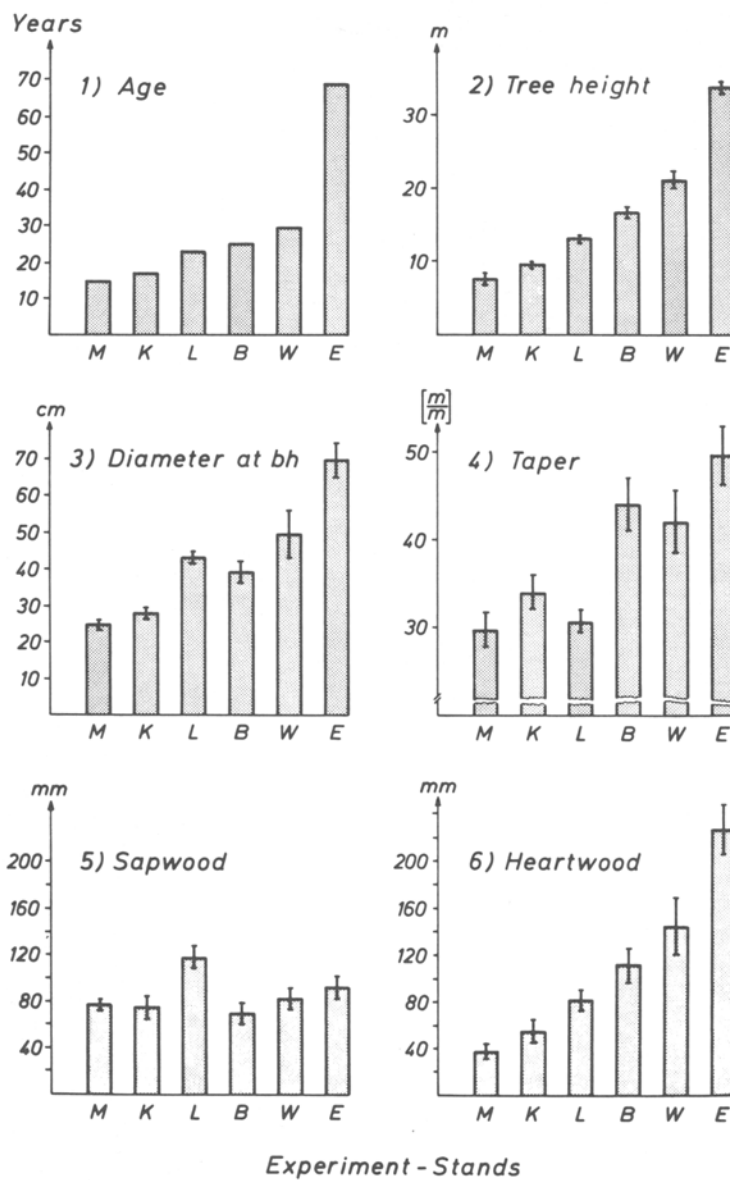


Figure 31 -Variation of wood quality of different Sequoias with age, here especially variation of taper.

States over 150 years. Because of *Sequoiadendron*'s limited strength, beautiful color, and high durability, planing-mill products such as doors, sidings and ceilings, and also fences, poles, boxes and crates could be produced like those recommended for redwood (Panshin and de Zeeuw 1980). The smoothness of its surface and its low shrinkage and swelling recommend its wood for pipes and flumes as well as for garden furniture and boat building. The pruned lower part of the trunk should permit the production of light plywood, which we need as an alternative to the heavy-weight technical plywood manufactured from European hardwoods (fig. 32). But we could use the wood of Giant Sequoia also for shingles and shakes, and, as experience indicated also, as a material for turned and carved articles if the width of the

annual rings does not exceed 10 mm. As long as pulp is produced in Central Europe only through the sulfite or magnefite process and related half-chemical acid methods, *Sequoiadendron*'s wood will not be acceptable there. But new techniques of pulping have been developed and new plants are under construction, for example, working along the Organocell-procedure, which can handle the wood of Giant Sequoia as any other softwood. Other parts of the harvest of thinnings may be used by the fiberboard and particle board industry. While most of these forms of intelligent utilization are still matters of careful planning and introduction, we nevertheless believe in a prospering future of the big tree in the western parts of Europe.

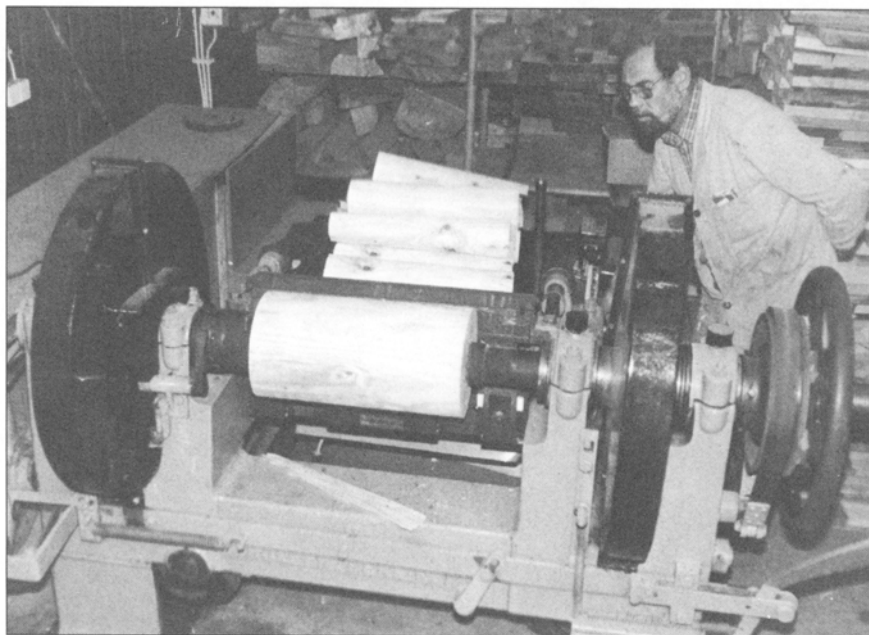


Figure 32-Peeling experiments in the Forest Products Laboratory of the University of Göttingen tested the quality of peeled veneers from middle-aged stems from Kaldenkirchen.

A Final Remark

The Georg-August-University of Göttingen is glad to be the German partner of the Education Abroad Program of the University of California. A bronze plaque donated by Dr. Henry Bruman, University of California, Los Angeles, commemorates the founding of this program in 1963 (*figs. 33 and 34*). Located just in the middle of a small grove of Giant Sequoias within the new Botanical garden, the plaque is close to our School of Forestry and very near our Forest Products Laboratory.



Figure 33-Stump of Giant Sequoia bearing a bronze plaque commemorating the University of California and the University of Göttingen in the mutual "Education Abroad Program" founded in 1963. While bark and sapwood were attacked by fungi, beetles, and birds, the heartwood remained practically untouched.



Figure 34-Bronze plaque commemorating the "Education Abroad Program" of the University of California cooperating with the Georg-August University of Göttingen, donated by Dr. Henry Bruman, University of California, Los Angeles.

References

- Bergel, D. 1969. Douglasien-Ertragstafel für Nordwestdeutschland. In Schober, R.: Ertragstafeln wichtiger Baumarten. Frankfurt am Main, Germany: J.D. Sauerländer's Verlag; 1975.
- Blank, R.; Buck-Gramcko, A.; Knigge, W. 1984. Physikalische Holzeigenschaften des Mammutbaumes (*Sequoiadendron giganteum* (Lindl.) Buchholz) aus europäischen Versuchsanbauten. Forstarchiv 55(5): 199-202.
- Cockrell, R.A.; Knudson, R.M.; Stangenberger, A.G. 1971. Mechanical properties of Southern Sierra old- and second-growth Giant Sequoia. Bull. 854. Berkeley: University of California, Agricultural Experiment Station.
- Cockrell, R. A.; Knudson, R.M. 1973. A comparison of static bending, compression and tension parallel to grain and toughness properties of compression wood and normal wood of a Giant Sequoia. Wood Science and Technology 7(4): 241-250.
- Dekker-Robertson, D.L.; Svolba, J. 1992. Results of a *Sequoiadendron giganteum* (Lindl.) Buchholz provenance experiment in Germany. Silvae Geneticae 42 [In press].
- Fins, L. 1979. Genetic architecture of Giant Sequoia. Berkeley: University of California, 258 p. Dissertation.
- Guinon, M.; Larsen, J.B.; Spethmann, W. 1982. Frost resistance and early growth of *Sequoiadendron giganteum* seedlings of different origins. Silvae Geneticae 31(5-6): 173-178.
- Guinon, M.; Hapla, F.; Lewark, S.; Schroeder, C. 1983. Holzeigenschaftsuntersuchungen an Bohrkernen der *Sequoiadendron giganteum* (Lindl.) Buchholz sowie Baumhöhe und Durchmesser von 6 mitteleuropäischen Versuchsanbauten. Holz-Zentralblatt 109(89) 1233-1237; (105): 1437-1440.
- Hartesveldt, R.J. 1969. Sequoias in Europe. Final Contract Report to the National Park Service, Contract 14-100434-3364.
- Kleinschmit, J. 1984. Der Mammutbaum (*Sequoiadendron giganteum* (Lindl.) Buchholz), nur eine faszinierende Exotenart? Beiheft zur Schweizerischen Zeitschrift für Forstwesen, No. 72: 61-77.
- Knigge, W.; Wenzel, B. 1983. Über die Variabilität der Faserlänge innerhalb eines Stammes von *Sequoiadendron giganteum* (Lindl.) Buchholz. Forstarchiv 54(3): 94-99.
- Knigge, W.; Pellinen, P.; Schilling, T. 1983. Untersuchungen von Zuwachs, Ästigkeit, Verkernung und Rindenstärke westeuropäischer Anbauten des Mammutbaumes (*Sequoiadendron giganteum* (Lindl.) Buchholz). Forstarchiv 54(2): 21-27.
- Landesanstalt für Ökologie, Landschaftsentwicklung und Forstplanung Nordrhein-Westfalen (LÖLF). 1982. Merkblatt für fremdländische Baumarten: *Sequoiadendron giganteum* (Lindl.) Buchholz; 3 p.
- Libby, W.J. 1981. Some observations on *Sequoiadendron* and *Calocedrus* in Europe. California Forestry and Forest Products, University of California, Department of Forestry and Conservation, Forest Products Laboratory, Berkeley, 12 p.
- Löffler, J. 1985. Mammutbäume und der Landkreis Calw. Jahrbuch des Landkreises, Calw: 85-92.
- Martin, E.J. 1957/58. Die Sequoien und ihre Anzucht. Mitteilungen der Deutschen Dendrologischen Gesellschaft 60:3-62.
- Panshin, A.J.; Zeeuw C. de. 1980. Textbook of wood technology, 4th ed. New York: McGraw Hill Book Co., Inc.; 722 p.
- Piirto, D.D.; Wilcox, W.W. 1980. Comparative properties of old-growth and young-growth Giant Sequoia of potential significance to wood utilization. Bulletin 1901. Berkeley: Division of Agricultural Sciences, University of California; 4 p.
- Piirto, D.D.; Wilcox, W.W. 1984. Causes of uprooting and breakage of specimen Giant Sequoia trees. Bulletin 1909, Berkeley: University of California, Division of Agricultural and Natural Resources.
- Schenck, C.A. 1953/54. Ergebnisse der II. Inventure ausländischer Holzarten durch die Deutsche Dendrologische Gesellschaft. Mitteilungen der Deutschen Dendrologischen Gesellschaft 58: 15-70.
- Schober, R. 1975. Ertragstafeln wichtiger Baumarten. Frankfurt am Main, Germany: J.D. Sauerländer's Verlag; 154 p.
- Wiedemann, E. 1949. Ertragstafeln der wichtigsten Holzarten. (Fichte 1936/1942; Kiefer 1943). Hannover, Germany: Verlag M. & H. Schaper; 76 p.
- Wolford, J.L.; Libby, W.J. 1976. Rooting giant sequoia cuttings. The Plant Propagator 22: 11-13.

Paleohistory of a Giant Sequoia Grove: The Record from Log Meadow, Sequoia National Park¹

R. Scott Anderson²

Abstract: The giant sequoia (*Sequoiadendron giganteum*) of California's Sierra Nevada, the world's largest living organism, includes some of the oldest trees known. Its modern distribution is among the most unusual of any major North American conifer, occurring as a local dominant in some 75 disjunct groves within the Sierra montane forest. Recent analysis of pollen and plant macrofossils from Log Meadow in the Giant Forest grove of Sequoia National Park has contributed to our understanding of the development of modern giant sequoia groves. Giant sequoia trees were rare around Log Meadow during the early and into the middle Holocene, increasing in abundance only after ca. 4,500 years ago. The rarity may have been due to the more arid climate predominating during the early Holocene. A return to a cooler or wetter climatic regime or both during the middle to late Holocene allowed the expansion of the tree, and the establishment of the modern grove.

The causes and mechanisms which force vegetation change within forest communities have been a dominant theme in ecological research. Plant communities have been continuously stressed by environmental variables such as geologic events, natural disturbances, climatic perturbations and human activities. Each of these variables operates on different timescales. For instance, extremely long-term changes in vegetation communities, occurring over millions of years, may be caused by movements of the Earth's crust, such as the rise of the Sierra Nevada itself. In addition, natural disturbances (i.e., fire and insects) and human activities measured over relatively short timescales of years to decades, contribute to vegetation disturbance as well. Thus, any or all of these variables may cause changes in structure or composition of plant communities.

Climatic perturbations, on the order of hundreds to thousands of years, have also been linked to vegetation changes; and in fact, evidence suggests that climatic change is the driving force behind major vegetation change (Imbrie and Imbrie 1979). Periods of interglaciation, e.g., warm periods of about 10,000 years, have alternated with glacial periods, which average about ten times longer. Assuming that species respond individually to varying climatic parameters, over geologic time then, it is clear that vegetation associations are temporary aggregates of species (Davis 1989).

This paper addresses the development of the Sierran mixed-conifer forest, which has occurred during the Holocene (last 10,000 years) interglacial period, but concentrates on

the history of giant sequoia (*Sequoiadendron giganteum*) from a site located within the sequoia/mixed-conifer forest.

The giant sequoia of California has been the subject of curiosity since its initial discovery and exploitation in the late 1850's (Hartesveldt and others 1975; Johnston 1983). Its modern distribution is among the most unusual of any major North American conifer. Although it rarely is found in monospecific stands, it occurs as a local dominant in approximately 75 disjunct groves within the mixed-conifer forest of the Sierra Nevada, California (Rundel 1969). Major associated tree species today include California white fir [*Abies concolor* (Gord. & Glend.) Lindl.], sugar pine (*Pinus lambertiana* Dougl.), and incense-cedar [*Calocedrus decurrens* (Torr.) Florin] (see *table 1* for scientific and common names of species mentioned in this paper). California red fir (*Abies magnifica* A. Murr.) is important at higher elevations, while ponderosa pine (*Pinus ponderosa* Dougl. ex P. & C. Lawson) and California black oak (*Quercus kelloggii* Newb.) are common at lower elevations. Minor associated trees include Jeffrey pine (*Pinus jeffreyi* Grev. & Balf. in A. Murr.), Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], Pacific yew (*Taxus brevifolia* Nutt.), Pacific dogwood (*Cornus nuttallii* Aud.), and white alder (*Alnus rhombifolia* Nutt.), along with species of buckthorn (*Ceanothus* L.), among others (Weatherspoon 1990).

Most individuals of the species occur within the southern portion of the range, and the groves become smaller and more disjunct to the north (Hartesveldt and others 1975) (*fig. 1*). Hypotheses for this disjunction include the effects of Pleistocene cooling (Muir 1876; Axelrod 1959) and middle Holocene warming (Axelrod 1986). Implicit in the latter is the suggestion that a wider distribution occurred at the end of the last glaciation. Although widespread reports of "red wood" are found in well logs from Pleistocene Lake Tulare at the western foot of the Sierra Nevada (Schmidt 1972), few data exist on the late Wisconsin distribution of the species (Cole 1983).

Log Meadow, in the Giant Forest of Sequoia National Park (*fig. 1*), was chosen as a study site for investigating the development of the sequoia/mixed-conifer forest type. The meadow occurs at an elevation of 2,048 m, and measures ca. 750 m long by ca. 125 meters wide. Sediments include accumulations of alluvial, colluvial and peaty deposits. Bedrock within the area consists of Cretaceous granodiorite (Sisson and others 1983). Local topography is a classic example of "stepped topography," where subaerial weathering of the granodiorite has caused formation of a local baselevel, in this case impeding streamflow and resulting in wet meadow formation (Wahrhaftig 1965).

¹An abbreviated version of this paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

²Assistant Professor, Environmental Sciences and Quaternary Studies Programs, Northern Arizona University Flagstaff, AZ 86011

Table 1-Scientific names of species mentioned in the text and figures, with common name equivalents.

Scientific Name	Common Name
<i>Abies concolor</i> (Gord. & Glend.) Lendl.	California white fir
<i>Abies magnifica</i> A. Murr.	California red fir
<i>Aesculus californica</i> (Spach) Nutt.	California buckeye
<i>Alnus</i> Hill	Alder
<i>Alnus rhombifolia</i> Nutt.	White alder
<i>Ambrosia</i> L.	Ragweed
<i>Arceuthobium</i> Bieb.	Dwarf mistletoe
<i>Arctostaphylos</i> Adans.	Manzanita
<i>Artemisia</i> L.	Sagebrush / wormwood
<i>Calocedrus decurrens</i> (Tory.) Florin	Incense-cedar
<i>Ceanothus</i> L.	Buckthorn
Chenopodiaceae	Goosefoot family
<i>Chrysolepis sempervirens</i> (Kell.) Hjelmquist	Bush chinquapin
Compositae	Sunflower family
<i>Cornus nuttallii</i> Aud.	Pacific dogwood
<i>Corylus cornuta</i> Marsh. var. <i>californica</i> (A. DC.) Sharp	California hazel
Cruciferae	Mustard family
Cyperaceae	Sedge family
<i>Galium</i> L.	Bedstraw
Gramineae	Grass family
Liliaceae	Lily family
<i>Mimulus</i> L.	Monkeyflower
<i>Oxyopolis occidentalis</i> Coult. & Rose.	Cow-bane
<i>Pinus jeffreyi</i> Grev. & Balf. in A. Murr.	Jeffrey pine
<i>Pinus lambertiana</i> Dougl.	Sugar pine
<i>Pinus murrayana</i> Grev. & Balf. in A. Murr.	Lodgepole pine
<i>Pinus ponderosa</i> Dougl. ex P. & C. Lawson	Ponderosa pine
<i>Polygonum</i> L.	Knotweed
Polypodiaceae	Ferns
<i>Pseudotsuga menziesii</i> (Mirb.) Franco	Douglas-fir
<i>Quercus</i> L.	Oak
<i>Quercus kelloggii</i> Newb.	California black oak
<i>Ranunculus</i> L.	Buttercup
<i>Rumex</i> L.	Sorrel
<i>Salix</i> L.	<i>Willow</i>
<i>Sequoiadendron giganteum</i> (Lindl.) Buchh	Giant sequoia
Taxodiaceae-Cupressaceae-Taxaceae	T-C-T
<i>Taxus brevifolia</i> Nutt.	Pacific yew
<i>Thalictrum</i> L.	Meadow-rue
<i>Tsuga mertensiana</i> (Bong.) Carr.	Mountain hemlock

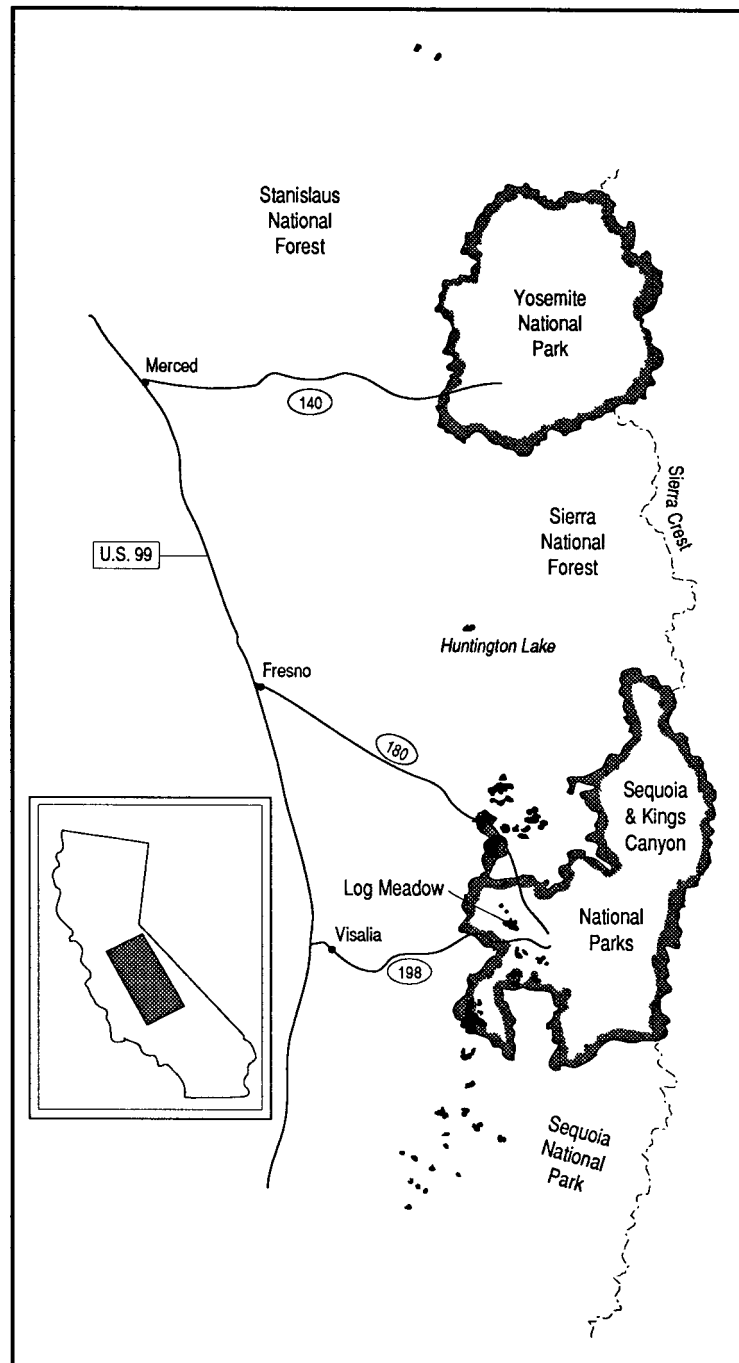


Figure 1-Location of study sites mentioned in the text, along with the modern distribution of giant sequoia groves (irregular blackened spots).

Methods

In July 1987 a Livingstone corer was used to collect a sediment core (Wright 1967). Sediments were retrieved in 1-meter increments for a total of 10.4 meters. In the laboratory, small sediment samples were extracted from the larger core for pollen and plant macrofossil analysis. For pollen analysis, 1-cc sediment subsamples were processed using a modified Faegri and Iversen (1989) technique. Some samples needed a sodium pyrophosphate treatment, including

seven um sieving to remove clays (Cwynar and others 1979). Resulting pollen assemblages were mounted in silicone oil. Pollen was identified and counted at 400X using a Reichert microscope, referring to the modern pollen reference collection as necessary at the Laboratory of Paleoecology, Northern Arizona University. Plant macrofossils were concentrated by gentle water washing of the delicate plant fragments through 20 and 80 mesh soil sieves. Plant materials

were identified by comparison with modern reference materials, or, in the case of pine needle fragments, through careful sectioning (Anderson 1990a).

Results

Sediment Stratigraphy and Radiocarbon Dates

From the top of the core down to about 2.25 meters were bands of medium to coarse peat alternating with medium grained colluvial/alluvial sediments. Below this, the organic content was reduced. The section from approximately 2.25 to 6.00 meters consisted of alternating bands of organic silts with medium to coarse grained colluvial and alluvial sediments. Below 6.00 meters the amount of sand increased, although the alternation with bands of organic silts continued. The sediments below 8.50 meters were predominantly medium to coarse sands.

A total of four radiocarbon dates were obtained from the core, providing chronologic control (table 2). The bottom date suggests that organic sedimentation began sometime after about 10,500 years ago. A constant rate of sedimentation is assumed between dates.

Pollen and Macrofossil Stratigraphies

The Log Meadow record can be divided into three distinct periods (not described here as formal pollen zones), based on changes in the pollen and macrofossil stratigraphies. These include sediments deposited between (a) approximately 10,500 and 9,000 yr BP (years before present), (b) 9,000 to about 4,500 yr BP; and (c) sediments deposited after 4,500 yr BP.

10,500-9,000 yr BP. In sediments deposited prior to 9,000 years ago, a diverse group of species of pine dominates the fossil assemblages. These species include sugar, ponderosa, and lodgepole (*Pinus murrayana* Grev. & Balf. in A. Murr.) pines (fig. 2). Fir pollen and macrofossils (white fir) are also abundant. Other commonly occurring pollen include bush chinquapin [*Chrysolepis sempervirens* (Kell.) Hjelmquist], hazel [*Corylus cornuta* Marsh. var. *californica* (A. DC.) Sharp], sagebrush (*Artemisia* L.), and ferns (Polypodiaceae). The frequency of giant sequoia pollen is extremely low, and macrofossils are absent, indicating the absence of the plant locally and in the immediate vicinity (Anderson 1990b).

Table 2 - Radiocarbon Dates from Log Meadow.

Laboratory Number	Depth (cm)	C ¹⁴ Date (yr BP)
Beta-25934	240 - 248	2,690±80
Beta-25935	355 - 392	4,190±90
Beta-25936	707 - 715	9,010± 120
Beta-22449	945 - 955	10,210±180

9,000-4,500 yr BP. This period encompasses most of the early Holocene and into the middle Holocene, ending about 4,500 years ago. During this time the major pollen types are once again pine (primarily sugar and ponderosa pines) and fir, this time with oak. A parasite primarily on pines, dwarf mistletoe (*Arceuthobium* Bieb.), occurs in maximum amounts. Because the pollen of mistletoe is not widely distributed, the proximity of pines to the site is indicated (Anderson and Davis 1988). Shrubby species which are common before this period are considerably diminished. Giant sequoia pollen remains very sparse, although the first macrofossils of the species are found shortly after the opening of the period. Increases in sedges (Cyperaceae), and somewhat later, cow-bane (*Oxyopolis occidentalis* Coult. & Rose.), indicate the inception of a moist meadow at the site.

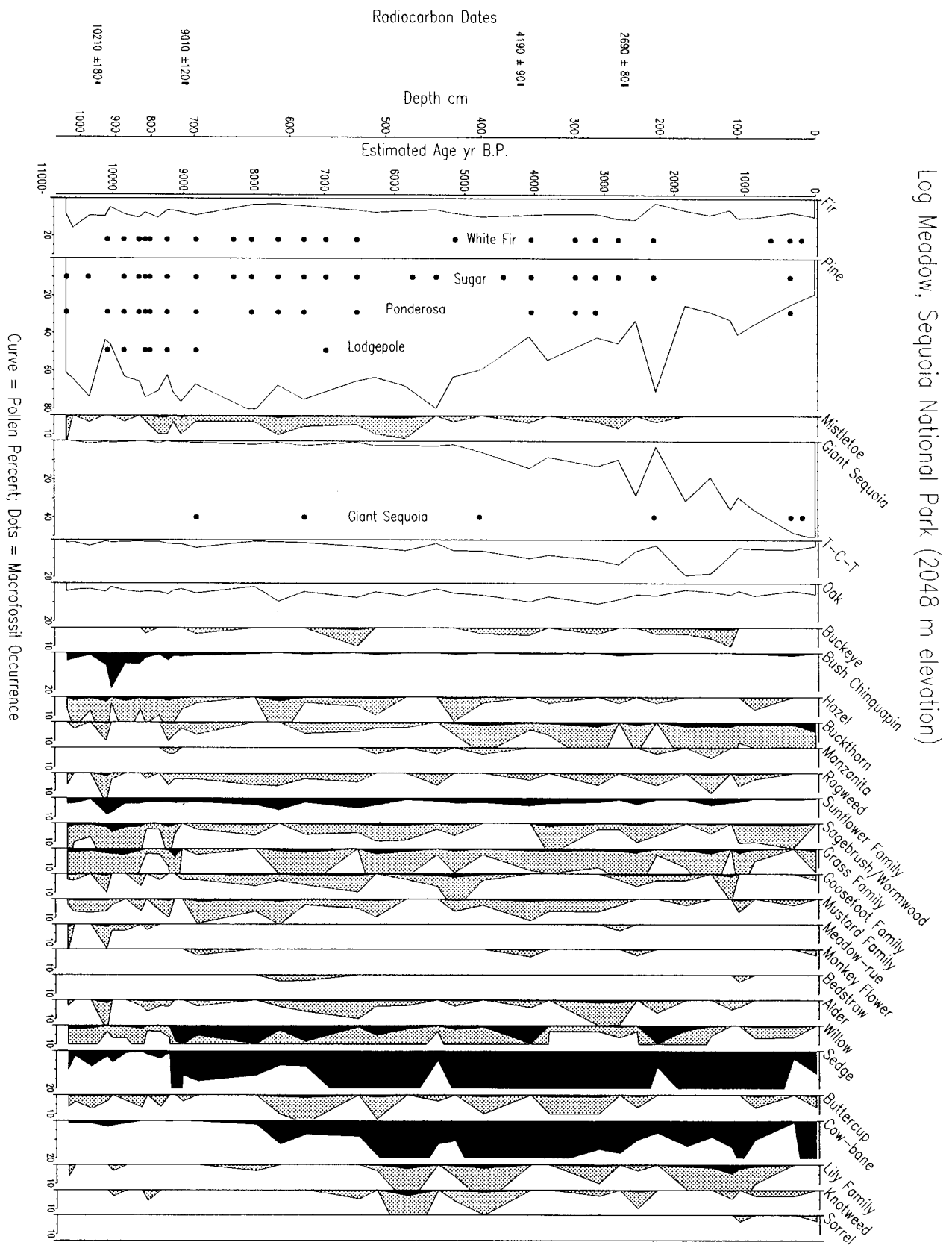
4,500 yr BP-Present. The greatest changes in the entire record occur subsequent to 4500 years ago. Giant sequoia pollen percentages increase from near absence, culminating in maximum percentages in the most recent centuries. Declines in oak, dwarf mistletoe and pine occur, while buckthorn and fir pollen increase slightly. Macrofossil remains indicate a mixed-conifer assemblage, dominated by sugar and ponderosa pine, and white fir.

Discussion and Conclusions

Pollen dispersal studies from modern stands of giant sequoia suggest that pollen is not widely dispersed from the source trees (Anderson 1990b). For small, isolated stands, giant sequoia pollen constitutes generally less than five percent of the total pollen assemblage at the grove boundary. For larger, less isolated stands, giant sequoia pollen is dispersed somewhat greater distances (five percent pollen at 450 meters). In other words, deposition of giant sequoia pollen is largely a local occurrence. Because modern pollen data are used to interpret fossil pollen in sediment cores, amounts of giant sequoia pollen as low as five percent within the core are interpreted as rarity or general absence locally of the plant itself.

The data from Log Meadow can be used to infer the establishment and development of one giant sequoia grove within the species' modern range. At least for this location, these data suggest that groves of middle elevations today have developed relatively recently, and that the tree was extremely rare during the first half of the Holocene. The macrofossil record (fig. 2) indicates that a few individual trees must have been present near the coring site at Log Meadow at times prior to 4,500 years ago. Based upon the modern pollen studies, however, the local giant sequoia population of the early and middle Holocene (when pollen percentages averaged less than two percent) must have been quite small compared to that after 4,500 yr BP.

Vegetation change at Log Meadow is summarized in figure 3. Dominant trees at the site prior to 9,000 years ago were lodgepole, sugar and ponderosa pines, which grew in a relatively dry meadow. A sugar and ponderosa pine/mixed-



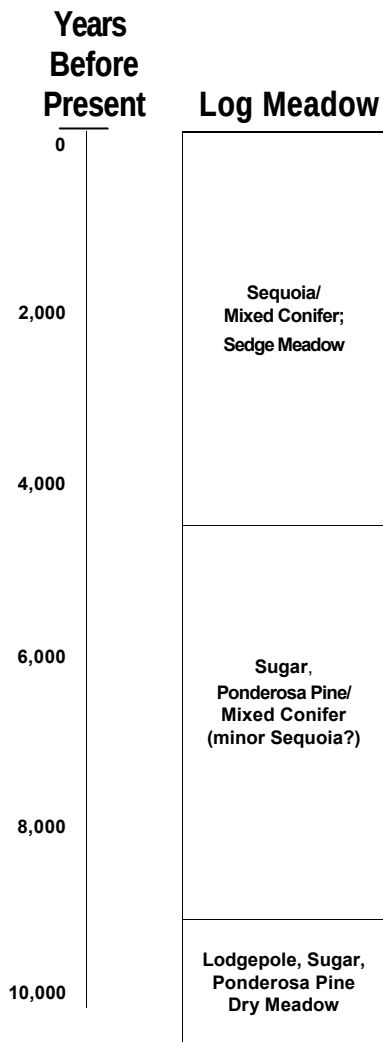


Figure 3-Summary of vegetation change at Log Meadow since the initial formation of the meadow about 10,500 years ago.

conifer forest, with very minor amounts of giant sequoia, grew there from roughly 9,000 to 4,500 years ago. Wetter meadow conditions prevailed during this time than during the previous period. The modern sequoia/mixed-conifer forest developed only over the last 4,500 years.

Additional biologic and geomorphic evidence provide support for the influence of climate in the expansion of giant sequoia during the late Holocene. For locations within the subalpine and upper montane, early Holocene forests were structurally different from those of today. From approximately 10,000 to 6,000 years ago, an open pine forest dominated most locations, with montane chaparral shrubs [buckthorn, bush chinquapin, manzanita (*Arctostaphylos* Adans.)] growing more commonly in forest openings. Several tree species characteristic of the modern subalpine forests [mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) and red fir] were rare or restricted to more mesic habitats (Anderson 1990a; Anderson and Smith 1991; Davis et al. 1985; Smith and Anderson 1992). In addition, trees grew in areas that

presently support wet meadows, lake levels in the Sierra Nevada were lower and flushing of small hollows by intense rain storms declined (Wood 1975; Anderson 1990a; Reneau and others 1986). Upper treeline was higher in the neighboring White Mountains (LaMarche 1973). These data suggest warmer temperatures and lower soil moisture conditions than the present, and thus, significantly drier conditions prevailed.

Recent paleoclimatic models provide possible explanation for these observations (COHMAP 1988; Kutzbach and Geutter 1986). During the late Wisconsin to Holocene transition the seasonal distribution of summer insolation differed from today. Seasonality was greater with seven percent more solar radiation in the summer and seven percent less in winter. Given the scale of the models, intensified summer drought is projected for the Sierra Nevada, with cooler winters. Since the most important single factor in mortality of seedlings and maintenance of adult individuals of the species is proximity to abundant subsurface moisture, a lengthening of the summer drought during the early Holocene may have precluded largescale establishment of giant sequoia through-out its modern elevational range (Harvey 1980). Only in particularly mesic locations did the species find refuge.

Preliminary data suggest that the tree disappeared from the fossil record below 1,300 meters elevation by 14,200 years ago (Cole 1983). Though present in its modern range at a few localities during the early Holocene, giant sequoia was apparently quite rare during that period, much more so than today. At Log Meadow, the species has not been as abundant at any time during the last 10,000 years as it is today, and aged individuals within the grove may be direct descendants-third or fourth generation-of initial pioneers.

Thus, this study suggests that the unusual distribution of giant sequoia in California can be attributed largely to changing climatic conditions during the Holocene. Additional research will investigate the importance of other factors, such as fire, on the biogeography of the species.

References

- Anderson, R.S. 1990a. Holocene forest development and paleoclimates within the central Sierra Nevada, California. *Journal of Ecology* 78: 470-489.
- Anderson, R.S. 1990b. Modern pollen rain within and adjacent to two giant sequoia (*Sequoiadendron giganteum*) groves, Yosemite and Sequoia national parks, California. *Canadian Journal of Forest Research* 20: 1289-1305.
- Anderson, R.S.; Davis, O.K. 1988. Contemporary pollen rain across the central Sierra Nevada, California: relationship to modern vegetation types. *Arctic and Alpine Research* 20: 448-460.
- Anderson, R.S.; Smith, S.J. 1991. Paleoecology within California's Sierra Nevada National Parks: an overview of the past and prospectus for the future. In: *Proceedings of the Yosemite Centennial Symposium, 1990, October 13-20; Concord, CA*. Denver, U.S. Department of Interior, National Park Service; 329-337.
- Axelrod, D.I. 1959. Late Cenozoic evolution of the Sierran bigtree forest. *Evolution* 13: 9-23.
- Axelrod, D.I. 1986. The sierra redwood (*Sequoiadendron*) forest: end of a dynasty. *Geophytology* 16: 25-36.
- COHMAP. 1988. Climatic changes of the last 18,000 years: observations and model simulations. *Science* 241: 1043-1052.

- Cole, K.L. 1983. Late Pleistocene vegetation of Kings Canyon, Sierra Nevada, California. *Quaternary Research* 19: 117-129.
- Cwynar, L.C.; Burden, E.; McAndrews, J.H. 1979. An inexpensive sieving method for concentrating pollen and spores from fine-grained sediments. *Canadian Journal of Earth Sciences* 16: 1115-1120.
- Davis, M.B. 1989. Insights from paleoecology on global change. *Bulletin of the Ecological Society of America* 70: 222-228.
- Davis, O.K.; Anderson, R.S.; Fall, P.L.; O'Rourke, M.K.; Thompson, R.S. 1985. Palynological evidence for early Holocene aridity in the southern Sierra Nevada, California. *Quaternary Research* 24: 322-332.
- Fægri, K.; Iversen, J. 1989. *Textbook of pollen analysis*. 4th ed. Chichester: John Wiley and Sons; 328 p.
- Hartesveldt, R.J.; Harvey, H.T.; Shellhammer, H.S.; Stecker, R.E. 1975. The giant sequoia of the Sierra Nevada. U.S. Department of Interior, National Park Service, Washington, D.C.; 180 p.
- Harvey, H.T. 1980. Giant sequoia reproduction, survival and growth. In: Harvey, H.T.; Shellhammer, H.S.; Stecker, R.E., eds. *Giant Sequoia Ecology*. U.S. Department of Interior, National Park Service, Scientific Monograph Series 12; 41-68.
- Imbrie, J.; Imbrie, K.P. 1979. *Ice ages: solving the mystery*. London: Macmillan Co; 224 p.
- Johnston, H. 1983. *They felled the redwoods*. Glendale: Trans-Anglo Books; 160 p.
- Kutzbach, J.E.; Guetter, P.J. 1986. The influence of changing orbital parameters and surface boundary conditions on climate simulation for the past 18,000 years. *Journal of the Atmospheric Sciences* 43: 1726-1759.
- LaMarche, V.C., Jr. 1973. Holocene climatic variation inferred from treeline fluctuations in the White Mountains, California. *Quaternary Research* 3: 632-660.
- Muir, J. 1876. On the postglacial history of *Sequoia gigantea*. *American Association for the Advancement of Science, Proceedings* 25: 242-253.
- Reneau, S.L.; Dietrich, W.E.; Dorn, R.I.; Berger, C.R.; Rubin, M. 1986. Geomorphic and paleoclimatic implications of latest Pleistocene radio-carbon dates from colluvium-mantled hollows, California. *Geology* 14: 655-658.
- Rundel, P.W. 1969. The distribution and ecology of the giant sequoia ecosystem in the Sierra Nevada, California. Durham: Duke University; 204 p. Ph.D. dissertation.
- Schmidt, K.D. 1972. Distribution of sequoia wood in alluvium of the San Joaquin Valley. Unpublished abstract of talk given at Sequoia National Park; 24 August 1972.
- Sisson, T.W.; Moore, J.G.; Wahrhaftig, C. 1983. Geologic map of Giant Forest and Lodgepole Area, Sequoia National Park, California. Department of Interior, U.S. Geological Survey, Open File Report 84 400. (Map).
- Smith, S.J.; Anderson, R.S. 1992. A late Wisconsin paleoecological record from Swamp Lake, Yosemite National Park, California. *Quaternary Research* 38: 91-102.
- Wahrhaftig, C. 1965. Stepped topography of the southern Sierra Nevada, California. *Geological Society of America Bulletin* 76: 1165-1190.
- Weatherspoon, C.P. 1990. *Sequoiadendron giganteum* (Lindl.) Buchholz Giant Sequoia. In: Burns, R.M.; Honkala, B.H. tech. coords. *Silvics of North America*. Volume 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture; 552-562.
- Wood, S.H. 1975. Holocene stratigraphy and chronology of mountain meadows, Sierra Nevada, California. *Earth Res. Monogr.* 4. Washington, DC: U.S. Department of Agriculture; 180 p.
- Wright, H.E., Jr. 1967. A square-rod piston sampler for lake sediments. *Journal of Sedimentary Petrology* 37: 975-976.

Long-term Dynamics of Giant Sequoia Populations: Implications for Managing a Pioneer Species¹

Nathan L. Stephenson²

Abstract: My colleagues and I have analyzed the age structure of four populations of giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz). We have found the following: (1) The amount of successful reproduction in a grove cannot be judged by the sizes of its trees. (2) Sequoia populations almost certainly were near equilibrium or increasing before the arrival of European settlers. (3) In this century, there has been a massive failure of sequoia reproduction in groves protected from fire but otherwise meant to be maintained in a natural state. (4) Before the arrival of European settlers, successful recruitment of mature sequoias depended on fires intense enough to kill the forest canopy in small areas. Thus, sequoia is a pioneer species, and this conclusion has specific management implications.

On walks I have taken through sequoia groves with members of conservation groups and the general public, our discussions raised several questions relevant to the preservation of sequoia groves. Here I will address four of these questions—four that I consider to be among the most important for understanding the dynamics and management of sequoia groves.

(1) *Can we determine whether a grove is successfully reproducing by the sizes of its sequoias?* Small sequoias, some less than 1 m (3.3 ft) tall, can be found in nearly any sequoia grove protected from logging and fire. Does this not contradict the popular and scientific literature, which abound with declarations that sequoias have not been reproducing successfully in otherwise undisturbed groves?

(2) *Were sequoia populations increasing, decreasing, or near equilibrium at the time of European settlement?* The answer to this question is critical as a backdrop for interpreting sequoia population trends during the post-settlement period.

(3) *Is reproduction sufficient to maintain sequoia populations in the absence of fire?* Even though sequoia seedling establishment declines precipitously in the absence of fire, might establishment on bare mineral soil exposed by treefalls be sufficient to maintain sequoia populations? After all, John Muir recognized that bare mineral soil was a necessary prerequisite for sequoia reproduction, and that fire created mineral soil seedbeds, but clearly stated that "[t]he fall of old trees ... furnishes fresh soil in sufficient quantities for the maintenance of the [sequoia] forests" (Muir 1878, in Jones 1977). Thus, is there really any reason for concern over sequoia reproduction, and is fire really necessary?

(4) *What were the key factors in the maintenance of sequoia populations before the arrival of Europeans?* This is the most all-encompassing question, and we must know

the answer if our goal is to maintain groves in as nearly a natural state as possible.

Methods

To answer these questions, my colleagues and I used increment cores to determine the ages of 659 mapped giant sequoias—nearly all of the living sequoias growing in four plots (6 to 18 ha in size) in Giant Forest and Atwell Grove (Sequoia National Park, California) and Mariposa Grove (Yosemite National Park, California). Two of the four study plots had recently been prescribed burned: Mariposa in the early 1970's, and central Giant Forest in 1982. Since we wished to collect data representative only of pre-burn conditions, we cored only those sequoias that were present before the two burns, ignoring seedlings that had become established as a result of the burns. Pre-burn sequoias were easily distinguished from post-burn seedlings, which had slender, flexible main stems. Reference to a pre-burn inventory of sequoias confirmed that only a few small pre-burn sequoias (usually 1 m [3.3 ft] tall or less) were killed in the central Giant Forest burn, meaning our estimates of the numbers of trees in different age classes were representative of pre-burn conditions.

Two-thirds of the living sequoias in our plots were less than 2 m (6.5 ft) in diameter. We were able to core these trees to the pith region, providing an accurate estimate of age from ring counts. Whenever possible, the cores were taken from ground level; when cores were taken from above ground level, the number of years missed to ground level was estimated using an approach modified from Agee and others (1986). If a core bypassed the pith, the number of years missed to the pith was estimated by first estimating the distance to the pith (Ghent 1955), then dividing by the average width of the innermost 10 rings. Analysis of error showed that even with these corrections, there was a tendency to underestimate the ages of trees, but usually by less than 10 years. Additionally, missing rings undoubtedly caused us to underestimate the ages of some very suppressed sequoias. However, underestimates from either of these sources are not large enough to affect the general conclusions of this paper.

Our increment borers were too short to reach the pith region of those sequoias greater than about 2 m diameter. Instead, we took two long cores from opposite sides of each tree, corrected tree diameter at core height for bark thickness (determined by probes), then applied an empirically-derived relationship (based on radial growth measurements from 451 stump tops; Huntington 1914) that sequoia age is a function of radial growth rate and radius to the 1.6 power. This approach has proved to be more accurate than that used

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²Research Ecologist, Sequoia and Kings Canyon National Parks, Three Rivers, California 93271.

by Hartesveldt and his colleagues (1975), though our age estimates on some large sequoias may have been off by one or more centuries. This error is of little importance for the purposes of this paper because it applies only to the largest trees and is unbiased.

Can We Determine Whether a Grove Is Successfully Reproducing by the Sizes of Its Sequoias?

A frequently quoted rule of thumb is that a giant sequoia adds one foot of diameter growth every 100 years. This generalization apparently originated with Harvey and his colleagues (1980, p. 48), who stated, "... for the first 800 years of growth the ratio of 1 ft in diameter growth equals 100 years is a reasonable estimate" By this rule, sequoias less than 30.4 cm (1 ft) diameter usually should be less than 100 years old; that is, they should be recent reproduction that became established during the era of fire suppression. The smallest sequoias we see in undisturbed groves—some of which are less than 1 m (3.3 ft) tall—should be particularly young. Since it is relatively easy to find small sequoias growing in groves protected from fire, it would appear that sequoias are successfully reproducing without fire or other disturbance.

However, our age determinations from increment cores show that the "one foot equals 100 years" rule of thumb usually underestimates the age of small sequoias, sometimes

drastically. For all four plots combined, 201 sequoias were less than 30.4 cm (1 ft) diameter, but only 54 of these (about one in four) were less than 100 years old. Even this is probably an overestimate, given that our age estimates tended to be conservative. Of these 54 sequoias less than 100 years old, only 10 were less than 70 years old. At the opposite extreme, one 30-cm diameter sequoia was nearly 300 years old, and at least eight sequoias that had not yet reached breast height (i.e., were less than 1.4 m tall) were more than 100 years old; we have even found 100-year-old sequoias less than 1 m (3.3 ft) tall. Thus, most of the small sequoias we see in protected groves are not recent reproduction, but are quite old—usually over 100 years.

If the old rule—one foot diameter equals 100 years—is flawed, can we come up with a new age versus size rule that will tell us which sequoias are recent reproduction? We cannot, for two reasons. First, the relationship between age and size is poor. To illustrate this point, I have plotted age versus size for central Giant Forest and Atwell, the two plots with the largest number of sampled trees. For sequoias of a given diameter at a particular site, age often will vary by as much as a factor of four (*fig. 1*). Second, the rules change from place to place. The best-fit lines (by least-squares regression) show that in the larger size classes, the ages of sequoias at central Giant Forest are nearly twice those at Atwell (*fig. 1*); therefore a rule relating age to size in one location will not necessarily hold in another location. In the particular case of central Giant Forest and Atwell, this is

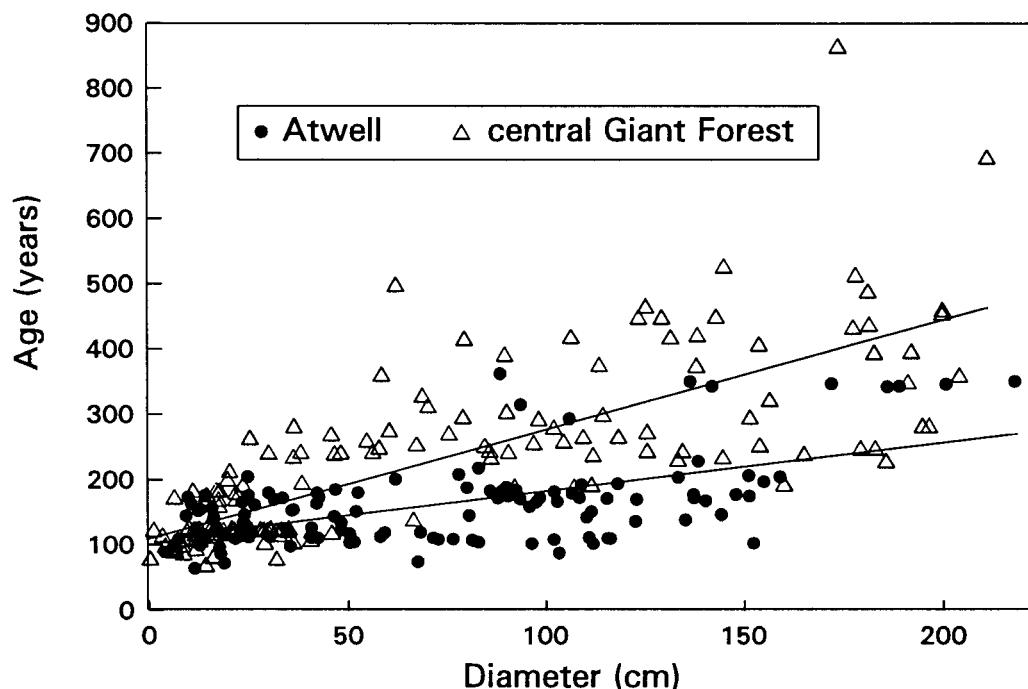


Figure 1—Age versus diameter for giant sequoias in the Atwell and Giant Forest groves. Only data from those sequoias whose ages were determined by increment cores that reached the pith region are included. The relationship between age and size is poor and changes from site to site. (Atwell: $y = 0.72x + 108$, $r^2 = 0.31$. Central Giant Forest: $y = 1.66x + 107$, $r^2 = 0.60$)

of little importance in the smaller size classes; at other locations, age differences in the smaller size classes might be important.

Clearly, we cannot use the sizes of sequoias to judge whether a grove is successfully reproducing. Very small sequoias can be quite old, and the relationship between age and size is poor.

Were Sequoia Populations Increasing, Decreasing, or Near Equilibrium at the Time of European Settlement?

To interpret recent sequoia population trends, we need to understand past trends. We can get clues to presettlement population trends by looking at the present overall age structure of sequoia populations, averaging across the four study sites and lumping sequoia ages by century to get a broad picture, smoothing out site-to-site and decade-to-decade variation in sequoia establishment.

Today, young sequoias (those less than a few hundred years old) far outnumber old sequoias (*fig. 2*). Ignoring, for the moment, sequoias that became established in the post-settlement period (the 1900's), we see that the youngest age class has the most individuals; nearly half of all sequoias alive today became established in the 1800's. Does this indicate that before European settlement there was a rapidly accelerating population boom in sequoias? Not necessarily. Forests with many more young trees than old trees are

typical the world over (Harper 1977). This is because death rates typically are very high in young trees, which are more vulnerable than old trees to drought, shading, fire, pathogens, browsing, and crushing by falling neighbors. Therefore very few young trees survive to be old trees, meaning there will always be many more young trees than old in an equilibrium population. (An equilibrium population is one in which the number of trees in each age class, and therefore the number of trees in the whole population, stays constant through time. Such populations are also called "stationary.") Thus, the pre-1900 age-structure of sequoias (*fig. 2*) has the general shape expected for a forest near equilibrium.

However, the pre-1900 age structure might also be consistent with an increasing population or even a decreasing population, depending on the probability of a sequoia surviving from one century to the next. To help distinguish among the possibilities, I used sequoia survival probabilities in both the presence and absence of fire (Lambert and Stohlgren 1988) to develop a hypothetical equilibrium age structure for sequoia populations; this hypothetical age structure closely matched the actual age structure shown in *figure 2*. Thus, independent survivorship data suggest that the age structure of the sequoias we sampled resembles that of a population near equilibrium, not a population in significant increase or decline.

But how can we explain data suggesting that sequoia populations were near equilibrium when we know that both climate and fire regimes have varied substantially in sequoia

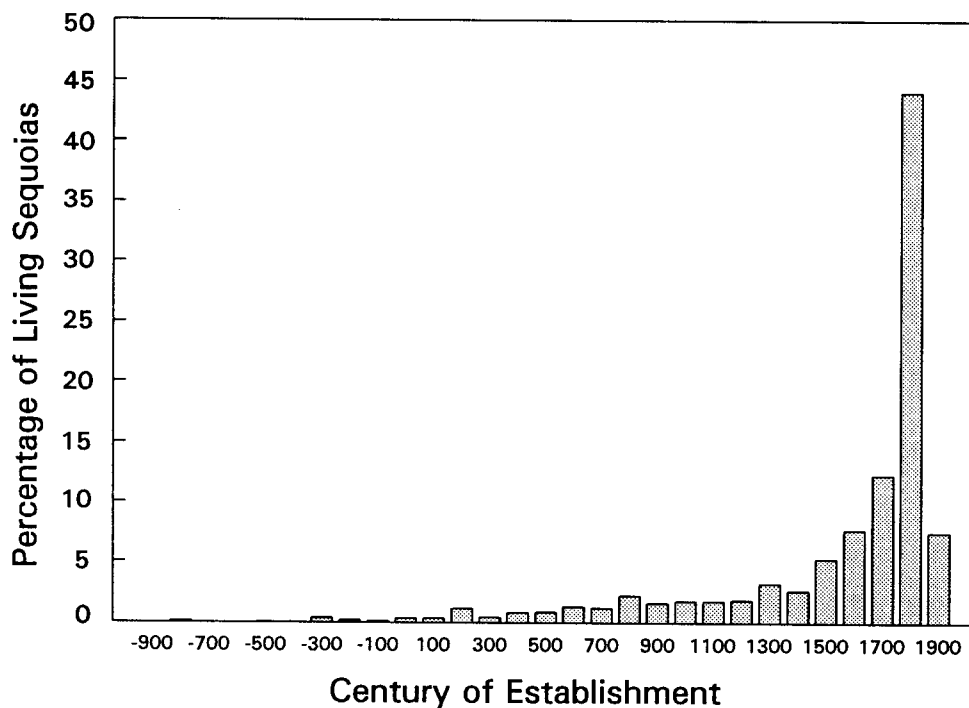


Figure 2—Percentage of living giant sequoias by century of their establishment. The data are from increment cores taken in four plots in the Atwell, Giant Forest, and Mariposa groves. This century—the 1900's—is at far right.

groves over the last few millennia (Graumlich 1993, Hughes and Brown 1992, Swetnam 1993, 1994)? I believe the answer lies in the scale and precision of our data. Changes in climate and fire regimes have been most pronounced at the scale of decades to a few centuries; consequently, century-scale drifts in sequoia population dynamics undoubtedly occurred and may show up in *figure 2* as deviations from the overall trend of continuously decreasing numbers with age. At the millennial scale, however, century-scale deviations appear to be small relative to the overall trend. However, we must also keep in mind that our age estimates for larger sequoias may be off by a century or more (as described earlier), potentially decreasing the apparent magnitude of some of the deviations from the overall trend of decreasing numbers with age. Fortunately, the latter problem will not change our qualitative conclusions about the overall status of sequoia populations, which depend on the overall shape of the curve, not the magnitude of individual deviations.

A compelling set of independent data suggests that, at roughly the time of European settlement, sequoia populations may have been increasing rather than staying near equilibrium. Anderson (1994) has found that relative concentrations of sequoia pollen in meadow sediment have been increasing almost continuously over the last four millennia, implying an increasing population, or at least a maturing population (assuming mature sequoias shed more pollen than young). A possible way to resolve the apparent contradiction between the age structure and pollen data is to assume that sequoia populations were indeed increasing or maturing over the last few millennia, but quite recently (within the last few centuries) finally approached an age structure near equilibrium. However, since we presently have no way to test this possibility, it is safest to remain skeptical.

With a good bit of confidence, then, we can state that sequoia populations were not significantly declining at the time of European settlement, but were either near equilibrium or were increasing. We presently cannot distinguish between the latter two possibilities.

Is Reproduction Sufficient to Maintain Sequoia Populations in the Absence of Fire?

Given that sequoia populations were almost certainly near equilibrium or increasing before European settlement, how much sequoia reproduction would we expect to find this century, assuming no radical departure from past conditions? The answer is simple: we would find more living sequoias with establishment dates in this century than in the preceding century, because this is the only way to maintain an equilibrium or growing population. (Though this century is not quite over, the conclusions of the following arguments will remain unchanged.) In fact, given the extremely low survival of sequoia seedlings in their first few years of life (Harvey and Shellhammer 1991), we would expect to find

many times more living sequoias (by orders of magnitude) that date to this century than to the preceding century.

Such is clearly not the case. In groves protected from fire but otherwise managed for natural conditions, far fewer living sequoias have establishment dates in this century than in the preceding century (*fig. 2*). There is not nearly enough reproduction to maintain sequoia populations in these groves. John Muir was wrong; establishment of seedlings on mineral soil exposed by treefalls is not nearly sufficient to maintain sequoia populations.

What Were the Key Factors in the Maintenance of Sequoia Populations Before the Arrival of Europeans?

We have seen that sequoia reproduction presently is far too low to maintain current sequoia populations. A large body of research links fire with successful sequoia seedling establishment (see especially Harvey and others 1980), and evidence is abundant that in the millennia before the arrival of Europeans, fires burned through sequoia groves every few years (Swetnam 1993, 1994). Was fire by itself sufficient to ensure sequoia regeneration?

Regeneration can be viewed as occurring in two steps: establishment and recruitment. Establishment refers to successful seed germination, rooting of the seedling, and survival for the first few summers; recruitment refers to the growth of the seedling into a mature, seed-producing tree. I argue that nearly any fire, by itself, is sufficient to promote at least some sequoia seedling establishment. Successful recruitment of mature sequoias, however, usually requires a narrower set of conditions: a fire intense enough to kill the forest canopy locally, and perhaps one or more wet summers following the fire. I will present three types of evidence to make the case for the importance of locally intense fire: (1) fires intense enough to kill the forest canopy locally did indeed occur in sequoia groves before forest structure and fuel loads were significantly altered by Europeans; (2) post-fire sequoia seed dispersal, seedling establishment, growth, and survival are highest where fires have burned most intensely; and (3) most living sequoias today occur in even-aged clumps that likely correspond to "hot spots" that killed the forest canopy in past fires.

Evidence of the first type comes from John Muir's vivid description of a fire he watched burn through a sequoia grove--probably Atwell Grove--in the fall of 1875 (Muir 1901). This was the last extensive fire to occur in the Atwell region (Swetnam 1992), and it likely took place before the newly-arrived European settlers had significantly influenced grove structure, composition, or fuel loads. In other words, the conditions under which the fire burned probably were representative of conditions before the arrival of Europeans. Muir watched the fire "... creeping and spreading beneath the trees ..., slowly nibbling the cake of compressed needles and scales with flames an inch high, rising here and there to

a foot or two on dry twigs and clumps of small bushes and brome grass." In other places, however, Muir saw "... big bonfires blazing in perfect storms of energy where heavy branches mixed with small ones lay smashed together in hundred cord piles ..., huge fire-mantled trunks on the hill slopes glowing like bars of hot iron ... [and] young trees vanishing in one flame two or three hundred feet high." Modern fires of this intensity kill the forest canopy locally. It appears, then, that within the matrix of a gentle surface fire, local patches burned intensely enough to open holes in the forest canopy (see also Stephenson and others 1991).

Modern observations provide the second type of evidence--that sequoia seed dispersal, seedling establishment, growth, and survival are highest where fires have burned most intensely. Seed dispersal depends on the drying of sequoia cones. By drying cones high in the canopy of mature sequoias, intense fires cause the release of much more seed than light fires; consequently, seedling densities can be more than five times greater where fires have burned most intensely (Harvey and others 1980, Kilgore and Biswell 1971). Since sequoia seedlings are intolerant of shade (Harvey and others 1980, Stark 1968), they grow fastest where the forest canopy has been opened, meaning that those seedlings germinating where fires have burned most intensely are most likely to outcompete other species and to survive subsequent fires (Harvey and others 1980, Harvey and Shellhammer 1991). Indeed, seedling survival is more than 10 times greater where fires have burned most intensely (Harvey and others 1980, Harvey and Shellhammer 1991).

A particularly vivid example of differences in seedling establishment, growth, and survival can be found in Redwood Canyon of Kings Canyon National Park, where a prescribed fire in 1977 accidentally killed all trees except large sequoias in an area of a few hectares. Fifteen years after the fire, the area supported the densest growth of sequoia seedlings found in the national parks of the Sierra Nevada (*fig. 3*). At the center of the hot spot, where the fire burned most intensely, about 0.16 ha (0.4 acres) of sequoia seedlings formed a nearly continuous cover, interrupted by only a few scattered deerbrush (*Ceanothus integrissimus*). The many other dense patches of seedlings within the hot spot were not as large, yet still formed overlapping groups that each included tens to hundreds of seedlings 3 to 8 m (10 to 26 ft) tall. I found one seedling that, 15 years after the fire, had reached a height of 8.7 m (nearly 30 ft), implying an average height growth of nearly 0.6 m (2 ft) per year. This sequoia had already begun to put on cones.

In stark contrast, to the west, south, and east of the hot spot I was unable to find a single sequoia seedling growing in those areas where the fire had burned, but the upper forest canopy had remained intact. I found sequoia seedlings under intact upper canopy only to the north of the hot spot, where the angle of the sun's rays allowed some sunlight to reach the soil surface. Even then, these seedlings occurred in only two main groups of a few square meters each, and most seedlings were only 0.1 to 0.5 m (0.3 to 1.6 ft) tall, the tallest



Figure 3—Vigorous sequoia reproduction where a locally intense fire created an opening in the forest canopy. The fire burned in Redwood Mountain Grove, Kings Canyon National Park, in 1977. The firs and cedars in the background were killed by the fire, whereas the large sequoia at right was not. In some areas of the burn, sequoia seedlings already had reached more than 8 m (26 ft) tall 15 years after the fire.

reaching 0.8 m (2.6 ft). In intermediate areas of the burn, where the upper forest canopy was partially killed, the abundance and height of sequoia seedlings was intermediate between those found under the intact canopy to the north of the hot spot and those found in the main body of the hot spot.

Our tour of the regeneration cycle is completed by the third type of evidence—that "hot spots" not only were the site of vigorous seedling establishment and growth, but also were the sites of recruitment of most mature sequoias. By mapping the sequoias of known age in the four study plots, we found that most sequoias occur in even-aged clumps corresponding to known fire dates in the tree-ring record (*fig. 4*; see also Stephenson and others 1991). In two of these sequoia clumps (dating to the 1860's at central Giant Forest and the 1870's at Atwell), we further determined the ages of all non-sequoia trees (mostly white fir). The vast majority of the non-sequoia trees were the same age as the sequoias, or younger. Since only a scattered few non-sequoia trees dated to before the last known fire, the implication is that this fire killed virtually all trees that had been growing where

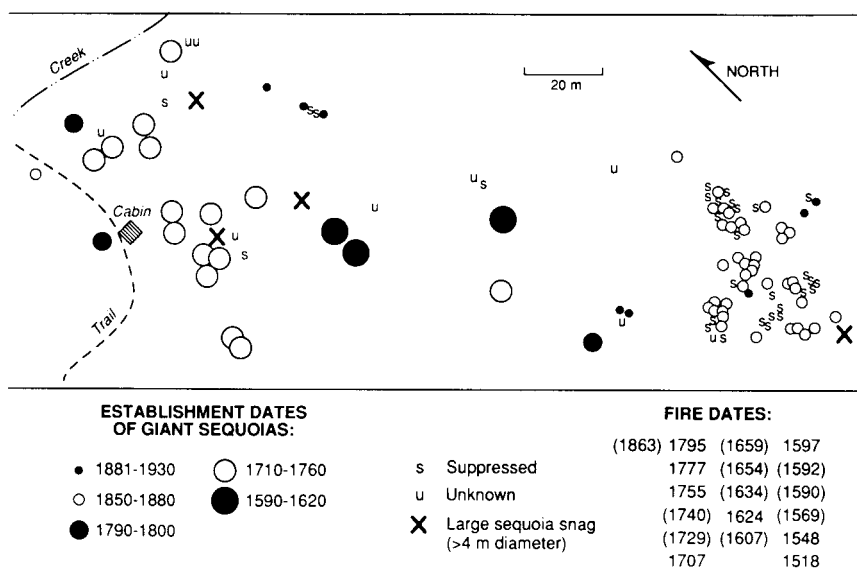


Figure 4—Even-aged clumps of sequoias in a portion of the central Giant Forest plot, Sequoia National Park. The clump at right corresponds to a "hot spot" where all but two established trees (white fir, not shown) were killed in a presettlement fire, almost certainly the fire of 1863. Most of the sequoias in the clump became established soon after the 1863 fire; the relatively wide range of dates given for their symbol (1850-1880) is meant to include temporal outliers, probably resulting from error in our ability to exactly determine ages. The clump at left presumably resulted from a hot spot during one or more of the fires of the early 1700's. Fire dates without parentheses indicate that distinct fire scars for that date were found on opposite sides of the plot; parentheses indicate that fire scars were found only on one side of the plot, hence it is somewhat less certain the fire actually burned through the plot. (Figure reprinted from Stephenson and others 1991, with permission of the Tall Timbers Research Station.)

the even-aged sequoias now stand. Collectively, the data presented in this section imply that most sequoia recruitment was limited to areas where fire killed all or most of the forest canopy.

Work by Harvey and his colleagues (1980) and my own observations suggest that summertime desiccation is the main cause of sequoia seedling death, and that seedling survival is greatest when the first few summers after a fire are wet, allowing the seedlings to develop a large enough root system to endure future droughts. This suggests the following scenario (*table 1*). After a locally high-intensity fire, seedling establishment is high and will yield high recruitment of mature trees if the next few summers are wet, or low recruitment if they are dry. After a low-intensity fire, seedling establishment is low and will yield insignificant recruitment regardless of the weather in the following summers. Intermediate levels of fire intensity and summertime moisture would yield intermediate levels of establishment and recruitment. This scenario should be viewed as probable but tentative, subject to more detailed investigation.

Implications: Managing a Pioneer Species

A large body of research points directly at fire suppression as the cause of this century's massive failure in sequoia

reproduction (see especially Harvey and others 1980). Therefore, if we wish to maintain sequoia groves in as nearly a natural state as possible (which is the National Park Service's goal), we must reintroduce fire. But not just any fire will do.

Giant sequoia is what is known as a "pioneer species," requiring canopy-destroying disturbance to complete its life cycle. Ecologists now recognize disturbance as a major shaper of plant communities the world over, opening new ground for colonization--especially by pioneer species--and creating a dynamic, shifting mosaic of patches of different ages. Sequoia forests are not unique; "patch dynamics" driven by canopy-destroying disturbance are the rule in forest communities, not the exception (Oliver and Larson 1990, Pickett and White 1985, Platt and Strong 1989).

We need to know the natural spatial scale of canopy-destroying disturbance in sequoia groves if we are to understand the management implications of patch dynamics. Gaps created by natural disturbance can range from a few tens of square meters, such as those created by treefalls in the deciduous forests of eastern North America, to thousands of hectares, such as the enormous areas burned in lodgepole pine forests of the Yellowstone region. Natural gaps in the sequoia/mixed-conifer forest were on the low end of this continuum in gap sizes. The even-aged patches of sequoias we have sampled so far have ranged from less than 0.03 ha

Table 1--Probable scenario of sequoia establishment and recruitment¹ resulting from different combinations of fire intensity and summertime weather following the fire.²

Summer	High fire intensity	Low fire intensity
Wet summer(s) following fire	Abundant establishment Abundant recruitment	Low establishment No or insignificant recruitment
Dry summer(s) following fire	Abundant establishment Low recruitment	Low establishment No or insignificant recruitment

¹Establishment is successful seed germination, rooting of the seedling, and survival for the first few summers; recruitment is the growth of the seedling into a mature, reproducing tree.

²Intermediate levels of fire intensity and summertime moisture would result in intermediate levels of establishment and recruitment.

(0.08 acre) to more than 0.4 ha (1 acre), suggesting that the minimum size of forest gaps leading to significant sequoia recruitment was 0.1 ha (to the nearest order of magnitude). This estimate of gap size almost certainly is low for two reasons: (1) successful sequoia recruitment often is limited to only a portion of a given gap, leading to an even-aged patch of sequoias that was smaller than the gap itself, and (2) subsequent fires and windthrows of sequoias undoubtedly reduced the area occupied by sequoias in a given patch. Much larger gaps surely were formed from time to time, such as during the AD 1297 fire in Mountain Home Grove (Stephenson and others 1991).

A bird's-eye view of a sequoia grove following a typical presettlement surface fire probably would have revealed a relatively open, green, mostly intact forest canopy with a scattering of small holes resulting from local hot spots. The canopy holes were the sites of most successful sequoia recruitment, leading to the stately groups of sequoias we admire today. The management implication is clear: if we wish to maintain sequoia groves in as nearly a natural state as possible, we must accept not only fire, but fire intense enough to open occasional holes in the forest canopy. Current management fires rarely meet this criterion, and then only by accident.

If we are willing to accept management practices that less closely mimic natural processes, we could physically cut openings in the forest, following with a light surface fire to prepare a mineral soil seed bed. We would usually then need to sow sequoia seeds or plant sequoia seedlings, since a light surface fire will induce little seed release from sequoia cones, leading to low seedling establishment. Although this approach may be successful on a small scale, I believe it has some serious drawbacks. First, it is impractical on a large scale. Sequoia and Kings Canyon National Parks, for example, have 35 sequoia groves totalling more than 3350 ha (8300 acres), and many of these groves lie in remote areas inaccessible by road or trail. Sending chainsaw crews through the groves at a frequency mimicking the natural fire interval, followed by burning and planting, would be a massive, prohibitively expensive undertaking. More important, intense fires probably do much more for sequoia seedlings than just open the canopy. To name two possibilities, intense

fire may kill pathogens and alter soil properties (such as friability and wettability) to favor seedling growth and survival (Harvey and others 1980, Harvey and Shellhammer 1991). Using patchy intense fire is conservative; it is the approach most likely to continue the processes that have maintained sequoia populations for millennia, whether we fully understand those processes or not.

Regardless of the management approach we may favor, I believe one message overrides all. For we who revel in the beauty of sequoia groves, this century's failure of sequoia reproduction is nearly invisible against a backdrop of seeming timelessness. We strain our necks to see the old trees, not noticing the lack of young trees. Given the great age attained by sequoias, this century's relatively short gap in reproduction will not endanger the long-term survival of the species in nature, assuming we take measures to reverse it. We must take seriously our role as stewards passing on the forest unimpaired to future generations and restore sequoia reproduction, soon.

Acknowledgments

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References

- Agee, James K.; Finney, Mark; de Gouvenain, Roland. 1986. The fire history of Desolation Peak. Seattle: Cooperative Parks Study Unit, University of Washington; Final contract report to the National Park Service, Cooperative Agreement CA-9000-3-0004.
- Anderson, R. S. 1994. Paleohistory of giant sequoia in the Sierra Nevada. [This volume.]
- Ghent, A. W. 1955. A guide for the re-alignment of off-center increment borings. *Forestry Chronicle* 31:353-355.

- Graumlich, Lisa J. 1993. A 1000-year record of temperature and precipitation in the Sierra Nevada. *Quaternary Research* 39:249-255.
- Harper, John L. 1977. *Population biology of plants*. London: Academic Press; 892 p.
- Hartesveldt, Richard J.; Harvey, H. Thomas; Shellhammer, Howard S.; Stecker, Ronald E. 1975. The giant sequoia of the Sierra Nevada. Washington, DC: National Park Service, U. S. Department of the Interior; 180 p.
- Harvey, H. Thomas; Shellhammer, Howard S. 1991. Survivorship and growth of giant sequoia (*Sequoiadendron giganteum* (Lindl.) Buchh.) seedlings after fire. *Madrono* 38:14-20.
- Harvey, H. Thomas; Shellhammer, Howard S.; Stecker, Ronald E. 1980. Giant sequoia ecology. Washington, DC: National Park Service, U. S. Department of the Interior; 182 p.
- Hughes, Malcolm K.; Brown, Peter M. 1992. Drought frequency in central California since 101 B.C. recorded in giant sequoia tree rings. *Climate Dynamics* 6:161-167.
- Huntington, Ellsworth. 1914. The climatic factor as illustrated in arid America. Publication No. 192. Washington, DC: Carnegie Institute of Washington; 330 p.
- Jones, William R., ed. 1977. The coniferous forests and big trees of the Sierra Nevada. Olympic Valley, CA: Outbooks; 40 p.
- Kilgore, Bruce M.; Biswell, H. H. 1971. Seedling germination following fire in a giant sequoia forest. *California Agriculture* 25:8-10.
- Lambert, Sherman; Stohlgren, Thomas J. 1988. Giant sequoia mortality in burned and unburned stands. *Journal of Forestry* 44:44-46.
- Muir, John. 1901. *Our national parks*. New York: Houghton Mifflin Co.
- Oliver, Chadwick D.; Larson, Bruce C. 1990. *Forest stand dynamics*. New York: McGraw-Hill, Inc.; 467 p.
- Pickett, S. T. A.; White, P. S., eds. 1985. *The ecology of natural disturbance and patch dynamics*. Orlando, Florida: Academic Press.
- Platt, W. J.; Strong, Donald R., eds. 1989. Special feature: treefall gaps and forest dynamics. *Ecology* 70:535-576.
- Stark, N. 1968. The environmental tolerance of the seedling stage of *Sequoiadendron giganteum*. *American Midland Naturalist* 80:84-95.
- Stephenson, Nathan L.; Parsons, David J.; Swetnam, Thomas W. 1991. Restoring natural fire to the sequoia - mixed conifer forest: should intense fire play a role? *Proceedings of the Tall Timbers Fire Ecology Conference* 17:321-337.
- Swetnam, Thomas W. 1992. Assistant Professor of Dendrochronology, University of Arizona, Tucson. [Telephone conversation with N. Stephenson]. 12 November 1992.
- Swetnam, Thomas W. 1993. Fire history and climate change in giant sequoia groves. *Science* 262:885-889.
- Swetnam, T. W. 1994. Giant sequoia fire and climate history. [This volume.]

Native American Views and Values of Giant Sequoia¹

Floyd J. Franco, Jr.²

He-Yuk. This means Hello in my Tribal language.

My name is Floyd Franco, Jr. I am the Tribal Chairman of the Tule River Tribe. Tribal members call me the Chief. I am glad to be here representing my Tribe.

The Tule River Reservation is located approximately 20 miles east of Porterville in Northern California. Our land base is about 56,000 acres. The elevation range is from 900 ft. to 7,000 ft. Yes, we do have (toos-pung-ish) (Hea-mi-withic) big trees, Ancient Ones that you call giant sequoia.

I have been asked to speak on the cultural significance of the giant sequoia in relationship to my Tribe. I would like to start by saying that from ancient times to modern times, trees have been very important to my Tribe.

Trees have provided nuts, fruits and berries to gather for food. Also, the leaves and roots of trees are used for medicines by Tribal members. Traditionally we continue to use the giant sequoia, when it has fallen by natural causes, for community projects such as fence posts, craft wood and recently, to purchase a surface water treatment plant to provide assistance in maintaining a domestic water supply during the summer months.

The giant sequoia also provide excellent recreation sites in which Tribal members can teach our youth tradition and respect for trees. The youth also learn a spiritual way to gain knowledge through fasting, holding sweats and praying for the ancient ones to pass on historical knowledge of past generations. Other activities for youth include looking for large hollows in giant sequoia, usually caused by lightening.

We also have a condors' nest which is visited by youth. There used to be a rope that Tribal members used to climb the giant sequoia to view the nest.

Trees are important in Tribal folklore. In creation stories the bald eagle represents the creator of all living things who lives in a tree growing in the sky.

After the eagle creates other animals, people, water and land, the tree comes down to the land to become the first tree in the world. And although in our creation story the tree is not a giant sequoia, it is through these stories that Tribal members are taught to respect trees at an early age.

In the logging industry, many Indian and non-Indian tree fallers believe that a prayer to a tree before falling it, such as thanking the tree for the contribution it will make to the community, has allowed old tree fallers to safely retire without becoming an accident statistic.

On the Reservation we have used Timber Salvage Sale proceeds to match grant funding to get an economic development plan implemented and a corporation started.

¹This paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

²Tribal Chairman, Tule River Tribe, P.O. Box 589, Porterville, CA 93258.

Genetics of Giant Sequoia¹

Lauren Fins W. J. Libby²

Besides being a national treasure because it is so spectacularly beautiful, giant sequoia is a genetically fascinating species. These most massive of all living organisms, some of which live more than 3,000 years, once flourished around the world in natural populations, and are currently planted worldwide as ornamentals and as a renewable wood resource. Yet their natural range today is confined to a narrow distribution along the west side of the Sierra Nevada Mountains in California, with eight disjunct populations, or groves, in the northern part of the range and a series of generally larger and more continuous populations in the southern part of the range. Fossil evidence indicates that the gross morphology of the species has changed little since the Miocene and early Pliocene, that is, for the past 20-30 million years! Given these facts, questions about the patterns and magnitude of genetic variation almost ask themselves.

In this paper, we try to answer broadly the question: "If you have seen one giant sequoia, have you, indeed, seen them all?" In more scientific terms, we have tried to detect, quantify and describe patterns of genetic variation in natural populations of this species. It is important to study this genetic variability for at least three practical reasons:

(1) Some populations may prove to be better adapted and faster growing than others when planted outside of the native range. Which populations do well may not be the same for different regions. Thus, a series of common-garden tests that sample many populations should be conducted in each region before a serious commitment to planting sequoia in that region is made.

(2) If planting is to be done in or near a native grove, it is important to know whether the propagules (seeds or cuttings) should be obtained from local parents only, or whether propagules from other parts of that grove, or even from outside the grove, should be permitted or even preferred.

(3) When giant sequoia is purposefully bred for one or more purposes, it will be useful to know the patterns of variation for a variety of traits in order to better devise effective breeding schemes.

More than 30 of the 73 named giant sequoia groves have been sampled, and various combinations of trees from these groves are now growing in common-garden provenance tests³

¹An abbreviated version of this paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California

² Professor, Department of Forest Resources, University of Idaho, Moscow, ID 83844-1133; and Professor, Department of Environmental Science, Policy and Management - Forestry, University of California, Berkeley, CA 94720

³Provenance tests are usually common-garden studies whose purpose is to describe and quantify genetic differences among the origin populations of the samples.

in California, Idaho, France, Germany, and New Zealand. Data are available from 4-, 7- and 12-year-old plantations in New Zealand, from a 5- and 6-year-old plantations in Idaho, from 9-year-old plantations in Germany, and from 11-year-old plantations in California.

At the risk of oversimplifying the answer to our question, we will state here for the record that if you have seen one giant sequoia, you *have not* seen them all. Although we do not yet have a complete picture of its genetic architecture, its levels of genetic variation appear to be lower than the average of those observed for other gymnosperms. Nonetheless giant sequoia displays substantial genetic variation in the biochemical, morphological, physiological, and growth traits thus far studied.

Variation Among Populations

Biochemical Traits

We began our studies of giant sequoia with the expectation that we would find high levels of biochemically expressed genetic variation distributed throughout the species' range. We based that expectation on the observation that many long-lived, woody species maintain high levels of genetic variation (Hamrick and others 1979), although recent analyses indicate that those with relatively narrow distributions tend to have lower levels of genetic variation than those that are widespread (Hamrick and others 1992). Our analyses of isozymes⁴ showed giant sequoia to be below average in this kind of genetic variability compared to other long-lived, woody perennials. For example, giant sequoia's average heterozygosity (one measure of variation) is 0.140 (Fins and Libby 1982) compared to an average of 0.177 for other long-lived, woody perennial species or compared to an average of 0.165 for those with narrow distributions (Hamrick and others 1992). Of this isozyme variability, about 10 percent was distributed among different giant sequoia groves; the remaining 90 percent occurred within groves. This pattern is similar to that of most of the long-lived, woody species thus far studied, or perhaps indicates slightly more variability among groves than the 7 percent variation among populations that is common for other gymnosperms (Hamrick and others 1992).

We also found clear differences between the northern and southern giant sequoia grove samples, with the northern groves less variable than the southern ones and a progressive

⁴Isozymes are alternative forms of enzymes and are used frequently to describe and quantify genetically determined biochemical variation within and among populations.

increase in within-grove isozyme variation from north to south. Although the differences we observed were relatively small, they were nonetheless statistically significant and may be important considerations both for the wise management of the native populations and for the distribution of seeds from the native populations for planting elsewhere.

Morphological Traits

Individual giant sequoias differ in traits such as foliage color, crown shape, and stem taper. Occasional trees have such deviations as variegated foliage or drooping branches. Yet, with a casual glance, most young giant sequoias appear to be remarkably similar in appearance. Although giant sequoia generally has a more predictable crown form in youth than is typical of most other conifers, a small study of rooted cuttings sampling five of the native populations and planted in northern Idaho showed statistically significant differences among populations in average branch angle, crown diameter, and crown shape (Du and Fins 1989).

In a study of seedlings from 26 of the native giant sequoia groves, cotyledon numbers ranged from 3 to 6 and varied in frequency among regions, among groves, and among families within groves. Twelve percent of that variation occurred among groves, 21 percent among families within groves, and 67 percent among individuals within families (Fins 1979; Fins and Libby 1982). The sample from the Placer Grove (the most northern native population) was particularly interesting, because, unlike other grove samples, it included a high proportion of 6-cotyledon seedlings and no 3-cotyledon seedlings.

Physiological Traits

Germination tests using seeds from 26 native groves showed significant differences among the population samples and among families within populations (Fins 1979; Fins and Libby 1982). Germination ranged from 2.1 percent for the Case Mountain Grove to 50 percent for the Cabin Creek Grove, with 13 to 17 percent of the observed variation attributable to variation among populations (groves) depending on whether nongerminating families were included in the analysis.

Work done in Germany found highly significant differences among populations in frost resistance of 2-year-old sequoias (Guinon and others 1982). This same study showed a large, negative, statistically highly significant correlation between frost resistance and winter damage of seedlings from the same populations. Correlations between frost resistance and elevation of the origin populations were statistically significant, but were weak or absent between frost resistance and grove latitude or longitude.

In the study conducted in northern Idaho, differences among populations were statistically significant for amount of winter damage to field-planted rooted cuttings in one of two years of assessment. Although seasonal patterns of the development of freezing tolerance were similar among four of the five population samples, the Cedar Flat Grove

displayed a seasonal pattern that was significantly different ($P < 0.05$) or nearly so ($P < 0.10$) compared to the patterns of the other four populations (Du and Fins 1989).

In the Idaho plantation, the dates when shoots began and ceased elongation were not statistically different among populations. However, in the Foresthill experiments in California, flushing date (measured as amount of new shoot growth in early May) varied both among groves and among individuals (clones) within groves, and there was a tendency for trees from the more northern groves (nearer to Foresthill) to flush earlier than trees from the more southern (distant) groves. But, like other traits, there was much variation in flushing date within the grove samples.

Early survival was generally high in the Idaho and New Zealand plantations. Substantial early mortality occurred in some German and California experiments, but in no case in these studies was there statistical significance for the differences observed among groves, or for differences among families or clones within groves.

Growth Traits

Table 1 presents a summary of results from the samples of nine groves that were included in most of 10 common-garden tests, plus results from the Placer and Deer Creek Groves in the few tests that included them.

With respect to height and stem-volume index, the provenance tests were consistent only for the small outlying Placer Grove (only six mature sequoias), the southernmost Deer Creek Grove (about 30 sequoias), the Raincliff Forest in New Zealand, and two trees at Hermeskeil in Germany (data for the latter are not shown in *table 1*), all of which exhibited below-average growth in all tests in which they were included. The likely explanation is that many of the propagules from these origins are inbred and do poorly as a result. For the rest of the 30+ groves that were sampled, the common-garden experiments that have data available do not provide a consistent picture, either with respect to the statistical significance of among-grove variation, or with respect to the relative performances of the various grove samples (*table 1*; Libby, Fins and Mahalovich, manuscript in preparation).

At the three German plantations, differences among grove samples in 9th-year height were statistically highly significant (Dekker-Robertson and Svolba 1993), as were several age-trait combinations in three experiments in two plantations at Foresthill, California (*table 1*; Libby, Fins and Mahalovich, manuscript in preparation). Differences among populations in 4th-year height, diameter, and terminal shoot elongation were statistically significant for the field-planted rooted cuttings from five populations growing in northern Idaho (Du and Fins 1989). Statistical tests were not available from the New Zealand plantations.

Performance of samples from the North Calaveras, Redwood Mountain (sometimes called Whitaker's Forest), and Mountain Home Groves is particularly interesting. Most early plantings, particularly in Europe, came from the North

Table 1 -Comparison of heights (H) and stem volume inF for selected provenances of giant sequoia in ten common-garden experiments.¹

Grove ²	United States						Germany			New Zealand				
	F1stek H	SV	F1seed H	SV	F2stek H	SV	Es H	BG H	Us H	Ra H	Ka H	Ha H	Be H	SV
Placer	---	---			---	---	-	---						
North Calaveras	+	-	---	---	-	-	---	+	+	+	---	-	++	+
Nelder	-	---			+	+		+				-	+	++
McKinley	+	++			+	+				+	++	+	---	---
Redwood Mountain	+	++	++	++	+	-	+	+	++	+	+	+	+	++
Giant Forest	+	++	-	-	+	+	+	-	+	---	---	-	+	-
Atwell Mill	-	-			-	-	+	+	-	---	-	++		
Mountain Home	++	+	+	+	+	++	+	+	+	+	++	---	+	-
Wheel Meadow	+	++			+	++	-	-	-	---	+	-	-	---
Black Mountain	+	-			+	-				++	-	---	-	---
Deer Creek	---	---						-						

¹ Flstek = Foresthill Experiment 1, stecklings (rooted cuttings); age 11
 Fl seed= Foresthill Experiment 1, seedlings; age 11
 F2stek = Foresthill Experiment 2, stecklings; age 11
 Es = Escherode, seedlings and stecklings; age 9
 BG = Bad Grund, seedlings and stecklings; age 9
 Us = Uslar, seedlings and stecklings; age 9
 Ra = Rai, stecklings; age 4
 Ka = Kakahu, seedlings; age 7
 Ha= Hamner, seedlings; age 7
 Be = Beaumont, seedlings; age 12

+, - indicates slightly above or below average for the plantation (including provenances not listed above).
 ++, -- indicates substantially above or below average for the plantation.
² Groves listed north to south.

Calaveras Grove, the discovery site of giant sequoia in 1852. More recently, many seed collections have been made and distributed from Mountain Home State Demonstration Forest and from the University of California's Whitaker's Research Forest in the Redwood Mountain Grove. Surprisingly, the North Calaveras Grove sample is performing poorly in the three Foresthill experiments, where (other than Placer Grove) it is the nearest native population. However, both the Mountain Home and Redwood Mountain/Whitaker's Groves samples are performing well at most of the test locations. Atwell Mill, earlier touted as doing well on cold sites, does not seem to be a generally good performer.

Variation Within Populations

Biochemical Traits

The genetic variation that occurs within a population is distributed among and within families largely as a function of the mating system. The isozyme analyses indicate that some inbreeding occurs in most natural populations of giant sequoia. This interpretation is based on an excess of homozygotes (same form of the isozyme within a gene-pair) among newly germinated embryos, compared to expectations based on observed allele frequencies (proportions of the different isozyme forms within the populations) and assumed random mating within the population. However, the mature trees in these same populations have a deficiency of

homozygotes, both compared to embryo data and to theoretical expectation. This indicates that there is selection against inbred offspring during the development of natural populations of giant sequoia (Fins and Libby 1982).

Growth Traits

At Foresthill, California, we have three experiments with giant sequoia that allow us to estimate the amounts and distribution of variation in growth traits. Two 21-grove experiments are designed to allow estimates of within-grove genetic variation. Both are clonal experiments and were begun when cloning of giant sequoia was not yet reliably done. Recognizing the uneven quality of propagules available at the time of planting, the better and more uniform propagules were allocated to the second experiment, which was also allocated a better balance of open-pollinated families per grove and cloned siblings per family. Thus, the data should be and probably are better in the second experiment than in the first.

To summarize the more reliable second Foresthill experiment, with one marginal exception, the families-within-groves components of genetic variation and most of the clones-within-families genetic components were all positive for the 17 traits tested (height at several ages, and stem diameter, stem volume, and crown shape at later ages). These components of variation were statistically significant more often than would be likely by chance alone. In general,

the families-within-groves component was slightly more than half as large as the clones-within-families component, indicating a high degree of relatedness among siblings. Matings in and among very large-crowned giant sequoia trees might be expected to produce a combination of some half-siblings, and many inbred siblings and full-siblings in open-pollinated families.

The third experiment at Foresthill has eight large "standard clones" interplanted in the first experiment. These were mostly drawn from different groves, so the among-clones component contains all three levels of genetic variation. Of the 17 traits analyzed in the standard clones experiment, all had positive among-clones variance components; only three were statistically non-significant, two were significant, four were highly significant, and the remaining eight were very highly significant ($P < 0.001$).

Discussion and Recommendations

Several lines of evidence indicate that there is a small-to-modest amount of genetic variation among populations of giant sequoia, and some north to south trends are evident. For the most part, the studies indicate at least modest levels of genetic variation within populations. The second Foresthill 21-grove experiment and the cotyledon data both indicate that approximately one-third of the within-population genetic variation occurs among open-pollinated families within groves; the remainder is segregating among siblings within families.

With the exception of samples from the probably inbred Placer and Deer Creek Groves, the differences among groves that have been observed for growth traits in the California tests have been small. Nonetheless, there was a wide diversity of tree sizes and growth rates within the population samples. Except for Placer and Deer Creek, the largest trees in samples from any of the other groves greatly exceeded the mean of the best of them, and the smallest trees in each grove sample were smaller than the mean of the worst of them (Mahalovich 1985).

The different relative performances of grove samples at different locations (*table 1*) may indicate either true genotype-by-environment interaction or inadequate and/or different sampling of groves for different experiments. In some cases, the sample may have been largely composed of one or a few above-average families; in other cases, of one or a few below-average families.

There are some indications that the genetic differences among groves, among families, and among clones within families are all increasing with age in the common-garden tests. This is not surprising and, in fact, is to be expected as the various test locations accumulate unusual environmental events. Thus, although these first-decade data indicate relatively small amounts of among-grove genetic variation, the conservative approach is to treat giant sequoia as if this among-grove variation might become more important.

This approach should be followed until such time as more extensive and longer-term data are available.

For the extant native populations, we recommend that the groves be managed to encourage and enhance natural regeneration. If, however, planting is necessary in the native groves, seeds should be used from at least 20 different trees from the part of the grove where planting is to occur. Such a strategy will maintain diversity and avoid increasing next-generation inbreeding. Isolated trees should not be used as sources of seeds for routine reforestation.

If giant sequoia is to continue to be planted as a renewable wood resource around the world, genetic information on population, family, and/or individual differences will become more critical for selecting the most appropriate sources to meet the long-term objectives of the plantings. Thus, the native groves of giant sequoia are not only a national treasure just as they are but will also be important sources of reliable genetic material for plantings in many other parts of the world. In this sense, we have a responsibility not only to maintain the genetic health of our native groves, but to maintain their genetic integrity as well.

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References

- Dekker-Robertson, D.L.; Svolba, J. 1993. Results of a *Sequoiadendron giganteum* ([Lindl.] Buch.) provenance experiment in Germany. *Silvae Genetica* 42(45):199-206.
- Du, W.; Fins, L. 1989. Genetic variation among five giant sequoia populations. *Silvae Genetica* 38(2):70-76.
- Fins, Lauren. 1979. Genetic architecture of giant sequoia. Berkeley: University of California; 255 p. Dissertation.
- Fins, L.; Libby, W.J. 1982. Population variation in *Sequoiadendron*: Seed and seedling studies, vegetative propagation, and isozyme variation. *Silvae Genetica* 31:102-110.
- Guinon, M.; Larsen, J.B.; Spethmann, W. 1982. Frost resistance and early growth of *Sequoiadendron giganteum* seedlings of different origins. *Silvae Genetica* 31:173-178.
- Hamrick, J.L.; Godt, M.J.W.; Sherman-Broyles, S.L. 1992. Factors influencing levels of genetic diversity in woody plant species. *New Forests* 6:95-124.
- Hamrick, J.L.; Linhart, Y.B.; Mitton, J.B. 1979. Relationships between life history characteristics and electrophoretically detectable genetic variation in plants. *Annual Review of Ecology and Systematics* 10:73-200.
- Mahalovich, Mary Frances. 1985. A genetic architecture study of giant sequoia: early growth characteristics. Berkeley: University of California; 98 p. MS Thesis.

Soil and Nutrient Element Aspects of *Sequoiadendron Giganteum*¹

Paul J. Zinke

Alan G. Stangenberger²

Abstract: A century ago, John Muir (1894) observed that the present range of bigtree is limited to ridgetops at middle elevations in the Sierra Nevada, apparently due to soil conditions related to glaciation. This paper will examine the relations between the trees and associated soils. The elemental content of a 1200-year-old 200-ton tree was examined and compared with the storage in litter and soil on the site. Twenty-two percent of total site nitrogen was in the tree, along with 27 percent of calcium and approximately 40 percent of magnesium and potassium, and 82 percent of on-site carbon. Remaining proportions were mainly in soil, with less than 10 percent of any element in leaf litter. A major influence of old *Sequoiadendron* on the soil is maintenance of a high base element status due to high contents in foliage and twigs returned in contrast to lower amounts in associated conifer species. Extremes of percentile arrays of foliar element analyses are used to identify sites with possible limitations for *Sequoiadendron*.

Several questions were raised by the topic of this paper. What are soil-related reasons for the present limited range of the species? What is the effect of long-lived trees on a soil? Soil factors may limit range or longevity of trees if essential elements become deficient or excessive on a site. This paper will present research data partially answering these questions. How the presence of a bigtree during more than a thousand years influences the soil and fertility elements, and how much is stored in the tree will be estimated by analyses of a tree which fell at U.C. Whitaker's Forest, Tulare County, California in 1965. These data will be compared with those obtained from soils influenced by old bigtrees at several groves from Giant Forest to Merced grove, and by comparison with soil properties typical of other sites in Sierra mixed-conifer forests. The question of limits to the range of giant sequoia will be examined in terms of the soil conditions existing at sites with extremes of analytical values for foliar elements.

Elemental Balance of an Old Tree and Its Soil

The growth of a single tree on a soil for millennial periods is evidence of a rapport between the elemental needs for tree growth and maintenance of chemical and physical soil conditions within the range of these needs. Thomas Edison noted (1926) the long life of sequoias indicates "that

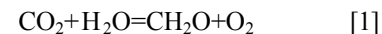
in that region there has been perfect balance between the redwood tree and all or nearly all surrounding conditions." Since the tree must remain on the soil in which it is rooted, an old *Sequoiadendron* must be in balance with the soil in this manner.

The balance of elements between tree and supporting soil was estimated through measurements on a fallen 1200-year-old tree which had a stem diameter of 26 feet (8 m) at the base, a crown diameter of 100 feet (30.5 m), and a height of 256 feet (78 m) including a pointed 10-foot dead top. During the early summer immediately after tree fall in 1965 the masses of foliage, twigs, small branches, cones, stem wood and bark, were measured and converted to mass of tree on an oven-dry basis. Samples of components were taken for analysis of elemental composition. Soil samples were obtained at uniform depth increments from pits at the base and at 15 feet (4.6 m) from the tree, and determination made of root contents and composition of major fertility elements, pH, bulk density, and stone content. Soil elemental storage and root contents were calculated to a meter depth over the area of the crown spread of the tree (731 m²).

The mass of material which the tree accumulated over 1200 years represents elements obtained from the atmosphere and the soil during this period. Van Helmont reported in 1652 the growth of a willow tree in sandy soil amounted to 164 pounds while the soil lost 2 ounces of material (Russell 1950). Presumably the major proportion of the weight of the tree measured in this study was also derived from elements from the atmosphere.

Elements Derived from the Atmosphere

The mass of the fallen tree was assumed to be derived from the atmosphere in combining proportions represented by the photosynthetic equation (1), with both carbon dioxide and water obtained from the atmosphere, although the water was derived from seasonal soil moisture storage enroute from the atmosphere.



The dry mass of the 1200-year-old tree that fell at Whitaker's Forest was estimated by weighing various parts of the tree, and adding the product of the volume of stem wood and bark and density to obtain the data in *table 1*. This totaled 199 metric tons (X 0.98 = long tons; X 1.1 = short tons) for an initial estimate of CH₂O in equation 1. The combining weights of atmospheric compounds to form the

¹ An abbreviated version of this paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

² Professor of Forestry Emeritus and Specialist, University of California at Berkeley 94720

tree and derived total weights in tons based on the estimated 199 tons are as follows:

grams:	44	18	30	32
$\text{CO}_2 + \text{H}_2\text{O} = \text{CH}_2\text{O} + \text{O}_2 \quad [2]$				
tons:	292	119	199	212

These estimates do not include deciduous material such as foliage, and branches, or those respired during the 1200 years.

The fallen Whitaker's tree is small compared to the bigtrees reported by Flint (1987) which range from 213 tons to more than 445 tons (stem volume X specific gravity of 0.3). Stagner (1952) reports trunk weights of 625 short tons for the General Sherman Tree, and 565 tons for the General Grant tree assuming a specific gravity of 0.4. Fry and White (1938) reported the wet field weight of the General Sherman tree at 2105 tons. By using the density of 0.3 (Cockrell and Stangenberger 1971), their volume of 42,650 cubic feet (1208 m³) yields an estimated dry weight of 623 tons (trunk, 362; bark, 54; limbs, 37; roots, 142; and foliage, 28 metric tons). The weights of the constituent parts of the Whitaker's tree (table 1) show that 97 percent or 193 metric tons of the tree was slowly-cycling material (wood and bark), while 3 percent was the material frequently returned to the soil as foliage, twigs, and small branches. The foliage, branches, and cone materials were all collected and weighed with the help of a California Division of Forestry conservation camp crew.

Elements Derived from Soil

The elements derived from soil, although low in proportion to those from the atmosphere, are also elements essential to tree survival. Questions regarding the effects of the mono-culture of a single tree for many years on a soil relate to the continuing availability of these elements, or to the potential of undesirable depletions, excesses, or toxicities of elements. The elements considered in this study are nitrogen, phosphorus, calcium, magnesium, potassium, iron, manganese, and zinc, borrowed by the tree from available soil storage or from current mineral weathering. These elements are either utilized for a short time in tissues returned quickly to the soil, or stored for a long time in the structural elements of the tree. Eventually all are returned to the soil and rendered available to subsequent generations of trees on the site. The composition and weight in grams of the major essential elements in tree parts are shown in tables 2 and 3. The sum of the weights of all these elements in the tree was 1.064 metric tons. Since this is a small proportion of the total 199 tons (0.5 percent) it was not taken into account in the initial estimates of total combining weights in equation 2.

The analyses of mineral soil samples from two soil pits associated with the Whitaker's tree were used to calculate soil mineral storage of the fine-earth fraction (<2mm) under the crown projection area. The average composition of duff

Table 1-Weights of parts of a fallen Sequoiadendron at Univ. of California's Whitaker's Forest, Tulare County, California

Component	Weight	
	Kilograms	Metric ton
Foliage		
200'-250'	83.8	
150'-200'	85.8	
100'-150'	34.0	
Total fol.	203.6	0.20
Branches		
200'-250'	145.2	
150'-200'	210.5	
100'-150'	96.2	
Total branch ¹	451.9	0.45
Bark-stem		
225'-250'	125	
175'-225'	470	
125'-175'	1190	
75'-125'	3840	
10'-75'	14100	
0'-10'	4140	
Total bark	23900	23.9
Wood-stem		
0-250'	168,993	169.0
Cones	382.2	
Seeds	7.9	
Cone resin	5.9	
Total cones	396	0.39
Roots		
0-25cm depth	2218	
25-50	767	
50-100	511	
100-150	1210	
150-200	438	
Total roots ¹	5130	5.1
Total tree ¹		199

¹Excludes large branches >12" dia. but includes small branches and twigs. Roots to 15.25 m radius from tree; large roots > 1 " dia. excluded. Wood specific gravity was 0.3 for old growth as reported by Cockrell, and others (1971), and bark specific gravity measured on four samples with a mean of 0.26 and a S.D. of.0244 when oven dried. and a S.D. of.0244 on four samples oven dried for 36 hours. Total Tree is sum of parts not including large branches and roots.

Table 2-*Major element composition of parts of Whitaker Forest fallen Sequoiadendron tree*

Component ¹	Element							
	N pct	P ppm	Ca pct	Mg pct	K pct	Mn ppm	Fe ppm	Zn ppm
Foliage								
200'-250'	.64	440	1.87	.07	.42	100	140	17
150'-200'	.92	729	1.70	.14	.42	99	142	19
100'-150'	.88	800	1.70	.17	.41	133	136	29
Branches								
200'-250'	.47	649	1.80	.14	.36	28	128	17
150'-200'	.45	460	1.74	.06	.33	25	133	15
100'-150'	.51	549	1.82	.10	.41	33	173	19
Bark								
225'-250'	.17	n.d.	.260	.033	.022	18	46	2
175'-225'	.14	70	.310	.034	.019	14	43	7
125'-175'	.14	20	.150	.016	.014	10	24	4
75'-125'	.14	20	.091	.016	.026	12	30	2
10'-75'	.21	70	.051	.011	.023	10	270	4
0-10'	.24	20	.076	.017	.027	20	151	2
Wood-stem								
Heartwood	.13	n.d.	.24	.02	.06	18	251	18
Sapwood	.08	n.d.	.43	.04	.06	18	15	2
Cones	.31	475	.51	.10	1.25	42	118	22
Seeds	1.50	5888	.57	.31	.44	111	24	100
Resin	.30	440	.32	.16	n.d.	145	4784	161
Roots								
0-25cm	.71	n.d.	1.50	.10b	n.d.	160	208	31
25-50cm	.68	n.d.	1.05	.29	.14	343	522	45
50-100cm	.45	n.d.	1.00	.15	.21	136	437	131
100-150cm	.24	n.d.	.26	.13	.28	80	332	47
150-200cm	.30	n.d.	.81	.12	.28	114	336	105

¹Excludes large branches and roots sampled at indicated levels. Heartwood analyses used in calculations of total tree storage, n.d. is not determined, and the 4784 for cone resin iron is okay.

layers associated with three old-growth giant Sequoias from a previous study (Zinke and Crocker 1962) was assumed to characterize the duff layers associated with the Whitaker's tree because litter was disturbed by tree fall.

The quantity of various elements in soil and leaf litter are shown in *table 4* and the distribution between tree and soil is shown in *table 5*. The distribution of elements on the site shows most of the mineral elements stored in soil and litter, but eighty percent of total site carbon stored in the tree. When compared to soil under other mature conifer trees, soils under old bigtrees have lower bulk densities, higher carbon and calcium contents, much higher base saturation of the soil exchange capacity due to calcium, a resultant higher soil pH, and higher nitrogen contents. Details are reported in an earlier study by Zinke and Crocker (1962).

The influences of old *Sequoiadendron* on soil are related to the composition of foliage and twigs recycled to soil. Foliar samples from a wide range of big tree sites, natural and artificial, were analyzed to evaluate the potential range of elemental content values.

Foliar Analyses as Indicators of Soil Limits

Sequoiadendron samples of current-, medium-, and old-age foliage were collected, analyzed for elemental composition, and the data arrayed in probability distributions as shown in *table 6*. The values in the table are useful to rank a foliage analysis by the equal or less than percentile in the array. In this process high or low extremes can be identified.

Table 3-*Total elemental weights in grams in fallen old-growth Sequoiadendron parts at Whitaker Forest.*

Component	N	P	Ca	Mg	K	Na	Mn	Fe	Zn
Live									
Foliage	1626	126	3609	235	849	99	21	28	4
Twigs, branches	2114	244	8037	432	1619	265	13	63	7
Cones	1321	231	2013	416	4813	38	18	73	10
Roots	27425	n.d.	52944	7293	7189	n.d.	833	1630	272
Total	32486	n.d.	66603	8376	14470	n.d.	885	1795	294
Dead									
Wood	215000		411000	38900	98000	43900	3040	42400	3040
Bark	47532		17427	3262	5645	4561	291	4605	81
Total	262532		428427	42162	103645	48461	3331	47005	3121
Tree	295018		495030	50538	118115	48863	4216	48800	3415

Cones include seeds. Tree sodium total exclusive of roots.

Table 4-*Average weights of elements in leaf litter from three old giant Sequoiadendron trees as grams/sq.meter; and total weights as kilograms under crown spread (731 sq.meters) of Whitaker Forest fallen tree.*

Element	C	N	Ca	Mg	K	Mn	Fe	Zn
Mean								
Grams/m ²	5169	83	240	15	8	16	2	0.6
X Crown Spread Kg	3805	61	176	11.2	5.8	11.8	1.6	0.3

Average at three locations for sum of L and F layers multiplied by crown spread area of fallen tree to estimate amount at Whitaker fallen tree.

Table 5-*Elemental distribution between tree, litter, and soil at the site of the fallen Whitaker Sequoiadendron¹*

Site component	Carbon	Nitrogen	Calcium	Magnesium	Potassium
Tree					
kilograms	79600	295	495	51	118
percent of total	80	22	27	37	40
Leaf Litter					
kilograms	3805	61	176	11.2	5.8
percent of total	3	5	9	8	2
Soil-1m					
kilograms	16045	957	1178	77	173
percent of total	16	73	64	55	58
Site Total					
kilograms	99,450	1313	1849	139.2	297
percent	100	100	100	100.0	100

¹Weights are in kilograms in whole tree and under crown spread for litter, and soil 1 meter deep. Litter values from means of samples under similar trees. Litter had 47 percent carbon, tree assumed at 40 percent carbon as per CH₂O.

Table 6-*Cumulative probability distributions of elemental composition of Sequoiadendron foliage derived from samples obtained from 28 sampling sites throughout range of species.¹ Population percentiles of species with analytical values equal or less than those listed based upon Weibull cumulative probability distribution.*

Percentile = or <	N <i>Pct</i>	P <i>ppm</i>	Ca	Mg	K <i>Pct</i>	Na	Mn	Fe <i>ppm</i>	Zn
Current year (scale + green twig)									
1	.580	482	.780	.110	.277	.001	49	30	9
10	.629	734	.919	.135	.403	.001	100	34	10
20	.677	862	1.000	.149	.466	.001	145	40	18
40	.777	1041	1.157	.170	.555	.001	233	53	25
50	.835	1120	1.230	.179	.594	.001	282	61	29
60	.901	1199	1.309	.189	.632	.001	337	71	34
80	1.089	1380	1.507	.211	.721	.002	487	103	48
90	1.261	1513	1.667	.228	.786	.003	620	135	60
99	1.774	1817	2.077	.268	.933	.014	1000	242	96
2 to 3 years (scale +twig still green -medium age)									
1	.520	371	.775	.084	.230	.001	30	32	7
10	.550	542	.975	.103	.340	.001	49	38	11
20	.584	641	1.093	.118	.398	.001	69	45	14
40	.658	791	1.275	.144	.480	.001	110	60	21
50	.703	860	1.360	.158	.517	.001	133	69	25
60	.757	932	1.448	.172	.553	.001	160	81	30
80	.915	1103	1.660	.211	.639	.002	239	114	43
90	1.067	1233	1.824	.243	.702	.003	311	145	54
99	1.543	1546	2.220	.328	.847	.016	529	247	88
5 years (scale brown + red twig, old age)									
1	.302	351	.772	.044	.254	.001	21	32	6
10	.327	383	.907	.052	.296	.001	28	36	8
20	.358	418	1.005	.061	.330	.001	36	41	10
40	.430	492	1.174	.081	.391	.001	55	53	14
50	.476	536	1.260	.093	.423	.001	65	61	17
60	.530	588	1.352	.108	.458	.001	79	70	20
80	.699	738	1.589	.153	.552	.002	116	100	30
90	.865	880	1.784	.196	.631	.003	152	130	40
99	1.408	1314	2.296	.332	.848	.019	265	229	70

¹Used to rate a foliage analysis in the expected range for the species. For example a value of .628 percent Nitrogen for current foliar growth would indicate it is at the 10 percent or less level of the species range.

Sites with such extremes in percentile range are shown in *table 7*. Where foliage showed low contents of nitrogen, phosphorus, magnesium, or iron; the soils were often sandy or stony. Where soils had high organic matter content from past occupancy by bigtrees with recycling interrupted by harvest (Indian Basin) foliar analyses were low in rank for nitrogen, phosphorus, potassium and zinc. Perhaps, following interruption of nutrient cycling by tree harvest these elements are temporarily tied up by the microbial population decomposing the stock of soil organic matter accumulated under the harvested forest. Areas influenced by human use often had foliage with excessive nitrogen, zinc, and sodium contents. High rankings of some elements occurred in foliage from trees on sandy or stony soils dominated by minerals containing these elements: for example, high magnesium and potassium were found in foliage on soil derived from granitic rocks with biotite mica. Soils at lower rainfall limits with high basic element content and resulting high pH tended to produce foliage with low ranking of elements rendered insoluble under these conditions such as zinc or phosphorus. The reverse occurred at high rainfalls, where resulting acid soils, wet and high in organic matter content, resulted in high percentile ranking of foliar manganese content.

Some examples of foliage that had extreme percentile values or showed deficiency symptoms are shown in *table 8*. Foliage sampled from bigtrees planted at low-rainfall areas outside the normal range (Wrightwood, San Bernardino County) displayed bronze-color foliage, and the contents of calcium, manganese, and zinc ranked very low in the probability distributions. A tree which was suppressed under

white fir at Whitaker's forest had foliage that ranked very high in potassium, and very low in manganese. The soil in which this tree grew was a young sandy granitic soil (Corbett series). A nursery tree grown on an acid sandy soil with high water table showed excessive manganese and iron, very low calcium and a very reddish-brown foliage. Magnesium, phosphorus, and nitrogen were very high due to fertilization. Foliar analyses with percentile extremes indicate possible nutrient imbalances or deficiencies. These hypotheses, however, still need validating by controlled experiments.

There is a soil microbiological component to the nutritional rapport which bigtrees reach with soil. The symbiotic effects of mycorrhizae are very important in maintaining phosphorus uptake in the presence of high soil calcium and pH resulting from the bigtree influence on soil. These relations are dealt with in more detail (Molina 1992) in these Proceedings. High potassium and nitrogen content in wood and roots may make these tissues attractive targets for fungal pathogens in soil. Piirto deals with these soil problems in these Proceedings and in an earlier paper (1974).

The optimum range in soil properties for *Sequoiadendron* as for any species should be found at sites where foliar quantities of essential elements are not excessively high or low; and a rapid elemental cycling rate occurs. For *Sequoiadendron* this would be in a climate with moderately high precipitation and with a well drained soil well stocked with available essential elements.

Physiological factors may also affect foliar composition. *Sequoiadendron giganteum* var *pendula* (Carriere) M.L. Greene is an interesting weeping form of the bigtree that

Table 7-Characteristics of sites on which *Sequoiadendron* foliage had low (< 10% values) or high (>90% values) concentrations of major elements as listed in table 6.

Low	Element	High
Immature stony sandy soils or cutover bigtree second growth. (Wawona, Indian Basin)	Nitrogen	Soils subject to septic tank or human influence (Crestline CA, Vancouver WA.)
Immature soils high in Calcium (McKinley, Indian Basin)	Phosphorus	Soils influenced by septic tanks and people (Crestline, Pack For. WA, Wawona)
Soils in mixed-conifer forest outside bigtree range acid sands (Vancouver, WA; Crestline)	Calcium	Cutover bigtree areas or understory of <i>Abies</i> or <i>Calocedrus</i> (Whitaker, Indian Basin, McKinley)
Stony sandy soils (Wawona)	Magnesium	Soils on granite with biotite mica or basalt (Chilao, Whitaker, Wawona)
Cutover bigtree soils and meadows (Indian Basin)	Potassium	Understory-mixed-conifer or young sandy soils on granite (Whitaker, Wawona)
Low rainfall sites outside natural range. Suppressed understory (Whitaker, Wrightwood CA)	Manganese	Sandy acid soils (Wawona, Grant Grove, Crestline)
Sandy Stony Soils (McKinley, Wawona)	Iron	Soils derived from basalt, or other soils at lower rainfalls (Vancouver, Pack For. WA, Crestline CA)
Soils in low rainfall or cutover bigtree areas (Wrightwood, Indian Basin)	Zinc	Soils having human inputs - Septic tanks etc. (Crestline, Chilao)

Table 8-Some examples of foliage samples obtained from trees showing elemental extremes in foliage, and their percentile rankings.

Location and foliage age ¹	Percent	ppm	Percent			Percent		
	N	P	Ca	Mg	K	Mn	Fe	Zn
Wrightwood	-----analytical values-----							
Current	1.81	1087	.824	.147	.515	47	86	10
Medium	1.060	1073	.831	.130	.599	30	30	7
	-----Percent of species population equal or below-----							
Current	79	46	3	18	30	1	71	1
Medium	90	77	2	29	71	1	75	1
Whitaker's	-----analytical values-----							
Current	.802	1292	1.241	.177	.924	85	65	29
Medium	.646	994	1.466	.155	.804	44	68	19
	-----percent of species population equal or below-----							
Current	44	71	51	48	99	7	54	4 9
Medium	37	68	62	48	98	7	49	34
Indian Basin	-----analytical values-----							
Current	.577	657	1.735	.209	.263	165	61	13
Medium	.558	553	1.613	.214	.230	56	66	10
	-----percent of species population equal or below-----							
Current	1	6	93	78	1	25	50	8
Medium	12	11	76	81	1	13	46	8
Nursery tree	-----analytical values-----							
Current	1.34	2014	.57	.26	.48	509	96	44
Medium	1.10	2292	.85	.31	.46	768	164	57
Dead current	1.42	1337	.95	.21	.08	1881	272	82
	-----percent of species population equal or below-----							
Current	91	>99	<1	99	23	82	76	7 5
Medium	91	>99	4	97	35	>99	93	8 8
Dead	93	>99	14	91	<1	>99	>99	97

¹Wrightwood tree had bronze appearance; Whitaker's was suppressed in understory (not the fallen tree of this study); Indian basin second growth growing poorly; Nursery was 4-year-old purple-bronze tree with some dead foliage on acid poorly-drained sandy soil. Population percentile ratings by using table 6.

illustrates this. Foliar samples from a specimen of this variety were analysed and the results shown in table 9. The foliar calcium content is strikingly low. Since calcium adds to the rigidity of cell walls this may explain the drooping form of the tree which would probably not survive in the heavy snowfall of the present range of the species. Thus, an extreme in a foliar analysis may occur due to a genetic anomaly.

Comparison with other Mixed-Conifer Species

Arrays of foliar analyses for other mixed-conifer species associated with *Sequoiadendron* have been published by

Zinke and Stangenberger (1979). Fifty-percentile values for other mixed-conifer species *Calocedrus decurrens*, *Abies concolor*, *Pinus ponderosa*, and *Sequoia sempervirens* are shown in comparison with *Sequoiadendron* in table 10.

The *Sequoiadendron* foliage is lower at the fifty percentile level in nitrogen, manganese, and iron than the foliage of any of the other species. Phosphorus and potassium contents are similar, magnesium contents slightly higher, and calcium contents of bigtree foliage much higher.

The differences in the soil composition under the influence of *Sequoiadendron* compared to other mixed-conifer species reflects these differences in foliage composition. During the lifetime of the 1200-year-old tree the foliage must

Table 9-Foliar analyses of a pendulous bigtree *Sequoiadendron giganteum* (Lindl.) Buch. var *pendula* (Carriere) M.L. Greene rated by the cumulative probability values in table 6.

Foliage age	Percent N	ppm P	Ca	Percent Mg	K	Mn	ppm Fe	Zn
Current	1.388	2020	.887	.297	.955	77	204	36
Medium	1.270	1864	.914	.264	.844	49	212	33
Old	.629	1036	1.008	.118	.658	25	86	2 1
-----percent of population equal or below -----								
Current	92	>99	8	>99	>99	6	96	63
Medium	94	>99	7	92	99	10	96	65
Old	72	91	20	64	91	6	71	62

Sample courtesy J. Cranmer, Vagabond Lodge, Hood River, Oregon.

Table 10-Values of 50 percent of foliage elemental concentrations in Sequoiadendron and associated mixed-conifer species with coast redwood for contrast.¹

Species, foliage year	N	P	Ca	Mg	K	Na	Mn	Fe	Zn
	<i>percent</i>	<i>ppm</i>	-----percent-----			-----ppm-----			
<i>Sequoiadendron</i>									
Current year	.835	1120	1.230	.179	.594	.001	282	61	29
2-3 yr	.703	860	1.360	.158	.517	.001	133	69	25
old	.476	536	1.260	.093	.423	.001	65	61	17
<i>Calocedrus</i>									
Current year	1.049	820	.677	.166	.370	.001	105	105	13
3 yr	.942	648	.711	.084	.307	.001	63	127	12
old	.767	478	.771	.066	.283	.001	40	123	12
<i>Abies concolor</i>									
Current year	1.086	987	.451	.092	.590	.001	412	73	27
3 yr	.891	522	.937	.088	.300	.001	466	96	26
5 yr	.798	452	1.097	.091	.254	.001	602	91	29
<i>Pinus ponderosa</i>									
Current year	1.147	1140	.127	.091	.541	.002	93	72	25
3 yr	.997	617	.335	.116	.361	.005	177	130	29
5 yr	.806	575	.368	.115	.304	.006	201	154	34
<i>Sequoia sempervirens</i>									
Current year	1.077	1270	.814	.166	.592	.027	209	173	33
2-3 yr	.962	899	.777	.150	.506	.039	199	190	28
old	.667	615	.887	.123	.389	.016	126	136	27

¹ These are values for the equal to or less than 50 percent level for comparison with other mixed conifer or related species. See table 6 for complete probability distribution for elemental composition of Sequoiadendron foliage.

have been dropped, decomposed, and elements recycled repeatedly. The high calcium turnover in the falling foliage results in the high calcium content of soil surface layers.

Conclusions

The estimation of the weight and elemental composition of a recently fallen giant Sequoia tree indicates that only one ton of the total of nearly 200 tons of weight is derived from the soil. These are essential mineral elements, however, allowing survival of the tree. The long-lived tree, on this soil for more than a thousand years, has maintained a soil with high base status due mainly to high exchangeable calcium, a high pH, and a high organic matter content. This is a contrast to base-depleted acid soils developed under associated mature conifer trees.

Foliar analyses are offered as one way to determine the limits to the range of soil conditions tolerated by individuals of the species. Indications from the data are that the optimum soil for the survival of giant sequoia from seedling to mature tree is a soil with development not too weathered nor excessively young and stony; a soil that is well-drained of moisture; and a soil high in organic matter recharged with basic elements in bigtree litter.

The result is, as noted by John Muir (1894), the soils supporting the bigtrees are: "just where, at a certain period in the history of the Sierra, the glaciers were not, there the Sequoia is, and just where the glaciers were, there the Sequoia is not." At elevations above the Sequoia belt, as well as along the steep canyon sides below, the soils are too immature (sandy and stony). At lower elevations soils are too weathered of secondary minerals and heavy in clay to meet the demands of the trees or precipitation is too low to prevent accumulation of carbonates from the high calcium amounts cycled by the trees. Transects showing these types of soil development sequences with elevation have been shown by Zinke and Colwell (1965).

The groves, as a result, are located away from steep canyon sides with their stony colluvial soils. They are found on ridge tops or gentler slopes at elevations above the zone of mature and well-developed red and reddish-brown soils of lower elevations, but below the stony shallow soils of the glaciated upper elevations. Finally, as noted by Thomas Edison, the tree over its long life maintains a soil within its rooting zone that is in balance with its requirements, otherwise it could not survive!

References

- Cockrell, Robert A.; Knudsen, Robert M.; Stangenberger, Alan G. 1971. Mechanical properties of southern Sierra old- and second-growth giant sequoia. California Ag. Exp. Sta. Bulletin 854; 9 p.
- Edison, Thomas A. 1926. Has man an immortal soul? The Forum 76(5): 641-650.
- Flint, W.D. 1987. To find the biggest tree. Three Rivers, CA: Sequoia Natural History Assoc.; 116 p.
- Fry, W.; White, J.B. 1938. Big trees. Palo Alto, CA: Stanford Univ. Press; 126 p.
- Molina, R. 1992. The role of mycorrhizal symbioses in the health of Giant sequoia and forest ecosystems. In: Proc. giant sequoia symposium, June 1992 Visalia, CA.
- Muir, John. 1894. The mountains of California. Berkeley, CA: Ten Speed Press (Facsimile 1988).
- Piirto, Douglas D.; Parmeter, J.R.; Cobb, Fields W. 1974. *Fomes annosus* in giant sequoia. Plant Disease Reporter 58:5.
- Russell, J. 1950. Soil conditions and plant growth. New York: Longmans, Green and Co.; 635 p.
- Stagner, H.R. 1952. The giants of Sequoia and Kings Canyon. Visalia, CA: Commercial Printing Co.; 31 p.
- Zinke, P.; Crocker, R.L. 1962. The influence of giant sequoia on soil properties. Forest Science 8(1):2-11.
- Zinke, P.J.; Colwell, W.L. 1965. Some general relationships among California forest soils. In: Proceedings of 2nd North Amer. For. Soils Conf.; Corvallis, OR: Oregon State Univ. Press; 353-365.
- Zinke, P.J.; Stangenberger, A.G. 1979. Ponderosa pine and Douglas fir foliage analyses arrayed in probability distributions. In: Proc. Conf. on Forest Fertilization. Seattle: Univ. Washington Press; 221-225.

The Role of Mycorrhizal Symbioses in the Health of Giant Redwoods and Other Forest Ecosystems¹

Randy Molina²

Abstract: The roots of nearly all land plants form mycorrhizal symbioses with specialized soil fungi. The mycorrhizal fungi serve as extensions of plant roots, taking up nutrients and water and transferring them to the roots. In return, the mycorrhizal fungi receive their primary energy source in the form of simple sugars from plant photosynthates translocated to the roots. *Sequoiadendron giganteum* forms a type of mycorrhizae referred to as vesicular-arbuscular mycorrhizae; seedlings inoculated with mycorrhizal fungi in nurseries can be two to three times larger than noninoculated control seedlings. Mycorrhizal fungi also function in soil nutrient cycling, and their hyphae and reproductive structures (spores, mushrooms, and truffles) are vital components in the complex forest food web. Management strategies that protect the biological component of the soil will ultimately protect the health and functioning of the entire forest ecosystem.

Ecological management of natural resources requires a broad understanding of how ecosystems function. Likewise, conserving biodiversity requires knowledge not only of the population biology of individual organisms but also the interactions and interdependencies of organisms. Such management perspectives provide a means to include the myriad of "less visible" organisms along with the "charismatic" megafauna and flora in our management schemes.

This integrated approach is essential for managing the great diversity of species and functions of soil microorganisms in forest ecosystems. Total species richness is greatest in the soil: the functions of soil microbes power the complex biochemistry of nutrient cycling that yields soil fertility and ultimately, plant and animal productivity.

This paper focuses on the role of fungi in forest ecosystems, particularly mutualistic mycorrhizal fungi of giant redwoods and other forest plants, and provides examples of biotic connections between forest organisms via belowground microbial linkages.

Intrinsic Value of Fungi in the Forest

Fungi must first be viewed for their intrinsic values. Many fungi produce beautiful and elegant reproductive structures known as mushrooms. These fruiting bodies or sporocarps are collected regularly by thousands of amateur and professional mycologists who marvel at their complex forms, learn their identification, study their ecology, or simply savor the edible species for their unique and delectable tastes. Regional mushroom clubs and societies are scattered across North America and other continents. They organize

collection trips and meetings to discuss their findings and share in their mycological experiences. Just as we recognize the enthusiasm of bird watcher, native plant, and other "nature loving" societies, so too must we recognize society's longtime interest in and fondness for fungi as part of our recreational pastimes.

Perhaps the most obvious social value of fungi comes from their use in medicine. Many "molds" are famous for their production of antibiotics, such as penicillin. Ancient pharmacopoeia list numerous medicinal uses of fungi. Yet, we have barely explored the medicinal potential of fungi. Any conservation discussion that emphasizes efforts to preserve plant species for as yet unknown medicinal value must also include the fungi.

Several species of wild, edible, forest mushrooms are harvested commercially in Alaska, Oregon, Washington, and California, and a multimillion dollar wild mushroom industry has developed (Molina and others 1993). This new industry has created conflicts between traditional recreational users of forest mushrooms and commercial mushroom harvesters and prompted resource managers to develop new permit systems to protect and regulate this resource. The monetary value of this new, special forest crop and the regional conflict over its proper use has brought attention to this previously unheralded group of forest organisms. Such social and economic values underscore the need to understand the biodiversity of fungi in relation to the forest community.

Ecosystem Functions of Fungi

Fungi are key organisms in the functioning of ecosystems, and while we may marvel at their great numbers, understanding their "functional diversity" is critical to comprehending their importance in ecosystem health. Fungi are most known for their role in the decomposition cycle, particularly for the breakdown and mobilization of recalcitrant organic compounds in dead wood. Fungi not only cycle nutrients through the decomposition process, they also retain nutrients within their enormous living biomass in the soil, thereby reducing nutrient loss through leaching. This great fungal biomass is a primary food source for many grazing soil insects. Indeed, most soil microarthropods feed strictly on fungal hyphae, and in so doing return these stored nutrients to the soil and make them available to plants.

Another important role of fungi is as pathogens, directly killing or weakening forest plants. Such a role is typically viewed as having negative impacts on forest health and productivity. But fungal diseases also have positive influences on ecosystem productivity and biodiversity (Trappe and

¹An abbreviated version of this paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

²Research Botanist, Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture, 3200 Jefferson Way, Corvallis, OR 97331.

Luoma 1992). For example, disease-killed trees leave openings in the forest where light-requiring-plants can establish. Such habitats are frequented by wildlife. Standing dead trees also provide habitat for cavity-nesting birds and mammals. Thus, although it is important that we not exacerbate diseases with our management practices, it is important to realize that pathogens are a natural component of the forest ecosystem and contribute to landscape diversity.

Another large group of forest fungi are the mutualists who live in beneficial symbioses with forest plants. Understanding the closeness of these co-evolved plant-fungus relationships helps us to visualize how organisms are ecologically linked, and from that understanding we can build a basis for ecological management.

Mycorrhizal Fungi of Forest Plants

Mycorrhiza literally translates as "fungus-root" and defines the common association of specialized soil fungi with the fine roots of nearly all forest plants. Mycorrhizal associations represent one of the more widespread forms of mutualistic symbioses in terrestrial ecosystems. Indeed, these plant-fungus associations have co-evolved over the millennia such that each partner depends upon the other for survival.

The mycorrhizal fungus basically serves as an extension of the plant root system, exploring soil far beyond the roots' reach and transporting water and nutrients to the roots. The uptake of phosphorus and nitrogen are especially critical functions of mycorrhizal fungi, which can release bound forms of these nutrients otherwise unavailable to the roots. In return, the plant is the primary energy source for the fungus, providing simple sugars and vitamins produced in photosynthesis and transported to the roots and then the fungus. It is important to realize that mycorrhizal fungi have limited saprophytic ability, that is, they possess few of the enzymes needed to break down efficiently complex organic matter in the soil. Therefore, their survival in natural ecosystems depends on the supply of sugar (photosynthate) from their associated host plants. Likewise, many plants strongly depend on their mycorrhizal fungi for nutrient and water uptake. This co-evolution in dependency reinforces the need to view organisms through their relationships within the forest.

There are several classes of mycorrhizae, but only the three most common will be discussed: ectomycorrhiza, vesicular-arbuscular mycorrhiza, and ericoid mycorrhiza (Harley and Smith 1983, for a comprehensive review of mycorrhizae; and Castellano and Molina 1990, for color photos of mycorrhiza morphology and anatomy). *Ectomycorrhiza* is the most common type appearing on forest trees in the Western United States and Canada. Ectomycorrhizal hosts include all species in the Pinaceae (*Abies*, *Larix*, *Picea*, *Pinus*, *Pseudotsuga*, and *Tsuga*), Fagaceae (*Castinopsis*, *Lithocarpus*, *Quercus*), Salicaceae (*Salix*, *Populus*), and Betulaceae (*Alnus*, *Betula*, *Corylus*). Additionally, scattered genera such as *Arbutus*, *Arctostaphylos*, *Cercocarpus*, and *Eucalyptus* form ectomycorrhizae. The dominant nature of

these species in western forest ecosystems, especially Pinaceae, contributes to the pervasiveness of ectomycorrhizae in western forests.

Ectomycorrhizae develop on the short, feeder roots. The fungus forms a sheath or *mantle* of fungal tissue around the feeder root. The mantle serves as a storage tissue for nutrients received from mycelium in the soil and physically protects the fine roots from some pathogens and desiccation. The fungus also penetrates between the root's cortical cells to form a network of fungus tissue called the *Hartig net*. Nutrient exchange occurs within this extensive, intimate contact zone: sugars and vitamins move into the fungus, and water and nutrients move into the plant. Many ectomycorrhizal fungi produce plant hormones that cause extensive branching of colonized feeder roots. This branching greatly increases the root surface area and provides an extensive contact zone between the fungus and root.

The fungus grows from the colonized roots into the surrounding soil. Mycelial colonization of the soil varies among ectomycorrhizal fungi; some may only grow a few centimeters into the soil and others can grow several meters from the ectomycorrhiza. Some fungi produce dense, hyphal mats that strongly bind the soil and organic matter. If the mycelium is white or brightly colored, these extensive mats may be readily visible when a bit of the upper organic layer is removed. Other fungi produce colorless or dark mycelia that are more difficult to see with the unaided eye, but their growth into the soil is likewise extensive.

Thousands of ectomycorrhizal fungus species occur in the forests of Western North America; Douglas-fir (*Pseudotsuga menziesii*) alone associates with nearly 2000 species (Trappe 1977). Most ectomycorrhizal fungi are basidiomycetes and ascomycetes and many produce mushroom fruiting bodies that abound in western forests during the moist times of the year. Many ectomycorrhizal mushroom-forming fungi are especially prized for their edibility. Well-known edible species occur in the genera *Cantharellus* (chanterelles), *Boletus* (boletes), *Lactarius* (milky caps), *Tricholoma* (matsutake), *Hydnum* (tooth fungi), and *Ramaria* (coral fungi) (Molina and others 1993 provide a complete listing of ectomycorrhizal fungus genera). Another large and diverse group of less well known ectomycorrhizal fungi are the truffles, which produce fruiting bodies beneath the duff or soil surface. Few truffle species are harvested commercially, but, as will be discussed later, truffle fungi are a central part of the forest food web.

The habitat requirements of ectomycorrhizal fungi and their interactions with particular plant species are poorly understood. Some fungi are more abundant in certain age classes of forests. As plant-species composition changes during forest succession, the fungus communities similarly undergo change. This fungus succession is in response to changes in tree composition, tree age, and soil qualities such as accumulation of organic matter. The ecological requirements of mycorrhizal fungi, particularly their relation to forest community succession and disturbance events, represent large knowledge gaps needing research attention.

The second important class of mycorrhizae in our forests is called *vesicular-arbuscular (VA) mycorrhiza*. Unlike ectomycorrhizae, VA mycorrhizae do not cause obvious morphological changes in colonized roots; the roots must be stained to reveal the internal fungus colonization. The fungus mycelium ramifies through the cortex of the fine roots, and produces the characteristic arbuscules and vesicles. *Arbuscules* (literally meaning 'little tree') are finely branched hyphal structures that proliferate within a single cortical cell and function as the exchange site between fungus and host. *Vesicles* are balloon shaped and function as storage organs. VA mycorrhizae also proliferate in the soil but their mycelium is typically colorless and thus not visible to the unaided eye.

Unlike ectomycorrhizal fungi, VA mycorrhizal fungi do not produce large, fleshy fruiting bodies. They typically produce large spores (50 to 1,000 µm in diameter) either singly or in clusters in the soil (Gerdeman and Trappe 1974). The spores can be sieved from the soil for identification, study, and inoculum production. The VA mycorrhizal fungi number only in the hundreds worldwide, so their species diversity is less than ectomycorrhizal fungi. But, because the vast majority of plants form VA mycorrhizae, the fungi are widespread throughout most terrestrial ecosystems. Western forests are no exceptions, because most understory plants and early successional herbs are VA mycorrhizal.

Giant redwood (*Sequoiadendron giganteum*) forms VA mycorrhizae as does the coastal redwood (*Sequoia sempervirens*) (Mejstrik and Kelly 1979). Other dominant VA mycorrhizal tree species in western forests include members of the Cupressaceae (*Calocedrus*, *Chamaecyparis*, *Juniperus*, and *Thuja*). Pacific yew (*Taxus brevifolia*, Taxaceae) also forms VA mycorrhizae. Common VA mycorrhizal broadleaf trees include species in the genera *Acer* (maples), *Aesculus* (buckeyes), *Cornus* (dogwoods), *Fraxinus* (ashes), *Platanus* (sycamores), *Prunus* (cherries), *Sambucus* (elderberries), and *Ulmus* (elms).

The third prevalent mycorrhiza type in western forests is called *ericoid mycorrhiza*. As the name implies, this type is restricted to the species in the Ericaceae. Because ericaceous plants (for example *Gaultheria*, *Rhododendron*, and *Vaccinium* spp.) are abundant and often dominant components of the understory, ericoid mycorrhizal fungi are likewise widespread. The fungal symbionts are mostly ascomycetes. Ericoid mycorrhizae are characterized by the intracellular colonization of the epidermal cell layer of the fine hair-like roots. Ericoid mycorrhizal fungi differ enzymatically from ectomycorrhizal and VA mycorrhizal fungi because they are able to breakdown and mobilize nitrogen from organic sources. Thus, ericoid mycorrhizae play an important role in nitrogen cycling in forest ecosystems.

Mycorrhizae of Giant Redwood

The physiology and ecology of giant redwood mycorrhizae are poorly known. In general, however, woody plants depend upon mycorrhizae for survival in natural ecosystems

(Trappe 1977) and giant redwoods are no exception. Kough and others (1985) inoculated seedlings of giant redwood, coastal redwood, incense cedar (*Calocedrus decurrens*), and western red cedar (*Thuja plicata*) with VA mycorrhizal fungi and compared them to noninoculated seedlings; superimposed on this design was high and low phosphorus fertilization. All species responded dramatically to VA mycorrhizal inoculation. At both high and low phosphorus fertilization, inoculated giant redwood seedlings were two to three times larger than noninoculated control seedlings. Adams and others (1990) report similar growth responses of redwood and cedar seedlings grown in bareroot nurseries. They developed a nursery management scheme to ensure mycorrhizal inoculation with selected beneficial VA mycorrhizal fungi that dramatically improves seedling productivity and health.

Because of the difficulty in separating mycorrhizal effects from other biological and environmental effects on mature plants in natural ecosystems, most work in mycorrhiza research has been done on seedlings under controlled conditions. Recent field studies in Oregon, however, show the strong dependence of forest recovery and productivity on maintenance of mycorrhizal fungus populations following disturbance (Molina and Amaranthus 1991, Perry and others 1987). Reports from Europe on forest decline also point to the positive relationship between abundant, active mycorrhizal activity with healthy forest stands (Jensen and others 1988). With this view in mind, it is important to manage our forests to maintain the health of beneficial soil microorganisms. For example, mycorrhizal fungi are strongly aerobic and need ample oxygen for efficient physiological functioning. Minimizing compaction disturbance that reduces soil aeration is critical to the functioning of these soil microorganisms. This management consideration is especially important in giant redwood groves that have frequent visitors and foot traffic.

Amaranthus and others (1989) and Molina and Amaranthus (1991) reviewed the ecology of soil microorganisms in forest ecosystems and discussed several management strategies to ensure their health and integrate their functions into an ecological management scheme. They stress that although soil microorganisms are adapted to disturbance, those adaptations fall within the limits of natural phenomena and intensity. They recommend management strategies that minimize disturbance to soil structure, maintain organic matter and woody debris, and promote rapid recovery of vegetation.

Trees, Truffles, and Beasts

Organisms do not live in isolation from other organisms. The ecological literature is rich with examples of interdependencies within plants, animals, or between plants and animals. Mycorrhizal interactions within forest ecosystems illustrate how "invisible" soil organisms that perform important ecosystem processes also serve as bio-

logical linkages between diverse groups of forest organisms. For example, research on the reproductive biology of mycorrhizal fungi shows its connection to ecology of the northern spotted owl (*Strix occidentalis*). A primary prey of the northern spotted owl is the northern flying squirrel (*Glaucomys sabrinus*). During certain times of the year, the northern flying squirrel feeds on a wide variety of mycorrhizal truffle fungi (Maser and others 1985). As truffles mature, the interior tissue fills with spores and emits a distinctive odor. Small mammals such as the northern flying squirrel forage for these truffles by smell, excavate, and devour them. The spores pass through the mammals unharmed and are dispersed during defecation. The spores then re-enter the soil where they germinate and form new mycorrhizae with tree roots.

Hundreds of truffle fungi occur in western forests and most forest mammals consume them. Thus, in this example of tree-fungus-prey-predator connections, resource managers can view the northern spotted owl within the context of its ecosystem linkages rather than through a simple dependency on old-growth forests. Such holistic perspectives enable development of ecosystem management tools and avoid the often devious nature of single species conservation approaches.

Conclusions

As we develop holistic approaches to understanding forest ecosystems and integrated, ecologically based management tools, we must factor in the inseparable connections to soil organisms. Forest fungi are one of the more numerous groups of forest organisms and play a critical role in nutrient cycling, soil fertility, and thus ecosystem productivity. They are also cornerstones in the complex forest food web. Forest plants have co-evolved mutualistic relationships with symbiotic root fungi such that their survival and fitness depends upon the healthy functioning of these fungi and vice versa. Just as forests invest tremendous capital in the form of photosynthates to fuel beneficial soil organisms, so too must we protect the unseen and overlooked belowground ecosystem.

References

- Adams, D.; Tidwell, T.; Ritchey, J.; Wells, H. 1990. Effect of nursery-produced endomycorrhizal inoculum on growth of redwood seedlings in fumigated soil. *Tree Planters' Notes* 40: 7-11.
- Amaranthus, M.P.; Molina, R.; Trappe, J. 1990. Long-term productivity and the living soil. In: Perry, D.A.; Meurisse, R.; Thomas, B.; Miller, R.; Boyle, J.; Means, J.; Perry, C.R.; Powers, R.F., eds. *Maintaining long-term productivity of Pacific Northwest ecosystems*. Portland, OR: Timber Press; 36-52.
- Castellano, Michael A.; Molina, Randy. 1989. Mycorrhizae. In: Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. *The Container Tree Nursery Manual, Volume 5. Agric. Handbk. 674*. Washington, DC: U.S. Department of Agriculture, Forest Service; 101-167.
- Gerdeman, J. W.; Trappe, James M. 1974. The Endogonaceae in the Pacific Northwest. *Mycologia Memoir* 5: 1-76.
- Harley, J.L.; Smith, S.E. 1983. *Mycorrhizal symbioses*. London: Academic Press.; 483 p.
- Jensen, A.E.; Dighton, J.; Bresser, A.H.M. 1988. Ectomycorrhiza and acid rain. In: *Proceedings of the workshop on ectomycorrhiza/expert meeting; 1987, December 10-11; Air Pollution Research Report 12.*: Bergen Dal, The Netherlands. Commission of the European Communities, 196 p.
- Kough, J.L.; Molina, Randy; Linderman, R.G. 1985. Mycorrhizal responsiveness of *Thuja*, *Calocedrus*, *Sequoia*, and *Sequoiadendron* species of western North America. *Canadian Journal of Forest Research* 15:1049-1054.
- Maser, Z.; Maser, C.; Trappe, J.M. 1985. Food habits of the northern flying squirrel (*Glaucomys sabrinus*) in Oregon. *Canadian Journal of Zoology* 63: 1084-1088.
- Mejstrik, Vaclav; Kelley, Arthur P. 1979. Mycorrhizae in *Sequoia gigantea* Lindl. et Gard. and *Sequoia sempervirens* Endl. *Ceska Mykologie* 33: 51-54.
- Molina, Randy; Amaranthus, Michael. 1991. Rhizosphere biology: ecological linkages between soil processes, plant growth, and community dynamics. In: *Proceedings, management and productivity of western-montane forest soils. Gen. Tech. Rep. INT-280*. Ogden, UT: Intermountain Research Station, Forest Service, U.S. Department of Agriculture; 51-58.
- Molina, Randy; O'Dell, Thomas; Luoma, Daniel; Amaranthus, Michael; Castellano, Michael; Russell, Kenelm. 1993. Biology, ecology, and social aspects of wild edible mushrooms in the forests of the Pacific Northwest: A preface to managing commercial harvest. *Gen. Tech. Rep. PNW-GTR-309*. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 42 p.
- Perry, D. A.; Molina, R.; Amaranthus, M.P. 1987. Mycorrhizae, mycorrhizospheres, and reforestation: current knowledge and research needs. *Canadian Journal of Forest Research* 17: 929-940.
- Trappe, J. 1977. Selection of fungi for ectomycorrhizal inoculation in nurseries. *Annual Review of Phytopathology* 15: 203-222.
- Trappe, James M.; Louma, Daniel L. 1992. The ties that bind: fungi in ecosystems. In: Carroll, George C.; Wicklow, Donald T., eds. *The fungal community, its organization and role in the ecosystem*. New York: Marcel Dekker, Inc.; 17-27.

Giant Sequoia Insect, Disease, and Ecosystem Interactions¹

Douglas D. Piirto²

Abstract: Individual trees of giant sequoia (*Sequoia gigantea* [Lindl.] Decne.) have demonstrated a capacity to attain both a long life and very large size. It is not uncommon to find old-growth giant sequoia trees in their native range that are 1,500 years old and over 15 feet in diameter at breast height. The ability of individual giant sequoia trees to survive over such long periods of time has often been attributed to the species high resistance to disease, insect, and fire damage. Such a statement, however, is a gross oversimplification, given broader ecosystem and temporal interactions. For example, why isn't there a greater representation of young-growth giant sequoia trees throughout the mixed-conifer belt of the Sierra Nevada? What other factors, in addition to physical site characteristics, limit giant sequoia to its present range and grove boundaries? How does fire and fire frequency affect disease and insect interrelationships in the giant sequoia/mixed-conifer ecosystem? Are current forest management strategies (e.g., fire suppression, prescribed burning programs) affecting these interactions? Giant sequoia trees are subject to the same natural forces (e.g., insect and disease organisms) as other tree species. An attempt is made in this paper to discuss some of the more common insect and disease associates of giant sequoia and their significance in relation to the more complex temporal (e.g., succession, aging and other time related events) and ecosystem interrelationships at work in the giant sequoia/mixed-conifer ecosystem.

Giant sequoia (*Sequoia gigantea* [Lindl.] Decne.)³ may be considered a long-lived species because of its high resistance to damage and mortality by insects, disease, and fire. Various attributes such as thick, fibrous bark, scalelike leaves, heartwood phenolic and tannin extractive content, general lack of resinous extractives in bark and wood, and rapid growth rates of young trees may be partly responsible for enabling individual giant sequoia trees to become very large and long-lived. We know very little, however, about what happens to giant sequoia throughout its lifetime. And, virtually nothing is known about predisposing growth-loss and mortality agents of young-growth giant sequoia in its native range.

Many people assume that once giant sequoia seeds germinate, they will live a very long time and become very large trees. It is not hard to understand why people still believe this, since the older literature is replete with statements that giant sequoia has relatively few insect and disease pests. For example, the statement by John Muir (1894) illustrates this misconception: "I never saw a Bigtree [giant sequoia] that had died a natural death; barring accidents they seem to be immortal, being exempt from all diseases that

afflict and kill other trees." Similarly Hartesveldt (1962) concurred that "Sequoia's longevity and great size have been attributed by nearly all writers, popular and scientific, to its few insect and fungus parasites and the remarkable resistance of the older trees to damage or death by fire. There is no record of an individual sequoia living in its natural range as having been killed by either fungus or insect attack." Even as recently as 1991 Harlow and others (1991) stated: "Insects and fungi cause but minor damage, and no large Bigtree killed by them has ever been found."

It is finally being recognized that giant sequoia is subject to the same natural forces as other tree species (Bega 1964, Harvey and others 1980, Parmeter 1987, Piirto 1977, 1984b, Piirto and others 1974, 1977, 1984a, Weatherspoon 1990). Weatherspoon (1990) has reported that "Although diseases are less troublesome for giant sequoia in its natural range than for most other trees, the species is not immune to disease as once assumed." Scientists have been recording disease associations with giant sequoia for some time (Seymour 1929, Bega 1964, Hepting 1971). But the significance, ecological role, and influences that affect these organisms is not well understood.

Further, recent research on insects associated with giant sequoia has set aside many long-standing misleading generalizations about insect relationships in giant sequoia (David and others 1976, David and Wood 1980, DeLeon 1952, Stecker 1980a,b, Tilles 1984, Tilles and Wood 1982, 1986). Stecker (1980a) in this regard reports that "In summary, the giant sequoia, the largest living organism past or present, and one of the oldest, is unusual in having relatively small insects comprising a relatively small insect fauna." These research findings have caused some people still to conclude that insect depredations are not seriously harming giant sequoias. Yet carpenter ants have been directly reported as being associated with old-growth giant sequoia trees (David and others 1976, David and Wood 1980, Piirto 1976, 1977, Piirto and others 1984, Stecker 1980a, Tilles 1984, Tilles and Wood 1982, 1986). Carpenter ants, bark beetles, wood borers, and a variety of other insects are commonly found in basal fire scars of old-growth giant sequoia. The role of these insects in predisposing a giant sequoia tree to failure or possibly in vectoring disease organisms is not completely understood (David and others 1976, Piirto 1976, 1977, Piirto and others 1984). And, even though the insect fauna seems to be smaller for giant sequoia based on present reports (Stecker 1980a), it is inconclusive that insects are not a problem to giant sequoia. The objectives, then, of this paper are to: briefly review some of the more common disease and insect organisms associated with giant sequoia; and discuss both temporal and ecosystem disease and insect interrelationships at work in the giant sequoia/mixed-conifer ecosystem.

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²Professor and Registered Professional Forester, Natural Resources Management Department, California Polytechnic State University, San Luis Obispo, CA 93407

³The correct scientific name for giant sequoia is currently a subject for disagreement. The common name, giant sequoia, and the scientific name *Sequoia gigantea*, will be used in this paper. Justification for this is detailed in Davidson (1972) and in Piirto (1977). The common name, coast redwood, will refer to *Sequoia sempervirens*.

Insect Relationships

The scientific study by Stecker (1980a) is the most complete work to date on insects associated with giant sequoia. Limited entomological research involving giant sequoia occurred prior to 1974 (DeLeon 1952, Fry and White 1930, Hopkins 1903, Keen 1952, Person 1933). DeLeon (1952) was one of the first entomologists to dispute the claim that coast redwood and giant sequoia have few insect enemies. DeLeon (1952) listed twenty insects which may use giant sequoia during all or part of their life cycles, including: bark and ambrosia beetles; flatheaded, roundheaded and other borers; leaf feeders; termites; carpenter bees; and carpenter ants.

Stecker (1980a,b) conducted detailed investigations on the invertebrates associated with giant sequoia seedlings, living trees and fallen trees. Stecker's sample sites included Redwood Canyon, Redwood Mountain, Whitaker's Forest, Converse Basin, and Mountain Home State Forest. Stecker (1980a) found that:

Of the 143 species of insects encountered in this study, 4 species were found on seedlings (3 of which were also in older trees). Thirty-two insects were found in different stages of downed and dead limbs of standing giant sequoias, while 3 of these were also observed in standing dead wood of the living host. One hundred and fourteen insect species were found only in the canopy of the living tree.

Stecker (1980a) explains the results of his scientific investigations as follows:

The insect fauna of the giant sequoia is small when compared to that of other conifers of the same region. It differs considerably from that treated by Southwood (1961) in the hypothesis that insect species associated with a tree are a reflection of the cumulative abundance of that tree throughout recent geologic history. Insect faunas of historically newer trees are considerably larger than those of the much older giant sequoia. The insect faunas of pines and firs are usually two to three times greater than the presently known fauna from the giant sequoia.

Several of the insects listed in his study such as termites, defoliators, various bark beetles (ambrosia beetle *Gnathotrichus sulcatus* LeConte and *Phloesinus punctatus* LeConte), wood borers (*Semanotus ligneus amplus* Casey and *Trachykele opulenta*) and carpenter ants (*Camponotus modoc*) can be very destructive to young- and old-growth giant sequoia. *T. opulenta* larvae mine in the wood around fire scars and apparently can also develop wholly in the bark (Furniss and Carolin 1977). In addition, prominent insects associated with seedling damage and mortality include the camel cricket (*Pristocauthophilus pacificus*), two geometrids

(*Sabuloides caberata* and *Pero behresarius*), and cutworms (*Noctuidae* spp.) (Parmeter 1987, Harvey 1980, Stecker 1980b, Metcalf 1948).

Very little scientific entomological research has been done to determine the ecological importance of some of the insects listed by Stecker and others (1980a,b). Stecker (1980b) determined that *Phymatodes nitidus* is very important in the continual release of seeds and subsequent reproduction of giant sequoia. Researchers at the University of California at Berkeley found carpenter ants (*Camponotus modoc*), which excavate nests in giant sequoia to rear their young, feeding on dead arthropods and honeydew from attended aphids (David and others 1976, David and Wood 1980, Tilles 1984, Tilles and Wood 1982, 1986). The attended aphid colonies were found in the upper crowns of nearby white fir trees (*Abies concolor* [Gord. and Glend.] Lindl. ex. Hildebr.). This research finding has some very interesting implications. For example, do the changes in white fir stand density in giant sequoia groves (which have occurred as a result of fire suppression programs) cause associated changes in aphid populations which in turn influence carpenter ant populations found nesting in living giant sequoia trees? Carpenter ants are known to cause excavations that are so extensive as to seriously impair structural stability (Furniss and Carolin 1977, Piirto 1977, Piirto and others 1984b). Piirto and others (1984b) found that:

Carpenter ants were found in or near the failure zone in 16 [out of 33] study trees: only six of these, however, contained carpenter ant galleries in the immediate failure zone. Microscopic examination of discolored wood associated with carpenter ant galleries revealed an early to moderate stage of decay.

A check of recent research records at Sequoia-Kings Canyon National Park (Esperanza 1992) showed very little entomological research done since 1982 on insect associates of giant sequoia. Piirto and others (1992a,b) identified six orders of insects found in association with giant sequoia fire scars. Thirteen individual insect species were identified, six of which have not been reported previously. Insects identified most frequently were *Ichneumonidae* spp. (Ichneumons), *Camponotus* spp. (carpenter ant), *Curculionidae* spp. (snout beetle), *Ceuthophilus* spp. (cave cricket), and *Blapyllis alticola* and *B. productus* (darkling beetles). On an infrequent basis, seven insects were found associated with giant sequoia fire scars. These insects were identified as *Sphexidae* spp. (thread-waisted wasp), *Pompilidae* spp. (spider wasps), *Dorcasinia grossa* (long-horned beetle), *Cantharidae* spp. (soldier beetle), *Anthomyiidae* spp. (Anthomyid fly), *Raphidiidae* spp. (snakeflies), and *Coreidae* spp. (leaf-footed bug). More research is needed, however, to determine the full ecological significance of insects associated with giant sequoia both inside and outside its native range.

Disease Relationships

For the purpose of this paper disease is defined as any deviation in the normal functioning of a plant caused by some type of persistent agent (Manion 1991). The abiotic and biotic agents that cause disease are referred to as pathogens. It is important to recognize that diseases which develop in plants and trees are the product of the tree/plant, the pathogen, and the interactions of these with the environment over time. Time is an important factor as it is related to both the rate at which a disease develops within an individual plant or tree and to the spread and increase of the pathogen population within a host population (Manion 1991).

Abiotic agents that can cause disease in forest trees include air pollution, high temperatures, freezing temperatures, phytotoxic gases, pesticides, moisture stress, salt, poor soil aeration, nutritional deficiencies/imbalances, mechanical damage and other abiotic factors. Any one or all of these factors may affect giant sequoia at one time or another during its life cycle. For instance, significant scientific information is becoming available on the impacts of air pollution on Sierra Nevada forests. Studies have been completed and many are underway which have/are evaluating the impacts of air pollution, climate change, acid rain and a number of other abiotic agents which affect these forest ecosystems. Even though it seems apparent that abiotic agents like air pollution are having dramatic impacts on the giant sequoia/mixed-conifer ecosystem, giant sequoia trees are rated as being most resistant to "smog" damage (Miller 1978). It is not known how this resistance varies with age of individual giant sequoia trees. The reader is referred to Manion (1991) for a general discussion of abiotic disease agents.

Some of the common biotic agents that cause disease in forest trees include nematodes, viruses, bacteria, fungi, and parasitic flowering plants (e.g., dwarf mistletoes). The symptoms of diseases caused by these biotic agents are usually expressed in disturbed or abnormal physiology of the host plant. Vascular wilt pathogens, for example, reduce the capacity of the vessels in trees to translocate water from the roots to the top of the transpiring tree. These diseases are typically classified into categories that are related to the stage of the host life cycle which the disease affects and/or to the expressed physiological effect seen in the forest tree. Diseases caused by biotic agents include seedling diseases, leaf and needle diseases, root and trunk rots, shoot blights, vascular wilts, or stem diseases. Full lists of these diseases associated with giant sequoia can be found in Seymour (1929), USDA (1960), Bega (1964), Hepting (1971), Davidson (1972), Peterson and Smith (1975), Piirto (1977), Piirto and others (1984a,b), and Parmeter (1987). Additional unpublished lists of disease organisms associated with giant sequoia can also be found in the records maintained by various herbariums (e.g., University of California at Berkeley, USDA Center for Forest Mycology Research at the Forest Products Laboratory in Madison, Wisconsin and the USDA Forest Service Pacific

Southwest Research Station in Albany, California). These lists are by no means all encompassing, as much remains to be learned about disease relationships in giant sequoia.

Comparatively little work has been done on the biotic and abiotic agents which damage seeds, seedlings, saplings and young-growth giant sequoia trees. Cone and seed molds, damping off fungi and rootrot fungi are suspected as being major factors in preventing seedling establishment in native giant sequoia stands (Stark 1968a,b; Parmeter 1987). These fungi have been shown to cause reduced seed viability and to prevent seedling establishment in undisturbed duff and litter areas within coast redwood stands (Davidson 1972). The role that these fungi play in native giant sequoia stands is not known. Shellhammer and others (1971) reported that mice (*Microtus* spp.), gophers (*Thomomys* spp.), Cerambycid beetles (*Semanotus ligneus amplius*) and a saprophytic fungus *Hyphloma* spp. possibly *fasciculare* were associated with dead and dying 10- and 11-year-old giant sequoias in the Abbot Creek drainage of the Cherry Gap Grove, a previously logged area near Converse Basin.

There are no known occurrences of any true mistletoe or dwarf mistletoe species on either coast redwood or giant sequoia (Hawksworth 1978, 1992).

Factors Associated With Tree Failure

A number of major findings were reported in a study evaluating causes for tree failure of old-growth giant sequoia trees (Piirto 1977, Piirto and others 1984a,b). Thirty-three tree failures were evaluated in this study. Of the 33 failures listed, 21 percent apparently fell mainly because of poor footing (wet soil, stream undercutting, etc.), 67 percent because of the failure of decayed roots and 12 percent because of stem breaks. All but two 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 six. Fire scars were present on 27 trees and 26 fell to the fire-scarred side. This phenomenon of giant sequoia tree failures falling to the scarred side was also reported by Hartesveldt and others (1975).

Fungal Agents Associated With Decay and Tree Failure

Many Basidiomycetes are responsible for the decay observed in giant sequoia trees. *Heterobasidion annosum*, also called *Fomes annosus*, has been frequently observed in both the upper and lower stems of recent tree failures of giant sequoia trees (Piirto 1977, 1984a,b, Piirto and others 1974,). Recent research (Piirto and others 1992a,b) is shedding new light on the hypothesis put forward by Piirto (1977) and Piirto and others (1984b) involving increasing stand density levels of white fir and other associated trees species in giant sequoia groves. White fir is highly susceptible to a variety of forest diseases, particularly *H. annosum*. Otrosina and others (1992) and Piirto and others (1992) reported that both *H. annosum* isolates from white fir and giant sequoia are of the 'S' intersterility Group meaning that

they are interfertile. Given the interfertility of isolates collected from giant sequoia and true fir, an increase of white fir density in the absence of natural and prescribed fire may result in the build-up of *H. annosum* inoculum that could affect giant sequoia trees. *H. annosum* may spread along with other means via root contacts from white fir to giant sequoia. In greenhouse seedling inoculation studies, isolates of *H. annosum* collected from true fir and isolates collected on giant sequoia were capable of causing pathogenesis on either species (Piirto and others 1992).

Other Basidiomycetes of particular note include *Poria albipellucida*, *Armillaria mellea*, *Poria incrassata*, *Stereum hirsutum*, and others (Piirto 1977, Piirto and others 1984a,b). *Armillaria* spp. as receiving increasing attention as being an important pathogen of giant sequoia both within and outside the native range of giant sequoia (Libby 1982). Libby (1992) reports *Armillaria* spp. as being the possible cause of mortality in young-growth giant sequoia trees (up to 20 years of age) planted in the Rhine River area of Germany. Trees older than twenty years of age seemed to be less susceptible to *Armillaria* spp. and hardwoods were known to have occurred in this Rhine River giant sequoia plantation.

Another recent and interesting report from Libby (1992) involves the forty-year old plantation of giant sequoia trees around the Forest Hill Seed Orchard. The study showed that up to forty percent of the planted young giant sequoia trees which are between 30 and 50 feet tall and up to 10 inches in diameter at breast height had thin crowns and bunches of trees were easily pushed over. Preliminary observations by Forest Service pathologists present with Bill Libby at the Forest Hill site indicate that *Armillaria* spp. may be responsible for the mortality that is occurring there. In the Forest Hill situation, stumps of California black oak (*Quercus kelloggii* Newb.) and dead deer brush (*Ceanothus integerrimus* H.&A.) were in the immediate vicinity of the dead giant sequoia trees. It can be inferred from previous research and from the Rhine River and Forest Hill Seed Orchard situations that 1) *Armillaria* spp in combination with other organisms may be important pathogens of both young- and old-growth giant sequoia; 2) *Armillaria* spp seems to be particularly aggressive in areas where hardwoods and possibly vulnerable species of *Ceanothus* spp. occur; 3) giant sequoia trees planted outside their natural range may be particularly vulnerable to a whole host of disease problems which as of yet are not completely understood.

Bega (1964), Libby (1982), Worrall and others (1986) have conducted studies on giant sequoia trees planted outside their native range and found some of them severely damaged by a canker fungus *Botryosphaeria* sp. In addition, giant sequoia seedlings in nurseries were found to be particularly vulnerable to charcoal root disease caused by *Macrophomina phaseoli* and grey mold caused by *Botrytis cinerea* (Peterson and Smith 1975). Understanding the organisms that cause disease and decay in giant sequoia is important, but it is equally important to understand the interactions that occur between organisms and the environment.

Fire/Pathogen Interactions

Research recently completed by Piirto and others (1992a,b) identified 17 new fungi from giant sequoia fire scar wood samples. The fungi most frequently isolated were *Byssoschlamys fulva* (a heat resistant fungus), which was isolated from 34 out of 90 fire scars sampled (38 percent); *Acrodontium intermissum* (a preservative detoxifier), isolated from 22 out of 90 fire scars (24 percent); and *Tritirachium* sp. (an entomogenous fungus), which was isolated from 14 out of 90 fire scars (16 percent). Other interesting fungi isolated include *Neosartorya fischeri* (a heat resistant fungus), *Epicoccum nigrum* (a soft rot fungus), *Leptographium* sp. (*L. wageneri* causes black stain root disease), *Hyalorhin-ocladiella* sp. (pentachlorophenol tolerant; see Wang 1989), *Mariannaea elegans* (capable of forming soft rot cavities in European birch and Scots pine wood; Levy 1969), and Basidiomycetes (fungi causing white or brown rots). A positive identification was made of one of the four confirmed Basidiomycete cultures isolated from giant sequoia fire scars. Referred to as *Phlebia subserialis* [(Bourd. et Galzin) Donk] of the Corticiaceae family and known to affect both hardwoods and softwoods this organism is classified as a white rotter which may have potential in biological pulping processes (Dorworth 1992, Burdsall 1992).

The majority of these fungi identified in the Piirto and others study (1992a,b) are microfungi. As described by Wang and Zabel (1990), microfungi are ubiquitous and cosmopolitan. Some are plant pathogens and some are human pathogens, but most are saprobes that derive nourishment from decaying organic matter that occupy all segments of the environment, most commonly the soil. The term microfungi is commonly used to describe fungi belonging to the Subdivision Ascomycotina. These microfungi have been found associated with utility poles made of Douglas fir, southern pine, and western red cedar. Some have shown to cause soft rot and degradation of wood structure. Recent research suggests some of the microfungi can also reduce the fungitoxicity of wood preservative chemicals (Wang and Zabel 1990). Based on previous research, it is possible the microfungi isolated from giant sequoia may play a role in the decay process. An interesting organism for instance, that has been known for some time to be frequently found on exudate of exposed heartwood of coast redwood and giant sequoia fire scars is *Mycocallicium sequoiae* (Bonar 1971, Piirto 1977, Piirto and others 1992a). More research is needed on the variety of microorganisms at work in the giant sequoia/mixed-conifer ecosystem.

Microorganisms and pathogens can be affected in a variety of ways by fire; and while none of these effects has been adequately evaluated for giant sequoia ecosystems, some possible fire effects with important management implications have been described (Parmeter 1977, Parmeter and Uhrenholdt 1975, 1976, Piirto 1977). It has been discussed that if *Heterobasidion annosum* may build up on white firs (*Abies concolor*) and then attack nearby giant sequoias (Piirto 1977), fires may "cauterize" giant sequoia

fire scars and thus reduce decay (Christensen and others 1987). While these aspects are recognized and in need of study, it is likely other fire effects on both the host and associated pathogens occur and only research monitoring these fire effects on microorganisms will allow recognition and further evaluation. These fire/pathogen interactions in the giant sequoia/mixed-conifer ecosystem are reported in Piirto and others (1992a,b).

The management implications of how a disease impacts stands of giant sequoias is incomplete (Parmeter 1987). Knowledge of giant sequoia disease is increasing, but specific effects on regeneration, stand development, old-growth and young-growth trees are still relatively unknown.

Wounds As Entrance Courts

Following fire, trees may show reduced growth and vigor, owing mainly to heat injury (Hare 1961) or perhaps to "shock" if stand density is changed. The ecological effects of this damage can result in numerous pathogens and insects adapted to attack the weakened yet surviving plants. The literature is replete with reports noting a strong association of insect, pathogen, and microorganism activity in fire damaged trees. In all of these reports, fire damaged roots and/or above ground basal fire scars served as an infection court for these organisms.

Perhaps the best documented effects of fire on disease involve the creation of infection courts for heart rot fungi (Boyce 1961; Harvey and others 1976; Hepting 1935; Nelson and others 1933; Nordin 1958). Heart rot which frequently develops in fire scars may in turn effect other processes, such as bark beetle activities in burned stands (Geiszler and others 1980a,b). Canker fungi may also be associated with fire scars (Hinds and Krebill 1975). Decay following fire scarring can reduce productivity in timber stands. It can also lead to hazard problems and to the loss of valuable specimen trees in parks and preserves, as may be the case with loss of giant sequoias (Piirto 1977). Gill (1974) reported secondary effects of fire on fire scars often lead to mechanical failure of *Eucalyptus pauciflora*.

Perry and others (1985) report that damage to living jarrah (*Eucalyptus marginata*), Karri (*E. diversicolor*), and maritime or cluster pine (*Pinus pinaster*) in southwestern Australia by fire or mechanical injury during forest operations emerges as a major factor facilitating the entry of fungi and termites that spread and degrade substantial areas of heartwood. Littke and Gara (1986) and Gara and others (1986) report that the extension of decay columns from fire damaged roots up into the boles of lodgepole pine (*Pinus contorta* var. *murrayana*) suggests root damage is their most important source of stem decay. Newly fire-damaged root tissues were infected with imperfect fungi and white rot basidiomycetes. Decayed material from previous fires yielded primarily brown rot basidiomycetes. It is important to know that the amount of microorganism, pathogen and insect activity associated with fire scars is influenced by the tree

species and environmental conditions. This has been emphasized by Hepting and Shigo (1972) for oaks in North Carolina and Maine. It is equally important to know that once infection has occurred, survival and damage may continue throughout the life span of a tree. This has been reported for fire-damaged white fir (*Abies concolor*) regeneration (Aho and Filip 1982).

In a recent study conducted by Piirto and others (1992a,b), it was determined, based on a quantitative evaluation of 90 living old-growth giant sequoias, that as much as 70 percent of the circumference (values ranged from 3.3 percent to 69.5 percent with an average of 27.3 percent) and as much as 54 percent of the cross-sectional area (values ranged from 3.2 percent to 53.7 percent with an average of 15.6 percent) were adversely affected by fire scars at groundline. This research work further demonstrated that prescribed burning programs caused damage to callus tissue around existing fire scars 52 percent of the time, with recession and enlargement damage noted 57 percent and 35 percent of the time respectively.

The role of fire scars on giant sequoia trees as entrance courts for decay and insect attack has been defined on the basis of numerous research studies. As we move forward with the reintroduction of fire in the form of prescribed burns in giant sequoia grove areas, the questions still remain as to what intensity, where, when, and how much should be burned to largely promote the positive values fire provides to the giant sequoia/mixed-conifer ecosystem while minimizing the negative consequences to specimen old-growth giant sequoia trees. The results by Piirto and others (1992a,b) confirm that the valued older trees in the giant-sequoia/mixed-conifer system are damaged, and that fire management strategies should be implemented to minimize these adverse fire impacts.

Summary and Conclusions

It is important to consider several factors when interpreting insect and disease relationships in the giant sequoia/mixed-conifer ecosystem including:

1. No single variable functions alone because insects, disease organisms and the ecosystems operate interdependently.
2. Various microorganisms have beneficial and antagonistic influences on disease development. Hepting (1935) was one of the first forest pathologists to note an association of various microorganisms (e.g., bacteria, *Trichoderma* spp. and *Penicillium* spp.) with decay fungi. These organisms can inhibit or facilitate decay development in forest trees. Many such known and unknown interactions are at work in the giant sequoia/mixed-conifer ecosystem.
3. Fire does influence the type and population levels of a vast variety and number of insects, pathogens and microorganisms found in the giant sequoia/mixed-

conifer ecosystem. These interactions are not well understood. These relationships are further complicated by changing climatic patterns such as drought. For example, a bark beetle like *Phloeosinus punctatus* (western cedar bark beetle), which is common in fallen branches of giant sequoia could, in drought periods, become more detrimental (Wood 1992). More research is needed.

4. Further complicating these complex ecosystem interactions is the influence of human activities. Fire suppression, whereas beneficial in many ways, has altered stand development in the giant sequoia/mixed-conifer ecosystem. Changes in stand density and species makeup may be aggravating disease and insect relationships (Piiro 1977). Prescribed burning, on the other hand, has both beneficial and detrimental effects. Wounds caused by fire have unquestionably been associated with both disease and insect attack in forest trees (Manion 1991).
5. Young-growth giant sequoia both in and planted outside its native range are vulnerable to a whole host of insect and disease problems. *Botryosphaeria* spp and *Armillaria* spp appear to be two major pathogens commonly associated with disease problems in young-growth giant sequoia trees. Little is known about the vulnerability of young-growth giant sequoia trees to insect and disease attack both within and outside of its native range.
6. Other time dependent events (e.g., aging) may be influencing susceptibility of giant sequoia to attack by insect and disease organisms; and insect/disease associations currently present may be to some degree affected by the age of the tree.
7. Fire and mechanically damaged roots, stems, limbs and other tree tissues serve as entrance courts to pathogen and insect attack. It is incumbent upon managers of giant sequoia groves to take appropriate protective measures to minimize deleterious effects of forest management practices on the giant sequoia/mixed-conifer ecosystem. At the very least, it is essential that we study these influences as we move forward with deciding which management approaches are appropriate for giant sequoia groves.
8. Much is still unknown about disease and insect relationships in the giant sequoia/mixed-conifer ecosystem.

It is important to remember insects, disease and other microorganisms when evaluating ecological relationships at work in the giant sequoia/mixed-conifer ecosystem.

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References

- Aho, P.E. ; Filip, G.M. 1982. Incidence of wounding and *Echinodontium tinctorium* infection in advanced white fir regeneration. Canadian Journal of Forest Research 12(3): 705-708.
- Bega, R.V. 1964. Diseases of sequoia. In: Diseases of widely planted forest trees. FAO/IUFRO Symposium on internationally dangerous forest diseases and insects; Oxford: 1964 July 20-30, 131-139.
- Bonar, L. 1971. A new *Mycocalicium* on scarred sequoia in California. Madrono 21(2): 62-69.
- Boyce, J.S. 1961. Forest Pathology. New York: McGraw-Hill Book Co.; 550 p.
- Burdsall, H. 1992. Personal Communication. June 29, 1992. Research Mycologist at the Center for Forest Mycology Research, USDA Forest Service Forest Products Laboratory, Madison, Wisconsin.
- Christensen, N.L.; Cotton, L.; Harvey, T.; Martin, R.; McBride, J.; Rundel, P.; Wakimoto, R. 1987. Final report-review of fire management program for sequoia-mixed conifer forests in Yosemite, Sequoia and Kings Canyon National Parks. USDI, National Park Service.
- David, C.T.; Wood, D.L. 1980. Orientation to trails by a carpenter ant (*Camponotus modoc*) (Hymenoptera, Formicidae) in a giant sequoia forest. Canadian Entomologist 112: 993-1000.
- David, C.T.; Tilles, D.A.; Wood, D.L. 1976. Factors associated with tree failure of giant sequoia-entomological aspects. In: Proceedings of the First Conference on Scientific Research in the National Parks. November 9-12, 1976. New Orleans, Louisiana.
- Davidson, J.G.N. 1972. Pathological problems in redwood regeneration from seed. Ph.D. dissertation. University of California, Berkeley.
- DeLeon, D. 1952. Insects associated with *Sequoia sempervirens* and *Sequoia gigantea* in California. Pan-Pacific Entomologist 23: 75-92.
- Dorworth, Elizabeth. 1992. Personal communication. April 1, 1992. Mycologist at the Center for Forest Mycology Research, USDA Forest Service Forest Products Laboratory, Madison, Wisconsin.
- Esperanza, Annie M. 1992. Personal communication. June 18, 1992. Research Technician for the USDI National Park Service, Sequoia and Kings Canyon National Park, Three Rivers, California.
- Fry, W. ; White, J.R. 1948. Big Trees. 9th Edition. Palo Alto: Stanford University Press; 114 p.
- Furniss R.L.; Carolin, V.M. 1977. Western Forest Insects. Misc. Pub. 1339. Washington, DC: Forest Service, U.S. Department of Agriculture; 654 p.
- Gara, R.I.; Agee, J.K.; Little, W.R.; Geiszler, D.R. 1986. Fire wounds and beetle scars. Distinguishing between the two can help reconstruct past disturbances. Journal of Forestry : 47-50.
- Geiszler, D.R.; Gara, R.I.; Driver, C.H.; Gallucci, V.F.; Martin, R.E. 1980(a). Fire, fungi and beetle influences on a lodgepole pine ecosystem of South-Central Oregon. Oecologia 46: 239-243.
- Geiszler, D.R.; Gallucci, V.F.; Gara, R.I. 1980(b). Modeling the dynamics of mountain pine beetle aggregation in a lodgepole pine stand. Oecologia 46: 244-253.
- Gill, A.M. 1974. Toward an understanding of fire-scar formation: field observation and laboratory simulations. Forest Science 20(3): 198-205.

- Hare, R.C. 1961. Heat effects on living plants. Occ. Pap. 183. Southeast Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 32 p.
- Harlow, W.M.; Harrar, E.S.; Hardin J.W.; White, F.M. 1991. Textbook of Dendrology. New York: McGraw-Hill Book Co.; 502 p.
- Hartesveldt, R. J. 1962. The effects of human impact upon *Sequoia gigantea* and its environment in the Mariposa grove, Yosemite National Park, California. Ann Arbor: University of Michigan; Ph.D. dissertation.
- Hartesveldt, R.J.; Harvey, H.T.; Shellhammer, H.S.; Stecker, R.E. 1975. The giant sequoia of the Sierra Nevada. Washington, DC: U.S. Department of Interior, National Park Service; 180 p.
- Harvey, A.E.; Jurgensen, M.F.; Larsen, M.J. 1976. Intensive fiber utilization and prescribed fire: effects on the microbial ecology of forests. GTR-INT-28. USDA, Forest Service.
- Harvey, H.T. 1980. Giant sequoia reproduction, survival and growth. In: Harvey, H.T.; Shellhammer, H.S.; Stecker, R.E. Giant sequoia ecology, fire and reproduction. Washington, DC: U.S. Department of Interior, National Park Service. Sci. Monogr. Series 12: 41-68.
- Hawksworth, F.G. 1978. Biological factors of dwarf mistletoes in relation to control. In: Scharpf, R.F.; Parmeter, J.R., eds. Proceeding of the symposium on dwarf mistletoes control through forest management. 1978 April 11-13. Berkeley, CA. GTR-PSW-31. Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 5-15.
- Hawksworth, F.G. 1992. Retired Research Scientist, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. [Personal communication]. 18 June 1992.
- Hepting, G.H. 1935. Decay following fire in young Mississippi Delta hardwoods. Tech. Bull. 474. Washington, DC: U.S. Department of Agriculture; 32 p.
- Hepting, G.H. 1971. Diseases of forest and shade trees of the United States. Agric. Handb. 386. Washington, DC: U.S. Department of Agriculture; 658 p.
- Hepting, G.H.; Shigo, A.L. 1972. Difference in decay rate following fire between oaks in North Carolina and Maine. Plant Disease Reporter 56(5): 406-407.
- Hinds, T.E.; Krebill, R.G. 1975. Wounds and canker diseases on western aspen (*Populus tremuloides*). Forest Pest Leaflet 152. Washington, DC: U.S. Department of Agriculture; 9 p.
- Hopkins, A.D. 1903. Insect enemies of the redwood. For. Bull. 38: Washington, DC: U.S. Department of Agriculture; 32-40.
- Keen, F.P. 1952. Insect enemies of western forests. Misc. Publ. 273. Washington, DC: U.S. Department of Agriculture; 280 p.
- Levy, J.F. 1969. Studies on the ecology of fungi in wood fence posts. In: Walters, A.H.; Elphick, J.J., eds. Biodeterioration of materials. New York: Elsevier Publishing Co.; 1: 424-428.
- Libby, W.J. 1982. Some observations of *Sequoiadendron* and *Calocedrus* in Europe. Calif. For. and Forest Prod. 49. Berkeley: University of California; 12 p.
- Libby, W.J. Professor of Forest Genetics, University of California at Berkeley. [Personal communication]. 18 June 1992.
- Littke, W.R. ; Gara, R.I. 1986. Decay of fire-damaged lodgepole pine in South Central Oregon with implications to mountain pine beetle activity. Forest Ecology and Management 17: 279-287.
- Manion, P.D. 1991. Tree Disease Concepts. Second edition. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.; 402 p.
- Metcalf, W. 1948. Youthful years of the big tree. Pacific Discovery 1(3): 4-10.
- Miller, P.R. 1978. Abiotic diseases. In: Bega, R.V., technical coordinator. Diseases of Pacific Coast conifers. Agric. Handb. 521. Washington, DC: U.S. Department of Agriculture; 5-41.
- Muir, J. 1894 (1961). The Mountains of California. Published in cooperation with the American Museum of Natural History, The Natural History Library, Anchor Books, Doubleday and Company, Inc.
- Nelson, R. M., Jr.; Sims, L.H.; Abell, M.S. 1933. Basal fire wounds on some southern Appalachian hardwoods. Journal of Forestry 31: 829-837.
- Nordin, V.J. 1958. Basal fire scars and the occurrence of decay in lodgepole pine. Forestry Chronicle 34: 257-265.
- Otrosina, W. J.; Chase, T.E.; Cobb, F.W., Jr. 1992. Allozyme differentiation of intersterility of *Heterobasidion annosum* isolated from conifers in the western United States. Phytopathology 82(5): 540-545.
- Parmeter, J.R., Jr. 1977. Effects of fire on pathogens. In: Proceedings of the symposium of fire and fuel management in Mediterranean ecosystems. 1977 August 1-5. Palo Alto, California.
- Parmeter, J.R., Jr.; Uhrenholdt, B. 1975. Some effects of pine-needle or grass smoke on fungi. Phytopathology 65: 28-31.
- Parmeter, J.R., Jr.; Uhrenholdt, B. 1976. Effects of smoke on pathogens and other fungi. In: Proceedings of Montana Tall Timbers Fire Ecology and Fire Land Management Symposium No. 14: 229-304.
- Parmeter, J.R., Jr. 1987. Diseases and insects of giant sequoia. In: Weatherspoon, C. Phillip; Iwamoto, Y. Robert; Piirto, Douglas D., technical coordinators. Proceedings of the Workshop on Management of Giant Sequoia, 1985 May 24-25, Reedley, California. GTR-PSW 95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 11-13.
- Peace, T.R. 1962. Pathology of trees and shrubs. Oxford: Clarendon Press; 753 p.
- Perry, D.H.; Lenz, M.; Watson, J.A.L. 1985. Relationships between fire, fungal rots and termite damage in Australian forest trees. Aust. For. 48(1): 46-53.
- Person, H. 1933. Redwood has few insect enemies. For. Worker 9: 15-16.
- Peterson, G.W.; Smith, R.S. 1975. Forest nursery diseases in the United States. Agric. Handb. 470. Washington, DC: U.S. Department of Agriculture; 125 p.
- Piirto, D. 1976. Factors associated with tree failure of giant sequoia-pathological aspects. In: Proceedings of the First Conference on Scientific Research in the National Parks. 1976 November 9-12. New Orleans. Louisiana.
- Piirto, D.D.; Parmeter, J.R., Jr.; Cobb, F.W., Jr. 1974. *Fomes annosus* in giant sequoia. Plant Disease Reporter 59: 478.
- Piirto, D.D. 1977. Factors associated with tree failure of giant sequoia. Berkeley: University of California; 155 p. Ph.D. dissertation.
- Piirto, D.D.; Parmeter, J.R., Jr.; Wilcox, W.W. 1977. *Poria incrassata* in giant sequoia. Plant Disease Reporter 61(1): 50.
- Piirto, D.D.; Parmeter J.R., Jr.; Wilcox, W.W. 1984a. Basidiomycete fungi reported on living or dead giant sequoia or coast redwood. Calif. For. and Forest Prod. 55. Berkeley: University of California;
- Piirto, D.D.; Wilcox, D.D.; Parmeter, J.R., Jr.; Wood, D.L. 1984b. Causes of uprooting and breakage of specimen giant sequoia trees. Bull. 1909. Berkeley: University of California, Division of Agriculture and Natural Resources.
- Piirto, D.D.; Piper, K.; Parmeter, J.R., Jr. 1992a. Final report. Biological and management implications of fire/pathogen interactions in the giant sequoia ecosystem; Part I-Fire Scar/Pathogen Studies. San Luis Obispo: Natural Resources Management Department, Cal Poly.
- Piirto, D.D.; Cobb, F.W., Jr.; Workinger, A.; Otrosina, W.J.; Parmeter, J.R., Jr. 1992b. Final report. Biological and management implications of fire/Ppathogen interactions in the giant sequoia ecosystem; Part II-Pathogenicity and Genetics of *Heterobasidion annosum*. San Luis Obispo: Natural Resources Management Department, Cal Poly.
- Seymour, A.B. 1929. Host index of fungi of North America. Cambridge: Harvard Univ. Press.
- Shellhammer, H.S.; Stecker, R.E.; Harvey, H.T.; Hartesveldt, R.J. 1971. Unusual factors contributing to the destruction of young giant sequoias. Madrono 20(8): 408-410.
- Southwood, T.R.E. 1961. The number of species of insects associated with various trees. Journal of Animal Ecology 30: 305-317.
- Stark, N. 1968a. The environmental tolerance of the seedling stage of *Sequoiadendron giganteum*. American Midland Naturalist 80: 85-95.
- Stark, N. 1968b. Seed ecology of *Sequoiadendron giganteum*. Madrono 19: 267-277.

- Stecker, R.E. 1980a. Arthropods associated with the giant sequoia. In: Harvey, H.T.; Shellhammer, H.S.; Stecker, R.E. Giant sequoia ecology, fire and reproduction. Washington, DC: U.S. Department of Interior; Sci. Monogr. Series 12: 69-82; 156-162.
- Stecker, R.E. 1980b. The role of insects in giant sequoia reproduction.. In: Harvey, H.T.; Shellhammer, H.S.; Stecker, R.E. Giant sequoia ecology, fire and reproduction. Washington, D.C.: U.S. Department of Interior; Sci. Monogr. Series 12: 83-100.
- Tilles, D.A. 1984. Feeding behavior of *Lacon profusa* (Candeza) (Coleoptera:Elateridae) in carpenter ant attended colonies of *Cinara* spp. (Homoptera: Aphididae). Pan Pacific Entomologist 60: 65-66.
- Tilles, D.A.; Wood, D.L. 1982. The influence of carpenter ant (*Camponotus modoc*) (Hymenoptera, Formicidae) attendance on the development and survival of aphids (*Cinara* spp.) (Homoptera, Aphididae) in a giant sequoia forest. Canadian Entomologist 114(2): 1133-1142.
- Tilles, D.A.; Wood, D.L. 1986. Foraging behavior of the carpenter ant (*Camponotus modoc*) (Hymenoptera, Formicidae) in a giant sequoia forest. Canadian Entomologist 118: 861-867.
- United States Department of Agriculture 1960. Index of plant diseases in the United States. Agric. Handb. 271. Washington, DC:
- Wang, C.J.K.; Terracina, F.C.; Zabel, R.A. 1989. Fumigant effectiveness in creosote-and penta-treated southern pine poles. Syracuse: State University of New York. College of Environmental Science and Forestry.
- Wang, C.J.K.; Zabel, R.A. 1990. Identification manual for fungi from utility poles in the eastern United States. Lawrence, Kansas: Allen Press Inc.
- Weatherspoon, C.P. 1990. *Sequoiadendron giganteum* (Lindl.) Buchholz. Giant Sequoia. In: Burns, Russell M.; Honkala, Barbara H., tech. coords. Silvics of North America. Volume I. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture; 552-562.
- Wood, D.L. Professor of Forest Entomology, University of California at Berkeley. [Personal communication]. 22 June 1992.
- Worrall, J.J.; Correll, J.C.; McCain, A.H. 1986. Pathogenicity and teleomorph-anamorph connection of *Botryosphaeria dothidea* on *Sequoiadendron giganteum* and *Sequoia sempervirens*. Plant Disease 70(8): 757-759.

Air Pollution Effects on Giant Sequoia Ecosystems¹

P. R. Miller

N. E. Grulke²

K.W. Stolte³

Abstract: Giant sequoia [*Sequoiadendron giganteum* (Lindl.) Buchholz] groves are found entirely within the Sierra Nevada mixed-conifer type. Several of its companion tree species, mainly ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and Jeffrey pine (*P. jeffreyi* Grev. & Balf.), show foliar injury after exposure to present levels of ozone in the southern Sierra Nevada. Observations at nine giant sequoia groves in Sequoia National Park from August 1983 through September 1986 showed that surviving seedlings in 1986 averaged 18 percent of the original number. These observations did not provide evidence of a causal relationship between ozone exposure and seedling mortality. Field fumigation studies with container-grown seedlings at Giant Forest during the summers of 1987 and 1988 tested morphological and physiological responses of seedlings exposed to charcoal-filtered air, 1 X, and 1.5X the ambient ozone concentration for the entire summer season. In both 1987 and 1988, very slight levels of visible ozone injury to cotyledonary and primary leaves were observed in fumigation chambers and at sites in natural groves at 1X ambient ozone concentrations; however, at 1.5X ambient in chambers the symptoms of foliar injury were extensive. The end-of-season harvests of seedlings exposed to 1.5X ambient ozone showed no significant reductions of root, shoot, or total plant weights in 1987 or 1988. Gas exchange measurements made during the 1988 experiment found that ozone exposure of seedlings and rooted cuttings to 1.5X ambient ozone over the duration of a growing season increased the light compensation point, lowered CO₂ exchange rate at light saturation, and increased dark respiration compared to controls. A 2-month branch-chamber fumigation of large giant sequoia saplings (120 years old) with charcoal-filtered air and ozone at 1X, 2X, and 3X ambient ozone concentrations did not yield visible injury or any detectable changes in photosynthetic rates.

Air pollution injury to two species of the Sierra Nevada mixed-conifer type, namely, ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and Jeffrey pine (*P. jeffreyi* Grev. & Balf.), has been evaluated along the western slope of the Sierra Nevada from Lake Tahoe to the region east of Bakersfield during the past 20 years (Miller and Millecan 1971, Peterson and others 1991, Stolte and others 1991). Injury to pines is due to elevated ozone concentrations in photochemical air pollution and is characterized mainly by chlorotic mottle symptoms leading to lower rates of photosynthesis and early loss of needles and, in extreme cases, by diminished annual ring width (Peterson and others 1987). Surveys have clearly identified the region east of Fresno, particularly the Grant Grove-Giant Forest areas, as having the most severe ozone damage to pines in the Sierra Nevada (Stolte and others 1991). Giant sequoia [*Sequoiadendron giganteum* (Lindl.)

Buchholz] groves are commonly found within the mixed-conifer stands where pines show chronic injury.

Anecdotal evidence from natural giant sequoia groves in Sequoia and Kings Canyon National Parks and from giant sequoias planted in heavily polluted areas of the San Bernardino Mountains east of Los Angeles suggests no visible ozone injury to foliage of trees in the small sapling to mature size classes. Yet, lack of visible injury is not sufficient to indicate the complete absence of pollutant effects. Since decreased carbon fixation may result with or without apparent morphological injury to subcellular components in leaf tissue, gas exchange measurements provide important supporting evidence of the total effects of ozone. The sensitivity of plants to ozone may vary with foliage age or phenological stage, i.e., foliage of very young seedlings or very old, mature individuals may react differently, or actively growing tissue may be sensitive to injury when cold-hardened tissue may not be. Therefore it is important to use more than one indicator to evaluate plant sensitivity to air pollutants.

The uniqueness of giant sequoia among conifer species is based on its enormous size and longevity, its relatively small population size, and apparent ecological restrictions on grove boundaries (Rundel 1972). Its societal importance is shown by its protection in National Parks and State Parks in the Sierra Nevada. Because of these attributes, the possible influence of a new environmental stress factor such as air pollution requires thorough examination. The focus of air pollution effects research with giant sequoia has been on regenerative capacity, growth, and competitive relationships within the Sierra Nevada mixed-conifer communities. The purpose of this paper is to review research carried out between 1983 and 1990 including (1) the results of experiments to test the visible injury and growth responses of seedling giant sequoias to ozone or ozone + sulfur dioxide in open-top fumigation chambers, (2) morphological responses and gas exchange responses of both seedlings and large saplings in fumigation experiments in Sequoia and Kings Canyon National Parks, and (3) the possible stand-level consequences of the chronic exposure of giant sequoia and companion tree species in native stands.

Air Pollution Effects on the Seedling Stage of Giant Sequoia

Beginning in 1982, the fumigation experiments conducted in open-top fumigation chambers at Riverside, California, included ozone and sulfur dioxide alone and in combinations (Taylor and others 1986). The inclusion of sulfur dioxide in this experiment was prompted by the State of California Air Resources Board's concern that sulfur

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²Research Plant Pathologist and Research Plant Physiologist USDA Forest Service, Pacific Southwest Research Station, 4955 Canyon Crest Drive, Riverside, CA 92507

³Research Ecologist, USDA Forest Service, Southeastern Forest Experiment Station, 3041 Cornwallis Road, Research Triangle Park, NC 27709

dioxide concentrations in the southern San Joaquin Valley may be sufficient to interact with ozone to cause increased injury at downwind mountain sites. During 1977 and 1978 the maximum hourly ozone concentrations in the Bakersfield area ranged from 10 to 13 pphm (parts per hundred million) and were frequently accompanied by daily average sulfur dioxide concentrations of 5 to 7 pphm, particularly in April through October (Duckworth and Crowe 1979). After two years of ozone and sulfur dioxide monitoring at two Sierra Nevada locations it became apparent that ozone concentrations were usually similar to those in Bakersfield. However, mean maximum sulfur dioxide concentrations were only about 0.2 pphm at a typical mixed-conifer forest site (Shirley Meadow) in the Sierra Nevada northeast of Bakersfield (Miller and Stolte 1984).

Pollutant combinations are known to result in less-than-additive, additive, or more-than-additive (synergistic) injury to both herbaceous and woody species (Reinert and others 1975). A fumigation experiment carried out at Riverside from April 1 to June 2, 1982, included ozone at 0, 10, 20, 30, and 40 pphm alone, sulfur dioxide at 0, 5, 10, 15, 20 and 25 pphm alone, and ozone + sulfur dioxide combinations including 10+5, 10+10, 10+20, 20+5, 20+10, and 20+20 pphm (Taylor and others 1986). The experiment included ponderosa pine and Jeffrey pine seedlings aged 2-3 years and 4-month-old giant sequoia seedlings.

The visible injury response of each species, expressed as the percentage of the total leaf area (*table 1*), indicated that the greatest injury to ponderosa and Jeffrey pines

resulted from 20 pphm ozone + 20 pphm sulfur dioxide, and from 40 pphm ozone. For giant sequoia, the exposure to 40 pphm ozone resulted in the highest observed values of visible injury, whereas mixtures of 10 or 20 pphm ozone with 20 pphm sulfur dioxide were associated with the 6th and 4th highest observed levels of injury. In this experiment, the exposure of giant sequoia to 10 pphm ozone alone did not result in injury significantly greater than the charcoal-filtered air control, and injury was not significant from ozone alone at 20 pphm.

The results of this work led to the question: Are giant sequoia seedlings injured in their natural forest environment by present ambient concentrations of ozone? This question was explored by fumigation of seedlings followed by evaluation of (1) histological examination of seedling foliage, (2) visible symptoms, (3) photosynthesis and respiration measurements, (4) biomass changes, and (5) seedling condition and mortality losses over a span of 4 years.

Ozone Exposure Experiments in Sequoia National Park

Biomass and Visible Injury Measurements

Fumigation experiments in open-top chambers were completed at Giant Forest in Sequoia and Kings Canyon National Parks in 1987 and 1988. Newly emerged giant sequoia seedlings, from seeds collected at the Giant Forest site, were grown in containers with natural soil. The containers were buried in order to prevent heating. From early June to late September seedlings were exposed to treatments

Table 1-Percent foliar injury response of 2- to 3-year-old ponderosa pine and Jeffrey pine and 4-month-old giant sequoia seedlings exposed to sulfur dioxide and ozone alone and in combinations from April 1, 1982 to June 2, 1982 (Taylor and others 1986)

Ponderosa Pine			Jeffrey Pine			Giant Sequoia		
O ₃	SO ₂	Average injury	O ₃	SO ₂	Average injury	O ₃	SO ₂	Average injury
--pphm--	--percent--		--pphm--	--percent--		--pphm--	--percent--	
20	20	57.40a	20	20	52.45a	40	0	91.60a
40	0	52.60ab	40	0	42.90a	20	10	79.80ab
20	10	48.60ab	20	10	40.40a	30	0	76.00abc
20	5	47.30ab	30	0	32.90ab	20	20	74.15abc
30	0	35.10 be	20	5	31.00ab	20	5	67.60abcd
10	20	21.20 cd	10	20	16.00 bc	10	20	63.20 bcde
20	0	16.55 cd	20	0	7.65 c	20	0	35.30 bcde
0	25	15.80 cd	10	10	6.40 c	0	20	35.10 bcde
10	10	8.40 d	10	5	5.10 c	10	5	32.30 cde
0	20	6.55 d	0	25	3.70 c	10	10	23.20 de
10	5	6.00 d	0	20	0.00 c	0	25	13.70 e
0	15	2.70 d	0	15	0.00 c	10	0	9.20 e
10	0	1.60 d	0	10	0.00 c	0	10	7.00 e
0	10	0.20 d	0	5	0.00 c	0	15	6.60 e
0	5	0.00 d	10	0	0.00 c	0	0	3.55 e
0	0	0.00 d	0	0	0.00 c	0	5	0.10 e

Upper bounds for pairwise comparison at p = 0.05, based on Tukey's multiple comparison method were ponderosa 22.09, Jeffrey 22.07, giant sequoia 46.13. Mean values of visible injury listed in columns are not significantly different if followed by the same lowercase letter.

including charcoal-filtered air, 1X ambient ozone within and outside chambers, and 1.5X ambient ozone in chambers. Treatments were replicated four times.

In 1987, the twelve chambers and four open plots were located on an old roadway so that no chambers or plots had shading from directly overhead. In spite of this attempt to obtain uniform sunlight, and no more than 2 hours of direct sunlight for all chambers and plots, one 1.5X and one ambient chamber received >4 hours during the first 30 days of the fumigation, and one filtered air chamber received more than 2 hours of direct sunlight per day during the entire fumigation. Because the durations of these exposures to sunlight greatly exceeded those received by other chambers, we decided to exclude them from the analysis because of the

potential influence of duration of direct sunlight on response to ozone treatments. Analysis of root, shoot, and total weights of the harvested seedlings found no significant differences due to ozone exposure (table 2). Chambers as a random factor were always significant. Open plots were not included in the analysis (Miller and others 1988).

The second experiment completed in 1988 was at the same site except that the chambers and plots were moved to nearby sites under a more evenly distributed canopy of white fir [*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.], sugar pine (*P. lambertiana* Dougl.), and giant sequoia. The purpose was to attain lighting conditions more typical of seedbeds where giant sequoia seedlings commonly germinate and establish.

Table 2-Dry weights of shoots and roots after exposure to 1 X ambient ozone in chambers and open plots and to 1.5X ambient ozone or filtered air in chambers from June 26 to September 24, 1987, at Giant Forest, Calif. The ANOVA was done on 12 of the 16 original chambers and plots in order to exclude one chamber in each treatment that had long durations of direct sunlight, namely, greater than 1.5 h day⁻¹ (Miller and others 1988).

Treatment	Shoot weight	Root weight	Total weight	Root percent of total
	g-----			pct
1 X Ambient Open				¹ -----
1 X Ambient Chamber	.0485	.0318	.0803	39.1
Filtered Air Chamber	.0452	.0311 ²	.0778	41.7
1.5X Ambient Chamber	.0459	.0325 ²	.0790	33.2
	.0387	.0202	.0589	
Percent Difference ³	-16	-38	-25	

¹Value omitted intentionally since only within-chamber comparisons were being considered.

²Total weight is not always the sum of shoot and root weight averages because in a few cases the value for a shoot or root system was missing.

³Filtered - 1.5X Ambient X 100 = Percent Difference (Not significant, p=.05) Filtered

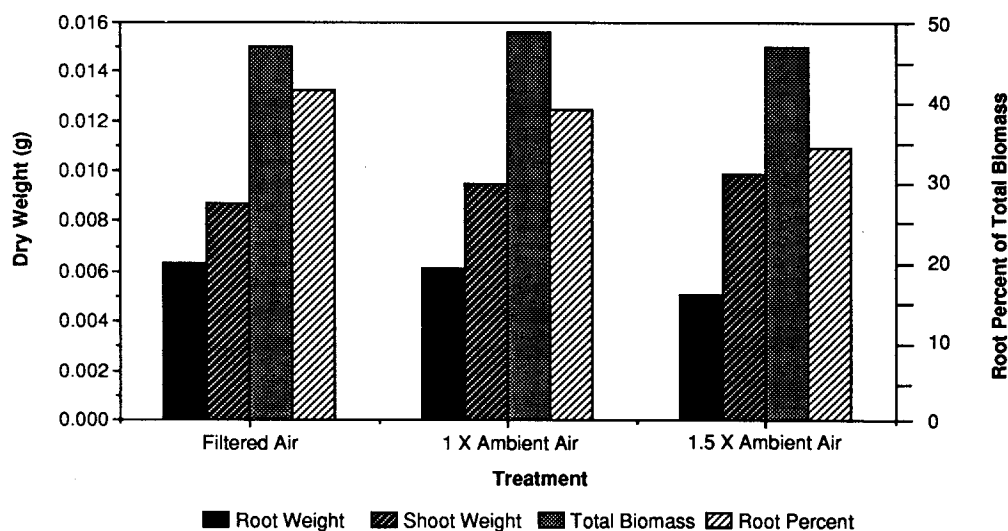


Figure 1-Distribution of plant weight into shoots and roots after exposure of containerized giant sequoia seedlings in natural soil following a 3-month exposure to ambient ozone (1X), 1.5X ambient ozone, and charcoal-filtered air at Giant Forest in 1988 (Miller and others 1991 a).

Seedlings harvested at the end of the 1988 fumigation showed effects on the weights of roots (*fig. 1*) that were not inconsistent with the results seen in 1987 (*table 2*). As in 1987, however, the ANOVA found no significant differences in root, shoot, or total plant weight due to ozone exposure. The experimental seedlings used in 1988 are illustrated in *figure 2*. These seedlings were selected at random from the harvested populations of each treatment. There appear to be fewer small feeder rootlets on seedlings exposed to 1.5X ambient ozone.

Our hypothesis was that there would be a decrease in the ratio of root weight to total plant weight as a result of exposure to 1.5X ambient ozone because the seedling may use carbon from the root system to repair foliar injury and thus decrease root development (Oshima and others 1979, Weinstein and Beloin 1990). Reduced root growth of giant sequoia seedlings was noticed in earlier fumigations completed in Riverside (Taylor and others 1986), but we were unable to detect any significant differences in 1987 or 1988.

The results for visible injury in 1988 (Miller and others 1991a) are representative of results in 1987. Amounts of chlorotic mottle or necrosis of cotyledonary and primary leaves were estimated in July, August, and September. These symptoms were essentially absent in trees exposed to filtered air, just detectable in ambient ozone treatments, and very prominent in 1.5X ambient ozone treatments (*fig. 3*).

Gas Exchange Measurements During the 1988 Experiment

The mechanism of ozone injury to seedlings and rooted cuttings was further characterized by measurements of gas exchange in situ (Grulke and others 1989). In this experiment, seedlings were asymptomatic in the charcoal-filtered chambers, but both asymptomatic and symptomatic in the 1.5X ambient ozone chambers. Rooted cuttings were asymptomatic at both ozone levels. Light response, respiration in the dark, and diurnal gas exchange of seedlings were characterized for asymptomatic seedlings in the charcoal-filtered chambers and for only symptomatic seedlings in the 1.5X ambient ozone chambers. For rooted cuttings the carbon dioxide (CO₂) exchange rate was measured under saturating light.

The principal results of this research are that the CO₂ exchange rate of symptomatic seedlings was significantly reduced (by 44 percent) relative to that of plants in charcoal-filtered chambers (n=8). The CO₂ exchange rate of rooted cuttings (all were asymptomatic) in the 1.5X ozone chambers was lower (by 20 percent), but differences were not statistically significant (n=5) compared to plants in the charcoal-filtered chambers (*fig. 4*). The decrease in CO₂ exchange rate in the seedlings could be explained principally by an increase in dark respiration rates for those plants exposed to elevated ozone. The light response was altered for seedlings in charcoal-filtered air versus 1.5X ambient ozone: light compensation point was greater, and CO₂ exchange rate at light saturation was lower for plants exposed to elevated levels of ozone. This result implies that if ambient ozone levels were to increase, seedlings may be

less damaged by ozone on microsites with longer durations of higher intensity sun flecks that would permit them to gain enough carbon to compensate for ozone injury.

Gas Exchange Measurements of Ozone-Fumigated Branches of Giant Sequoia Saplings

The gas exchange results from seedlings and rooted cuttings led to the question: Are older giant sequoias affected in any detectable way by ambient or elevated ozone? We chose three large saplings, approximately 50 m tall and 120 years old, at a site within 200 m of the seedling fumigation experiments of 1987 and 1988 (midway between Giant Forest Village and Sunset Rock). Access to the upper crowns of these trees was provided by a scaffold. At about 30 m above the ground, branches were enclosed in chambers and exposed to either charcoal-filtered air or ozone at IX, 2X, and 3X ambient concentrations. One additional branch without a chamber was used as a control for chamber effects (statistically compared with the IX ambient treatment).

After exposure for both 1 and 2 months, there were no significant differences in gas exchange rate between chambered and unchambered branches at IX ambient ozone levels (Grulke and Miller 1993). Although not statistically significant, branches in subambient ozone chambers had a slightly higher CO₂ exchange rate than those in 1X, 2X, and 3X ambient ozone. This suggests that additional research should be directed toward increased replication and be focused on the subambient to ambient ozone levels. No significant effects were found on dark respiration, chlorophyll fluorescence, or water relations (pre-dawn and solar noon, total needle and osmotic + matric water potential) between the charcoal-filtered air, and 1 X, 2X, and 3X ambient ozone treatments.

In summary, sensitivity of giant sequoia to ozone declines from current year seedlings to rooted cuttings from 12-year-old seedlings (Grulke and others 1989). With foliage on 120-year-old trees, there were no significant differences in physiological characteristics across a wide range of ozone exposure levels. It may be, with the changing morphology of the needles (attached to older and older stems), that ozone entry into the needles becomes more limited or the foliage attached to older stems produces increasing amounts of anti-oxidants which destroys the ozone that does enter the leaf more effectively, or both. The maximum stomatal conductance declines with older trees, and mesophyll tissue becomes more compact.

Stand-Level Consequences of Chronic Ozone Exposure of Giant Sequoia Ecosystems

Seedling Condition and Survival in Natural Groves

Fumigation experiments, namely the assessment of visible symptoms, and photosynthesis after summer-long experiments have indicated that small seedlings are sensitive

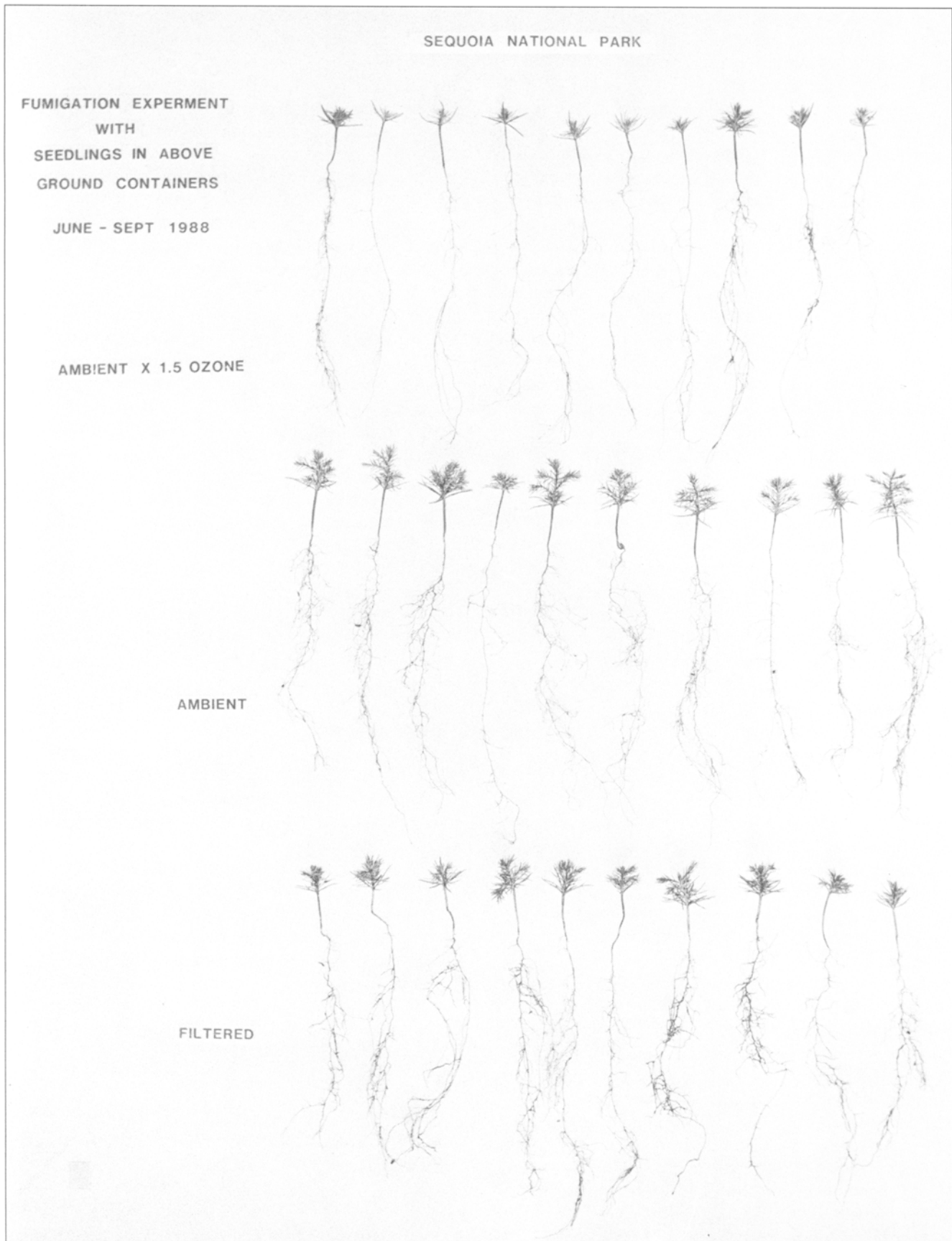


Figure 2-One set of several randomly selected samples of experimental seedlings after harvest 6 months after germination in 1988 from Sequoia National Park (Miller and others 1991 a).

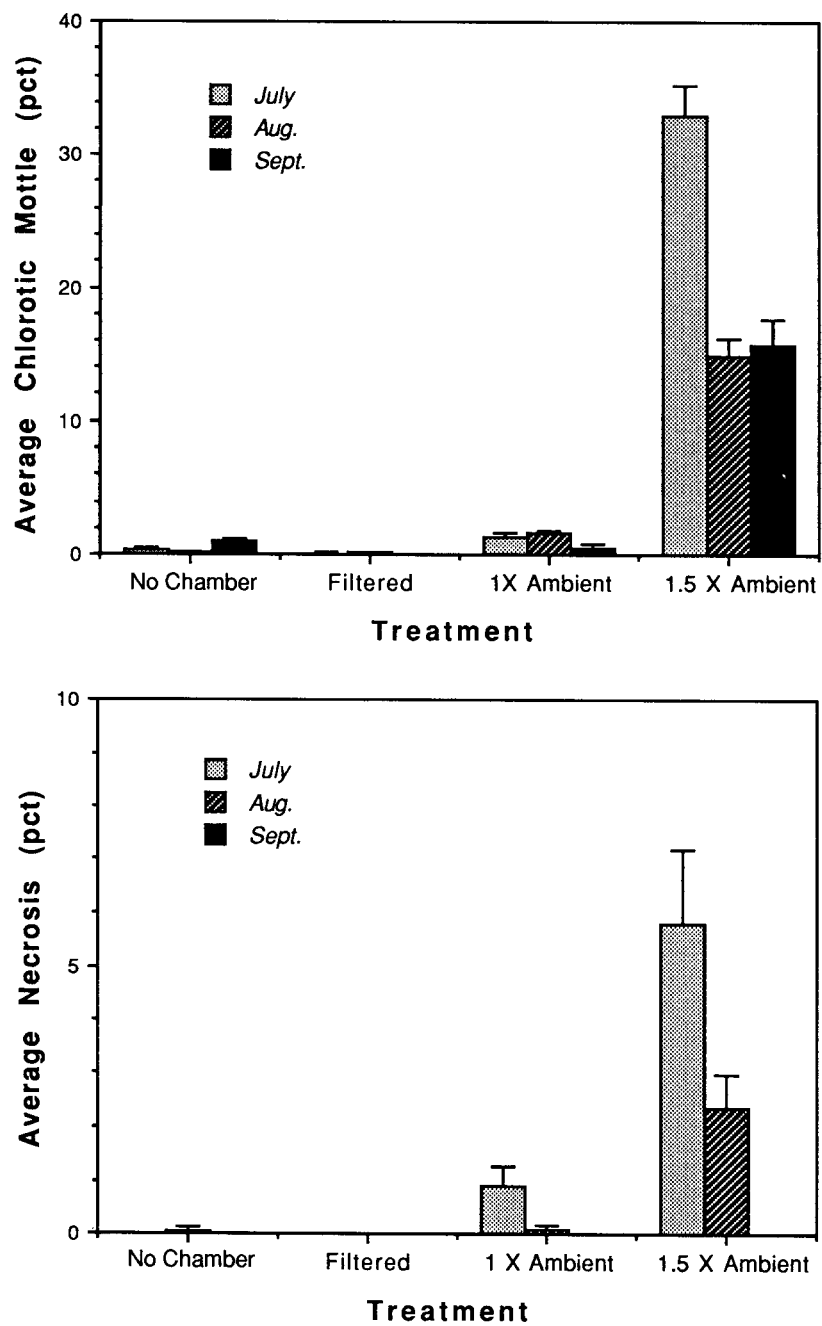


Figure 3-Estimates of the percent of total foliage surface area of giant sequoia seedlings with visible injury during exposure to ambient ozone (1X) or ambient ozone or charcoal-filtered air on July 10, August 8, and September 14, 1988 at Giant Forest (Miller and others 1991 a).

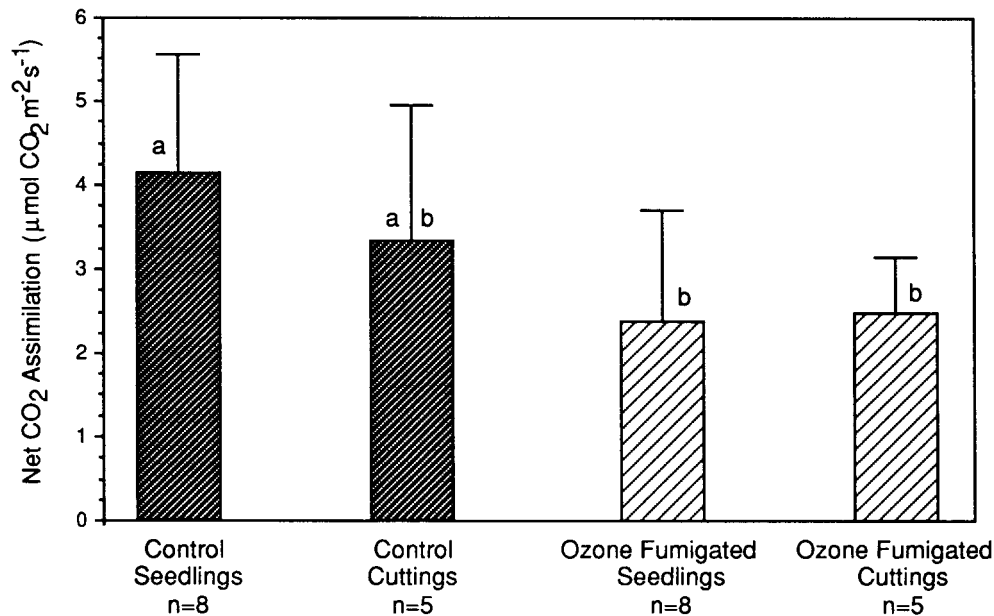


Figure 4—Net CO₂ assimilation of giant sequoia seedlings and rooted branchlets from sapling giant sequoias after a 3-month exposure to charcoal-filtered air or 1.5X ambient ozone at Giant Forest in 1988 (Grunke and others 1989). Bars with the same lowercase letter (e.g., a,a or b,b) are not significantly different, $p = 0.05$.

after exposure to 1.5X ambient ozone during the first 3 months after emergence. An additional approach was taken to determine whether seedling injury by ozone was detectable in natural groves where recent prescribed fires had resulted in abundant regeneration. Randomly selected samples of primary needles from giant sequoia seedlings were collected in 1987 from three sequoia groves in Sequoia National Park and examined histologically (Evans and Leonard 1991). These results suggest that primary needles of seedlings from groves show histological evidence of ozone effects similar to those of needles from ozone fumigation experiments. Thus, present ambient levels of ozone exposure are sufficient to cause detectable ozone injury to recently emerged seedlings.

Seedling plots were established at nine locations in natural giant sequoia groves in 1983. At each location five 1-m² subplots were randomly selected from a 5- by 20-m grid. The appearances of symptoms and the mortality of seedlings were recorded in early and late summer each year from August 1983 to September 1986 (Miller 1987). A variety of leaf injury symptoms were observed that resulted in a gradual increase in the number of partially or wholly dead primary needles after which the seedlings died. There was no way to confirm that ozone was contributing to this symptom pattern. Seedlings that died early in the 3-year observation period had a uniform, light-straw-yellow color. It appeared that rapid desiccation had occurred because the root system had failed to become established. Many of the seedlings that died in the last year of observation had been buried by leaf and twig litter from nearby overstory trees. Between August 1983 and September 1986 at the nine plot

locations, the seedling density decreased from an average of 12 seedlings to 2 seedlings per square meter.

Four of these plots had received a prescribed burn treatment in 1982, and the others had been burned between 1979 and 1981. The overwinter and summer mortality at four of the nine plots burned in 1982 is shown in *figure 5*. The seedlings at the General Grant Tree plot were growing on an extremely dry site with a very long daily duration of direct sunlight, and there was 42 percent mortality in the August 1983 to October 1983 period. Circle Meadow was a more mesic site, and mortality was not as rapid in the initial year. Three plots had less than 15 percent survival at the final observation, and one plot (General Grant Tree) had no survivors (Miller 1987).

Chronic Ozone Effects on Tree Species Competing with Giant Sequoia

It is clear from repeated surveys of ponderosa and Jeffrey pine plots in Sequoia and Kings Canyon National Parks that the most injury to these species is found in the Giant Forest-Grant Grove regions (Stolte and others 1991). There is some evidence that large-diameter Jeffrey pines on severe sites are showing a decline in annual ring growth that is related to crown condition (Peterson and others 1987). A similar study of ponderosa pines in the region failed to show any change in ring growth (Peterson and others 1991). Mortality of ponderosa and Jeffrey pines in the southern Sierra Nevada that is clearly related to ozone stress has not occurred as has already happened in the San Bernardino Mountains where ozone concentrations are higher. Other

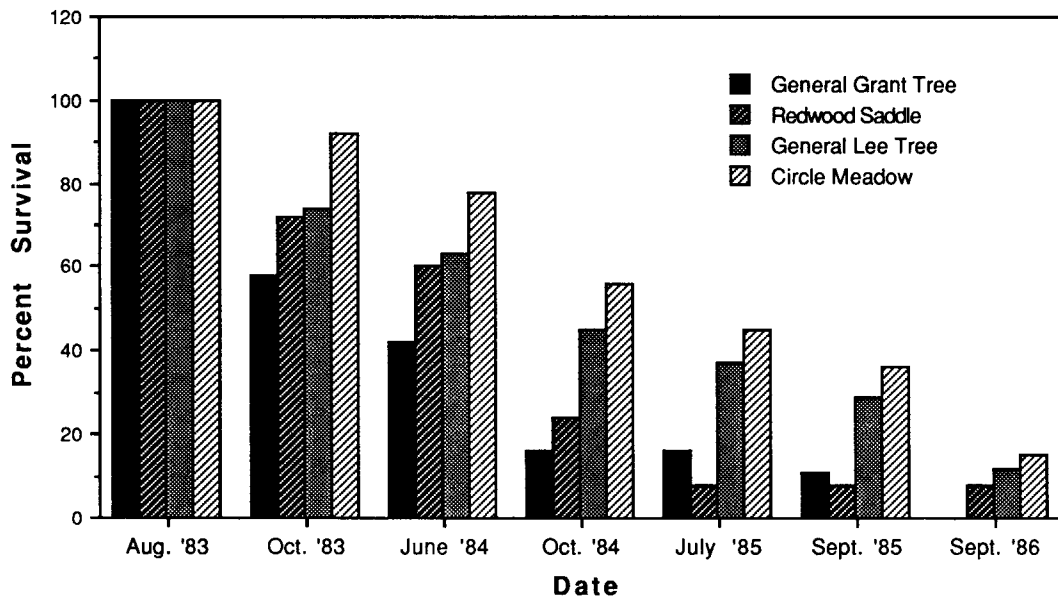


Figure 5-Survival of giant sequoia seedlings regenerated at four locations after prescribed burns in 1982. Survival counts were made in mid and late summer from August 1983 to September 1986 (Miller 1987).

companion species including white fir, sugar pine, incense cedar [*Calocedrus decurrens* (Tory.) Florin], and California black oak (*Quercus kelloggii* Newb.) are more tolerant to ozone. These species have shown generally larger increases in basal area than ponderosa or Jeffrey pines at plots in the San Bernardino National Forest where ozone exposure levels are nearly double those found in Sequoia and Kings Canyon National Parks (Miller and others 1991b). It is prudent to be vigilant for ozone-induced interspecific competitive changes in the southern Sierra Nevada mixed-conifer forests that could have an influence on well-established giant sequoias and the success of new seedling establishment.

Discussion

The objectives of this work were centered around the question: Is any age class of giant sequoia injured directly by ambient ozone levels currently measured or potentially possible in the atmosphere at Sequoia and Kings Canyon National Parks? Several lines of evidence indicated that symptoms of ozone injury are detectable on seedling foliage in natural groves in the first months after emergence. Two field fumigation experiments had consistent results; however, shoot, root, and total plant weights of fumigated seedlings were not significantly different from those of seedlings in charcoal-filtered air after exposures to 1.5X ambient ozone for 3 months. Visible symptoms of ozone injury were very prominent in seedlings treated with 1.5X ambient ozone in both experiments.

Seedlings growing in microsites with short durations of direct sunlight may be more at risk from ozone injury because insufficient light would not permit compensation

for the reduced photosynthesis and increased respiration caused by ozone injury (Grulke and others 1989). Successful development of root systems to depths sufficient to reach subsoil moisture and thus avoid the typical summer drought is essential for survival in the first season of growth. If ozone injury leads to reduced root development (Oshima and others 1979), it is possible that seedling survival could be curtailed in an environment of deteriorating air quality.

In past centuries, giant sequoia has not been exposed to elevated ozone concentrations (Kasting 1993); therefore, there would have been no opportunity for natural selection of tolerant individuals. Instead, fire and drought are generally recognized as the principal selective agents for seedlings. Our observations in natural groves between 1983 and 1986 showed an average reduction in seedling density from 12 to 2 seedlings per square meter. If ozone air quality should deteriorate more, it is possible that ozone could act as a new selection pressure during the early seedling stage. Genotypes that may be eliminated by ozone selection may have important attributes that contribute to the future success of the species.

For the large sapling stage of giant sequoia, the measurement of photosynthesis and other physiological parameters did not reveal any impairment after exposure for 2 months to concentrations up to 3X ambient ozone. Ponderosa and Jeffrey pines would have been very seriously damaged by such a treatment. These results of sapling fumigation are supported by observations of vigorous health of giant sequoias growing in the San Bernardino Mountains at seasonal ozone concentrations that approach 2X the ambient concentration in the Sierra Nevada.

Acknowledgments

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References

- Duckworth, S.; Crowe, M.R. 1979. Sulfur dioxide and sulfate survey ...Bakersfield 1977-1978. Sacramento: California Air Resources Board, Technical Services Division; 34 p.
- Evans, L.S.; Leonard, M.R. 1991. Histological determination of ozone injury symptoms to primary needles of giant sequoia (*Sequoiadendron giganteum* Buchh.). *New Phytologist* 117:557-564.
- Grulke, N.E.; Miller, P.R. 1993. Gas exchange characteristics from seedlings to mature trees in giant sequoia: Implications for response to current and future levels of atmospheric ozone. Unpublished draft supplied by author.
- Grulke, N.E.; Miller, P.R.; Wilborn, R.D.; Hahn, S. 1989. Photosynthetic response of giant sequoia seedlings and rooted branchlets of mature foliage to ozone fumigation. In: Olson, R.K.; Lefohn, A.S., eds. *Effects of air pollution on western forests*. AWMA Symposium Transactions Series ISSN 1040-8177; No. 16; 429-441.
- Kasting, J.F. 1993. Earth's early atmosphere. *Science* 259:920-926.
- Miller, P.R. 1987. Ozone effects on important tree species of Sequoia and Kings Canyon National Parks. Final Report on 1985 and 1986 Research for the Interagency Agreement #0475-4-8007 to the Air Quality Division, National Park Service, Denver, CO; 43 p.
- Miller, P.R.; McBride, J.R.; Schilling, S.L. 1991. Chronic ozone injury and associated stresses affect the relative competitive capacity of species comprising the California mixed conifer type. In: *Proc. Simposio Nacional Agricola Sostenible: Una opcion para el desarrollo sin deterioro ambiental*. Colegio de Postgraduados, Montecillo, Edo. de Mexico, 9-10 Diciembre 1991, Commission de Estudios Ambientales, C.P. y M.O.A. International; Montecillo, Edo. de Mexico; 161-172.
- Miller, P.R.; Millecan, A.A. 1971. Extent of air pollution damage to some pines and other conifers in California. *Plant Disease Reporter* 55:555-559.
- Miller, P.R.; Schilling, S.L.; Wilborn, R.D.; Gomez, A.P.; Wilborn, J.; Grulke, N.E. 1991. Ozone injury to important tree species of Sequoia and Kings Canyon National Parks. Final report on 1988 experiments for Interagency Agreement #0475-4-8007 to the Air Quality Division, National Park Service, Denver, CO; 54 p.
- Miller, P.R.; Stolte, K.W. 1984. Response of forest species to O₃, SO₂, and NO_x mixtures. Paper 84-30.5. Presented at the 77th annual meeting, Air Pollution Control Association, Pittsburgh, PA; 15 p.
- Miller, P.R.; Wilborn, R.D.; Schilling, S.L.; Gomez, A.P. 1988. Ozone injury to important tree species of Sequoia and Kings Canyon National Parks. Report of research completed during FY 1987 for Interagency Agreement #0475-4-8007 to the Air Quality Division, National Park Service, Denver, CO; 56 p.
- Oshima, R.J.; Braegelmann, P.K.; Flagler, R.B.; Teso, R.R. 1979. The effects of ozone on the growth, yield, and partitioning of dry matter in cotton. *Journal of Environmental Quality* 8:474-479.
- Peterson, D.L.; Arbaugh, M.J.; Robinson, L.J. 1991. Regional growth changes in ozone-stressed ponderosa pine (*Pinus ponderosa*) in the Sierra Nevada, California, USA. *The Holocene* 1:50-61.
- Peterson, D.L.; Arbaugh, M.J.; Wakefield, V.A.; Miller, P.R. 1987. Evidence of growth decline in ozone-stressed Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) in Sequoia and Kings Canyon National Parks. *Journal of the Air Pollution Control Association* 37:906-912.
- Reinert, R.A.; Heagle, A.S.; Heck, W.W. 1975. Plant responses to pollutant combinations. In: Mudd, J.B.; Kozlowski, T.T., eds. *Responses of plants to air pollution*. New York: Academic Press; 159-177.
- Rundel, P.W. 1972. Habitat restriction in giant sequoia: The environmental control of grove boundaries. *American Midland Naturalist* 87:81-89.
- Stolte, K.W.; Flores, M.I.; Mangis, D.R.; Joseph, D.B. 1991. Concentrations of ozone in National Park Service Class I areas and effects on sensitive biological resources. Paper 9 1-144.3. Presented at the 84th Ann. Mtg. Air and Waste Management Association, Pittsburgh, PA; 25 p.
- Taylor, O.C.; Miller, P.R.; Page, A.L.; Lund, L.J. 1986. Effects of ozone and sulfur dioxide mixtures on forest vegetation of the southern Sierra Nevada. Final Report, Contract No. AO-135-33. Sacramento: California Air Resources Board.
- Weinstein, D.A.; Beloin, R.M. 1990. Evaluating the effects of pollutants on integrated tree processes: A model of carbon, water and nutrient balances. In: Dixon, R.K.; Meldahl, R.S.; Ruark, G.A.; Warren, W.G., eds. *Process modeling of forest growth responses to environmental stress*. Portland, OR: Timber Press; 313-323.

The Visual Ecology of Prescribed Fire in Sequoia National Park¹

Kerry J. Dawson

Steven E. Greco²

Abstract: Preservation and restoration of natural ecosystems is important to maintain the dynamic character which ultimately formed the giant sequoia/mixed-conifer forests prior to human interference. In the Giant Forest, aesthetic and ecological goals need not conflict, but should complement each other as much as possible. This can be achieved by utilizing the recommendations from recent aesthetic research on prescribed fire management sponsored by Sequoia National Park. Management should seek to mitigate the effects of past fire suppression and mimic natural fire patterns while educating park visitors about fire ecology. Management must also recognize that areas of intense cultural use have impacts that are not natural, and these areas must be managed intensely to preserve and restore naturalness.

The National Park Service Act of 1916 (USA 1916) declared that "the fundamental purpose of [a National Park] is to conserve the scenery and, the natural and historic objects and the wildlife therein and to provide for enjoyment of the same in such a manner and by such a means as will leave them unimpaired for the enjoyment of future generations." Interpretation of this mandate with a sophisticated level of management was clearly demanded by the release of the Leopold Panel Report (Leopold and others 1963). The relationship between aesthetics and natural process is a complex natural and cultural issue that continues to evolve and will do so through ongoing multidisciplinary research. Visual resources are a prime asset in our National Parks and they must be conserved and managed sensitively.

Prescription burning began in the Giant Forest of Sequoia National Park in 1979. Since then several burns have been conducted. The management objectives of these burns have been primarily to reduce hazardous fuel accumulations and to restore the forest to a more natural ecosystem while sustaining populations of giant sequoias (*Sequoia-dendron giganteum*) (National Park Service 1987a). The overall burn pattern on the forested landscape was originally designed to prevent or minimize the potential risk of a catastrophic fire sweeping over the Giant Forest plateau. In an effort to accomplish these objectives, park resource managers were presented with a variety of sometimes conflicting goals. In 1986, an independent review was commissioned by Mr. Chapman, then Director of the USDI National Parks Service Western Region.

The independent review of the giant sequoia/mixed-conifer prescribed burning program of Sequoia and Kings

Canyon National Parks by the Christensen Panel resulted in a report (Christensen and others 1987). Which among many recommendations, explicitly addressed aesthetic concerns within the park's "Showcase" areas. The Sequoia Natural Resources Management Division has since changed the term "Showcase" to Special Management Areas (SMA). The Sequoia and Kings Canyon Vegetation Management Plan (NPS 1987b) notes that SMAs are designated "where maintenance of natural processes is guided more by scenic concerns." The Panel Report specifically recommended consultation with landscape architects in the development of burn plans with special emphasis on the SMAs. The three primary sources of visual impact of concern to landscape architects and many others are the reintroduction of fire, visitor overuse, and overgrown thickets of non-fire climax species.

Special Management Areas are located in the most heavily visited portions of the park. High visitation via roads and trails are a significant anthropogenic impact within an ecosystem that has management goals for 'naturalness.' The challenge of maintaining a natural aesthetic for this type of visitation is made compelling by the fact that roads and trails concentrate human impacts and have human facilities associated with them (food vendors, parking lots, restrooms, etc.). Current management goals of 'naturalness' are further complicated by historic-cultural values that have developed over the past one hundred years since the establishment of the park. The named trees and logs have become 'cultural objects' along trails and roads, such as the General Sherman Tree and other named trees, groves, logs, and stumps in the Giant Forest. These areas of heavy visitation and subsequent substantial human impact must be managed more intensively than elsewhere in the park and thus are termed SMAs.

As stated in the Panel Report, SMAs should not be seen as "static museums," created through "scene" management, but rather as a part of dynamic ecosystems, sensitively managed to preserve scenic and ecological resources (Christensen and others 1987). The Prescribed Fire Management Program (1987a) notes that the intention of management in these areas is not to apply a method of "greenscreening," whereby dramatically different appearing landscapes exist behind SMAs. Instead, these areas should be burned as more sensitive units with special attention given to specific goals and objectives for visual quality and interpretation, as complemented by associated resource objectives.

Historically, the giant sequoia/mixed-conifer ecosystem experienced frequent, low intensity fires which structured the forest prior to human interference (Kilgore 1987). The effects of past management actions in suppressing all natural

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²Professor of Environmental Design, University of Georgia, Athens, GA 30602-1845; and Postgraduate Researcher in Ecology and Landscape Architecture, University of California, Davis, CA 95616.

lightning fires, for some seventy-five years (representing many natural fire cycles), has resulted in an altered forest structure and high ground fuel accumulation in many areas. The forest structure has been changed to favor shade tolerant fir and incense cedar while unnaturally high fuel accumulation risks increased mortality of giant sequoias and understory species during a fire (Harvey 1985; Kilgore 1985; Bonnicksen and Stone 1982; Bonnicksen 1975). Past prescribed fires have resulted in what many environmental groups see as unnatural due to inadequate mitigative measures and procedures. Prescription fires are now designed to mitigate these effects through "cool burns" meant to restore natural conditions. The overall concern is to have the forest "look" like a low intensity burn has moved through the forest even though the fuel load has the potential for a high intensity fire.

Research Procedures and Methodology

The procedures applied for this research (Dawson and Greco 1987) were determined based on the specific needs of management and recommendations from the Panel Report (Christensen 1987). They consist of (1) delineation of the viewshed boundaries of the SMAs, (2) inventory and analysis on the visual resources within the SMAs, (3) ecologically acceptable visual resource management goals and objectives, and (4) management treatments which fulfill the visual quality goals and objectives.

The research consisted of an inventory of visual resource elements, formulation of goals and objectives, and development of a set of guidelines for treatments of fire effects on the character of the landscape and on the character of individual giant sequoia features. The methodology developed for assessing the visual resources at Sequoia National Park can be applied to all roadways and trails within the park. The process model (*fig. 1*) graphically depicts the recommended methodology for SMA visual resource planning.

SMA Boundary Delineation

The study areas within the SMAs are defined in terms of their respective viewshed boundaries. A viewshed, or visual corridor, is a routed (by road or trail), physically bounded area of landscape that is visible to an observer (Litton 1979). A viewshed delineates the dimensions of the "seen" environment in terms of visual penetration. The viewshed boundary is formed from the dynamic composition of viewing points on a continuum (i.e., a road or trail). Viewing points are representative of a number of observer positions accounting for several viewing orientations (Litton 1973, 1968). It should be noted that because natural features often delineate visual units (ridges, streams, etc.), ecological units (i.e., watersheds) and visual units (i.e., viewsheds) are closely related.

Visual Resources Inventory and Analysis

An inventory of visual resources is a descriptive field survey that identifies the seen areas, and physically locates

visual and perceptual elements within the selected SMA study areas. It consists of several parts including viewshed delineation, areas of viewshed overlap, visual unit delineation, identification of special features and visual element subunits, determination of giant sequoia visibility through a visual prominence rating, and the location of impacted views due to fire suppression. An inventory was surveyed and compiled for each study area SMA.

The goal of the feature analysis is to provide park managers with a tool to assess the relative difficulty of achieving the visual quality objectives. The Management Scale provides an indexed classification for each visual unit to indicate pre-burn planning intensity and (burn) labor requirements that will be necessary for any given burn unit. For example, in an area with many visual features (i.e., giant sequoias, logs, etc.) the Management Scale value could be rated as class "1" and an area with few visual features could rate as a class "4" value. Thus, if a burn unit contains several class "1" values, then more labor will be required to mitigate excessive fire effects. This would be the case whether or not a biological or aesthetic basis was used simply because of the resource base. The formulation of the Visual Unit Management Scale is composed of five steps: a tabulation of features per visual unit; a feature aggregation index calculation; determination of visual unit acreage; a feature density value calculation; and an indexed classification of those values into the Visual Unit Management Scale values.

SMA Visual Management Goals and Visual Quality Objectives

Fire management planning in SMAs requires the development of clear goals and specific objectives as a critical step in the prescribed fire planning process (Bancroft 1983; Fischer 1985). Clear exposition of goals and objectives is necessary to evaluate the effectiveness of management actions. Management goals should be broad in scope and attainable through specific objectives that address issues within each goal. The three central issues for visual quality goals and objectives are (1) fire effects on the character of the landscape, (2) fire effects on individual giant sequoias, and (3) enhancement of currently affected visual resources.

Fire Effects on Landscape Character

The giant sequoia/mixed-conifer forests have evolved in context of frequent fire return intervals and low fire intensities although less frequent, more extensive and intense events have also played an important role in this ecosystem (Kilgore 1987; Van Wagtenonk 1985). Kilgore and Taylor (1979) found through tree ring analysis that historical fires near the Giant Forest area were frequently small in size and generally confined to a single slope or drainage. They also report that fires ranged in size between 0.001 ha to 16 ha. In the same study area, Harvey and others (1980) confirm the small nature of these burns, suggesting they were about 10 ha.

In the Redwood Mountain area, the Kilgore and Taylor study (1979) also found fire return intervals on west-facing

METHODOLOGY: PROCESS MODEL

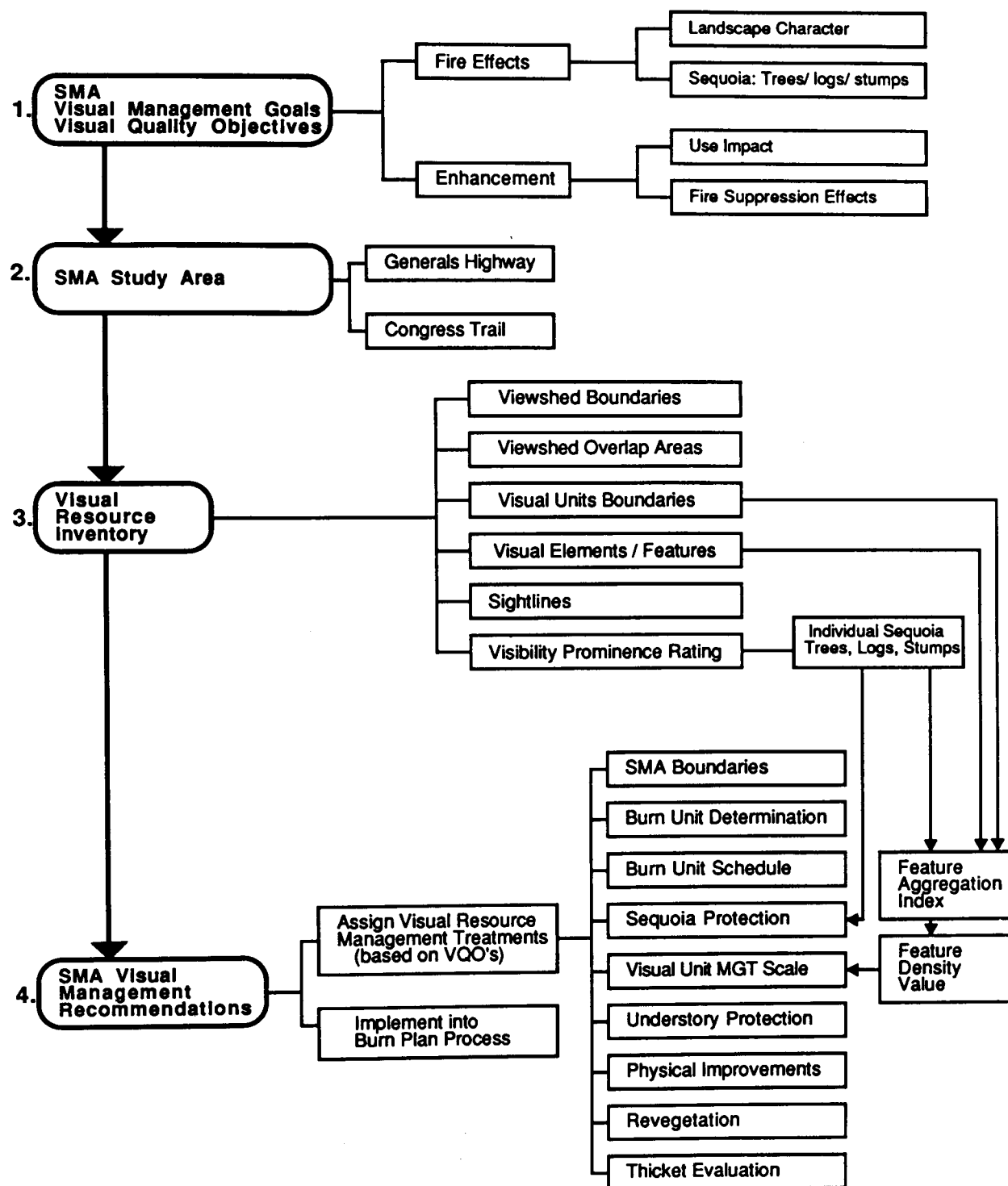


Figure 1-Visual resource research methodology and planning approach.

slopes to be about every nine years, and on east-facing slopes to be about every 16 years. They also report mean fire-free intervals of five years on dry ridges of ponderosa pine and 15 to 18 years in moist sites of white fir. The average maximum fire-free interval was found to be 14 to 28 years. Nonetheless, their data also reveals that some clusters of giant sequoias have escaped fire for up to 39 years. Some areas have possibly escaped fire for a hundred or more years.

Restorative SMA prescription fires should be planned within an appropriate temporal and spatial framework. The juxtaposition of prescribed burns can greatly enhance or detract from the visual and ecological diversity of the forest. The goal should not be to create burns that result in large scale areas of an early successional stage. Rather, management burns should concentrate on maintaining, or creating, successional diversity throughout the forest (Harvey 1980). Fire should be introduced on a gradual spatial and temporal basis to restore the forest to a more natural state. Although reducing fuel accumulations is important, it is not necessary that this be the immediate objective of an SMA burn. Small-scale burns should be designed that maintain ecological and visual diversity over appropriate time scales. Planning should incorporate available site-specific fire history research.

To preserve successional and visual diversity, management plans should include small-scale burns, random juxtaposition of burns (variety of burn unit contrasts), selected retention of understory vegetation, and limiting the number of burn units treated each year. Planned variation in future burn unit boundaries will also help maintain an ecologically and visually diverse park environment. To increase visual diversity and maintain a sense of ecological continuity along travel corridors, burn unit boundaries should cross roads and trails in some areas and remain adjacent to them in others. If roads and trails are always used as boundaries, one side will always appear different than the other creating an unnatural experience. Human infrastructure should be avoided or limited as burn unit determinants. Overuse of them could lead to a confused perception of the forest to some visitors and contribute to a less naturalistic aesthetic. Extended long-range plans, or areas in need of a second prescribed burn, should include planned variation from the boundaries of the first prescribed burn, or possibly the relocation of trails during this planning process. It is not recommended that the same boundaries be used for future burns. The return of fire should also be variable, both spatially and temporally. Variation is another very important aspect of visual and ecological diversity, as pointed out in the Christensen Report (1987).

Treatments of designated SMA burn units should be "cooler" prescriptions as noted in the Grant Tree SMA plan (NPS 1980a). Taylor and Daniel (1985) confirm that fire intensity correlates with scenic quality and recreational acceptability in ponderosa pine forests. They found that in comparison to unburned areas, low intensity fires produced improved scenic quality ratings after 3 to 5 years, but that high intensity fires "seriously declined" in scenic quality

ratings after the same time period. This is especially true of areas that are under intense recreational pressure where regeneration is hindered by trampling impacts.

Efforts to provide a high value interpretive program are essential to educate the public about fire ecology and the aesthetic implications of fire ecology in the Giant Forest SMAs. The program is important because visitors are barraged with fire danger signs as they approach the park. McCool and Stankey (1986) found that visitors who were confused and uncertain about the effects of prescribed fire were afraid that it could be "detrimental" and negatively impact the park, but that visitor center exhibits and guided tours help engender an understanding and appreciation of the dynamic processes of forest succession and fire ecology. Roadside and trailside interpretive displays in appropriate locations, with descriptive graphics facilitate this objective. The Hazelwood Nature Trail is an excellent example. Hammit (1979) indicated that the value of interpretive displays located in visually preferred areas can be more rewarding and more likely remembered. Proper placement of displays in the environment appears to aid in the memory process of park visitors.

Fire Effects on Individual Giant Sequoia Trees, Logs, and Stumps

Visual features in the Giant Forest are highlighted by the grandeur and presence of a high density of giant sequoias. As a result of this density and the park's design, visitor appreciation of the giant sequoias has rendered many of them as unique natural/cultural objects in the landscape. Hammit (1979) reports that the most remembered scenes by visitors are characterized by visually distinct features. It appears there is a strong correlation between familiarity and preference of scenery. Familiarity is highest in both most preferred and least preferred scenes, indicating that visitors are affected by both positive and negative features observed in landscape experiences. Preferred areas within the park are trails, such as the Congress Trail, that were designed with the objective to guide visitors to experience the high densities of giant sequoia groves.

Maintaining high scenic and recreational values in the Giant Forest requires sensitive visual resource planning of fire effects and a strong interpretive program to effectively communicate fire ecology to the public. Protecting all sequoias from intensive fire effects however, may not be possible. Since the giant sequoias are a primary visual resource (and biological resource) in the Giant Forest, the most prominent trees should receive the greatest mitigative measures (if resources are limited) to retain a natural character following restoration burns. It is recommended as a visual quality management goal that distinct foreground features receive judicious burning, especially around the bases of the giant sequoias in the SMAs of Sequoia National Park. The foreground trees are most impacted by intense human use and, therefore, most impacted and most visually vulnerable.

For visitors to gain a sense of appreciation for a wide range of fire effects, some of the less prominent trees could provide an opportunity for such diversity. It is not intended that foreground trees should be protected at the expense of background giant sequoias. Rather, since foreground sequoias are proximate to high human use pressures and park infrastructure—which result in decreased duff cover soil compaction, increased erosion and lack of understory regeneration—these trees should receive more sensitive treatment. Background trees could receive wilderness standards for giant sequoia protection.

To gain better insight and understanding of visitor sensitivity to singeing and charring on highly visible giant sequoias, a special study would have to be conducted. A study has been completed of visitor perceptions of recent prescribed fire management in Sequoia National Park and generally, visitors were not adverse toward fire scars (Quinn 1989). No research however, was conducted on reaction to singeing versus charring in recent burn units within the park.

The last issue regarding protection of individual giant sequoias is the maintenance of ecological and visual/cultural values associated with horizontal features in the forest landscape experience. The preservation of a select number of highly visible sequoia logs (in addition to named logs) along trails and roadways has been strongly recommended by some groups (Fontaine 1985). The interpretive value of these logs stems from the direct "involvement" the public has with these elements. The tactile experience of touching and passing through these logs can engender a strong appreciation for the grandeur of the giant sequoias. They also demonstrate the dynamic nature of succession in the giant sequoia/mixed-conifer ecosystem. Hammit (1979) suggests that prolonged contact with such features increases familiarity. It was recommended that a balanced number of strategically located logs be protected from intense prescribed burns and not burned unnaturally.

Currently Affected Visual Resources

Scenic resources that are currently impacted are the result of intensive recreational use, and the structural changes of vegetation in the giant sequoia/mixed-conifer forest. The first is due to the effects of visitor overuse and the lack of facilities to accommodate the use volume. The second impact results from fire suppression which promote the growth of shade tolerant conifer thickets (non-fire climax species) that unnaturally limit the visibility of numerous giant sequoias within the viewshed. Management goals to alleviate both of these impacts would enhance the overall experience of the park.

Many high visitation areas such as the Congress Trail, General Sherman Tree, and Hazelwood Nature Trail suffer from severe overuse. Strategic signs in these areas is essential to better guide foot traffic (trampling) in these areas which has caused the disintegration of duff and subsequent erosion of surface soil inadvertently creating biological and visual resource problems. Problems include erosion around sequoias

exposing fibrous roots, erosion and decay of asphalted edges in parking areas and on trails, and a lack of understory vegetative cover due to soil compaction. Means to reduce these effects include redirecting foot traffic in and around facilities and reduced trampling around the trees.

The second issue concerning enhancement of affected visual resources centers on the extensive growth of shade tolerant conifer thickets (non-fire climax species) resulting from fire suppression and the disturbances due to road and trail construction (Bonnicksen 1985; NPS 1980b). In the absence of regular fire disturbance cycles these thickets have grown unchecked by natural process, thus hindering the ability of the giant sequoia to reproduce successfully and also blocking both historic views and potentially valuable views of the giant sequoias in the Giant Forest SMAs. In addition to these problems, the thickets also represent future fuel load and fuel ladder problems. The visual resource goal should be to conserve the scenery while enhancing natural visitor experience within the SMAs through active management of the thickets. The means to achieve this goal include increasing the visibility of the affected giant sequoias through limited and strategic removal of these "overrepresented aggregation types" to maintain a more natural aesthetic in the Giant Forest (Bonnicksen 1985; Cotton and McBride 1987).

Visual Resource Treatments

The recommended treatments are composed of a Landscape Management Plan and a set of guidelines for visual resource management in the SMAs. Visual resource treatments are management actions designed to fulfill management goals and visual quality objectives. A photographic monitoring program is also recommended.

Landscape Management Plan

The SMA Landscape Management Plan identifies proposed burn units, planning units, past prescribed burns, burn exclusion areas and thicket problem areas. The burn units have been designed in accordance with the visual quality objectives to maintain a diverse visual character within the SMA study areas. Sections requiring additional research studies are classified as "planning units" and "SMA planning units" on the plan. Small areas of cultural value that are recommended to be excluded from prescribed fire are also indicated on the plan. Additionally, thickets that block views of giant sequoias, and thickets that present future visual resource problems are identified for treatment. Finally, measures to protect visually prominent giant sequoias are based upon the visual prominence ratings as shown on the Visual Resource Inventory maps.

Protection of visual elements is also meant to preserve pockets of mature understory vegetation in addition to giant sequoia protection. These pockets are ecologically important because they function as vegetative buffers which are needed to avoid further damage from intensive human use interfering with regeneration and colonization sources. These, too, are

identified on the Visual Resource Inventory Maps. The analysis of visual features within the visual units provides a guide for resource managers to evaluate labor requirements when planning burn units. A feature "density" value was generated for each visual unit and broken down into management intensity classes.

Burn Unit Design and Schedule

Burn units were designed based on the Fire Effects Guidelines for SMA Landscape Character. Natural boundaries for the SMA burn units are preferred to artificial boundaries. It is recognized that the use of roads and hiking trails for fire breaks is essential in many cases due to economic constraints. Alternatives to their use however, should be explored, such as streams, drainages, ridges, old fire lines, meadows, rock outcrops, and new fire lines.

The burn units in a maintenance fire regime should be varied from previous prescribed burns. It is not recommended that the same burn unit boundaries be used more than once if they are unnatural boundaries (trails or roads). Using the same boundaries runs an ecological and visual risk of creating an unnatural mosaic of forest succession. The maintenance burn regime units should concentrate on natural fire breaks that travel across trails instead of being bound by them.

Timing of the burn units is a very important aspect of planning. The burn units have been designed to restore

the Congress Trail and the SMA section of the Generals Highway to more natural conditions. Following the restoration burn regime, a long-term maintenance fire regime should be formulated for the Giant Forest. It is recommended that this regime be based on area-specific fire history research. A computer geographic information system (GIS) would greatly enhance the analysis and planning of the burn units in the Giant Forest because it is a very useful tool for evaluating large spatial data sets and many variables.

Guidelines for Thicket Problem Areas

The visual quality objectives regarding enhancement are designed to increase the visibility of giant sequoias affected by extensive thicket growth throughout SMA viewsheds. These thickets are blocking numerous potentially valuable views of giant sequoias (*fig. 2*). Management for a natural aesthetic and increased visual penetration into the forest within the SMAs warrants judicious mechanical thinning of some of these thickets (Bonnicksen and Stone 1982; Christensen 1987; Cotton and McBride 1987).

The thickets were mapped on the SMA Landscape Management Plan in two ways. Existing "blocked" views were mapped, and visually "encroaching" thickets are also shown. The encroaching thickets did not present a visual problem at the time the field work was conducted, but will



Figure 2—Thickets of mixed conifers encroaching on the views of giant sequoias due to the disturbance of road construction.

cause visual penetration problems in the near future. They should be monitored photographically and evaluated for mechanical thinning. It was recommended that this be incorporated into the park's Vegetation Management Plan for the development zone (NPS 1987b).

Guidelines for Giant Sequoia Fire Effects Mitigation

As discussed in the visual quality objectives, it is the visually prominent trees which are impacted most by human use pressures. Park infrastructure, such as trails, roads, signs, restrooms, etc., are proximate to the visually prominent trees. The most valuable scenic resources are also the most visually prominent trees. Mitigative measures to protect these trees are critical in terms of ecological, scenic, and park infrastructure resources. The objective is not to leave these trees unburned, but to mitigate fire effects. Trees impacted by intensive human use are under stress and unsuppressed fire risks unnatural mortality. The four categories of giant sequoia protection (mitigation measures) are illustrated in figure 3 and include: (1) scorch exclusion, (2) minimal scorch, (3) limited scorch, and (4) unsuppressed scorch (within standard management tree protection guidelines). These relate directly to visual proximity as well as distance from human impact (Dawson and Greco 1987).

To understand properly the descriptions of the four categories of giant sequoia protection, definitions of scorching, singeing and charring are needed. In this study, "scorching" is the singeing or charring of sequoia bark. "Singeing" is bark ignition to a depth under one-half inch ($<1/2$ "). "Charring" is defined as bark ignition to a depth over one-half inch ($>1/2$ "). The question of singeing is not an intense aesthetic issue because park visitors seem to accept some fire damage to sequoias (Quinn 1989). However, reaction to varying levels of charring is undetermined and can impair the scenic quality of giant sequoias for longer time periods if the trees are under stress, especially when there is increased mortality. Therefore, it was recommended that scorch and char guidelines be established in addition to current tree preparation standards (pre-fire) and firing techniques. It should be remembered that the guidelines apply only during the restoration fire phase.

Guidelines for Understory Protection

Planned retention of pockets of understory vegetation is recommended in the SMA burn units. They offer opportunities to maintain visual and ecological diversity while increasing the probability of regeneration by providing colonization sources. Often, these pockets grow among rock outcrops and may have escaped fire for long periods under more natural wildfire conditions. Historically, natural burns have undoubtedly missed many areas creating a mosaic of vegetation characteristic of the sequoia/mixed-conifer ecosystem. The most obvious pockets for retention would be growing among rocks that could be supplemented with fire lines to lengthen their presence.

For aesthetics, these groups of plants provide a visual focus, diversity of elements, and demonstrate the scale

between visitors and the large-scale giant sequoias and older conifers. Some good examples in the Giant Forest are native dogwoods (*Cornus nuttallii*), Sierra chinquapin (*Castanopsis sempervirens*), and greenleaf manzanita (*Arctostaphylos patula*). Although some are adapted to fire and regenerate after a fire, their rate of growth is slow. Their visual, ecological, and interpretive qualities could be diminished for many years.

Discussion

There has been concern on the part of National Park Service scientists about some of the research recommendations on visual resources (Dawson and Greco 1987). An interdisciplinary group of staff from Sequoia National Park representing science, administrative management, visitor interpretation, fire management, and resource management met and forwarded comments. The following discussion presents these views as well as further discussion on the visual resource research.

NPS and Understory Issues

The NPS group does not favor "the deliberate retention of mature groups of understory plants, since prescribed fire tends to leave mosaics of burned and unburned areas, and the recovery of the understory plants in post-fire succession is an important part of the forest story" (NPS 1988).

At several prescribed burns in the Giant Forest, the visual resource research team observed that fire was applied homogeneously within the burn units. Fire management staff frequently burn areas completely and uniformly, and if fire bypassed any fuel loads, the fire technicians returned moments later to fire that area. This does not mimic natural fire patterns and as a result, pockets of understory plants rarely survive. The practice of multiple-spot firing after the fire has moved through should be modified to rely on this technique only in situations where absolutely necessary. Kilgore (1985) supported this concept by pointing out that increased uniformity and lessened mosaic pattern is also ecologically unnatural. Again, visual ecology and biological ecology coincide.

Litton (1988) has written to staff at Sequoia National Park that "In addition to modifying fuel concentrations, both down material and standing live trees, related to dominant specimens, I further urge protective measure for certain visually significant understory-ground floor components. Several obvious examples of these subordinate features are snags, fallen big trees and mature, tree-form dogwoods; these and others contribute significantly to experiencing a rich landscape, are signs of time and succession, and represent considerably more than fuel needing to be burned."

Litton further added,

"Brewer, King, and Muir confirm and give emphasis to other contemporary accounts that the Sierra Nevada forest were [sic] impressive for their [sic] openness and for the large scale of mature trees. At the same time, these three early observers note the diversity of what they saw in the

various forest and woodland species, their associations, regeneration and some of the ground plane and understory characteristics. Brewer notes species or type distribution in space and elevation, the combinations of the mixed conifers --some with Big Trees, the array of ages and sizes in Big Trees, [and] the significance of fallen Big Trees in appreciating their size and age. King emphasizes the impact of contrasts found in the association of Big Trees and Sugar Pine and White Fir as well as the experience of the spatial quality found in the open forest. Muir comments on openness, on spatial distribution, on the smooth floor, but also points to the contrast of underbrush with Big Tree bark and speaks in considerable detail about Big Tree regeneration. Diversity, then, appears to be an historic clue about the historic forest in addition to the frequently stated perception of openness."

NPS and Visibility Issues

The NPS group "was unanimously opposed to allowing changes in appearance due to fire only in the medium and low visibility trees, while retaining foreground trees in their present unburned state... in general, all trees regardless of [visibility] rating will be prepared and burned according to current standards" (NPS 1988).

In the visual resource recommendations, scorch exclusion does not mean "unburned." More importantly, it will be very difficult to treat focal point trees, such as the General Sherman Tree, with intense prescribed fire. These trees are surrounded by trails, fences, facilities, and/or roads and are also subject to intensive visitor use and abuse. Most foreground trees in special management areas are stressed by pavement, soil compaction and altered topography. As one moves farther from view corridors, this type of impact (direct human disturbance) is lessened. It is evident that there is an ecological relationship between aesthetics and human use of the built environment. Treating giant sequoias in the foreground more sensitively than those further away actually recognizes the reality of conditions.

NPS and Downed Log Issues

The NPS Group agreed that "logs identified by interpretation as having cultural or interpretive value will be protected from fire. However, no effort should be made to preserve logs as horizontal elements, since these logs are important sources for seedbeds, which are an important part of the forest story. In addition, the SMA burn units are small, and it is not likely the loss of logs will produce an impact on the visual resources of the area as a whole" (NPS 1988).

Many western wildfires document that horizontal elements (logs) are increased by fire, not decreased, regardless of fire intensity (Ekey 1989; Guth 1989; Simpson 1989). Although it is difficult to compare many wildfire situations, logs are universally important ecologically and visually for the maintenance of habitat diversity. It is important to avoid the homogeneous burn coverage typical of hot fires in unnatural fuel accumulations. While totally burnt logs can

play a role in sequoia regeneration, firing techniques which attempt to burn all logs does not recognize that some logs also play an important role in the nutrient cycling of the forest by acting as nutrient reservoirs, biological reservoirs, and reducing soil erosion following a fire. If the fire burns a log as it moves through, this seems acceptable and natural. The problem is when fire crews return to spot-burn a log that the fire has by-passed.

NPS and Thinning Issues

The NPS group also agreed that "existing vistas of the Sherman, Grant, and McKinley trees should be preserved. The group was opposed to pre-burn thinning of trees which obstruct sequoias as well as to the suggestion that trees killed by the fire should be cut out" (NPS 1988).

In discussing visual resources, the many thickets exist because of park development (i.e., canopy opening) and are diminishing the scenic value of the park from roads and trails (*fig. 3*). Many of these thickets are less than fifty years old and exist as a result of managed fire exclusion and site disturbance, such as road construction. These newer thickets do block historic views, but just as importantly, also impact biological processes. Kilgore (1987) states that "removing fuel from the intermediate layer between surface and crown fuels greatly reduces the potential for high intensity surface fires that could lead to crown fires." Under a more natural fire cycle, crown fires are a relatively rare event in the giant sequoia/mixed-conifer ecosystem and would be an unnatural and unfortunate consequence of fuel load due to past fire suppression. The Christensen Report (1987) indicates approval of judicious pre-burn cutting of understory trees ... where ignition of such trees might have a negative effect on stand appearance and/or when their removal would enhance the visual effect of adjacent specimen trees."

Conclusion

Past human interference with the ecosystem of the giant sequoia/mixed-conifer forests has impacted the visual and ecological resources in Sequoia National Park. These impacts have been augmented by concentrated visitor pressure in the areas of the park with roads, trails, and built facilities. "Special Management Areas" SMA's have been established to address these complex management problems of balancing cultural and natural ecosystem interests.

The management goals at Sequoia National Park are to restore the fire climax ecosystems of the giant sequoia/mixed-conifer forests to more natural conditions through the reintroduction of fire after many years of fire suppression (Parsons and Nichols 1985). Objectives of past burns to reduce fuel loads have overlooked the need for mitigation in the areas that are under heavy impact from human use. The sensitive treatment of scenic resources in these SMAs can augment natural diversity if the structure of "naturalness" is given priority over uniformity of fuel load reduction. Management actions should seek to: (1) mimic natural fire

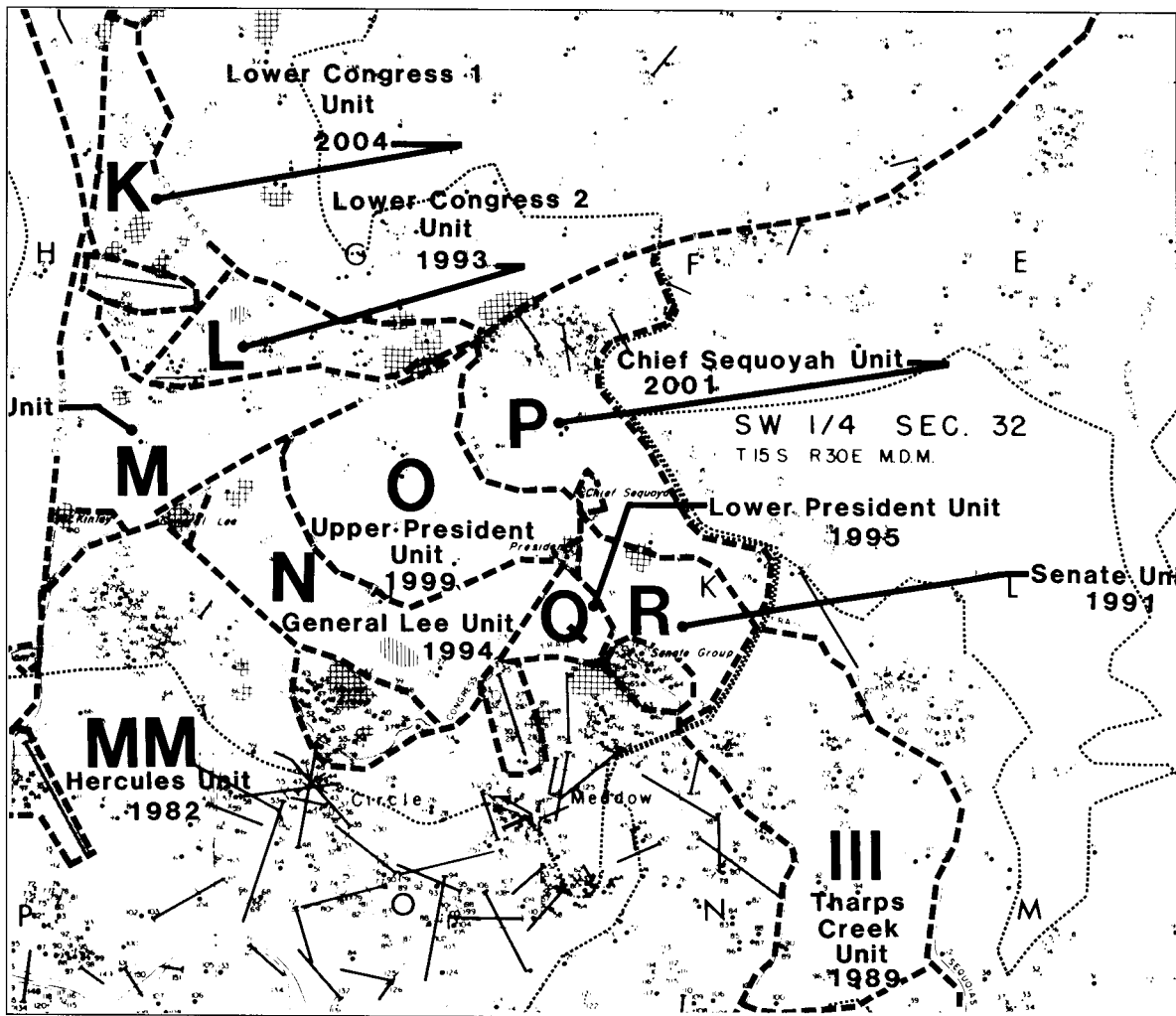


Figure 3-SMA mitigation measures for giant sequoias.

patterns whenever possible; (2) avoid artificial infrastructure as burn unit determinants; and (3) conserve and enhance scenic resources in areas threatened by intensive human use.

The detailed visual resource database and mitigation guidelines developed for the Sequoia Prescribed Fire Management Program were designed to provide park resource managers with tools to achieve more natural fire effects for the landscape and giant sequoia visual resources. There were forty-four separate treatments recommended with roughly half of the recommendations known to be implemented (Dawson and Greco 1987). It is pleasing and appreciated that support was readily forthcoming from the National Park Service for over half of the treatments. This paper has attempted to explore the complexities of the remainder. Creating favorable ecological conditions for the perpetuation of the giant sequoia is supported in this paper and prescribed fire management is a necessary approach. The goal of visual resource research has been to present ecologically acceptable solutions to problems of culture in the context of the natural environment and to study and manage the role of fire in supporting this continued improvement.

References

- Bancroft, W.L.; Nichols, H.T.; Parsons, D.J.; Graber, D.G.; Evison, Q.B.; Wagtendonk, J. Van, editors. 1985. Proceedings symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 26-29.
- Bonnicksen, Thomas M. 1985. Ecological information base for park and wilderness fire management planning. In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C.; Mutch, Robert W., tech. coords. Proceedings-symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 168-173.
- Bonnicksen, T.M. 1975. Spatial pattern and succession within a mixed conifer-giant sequoia forest ecosystem. Berkeley: University of California; Ph.D. dissertation.
- Bonnicksen, T.M.; Stone, E.C. 1982. Reconstruction of a presettlement giant sequoia-mixed conifer forest community using the aggregation approach. *Ecology* 63(4): 1134-1148.
- Christensen, N. L.; Cotton, L.; Harvey, T.; Martin, R.; McBride, J.; Rundel, P.; Wakimoto, R. 1987. Final report: review of fire management program for sequoia-mixed conifer forests of Yosemite, Sequoia and

- Kings Canyon National Parks. San Francisco, CA: U.S. Department of Interior, National Park Service; 37 p.
- Cotton, L.; McBride, J.R. 1987. Visual impacts of prescribed burning on mixed conifer and giant sequoia forests. In: Davis, James B.; Martin, Robert E., tech. coords. Proceedings of the symposium on wildland fire; 1987 April 27-30; South Lake Tahoe, CA. Gen. Tech. Rep. PSW-101. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 32-37.
- Dawson, K.J.; Greco, S.E. 1987. Special management area visual resources management study for the Sequoia National Park Prescribed Fire Management Program. Center for Design Research, Davis: University of California; 96 p.
- Ekey, R. 1989. Yellowstone on fire. Billings, MT: Billings Gazette; 128 p.
- Fischer, W.C. 1985. Elements of wilderness fire management planning. In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C.; Mutch, Robert W., tech. coords. Proceedings-symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 138-144.
- Fontaine, Joseph 1985. Recommendations from the Sierra Club for managing giant sequoia. In: Weatherspoon, C. Phillip; Iwamoto, Y. Robert; Piirto, Douglas D., tech. coords. Proceedings of the workshop on management of giant sequoia; 1985 May 24-25; Reedley, CA. Gen. Tech. Rep. PSW-95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 24-25.
- Guth, A.R.; Cohen, S.B. 1989. Red skies of '88. Missoula, MT: Pictorial Histories Publishing Co.; 124 p.
- Hammitt, W.E. 1979. Measuring familiarity for natural environments through visual images. Presented at the National Conference on Applied Techniques for Analysis and Management of the Visual Resource, Incline Village, Nevada, April, 1979. National Forest Landscape Management, volume 2. Agric. Handb. 559. Washington, DC: U.S. Department of Agriculture; 217-226.
- Harvey, H. Thomas. 1985. Evolution and history of giant sequoia. In: Weatherspoon, C. Phillip; Iwamoto, Y. Robert; Piirto, Douglas D., tech. coords. Proceedings of the workshop on management of giant sequoia; 1985 May 24-25; Reedley, CA. Gen. Tech. Rep. PSW-95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1-3.
- Harvey, H. Thomas; Shellhammer, Howard S.; Stecker, Ronald E. 1980. Giant sequoia ecology, fire and reproduction. Sci. monogr. Series 12. Washington, DC: U.S. Department of the Interior, National Park Service; 182 p.
- Kilgore, Bruce M. 1987. The role of fire in wilderness: a state-of-knowledge review. In: Lucas, Robert C., compiler. Proceedings-national wilderness research conference: issues, state-of-knowledge, future directions; 1985 July 23-26; Fort Collins, CO. Gen. Tech. Rep. INT-220. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 70-103.
- Kilgore, Bruce M. 1985. What is "natural" in wilderness fire management? In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C.; Mutch, Robert W., tech. coords. Proceedings-symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; p. 57-66.
- Kilgore, B.M.; Taylor, D. 1979. Fire history of a sequoia-mixed conifer forest. *Ecology* 60: 129-142.
- Leopold, A.S.; Cain, S.A.; Cottam, C.M.; Gabrielson, J.N.; Kimball, T.L. 1963. Wildlife management in the national parks. *American Forests* 69: 32-35, 61-63.
- Litton, R. Burton, Jr. 1988. The forest landscape and fire management: a report to Sequoia National Park. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 36 p.
- Litton, R. Burton, Jr. 1979. Descriptive approaches to landscape analysis. Presented at the National Conference on Applied Techniques for Analysis and Management of the Visual Resource, Incline Village, Nevada, April, 1979. National Forest Landscape Management, volume 2. Agric. Handb. 559. Washington, DC: U.S. Department of Agriculture; p. 77-87.
- Litton, R. Burton, Jr. 1973. Landscape control points: a procedure for predicting and monitoring visual impacts. Res. Paper PSW-91. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 22 p.
- Litton, R. Burton, Jr. 1968. Forest landscape description and inventories--a basis for land planning and design. Res. Paper PSW-49. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 64 p.
- McCool, S.F.; Stankey, G.H. 1986. Visitor attitudes toward wilderness fire management policy from 1971-84. Res. Paper INT-357. Ogden, Utah: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 7 p.
- NPS (Sequoia and Kings Canyon National Parks). 1988. Unpublished letter Y 1421. Three Rivers, CA, 4 p.
- NPS (Sequoia and Kings Canyon National Parks). 1987a. Prescribed fire management program. Three Rivers, CA: Sequoia and Kings Canyon National Parks; 26 p.
- NPS (Sequoia and Kings Canyon National Parks). 1987b. Vegetation management plan (for the development zone). National Parks Service, San Francisco, CA: Western Regional Office; 140 p.
- NPS (Sequoia and Kings Canyon National Parks). 1980a. The effect of past management actions on the composition and structure of vegetation in the Grant Tree portion of Grant Grove, Kings Canyon National Park, California. Three Rivers, CA: Ash Mountain; 174 p.
- NPS (Sequoia and Kings Canyon National Parks). 1980b. Development concept plan, giant forest/lodgepole area of Sequoia and Kings Canyon National Parks. Washington, DC: U.S. Department of the Interior; 46 p.
- Parsons, D.J.; Nichols, H.T. 1985. Management of giant sequoia in the National Parks of the Sierra Nevada, California. In: Weatherspoon, C. Phillip; Iwamoto, Y. Robert; Piirto, Douglas D., tech. coords. Proceedings of the workshop on management of giant sequoia; 1985 May 24-25; Reedley, California. Gen. Tech. Rep. PSW-95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 26-30.
- Quinn, J. 1989. Visitor perception of NPS fire management in Sequoia and Kings Canyon National Parks: results of a survey conducted summer 1987. Technical Report Number 36. Davis: University of California; 108 p.
- Simpson, R. 1989. The fires of '88. Helena, MT: American Geographic Publishing; 80 p.
- Taylor, J.G.; Daniel, T.C. 1985. Perceived scenic and recreational quality of forest burn areas. In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C.; Mutch, Robert W., tech. coords. Proceedings-symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 398-406.
- United States Congress. 1916. Enabling legislation for the National Park Service.
- Van Wagtenonk, J.W. 1985. Fire suppression effects on fuels and succession in short-fire-interval wilderness ecosystems. In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C.; Mutch, Robert W., tech. coords. Proceedings-symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; p. 119-126.

Objects or Ecosystems? Giant Sequoia Management in National Parks¹

David J. Parsons²

Abstract: Policies and programs aimed at protecting giant sequoia (*Sequoiadendron giganteum*) in the national parks of the Sierra Nevada have evolved from the protection of individual trees to the preservation of entire ecosystems. We now recognize that the long-term preservation of giant sequoia depends on our ability to minimize and mitigate the influences of human activities. National Park Service management strategies for giant sequoia focus on the restoration of native ecosystem processes. This includes the use of prescribed fire to simulate natural ignitions as well as the movement of visitor facilities out of the groves. Basic research is being carried out to improve our understanding of the factors influencing giant sequoia reproduction, growth, and survival. Future management decisions must recognize that giant sequoia are only part of a complex ecosystem; they cannot be managed as objects in isolation of their surroundings.

Management of giant sequoia (*Sequoiadendron giganteum*) on national park lands has evolved from emphasizing the protection of individual trees to recognition of the species as an integral part of a complex ecosystem. Improved understanding of the complex and dynamic nature of the giant sequoia ecosystem, including its dependence on periodic disturbance and its sensitivity to human activities, has forced the USDI National Park Service to periodically reassess management policies and practices.

It is now recognized that the overriding goal of preserving naturally functioning ecosystems can often not be achieved by simply letting nature take its course. Impacts from fire suppression, air pollution, visitor use and associated facilities, and other human induced changes must be mitigated through active management action. This requires difficult decisions based on the best possible scientific data. Management objectives and strategies must be scientifically based, clearly articulated, and periodically reassessed.

Within the National Park system the giant sequoia is native only to Sequoia, Kings Canyon, and Yosemite National Parks in California. The history of management of giant sequoia within these parks has closely mirrored the history of National Park Service resource management policy. From an "era of spectacles" in which objects and scenes (big trees, deep canyons, and high mountains) were "protected" from all injury, the management of National Park resources has evolved to an emphasis on the restoration and preservation of natural biotic communities (Graber 1983). In the case of giant sequoias, management concern now focuses on restoring natural fire regimes, mitigating the impacts of increasing visitor use and associated developments, and understanding

the effects of such external threats as air pollution and projected human induced climatic change. The challenges associated with assuring the long-term preservation of giant sequoia have become increasingly complicated as we have learned more about the complexity and inter-relatedness of the greater Sierra Nevada ecosystem.

This paper briefly reviews the history of giant sequoia management in the National Parks of the Sierra Nevada, emphasizing a gradually improved understanding of giant sequoia ecosystems and how management has attempted to incorporate this understanding; outlines current management philosophy and strategies; and reviews issues and concerns for the future of giant sequoia management in national parks.

History of Giant Sequoia Management in National Parks

Giant sequoia have been "protected" within the boundaries of Sequoia, Kings Canyon, and Yosemite National Parks since the creation of the three parks in 1890 (the portion of Kings Canyon containing giant sequoia was originally established as General Grant National Park). The strategies employed to insure this protection have evolved from relatively simple protection from logging, fire, and visitor abuse to more complex efforts to preserve naturally functioning ecosystems, including the restoration of fire as a natural process.

Deeded to the State of California as part of the Yosemite Act of 1864, the Mariposa Grove of giant sequoias was included in the first public reservation designated by the Federal government for the long-term protection of natural features (Runte 1990). This action protected the Mariposa Grove from the extensive logging activities that devastated many sequoia groves in the years that followed. Such protection was extended to include other groves with the creation of Sequoia, General Grant (enlarged to become Kings Canyon in 1940), and Yosemite National Parks in 1890. Interest in protecting remaining intact sequoia groves from timber harvest was a primary motivation in the creation of these parks (Dilsaver and Tweed 1990). For the next 26 years park management consisted largely of Cavalry troops patrolling to stop poachers and illegal timber harvest and to deal with the growing problems associated with increasing visitation. Creation of the National Park Service in 1916 symbolized the beginning of a new era, characterized by on-site, year round management attention and an increased emphasis on attracting tourists and developing a supportive clientele.

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²Research Scientist, National Park Service, Three Rivers, CA 93271

In the early days, National Park Service management of giant sequoia focused on protection of the big trees from logging, fire, and other injury. Fire and pests were aggressively controlled and the cutting of live trees prohibited. Often phrased in terms of "preservation," the actual practice was a hands-off policy of protection (Hartesveldt 1962). Many of the larger trees were named after generals or other heroic figures, emphasizing their status as objects apart from the surrounding ecosystem. Little thought was given to preserving the ecological processes necessary to preserve the health of the giant sequoia ecosystem.

As early as 1864 concern was first expressed over the importance of preserving the "natural scene" of the Mariposa Grove from expected increases in human visitation (Olmsted 1865). Yet many decades passed before this wisdom was widely accepted. Well into the 20th century giant sequoia management in the national parks continued to focus on "protecting" the big trees from damage, while simultaneously providing for a pleasurable visitor experience.

The 1916 Organic Act which created the National Park Service called for leaving resources "unimpaired." Yet the meaning of this term was not clearly defined, often leaving policy direction ambiguous and imprecise. A 1926 report by the forest pathologist Meinecke (1926) emphasized the importance of protecting the largest and oldest specimen sequoias because of their inherent attractiveness. Hartesveldt (1962) has detailed the struggles of National Park Service administrators to protect giant sequoias in the decades following Meinecke's report. During this time, trees continued to be named and protective fences were built-including one best described as a "barbed wire entanglement,"-around the more popular specimens. Campgrounds, visitor centers, parking lots, lodging facilities, and roads and trails were built within the sequoia groves. And whereas great care was often taken to hand excavate around the larger feeder roots, little concern was shown for the potential long-term effects of soil compaction or the eventual failure of underground water and sewer systems on the shallow rooted big trees. Fire continued to be viewed largely as a destroyer of forest values.

Understory thinning carried out in the 1930's in the Mariposa Grove to reduce both competition from white fir (*Abies concolor*) and hazardous fuel accumulations spurred considerable debate over the need for active management in the sequoia groves. For the first time it was suggested that both preservation in the "natural" or "original" conditions was an impossibility and fire protection should be regarded as unnatural and steps be taken to compensate for its effects (Hartesveldt 1962). A limited understanding of the ecology of the giant sequoia ecosystem together with an apparent inability to clearly define such ambiguous terms as "natural," "unimpaired," "protection," and "preservation," hindered development of definitive objectives for giant sequoia management. Thus the need for scientific data upon which to make management decisions first became recognized.

Mitigating Human Impacts:

Increased recognition of the importance of scientific data eventually led to the support of comprehensive studies of management and visitor impacts in the giant sequoia groves. The combination of Hartesveldt's studies of human impacts to soil and vegetation in the Mariposa Grove of Yosemite National Park (Hartesveldt 1962) and subsequent studies in Sequoia and Kings Canyon (Hartesveldt 1963, 1965) were the first to quantitatively analyze the effects of historic management practices-which had been a concern since at least the 1920's (Hartesveldt 1962).

Other than occasional fences, understory thinning, or rerouting of trails and roads one of the first major efforts to mitigate the effects of human activities on giant sequoias involved the movement of campgrounds and picnic areas from the heart of the Giant Forest Grove during the 1960's. In the 1970's a development plan was approved to move most of the other visitor facilities out of the Giant Forest. Today, construction continues on new visitor facilities outside of the grove. When completed, only roads, trails, and a small visitor contact center will remain in the grove. All lodging and food facilities will be moved and the heavily impacted portions of Giant Forest restored to a more natural condition.

In Yosemite's Mariposa Grove, extensive understory thinning has been used to reduce fuel hazards and open vistas. The heavy visitor use in this grove is now restricted to access by foot or through an interpretive tram system. Other than a museum, the once extensive visitor facilities and access by private auto have been eliminated.

Fire Management:

Concern over the effects of fire suppression on increasing fuel hazards in the mixed-conifer forests of the Sierra Nevada (Agee 1968, Biswell 1961, Leopold and others 1963) led to the first experimental burns in the Redwood Mountain Grove of Kings Canyon National Park in the mid 1960's. Studies conducted in conjunction with these first burns documented significant fuel reduction and the dependence of giant sequoia on fire for regeneration (Hartesveldt and Harvey 1967, Harvey and others 1980). By 1972 prescribed burning had become firmly established as a routine management program in all three Sierra Nevada parks. Burns in the sequoia groves of Sequoia and Kings Canyon were conducted with minimal preburn manipulation whereas extensive preburn cutting of understory species was carried out in the Mariposa Grove of Yosemite. Scientific studies accompanying these early burns provided an improved understanding of the effects of fire on ecosystem properties (Kilgore 1973) as well as documentation of the results of individual prescribed burns (Parsons and van Wagtenonk 1994).

Goals for sequoia/mixed-conifer prescribed burns conducted during the 1970's focused largely on fuel reduction and understory removal. Burning prescriptions were based on fire behavior characteristics and burns were usually of small size and uniform intensity with little attention given to

preserving the patchiness of the forest (Bancroft and others 1985). If areas were left unburned additional fire was added. As the program matured there was increased recognition of the natural role of fire in creating and maintaining species and age class mosaics, cycling nutrients, and controlling disease organisms. More recently, evidence has been presented supporting the importance of locally high intensity fires in opening the canopy and favoring the establishment of giant sequoia (Stephenson and others 1991). Such information led to a revaluation of the goals of the fire management program and subsequent adoption of the overall goal of restoring "natural" fire regimes. As a result, prescribed burns are now ignited with spot ignitions and fuels, and weather and topography are permitted to produce a mosaic of fire behaviors and effects. Burn units are larger, frequently in the hundreds of acres, and if some areas within a unit do not burn they are left unburned.

The program of prescribed burning in the sequoia groves has been criticized for failure to recognize the "unnaturalness" of the preburn forest structure (Bonnicksen and Stone 1982) and for the visual impacts of bark char and canopy scorching (Cotton and McBride 1987). These issues stimulated a thorough review of program objectives and practices. Today, individual prescribed burns are classified as either restoration burns or simulated natural fires depending on the unnaturalness of preburn fuel conditions. Monitoring of fire effects is now much more comprehensive while extensive new research has been undertaken on fire history and the effects of fire intensity on forest structure and pathogen populations (Parsons 1990).

Current Management Philosophy and Strategies

Today, approximately 33 of the 75 natural groves of giant sequoia are under national park jurisdiction (Rundel 1972). These include the Redwood Mountain Grove in Kings Canyon and the Giant Forest Grove in Sequoia National Park, the two largest remaining uncut groves. The combined 33 groves occupy about 11,223 acres of giant sequoia, including over 54,400 trees greater than one-foot in diameter (*table 1*). All of the sequoia groves on National Park land are managed as natural areas.

National Park Service Management Policies (NPS 1988) for natural zones call for the "protection of natural resources and values for appropriate types of enjoyment while ensuring their availability to future generations." They further state that management "will not attempt solely to preserve individual species (except threatened or endangered species) or individual natural processes; rather, they will try to maintain all the components and processes of naturally evolving park ecosystems." As applied to the giant sequoia, this policy simply emphasizes the importance of understanding and preserving the entire ecosystem rather than focusing solely on the sequoia. It also emphasizes the importance of restoring the fire regime, including its varying nature and its myriad

of effects, not simply the restoration of the process of fire itself. Other significant direction found in the Management Policies includes recognition that change is "an integral part of the functioning natural system" and "that management activities may be required to either reverse past human activities or to maintain the closest approximation of the natural ecosystem where a truly natural system is no longer attainable" (NPS 1988).

Given this policy direction, strategies for managing giant sequoias in national parks today focus on the restoration of fire as a natural process, the removal of visitor facilities from groves and mitigation of associated impacts, and increased emphasis on education and research. Most recently, the importance of coordinating such activities with surrounding land management agencies has been emphasized.

Fire Management:

The use of prescribed fire to restore more natural conditions to ecosystems provides an excellent example of the value of proactive management and clearly articulated management objectives. Yet, since many aspects of the nature and effects of varying fire regimes remain unknown, it is often difficult to be sure what specific objectives would be most appropriate for individual burns. Burns designed to restore some previous condition are dependent on an understanding of that condition. Arguments in favor of either protecting individual trees as objects or restoring or maintaining sequoia groves in a static state, as if they were a snapshot in time, the (Leopold and others 1963, Bonnicksen and Stone 1982) run counter to current management policy (Parsons and others 1986, Lemons 1987). Today, the parks' fire management programs attempt to restore fire as a natural process, burning in the range of frequencies and intensities and with a similar range of effects as would have occurred had modern humans not interfered. Although this goal may never be fully attained, it provides both a target and a means for establishing standards against which success can be evaluated. The major obstacles continue to be the difficulty in understanding just what is natural and thus articulating specific objectives for individual burns.

Specific techniques designed to minimize blackening of the bark and scorching of the crown on sequoia trees are now incorporated in the Fire Management Plans for the Parks. These techniques, which include the removal of fuels around the base of trees, burning out from the base, use of foam or water to protect fire scars, and burning with moderate prescriptions (Sequoia and Kings Canyon 1992), are designed to reduce the aesthetic impacts of prescribed burning to which Cotton and McBride (1987) and others object (Parsons 1990). In addition, Special Management Areas (SMAs), where small burns are conducted emphasizing scenic and smoke management concerns, have been identified in several groves (Sequoia and Kings Canyon 1992). The long-term effects of such concessions to protect visual resource values at the expense of natural ecosystem processes are largely unknown.

Table 1-Giant sequoia groves, including size and number of trees over 1 foot in diameter (dbh) for the three Sierran National Parks.

Park	Grove	Acres	#Trees>1'dbh
Kings Canyon	Big Stump	257	2,237
	Grant	154	411
	Redwood Mountain	3,154	15,809
	Sequoia Creek	21	35
	Total:	3,586	18,492
Sequoia	Atwell	1,335	4,619
	Cahoon Creek	14	96
	Castle Creek	197	790
	Clough Cave	0.5	3
	Coffeepot Canyon	5	41
	Dennison	11	49
	Devils Canyon	6	34
	East Fork	751	4,773
	Eden Creek	361	1,327
	Garfield	1,130	7,254
	Giant Forest	1,800	8,411
	Homers Nose	245	1,108
	Horse Creek	42	157
	Lost	54	220
	Muir	272	1,163
	New Oriole Lake	21	50
	Oriole Lake	147	693
	Pineridge	94	122
	Putnam-Francis	0.1	1
	Redwood Creek	105	217
	Redwood Meadow	223	2,727
	Skagway	94	254
	South Fork	210	917
	Squirrel Creek	2	2
	Surprise	4	37
	Suwanee	100	289
	Total:	7,224	35,354
Yosemite	Mariposa	333	-
	Merced	45	-
	Tuolumne	35	-
	Total:	413	-
	Total:	11,223	53,846

In practice, fire management in national park sequoia groves continues to include active suppression of all fires not either intentionally set or, if lightning ignited, falling within preestablished prescriptions. It is hoped that prescribed burns can be used to reduce fuels to the point where natural ignitions can be permitted to burn without fear of escape or unnatural effects. The long-term goal is to include the sequoia groves and the rest of the mixed-conifer forest, in a prescribed natural fire zone in which most lightning ignitions would be allowed to burn. Under such a condition, fires starting within the groves, or burning into the groves but suppressed for safety or other reasons, would be simulated by prescribed burns set at a later date. Fire growth

models are being developed to help understand which fires would have burned into the groves had they not been suppressed (M. Finney, pers. comm.). Other computer models that identify the "natural" range or variability of fuel accumulation for a given area are available to help managers determine if and when a prescribed burn is needed by (van Wagtenonk 1985).

Although two lightning ignitions (burning 150 acres in the Muir Grove in 1986 and 720 acres in the Atwell Grove in 1991) have been permitted to burn within sequoia groves and shown what is thought to be relatively natural behavior and effects, no target date has been set for the placement of all sequoia groves within a natural fire zone.

Despite the increased understanding of both the role of fire in giant sequoia forests and the techniques of prescribed burning, numerous problems and questions remain unanswered. If the effects of fire suppression from the past century are to be fully mitigated, methods must be found to increase the acreage burned. Problems of smoke production and restrictions on burning due to air quality controls must also be resolved. The task of emphasizing the importance of fire to the public must be continued and intensified. And finally, we must continue to improve our understanding of the long-term effects of different intensities and seasons of fires on various ecosystem properties. As the goals of individual burns change from fuel reduction to the mimicking of natural conditions, increased attention must be given to simulating the variability of behavior and effects of natural fire regimes, including the variable effects on ecosystem properties.

Human Intrusion:

In addition to the efforts to restore fire as a natural ecosystem process, National Park Service management of sequoia groves now emphasizes managing human intrusion in the groves. In the early years of the Parks, the sequoia groves presented a tremendous aesthetic attraction and thus much of the early development was concentrated within them. Recognition of the negative aesthetic, ecological, and safety impacts of excessive development (a visitor was killed by a falling tree while picnicking in a designated picnic area in 1969) has led to the progressive removal of visitor facilities over the years (Dilsaver and Tweed 1990).

The impacts of human intrusion on the giant sequoia have especially affected the Giant Forest of Sequoia National Park. Facilities within the Giant Forest include a lodge, cabins, dining room, cafeteria, gift shops, market, parking lots, and employee housing. Together with antiquated water and sewage facilities and increasingly hazardous trees, these facilities negatively impact the health, safety, and appearance of the area. Public hearings in the early 1970's provided direction for the removal of most developments within the Giant Forest (Dilsaver and Tweed 1990). A new visitor center and associated lodging, food, and employee facilities were to be built outside of the grove. Today, 20 years later, most of the Giant Forest facilities continue to be used. Campgrounds and picnic grounds have been moved and a new Visitor Center built. Yet, while construction is underway on major new lodging and food facilities that will finally permit the abandonment of most of the remaining facilities in Giant Forest, funding problems have pushed the projected completion date into the 21st Century. But once the facilities have been constructed considerable effort will remain in removing existing facilities and rehabilitating the disturbed sites. No plans exist for removing roads, campgrounds (Atwell Grove), cabins (Merced Grove), or museums (Mariposa Grove) from other groves with such developments.

Education:

Education provides one of the most effective strategies for assuring the long-term perpetuation of giant sequoia. An understanding of the nature and sensitivity of the species and its surrounding ecosystem provides both managers and visitors with the tools and motivation necessary to minimize many potentially damaging impacts. The Sierra Nevada national parks have given significant emphasis to developing diverse interpretive and education programs to provide information on factors influencing giant sequoia. These include guided walks, evening seminars, park newspapers, and books and brochures. A review of the effectiveness of the interpretive program in Sequoia and Kings Canyon in providing information on the prescribed fire program confirmed the value of these efforts (Quinn 1988). Other issues that are routinely addressed in interpretive programs and publications include wildlife associated with the big trees, the effects of air pollution, and the value of sequoia tree rings in understanding fire and climate history and the influences of climate on tree growth.

Research:

Scientific research and associated monitoring provide the understanding necessary to make management decisions. The recent evolution of management policies as well as specific management decisions related to giant sequoia have been largely based on improved scientific data. Beginning with the studies of Hartesveldt (1962, 1963) on human impacts, and Harvey and others (1980) and Kilgore (1973) and others on fire ecology, a firm basis has been provided for decisions to remove visitor intrusions and establish a prescribed fire program. Challenges to the prescribed fire program (Bonnicksen and Stone 1982, Cotton and McBride 1987) have spurred additional studies which in turn have provided increased understanding and an improved basis for adjusting policies and strategies (Parsons 1990). Today, research emphases include collection of basic data on forest dynamics (recruitment, mortality, influences of disturbances, etc.) as well as development of a forest simulation model that will permit managers to ask "what if" questions related to different fire, climate, or management scenarios (Stephenson and Parsons 1993). In addition to a continuing emphasis on research, a scientifically based monitoring system is in place to help with the periodic evaluation of management actions as well as the detection of possible change.

Regardless of the strength of the research history associated with giant sequoias, the need for improved understanding of ecosystem processes and management consequences cannot be overemphasized. Specific questions regarding fire effects must still be addressed. These include the effects of burn intensity, seasonality, and frequency; the unnaturalness of ground or crown fuels; and the effects of predicted future increases in air pollution or human induced climate change on the distribution of the species. Research

on fire and forest ecology, air pollution effects, and potential effects of global climate change (Stephenson and Parsons 1993) should be continued in order to answer such questions.

Issues and Concerns for the Future

Despite the fact that giant sequoia have been a focus of public attention and management dilemma for well over a century, we are only now beginning to understand many of the factors influencing recruitment and survival of the species. For example, recent research has provided a greatly improved understanding of the often subtle interactions of climate, fire, and vegetation. It has also improved our understanding of the effects of human activities, such as trampling and air pollution, on giant sequoia. Yet, despite these advances in knowledge, most management decisions continue to be made without sufficient information to accurately assess either the short or long-term ramifications of the action. It is virtually impossible to fully anticipate future issues and concerns.

The importance of continued and enhanced monitoring and research, coupled with mechanisms to assure that new information is incorporated into management decisions, cannot be overemphasized. The ultimate goal of such programs should be the development and testing of predictive models capable of forecasting the consequences of alternative management strategies. It will become increasingly important that managers understand the implications of decisions before they are made.

In addition to improving our information base, key ecosystem management decisions should be based on a regional or even global perspective. We now recognize that many of the most important influences on species distributions and general ecosystem health transcend administrative boundaries. Climate, air pollution, and large scale fires, for example, operate without regard for such administrative delineations. An increasing emphasis on a bioregional approach to resource and management issues is evident in ongoing research on global climate change (Stephenson and Parsons 1993), a new statewide interagency memorandum of understanding on biodiversity and bioregional planning (State of California 1992), and the formation of an interagency managers group to deal with diverse resource issues (Parsons 1991 a). These early stages of interagency cooperation need to significantly expand if the land management agencies can adequately face the key resource issues likely to arise in the next century.

Many resource issues related to giant sequoia are likely to become intensified in the 21st century. Growing population in the neighboring regions can be expected to increase visitation to the parks. This will mean larger numbers of people driving to the parks, walking the trails, and desiring food and lodging facilities. The parks will need to address these needs by considering improved transportation systems and locations for new facilities. Air pollution, which has already been shown to impact other tree species in the parks (Duriscoe and Stolte 1989) can be expected to increase, with

uncertain effects on giant sequoia and its associated species. Prescribed burn programs to both reduce unnatural fuels and simulate natural fires must face the challenge of increasing restrictions on smoke production designed to protect air quality. In addition, management must address the increasing evidence that locally intense fires may have played an important prehistoric role in opening the canopy and preparing favorable microsites for sequoia recruitment (Stephenson and others 1991). Yet, perhaps the most uncertain of the future stresses is that associated with predictions of human-induced climatic change. Such change could be expected to alter species distributions, disrupt communities as we know them, and increase the frequency and intensity of extreme climatic events (and concomitantly the frequency and intensity of fires). Such changes could force a re-examination of the role of national parks (Parsons 1991b), including a redefinition of the goals of preserving examples of "natural" ecosystems.

The long-term preservation of giant sequoia will require an improved understanding of the factors controlling species distribution and other natural ecosystem processes. An accelerated research and monitoring program must be accompanied by an increased emphasis on education. By applying these programs, managers and the public will help assure the long-term preservation of both the species and associated ecosystem. It is critical that science play an increasing role in the difficult decisions that must be made to ensure the long-term preservation of both giant sequoia and the greater Sierra Nevada ecosystem.

References

- Agee, James K. 1968. Fuel conditions in a giant sequoia grove and surrounding plant communities. Berkeley: University of California; 55 p. M.S. Thesis.
- Bancroft, Larry; Nichols, Thomas; Parsons, David; Graber, David; Evison, Boyd; van Wagendonk, Jan. 1985. Evolution of the natural fire management program at Sequoia and Kings Canyon National Parks. In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C.; Mutch, Robert W., technical coordinators. Proceedings of the Symposium and Workshop on Wilderness Fire. 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182; Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 174-180.
- Biswell, Harold H. 1961. The big trees and fire. National Parks and Conservation Magazine 35: 11-14.
- Bonnicksen, Thomas M.; Stone, Edward C. 1982. Managing vegetation within U.S. national parks: a policy analysis. Environmental Management 6: 101-102, 109-122.
- Cotton, Lin; McBride, Joe R. 1987. Visual impacts of prescribed burning on mixed-conifer and giant sequoia forests. In: Davis, James B.; Martin, Robert E., technical coordinators. Proceedings of the Symposium on Wildland Fire 2000. 1987 April 27-30. South Lake Tahoe, CA. Gen. Tech. Rep. PSW-GTR-101, Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 32-37.
- Dilsaver, Larry; Tweed, William. 1990. Challenge of the Big Trees. Three Rivers, CA: Sequoia Natural History Association; 378 p.
- Duriscoe, Daniel M.; Stolte, Kenneth W. 1989. Photochemical oxidant injury to ponderosa pine (*Pinus ponderosa* Laws.) and Jeffrey pine (*Pinus jeffreyi* Grev. and Balf.) in the national parks of the Sierra

- Nevada of California. In: Olson, Richard K.; Lefohn, Allen S., editors. Transactions Effects of Air Pollution on Western Forests. Pittsburgh, PA: Air and Waste Management Association; 261-292.
- Hartesveldt, Richard J. 1962. The effects of human impact upon *Sequoia gigantea* and its environment in the Mariposa Grove, Yosemite National Park, California. Ann Arbor: University of Michigan; 310 p. Ph.D. dissertation.
- Hartesveldt, Richard J. 1963. Reconnaissance study of the effects of human impact upon moderately to heavily used sequoia groves in Sequoia and Kings Canyon National Parks. Unpublished report to National Park Service. 46 p.
- Hartesveldt, Richard J. 1965. An investigation of the effect of direct human impact and of advanced plant succession on *Sequoia gigantea* in Sequoia and Kings Canyon National Parks, California. Unpublished report to National Park Service. 82 p.
- Hartesveldt, Richard J.; Harvey, H. Thomas. The fire ecology of sequoia regeneration. In: Proceedings of the California Tall Timbers Fire Ecology Conference; 1967 November 9-10; Hoberg, CA. Tallahassee: Tall Timbers Research Station; 7:65-77.
- Kilgore, Bruce M. 1973. The ecological role of fire in Sierran conifer forests: its application to national park management. Journal of Quaternary Research 3: 496-513.
- Leopold, A. Starker; Cain, Stanley A.; Cottam, Clarence; Gabrielson, Ira N.; Kimball, Thomas L. 1963. Wildlife management in the national parks. American Forestry 69: 32-35, 61-63.
- National Park Service. 1988. Management policies. Washington, DC: U.S. Department of Interior.
- Olmsted, Frederick L. 1865. The Yosemite Valley and the Mariposa big trees: a preliminary report, 1865. Landscape Architecture 43(1): 12-25.
- Parsons, David J. 1990. The giant sequoia fire controversy: the role of science in natural ecosystem management. In: van Riper, Charles, III; Stohlgren, Thomas J.; Veirs, Stephen D., Jr.; Hillyer, Silvia Castillo, editors. Examples of resource inventory and monitoring in National Parks of California. Transactions and Proceedings Series No. 8. Washington, D.C.: National Park Service, U.S. Department of Interior; 257-267.
- Parsons, David J. 1991 a. Preparing the Sierran parks for global issues of the 21st Century. In: Yosemite Centennial Symposium Proceedings; 1990 October 13-20; Walnut Creek, CA. El Portal, CA: Yosemite Association; 150-155.
- Parsons, David J. 1991 b. Planning for climate change in national parks and other natural areas. The Northwest Environmental Journal 7: 255-269.
- Parsons, David J.; Graber, David M.; Agee, James K.; van Wagtendonk, Jan W. 1986. Natural fire management in national parks. Environmental Management 10: 21-24.
- Parsons, David J.; van Wagtendonk, Jan W. 1994. Restoring fire to the national parks of the Sierra Nevada. In: Halvorson, William; Davis, Gary, editors. Proceedings of the AAAS Conference, Efficacy of Long Term Research in National Parks. Tucson, AZ: University of Arizona Press; in press.
- Quinn, Joyce A. 1988. Visitor perception of NPS fire management in Sequoia and Kings Canyon National Parks: results of a survey conducted summer 1987. National Park Service CPSU-UCD Technical Report No. 35. Davis: University of California; 35 p.
- Rundel, Philip W. 1972. An annotated check list of the groves of *Sequoiadendron giganteum* in the Sierra Nevada, California. Madrono 21(5): 319-328.
- Runte, Alfred. 1990. Yosemite, the embattled wilderness. Lincoln: University of Nebraska Press; 271p.
- Sequoia and Kings Canyon National Parks. 1992. Fire Management Plan. Three Rivers, CA: U. S. Department of Interior National Park Service.
- State of California. 1992. The Sierra Nevada: Report of the Sierra Summit Steering Committee. Sacramento, CA: Resources Agency of California; 54 p.
- Stephenson, Nathan L.; Parsons, David J. 1993. Implementing a research program to predict the effects of climatic change on the Sierra Nevada. In: Veirs, Stephen D.; Stohlgren, Thomas J.; Schonewald-Cox, Christine, editors. Proceedings of the Fourth Conference on Research in California's National Parks. 1991 September 10-12; Davis, CA. Denver, CO: Transactions and Proceedings Series 9. National Park Service, U.S. Department of Interior; 93-109.
- Stephenson, Nathan L.; Parsons, David J.; Swetnam, Thomas W. 1991. Restoring natural fire to the sequoia-mixed conifer forest: should intense fire play a role? In: Proceedings 17th Tall Timbers Fire Ecology Conference, High Intensity Fire in Wildlands: Management Challenges and Options. 1989 May 18-21; Tallahassee, FL. Tallahassee: Tall Timbers Research Station; 321-337.
- van Wagtendonk, Jan W. 1985. Fire suppression effects on fuels and succession in short-fire-interval wilderness ecosystems. In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C.; Mutch, Robert W., technical coordinators. Proceedings of the Symposium and Workshop on Wilderness Fire. 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182; Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 119-126.

Giant Sequoia Management Strategies on the Tule River Indian Reservation¹

Brian Rueger²

Abstract: Giant sequoia trees and forests have long been valued by members of the Tule River Tribal community. Management of the Reservation forests emphasize the enhancement of overall forest health and productivity while maintaining cultural and esthetic values. Strategies for managing giant sequoia forests have been developed and are implemented on a site specific basis. Projects are initiated and completed by the Tribe's Natural Resources Department.

Located in southern Tulare County, California, the Tule River Indian Reservation was established in 1873. The Tule River Tribe is a federally recognized Indian Tribe governed by a nine-member Tribal Council. The tribe's land base encompasses nearly 55,000 acres. Giant Sequoia (*Sequoia-dendron giganteum* [Lindl.] Buchholz) occurs with other conifer species at almost 5,500 to 6,000 feet elevation. The Tule River Tribal Council manages their sequoia groves with general oversight provided by the USDI Bureau of Indian Affairs. For over 40 years, Tribal use of the groves has focused on recreation, whitewood timber production, and utilization of dead and down wood for minor forest products. Current grove management strategies emphasize protecting the old-growth sequoias and selected young-growth replacements, maintain esthetic and cultural values, reducing fuel loads, improving sequoia regeneration, and integrating young-growth sequoia as a mixed-conifer timber component.

The Reservation is characterized by a variety of land-forms and vegetation types. Grassland, blue oak woodland and chaparral occupy the foothills below 4,000 feet. Black woodland and ponderosa pine forest dominate the 4,000 to 5,000 foot level. Mixed-conifer forest begins at about 5,000 feet and extends upwards to 7,000 feet. True fir forest can be found on north-facing slopes above 7,000 feet. Giant sequoia commonly mixes with ponderosa and sugar pine, white fir and incense-cedar between 5,500 and 6,500 feet. This diversity of forest and range resources has provided the Reservation community with recreational opportunities, cultural values, and economic benefits for many years.

Forest management activities are planned in response to Tribal Council objectives and policy. Individual projects are implemented by the Tribe's Natural Resources Department with assistance from its forestry consultant, Integrated Forest Management. General oversight and assistance is provided by the Bureau of Indian Affairs.

Giant sequoia is found in relatively open stands and is the dominant species whenever it occurs in the mixed-conifer forest. These sites are among the highest, in terms of their productivity and potential for conifer growth, of any found on the Reservation. Subsequently, these locales were among the first to be entered when whitewood timber harvesting began more than 40 years ago. Except for the dead and down trees, the giant sequoias have not been used for forest products.

Community use of giant sequoia areas has historically been for recreation, cultural values, and for products derived from the dead and down trees. These same areas comprise a high percentage of the best growing sites for the other mixed-conifer species and generate a significant portion of the whitewood timber sale revenue for the Tribal Council. Giant sequoia management strategies, therefore, involve providing both cultural and economic benefits to the Reservation community.

'Micro' Forest Management

Although it is not Tribal custom to name and delineate 'grove' boundaries, the forest is broken into smaller aggregates, or 'micro' forests, each sharing one or several common characteristics. For example, a 300-acre giant sequoia forest may be further divided into smaller forests of similar species composition, density, age class or a combination of these and other characteristics. These aggregates are then mapped and the data entered into a geographic information system (GIS) database and combined with other resource information, such as cultural resources sites, soils, and fuel loads, for developing management strategies on a site specific basis.

Generally, giant sequoia management strategies include:

- Protecting the ancient giant sequoias and selected young 'replacement' trees
- Maintaining esthetic and cultural values, particularly at those sites identified by the Tribal Council
- Continuing to manage whitewood species for timber production, with emphasis placed on removing dead, dying, and hazardous whitewoods
- Creating conditions favorable for giant sequoia establishment and growth
- Reducing fuel loads within and adjacent to giant sequoia management units
- Integrating young-growth giant sequoia as a mixed-conifer timber component.

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²Consulting Forester, Integrated Forest Management, P.O. Box 711, Springville, CA 93265

Observations following whitewood timber harvests in the 1950's and 1960's and more recent trials suggest that natural giant sequoia regeneration is best, and in many cases prolific, where openings larger than 1/2 acre were created and the surface of the ground was sufficiently disturbed to expose mineral soil for seedling establishment. If giant sequoia regeneration is a priority when planning a whitewood timber sale, the group selection or similar site specific silvicultural method is often applied.

When a light whitewood harvest has occurred, an understory of white fir and incense-cedar usually follows with little or no sequoia establishment. Such silvicultural methods as individual tree selection, intermediate thinning, and sanitation cuts on the associated whitewoods may promote growth on younger sequoias and reduce fuel loads, but do little to enhance sequoia establishment.

The Tribal Council is now concerned with the widespread mortality of whitewood species due to forest insect infestation. The resultant build-up of hazardous aerial fuels presents a significant fire hazard to the entire Reservation forest. Timber sales are currently geared towards removing dead, dying, and insect-infested whitewoods both within and outside giant sequoia sites.

Where giant sequoia has naturally regenerated it usually outgrows the other mixed-conifer species. Since these areas are good growing sites they often support an overabundance of young trees of all species. Overstocked 15-30 year old stands are identified and considered for pre-commercial thinning through the Tribe's forest improvement program. Improving the mix of species and conditions for growth are important goals of the pre-commercial thinning program.

Giant sequoia is planted periodically with other conifer seedlings. Successful plantings have been made outside existing sequoia growing sites. Seedlings are purchased from the California Department of Forestry nursery system. We hope to begin collecting sequoia cones to eventually build a Reservation seed bank.

Site preparation and ground fuel reduction is generally accomplished by using mechanical and manual methods. The Tribe can complete many of these tasks through timber sale proceeds or contracts. Prescribed burning has been used sparingly to date, primarily because of the narrow burning window, high cost, and risk. Burning is being given greater consideration, although it may have limitations when managing for all-aged stands.

Conclusion

Our goal in managing the giant sequoia, as with each of the conifer species, is to maintain a healthy mix of all ages and sizes. The forest and Reservation community is best served when a diverse selection of vigorous trees is supported.

We have found that recreational opportunities for the Reservation Community can be enhanced, cultural and esthetic values of the forest maintained, and the Tribe's financial security met through prudent forest management strategies can enhance the health and vigor of the Tribe's giant sequoia, as well as their mixed-conifer forest. Although these objectives are inherently quite different, we have found they are not mutually exclusive.

Management of Giant Sequoia on Mountain Home Demonstration State Forest¹

David Dulitz²

Mountain Home Demonstration State Forest is a 4,800 acre tract of forest land in Tulare County managed by the California Department of Forestry and Fire Protection. The State Forest lies within the Tule River watershed some 22 air miles northeast of Porterville. Elevations range from 4,500 feet to 7,500 feet. Vegetation on the forest is dominated by a mixed-conifer forest with over 5,000 individual old-growth giant sequoia trees.

History

The Mountain Home Tract has a long history of timber and recreational use. Lumbering began on Mountain Home in 1885 with the construction of several sawmills. Many giant sequoias were logged from the Mountain Home area in the period from 1885 through 1905.

Recreational use of the Mountain Home area began at the same time as the lumbering activity. Mountain Home was a popular destination for people trying to escape the heat of the San Joaquin Valley in the summer. Several resorts and a hotel were established at Mountain Home around the turn of the century.

In the early 1940's, old-growth giant sequoias were again being cut at rapid rate in the southern Sierra Nevada. In the Visalia-Fresno area, the Native Sons and Daughters of the Golden West made a special project of saving the mammoth trees of the Mountain Home Tract. As a result of their efforts, the State of California purchased the Mountain Home Tract in 1946 from the Michigan Trust Company and it became a State Forest.

Authority and Statutes

The statute under which Mountain Home Demonstration State Forest is managed is found in Section 4658 of the Public Resources Code. It reads "The Mountain Home Tract Forest in Tulare County shall be developed and maintained, pursuant to this chapter, as a multiple-use forest, primarily for public hunting, fishing, and recreation." Policy direction which is provided by the State Board of Forestry, states that "The primary purpose of the State Forest program is to

conduct innovative demonstrations, experiments, and education in forest management. All State Forest land should serve this purpose in some way." In addition, "timber production will be subordinate to recreation" on Mountain Home Demonstration State Forest.

The 1986 Management Plan for the State Forest adopted by the State Board of Forestry provides for the following management guidelines for giant sequoia: old-growth giant sequoias will be protected in all management activities and young-growth giant sequoia will be considered as replacements for the old-growth component with selected trees allowed to grow into the old-growth class. These young stands will also be considered as a marketable and valuable timber resource and should be managed as a commercial species. Harvesting of the young stands should be done in conjunction with studies to determine the best management strategies for the species.

Recreation

The extensive groves of old-growth giant sequoias are a major attractive feature of Mountain Home Demonstration State Forest. Many visitors come specifically to the State Forest to view these magnificent trees. Visitor use on the State Forest in 1991 totaled over 78,000 visitor days. The State has developed 96 campsites in six campgrounds on the forest. The decision has been made to construct and maintain recreational facilities in a rustic condition and discourage commercial recreational development. In addition, management activities undertaken on the forest are specifically tailored to be compatible with the recreational use of the forest.

Experiments and Demonstrations

One of the primary purposes of the State Forest is to conduct experiments and demonstrations in forest management. Much of the research on Mountain Home has been focused on giant sequoia. Research on giant sequoias has been conducted under contract by the University of California, Berkeley, California Polytechnic State University at San Luis Obispo, and the University of Arizona Tree Ring Laboratory. Experiments have also been conducted by the State Forest staff.

Major experimental work has included management strategies for young-growth giant sequoia, young-growth giant sequoia volume tables, regeneration and response of giant sequoia to different management activities, fire history, and growth and yield of young-growth stands.

¹An abbreviated version of this paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

² Forest Manager, Mountain Home Demonstration State Forest, P.O. Box 517, Springville, CA 93265.

Results of experimental work is published in California Forestry Notes and in university and experiment station publications. A periodic newsletter is also published which describes the various management activities undertaken on the State Forest.

Timber Management

The State has been active in timber management on Mountain Home since its acquisition. Commercial species on the forest include ponderosa pine, sugar pine, white fir, incense cedar, and young-growth giant sequoia. Standing old-growth giant sequoia are protected and not considered a commercial species. Estimated volume of timber on the forest, excluding old-growth giant sequoia, totals over 110 million board feet. Total growth is over 2 million board feet per year.

Silvicultural systems on the State Forest are predominantly single tree and group selection. This selective cutting has been used around and within giant sequoia groves. The objectives of this harvesting has been the removal of overmature pine, fir, and cedar while encouraging natural reproduction of giant sequoia and other species. The soil disturbance that results from timber harvesting activities provides an ideal seedbed for giant sequoia reproduction.

Excellent reproduction of giant sequoia has occurred after timber harvesting in most areas. Tree planting of giant sequoia and other species is also undertaken to insure reproduction. An additional benefit of timber management has been the improved vistas of the old-growth trees. The giant sequoias are more visible and impressive in areas where selective removal of the other species has occurred.

Extensive stands of young-growth giant sequoias also exist on Mountain Home. The primary goal in the management of these stands is the perpetuation of selected trees into the old-growth class. We are experimenting with thinning these dense stands to increase the growth on selected leave trees. Prescribed fire has also been used to reduce the fuel loading and protect the stands from a catastrophic wildfire.

The Future

Mountain Home will continue to be managed as a working forest, outdoor laboratory and an area for public recreation and enjoyment. We will try to broaden our understanding of giant sequoia through experimental work and observations following management activities. Our primary objective for the future will be to protect and insure the continuation of the giant sequoia as a part of the forest.

Young Growth Management of Giant Sequoia¹

Donald P. Gasser

Giant sequoia is an outstanding candidate species for management for a variety of reasons, including the production of wood products. This species combines fast growth with high quality wood production, and it should be considered as an alternative when planting new forests, replacing old, or managing those begun in previous eras. The biology and ecology of giant sequoia has been addressed in other papers in this proceedings as well as in recent publications (Hartesveldt and others 1975; Weatherspoon 1985). This paper attempts to put this information into a management context, with particular emphasis on goals which may be accomplished through manipulation.

Growth

The growth of giant sequoia is of interest to managers throughout the world. Growth has been examined within, near, and outside existing groves. Rapid tree growth is an indicator of how quickly various goals can be reached in most strategies of management. Within existing sequoia grove environs, giant sequoia seedlings and saplings consistently outperform native competitors in height, diameter, and dominance. They have proven to do the same in many places outside of these groves and well outside of the giant sequoia range. European results show very impressive growth which often outperforms both native and exotic conifers (Knigge and Lewark 1982; Knigge and others 1983; Libby 1981).

At Blodgett Forest Research Station, on the Georgetown Divide near the northernmost existing grove of giant sequoia, experimentation with giant sequoia out plantings has been conducted since the early 1960's. Growth of giant sequoia planted in selectively cut as well as clearcut stands has outstripped that of other species.

Compartment 321 was planted in 1981 with six species following an earlier clearcut. Recent measurements show giant sequoia height growth (*fig. 1a*) to be 20 percent greater than its nearest competitor (ponderosa pine), while it averages nearly double that of the other native species. Giant sequoia diameter growth in this same compartment (*fig. 1b*) is over 20 percent greater than ponderosa pine and nearly triple that of Douglas-fir, sugar pine, and white fir. A nearby group selection planted in 1982 shows average height of giant sequoia 50 percent greater than the nearest competitors (ponderosa and sugar pines), while its growth triples or even

quadruples the other mixed-conifer natives. Diameter growth in this same stand is over 60 percent greater than the nearest competitors, and four to seven times that of other coniferous species (Heald 1989).

On Whitaker's Forest, which is located in the Redwood Mountain grove, giant sequoia in mixed stands has consistently shown superior growth since early comparisons were made by Metcalf (1948). Areas within the giant sequoia range, such as Mountain Home Demonstration State Forest, document this same dominance of early growth (Dulitz 1988). Research areas outside the range of giant sequoia where spectacular giant sequoia growth is recorded include two properties managed by the University of California: Baker Forest near Quincy, and Russell Reservation near Lafayette (Libby 1992).

At Foresthill, and within 15 miles of the northernmost grove of natural giant sequoia, a plantation was planted in 1981 on site I A land on deep soils with good rainfall. On this site, the giant sequoia in mixed plantings were initially the top growers but have since fallen off, while the ponderosa pine has surpassed them. An earlier plantation near this same site, (planted in 1966), shows that the trees have also slowed their growth, and the color after five years of drought is chlorotic.

Individual tree growth appears to be affected by the availability of moisture throughout the growing season. Site differences are not well understood, and more studies are needed to determine water timing and amount, genetic differences between groves, soil responses, and measures of susceptibility to root disease.

Forest Dynamics

Growth of individual trees is only one measure of the dynamic nature of the giant sequoia forest. Long-term studies allow the nature of forest development to be examined. Woody Metcalf (1915) established six permanent growth plots at Whitaker's Forest which are probably the oldest such plots in existence in any forest in California. These have been remeasured over the decades, but now only one quarter-acre plot has not been disturbed or destroyed by storms, roads, or otherwise compromised by time or progress. Despite the lack of degrees of freedom in this data, Metcalf Plot One shows us some of the dynamics affecting sequoia young growth.

Figure 2a shows 77 years of stand development in terms of number of stems in this nearly pure stand of giant sequoia-facts that are neither new nor startling, but which do reaffirm basic forestry principles. Many more trees can be supported on a site when the trees are young than can be grown on that same site as the trees age. The heavy mortality

¹An abbreviated version of this paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

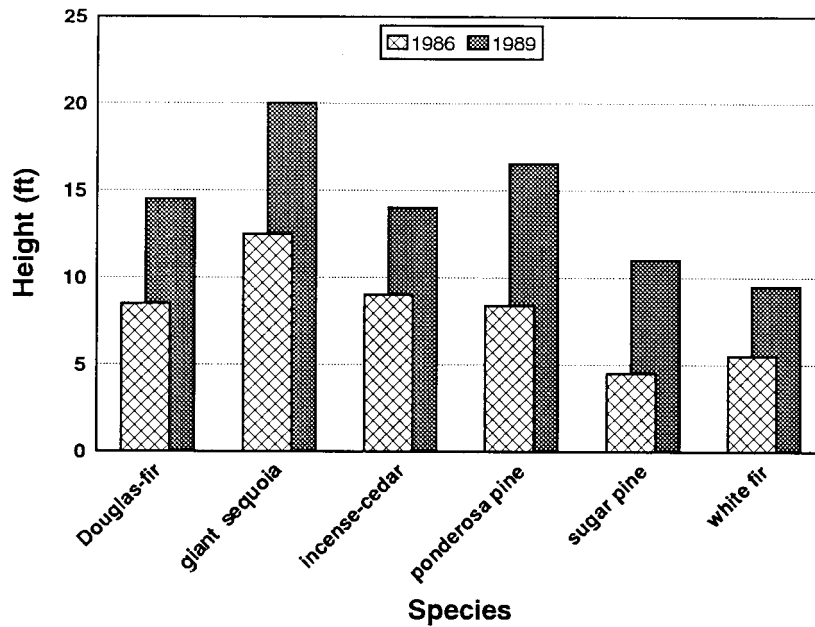


Figure 1a-Height in plantation following clearcut (Blodgett Forest Research Station, Compartment 321)

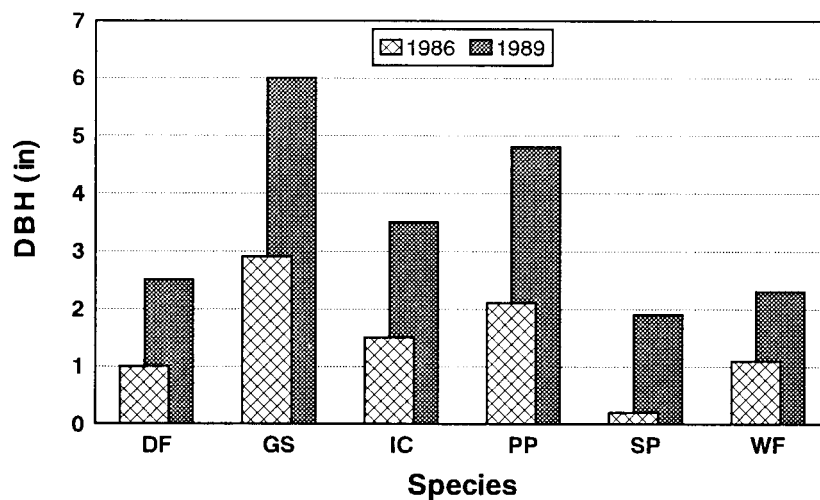


Figure 1b-Diameter at breast height (in.) in plantation following clearcut (Blodgett Forest Research Station, Compartment 321)

that has occurred (over 60 percent of the original trees have died) has all been natural, and the stand is now a fire hazard of standing and fallen dead trees. Some trees are still alive, but barely, and the data show that some trees may have virtually the same diameter and height for up to five decades. While intolerant of shade, once established, giant sequoia is not readily killed by shade.

Figure 2b details the average diameter of the trees on this plot. The slow growth in average diameter and the recent slowing in increase of average diameter at breast height (DBH) shows the ingrowth of white fir. There is virtually no other regeneration of any vegetation in this plot.

The development of this stand in which stagnating trees and huge second-growth trees are side by side begs the question of appropriate stocking and spacing of sequoia. A variety of studies are currently underway in a number of localities throughout California. Plots already established at Whitaker's Forest, Blodgett Forest, Mountain Home Demonstration State Forest, and other sites should help answer these questions.

Basal area measures are those which total the combined tree girth on an area of land, and these often correlate to an index of site productivity. The development of basal area on the Metcalf Plot is shown in *figure 2c*. It is expected that the

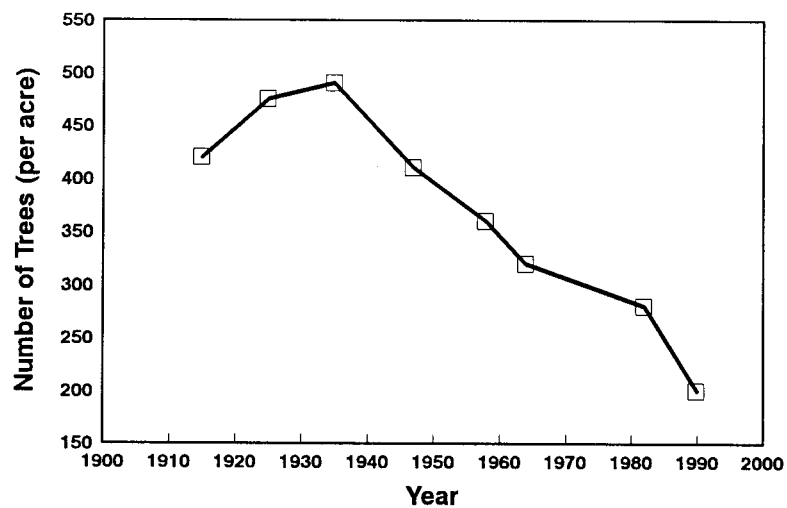


Figure 2a-Whitaker's Forest, Metcalf Plot One --Number of Trees

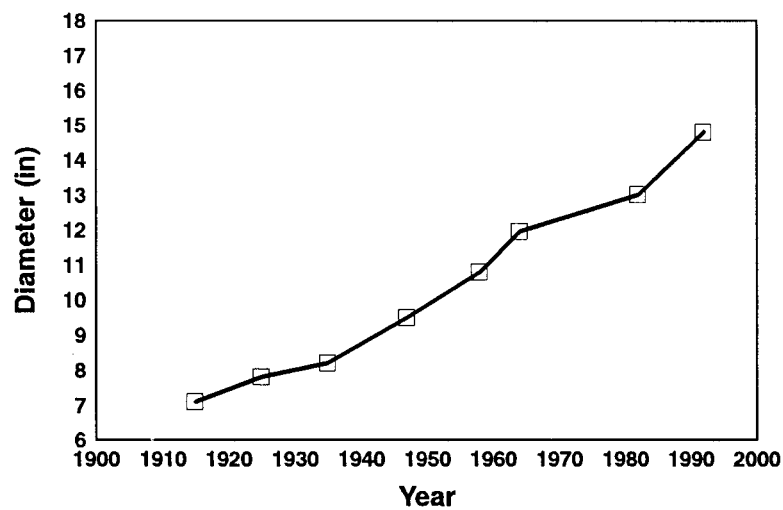


Figure 2b-Whitaker's Forest, Metcalf Plot One--Tree Diameter

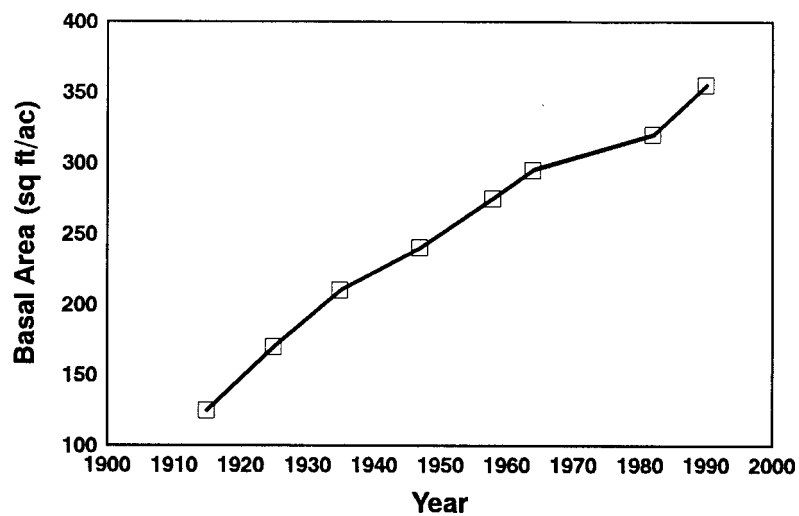


Figure 2c-Whitaker's Forest, Metcalf Plot One--Basal Area

limit of growth on this plot may be reached in the next several decades, for a series of inventory plots on Whitaker's Forest has shown that much of the giant sequoia/mixed-conifer forest stabilizes at about 400 square feet of basal area per acre. This is a measure of the limit of productivity of this site, and other sites may have a greater or lesser productive capacity.

It is clear that giant sequoia is capable of holding levels of growing stock that other species may not attain before stagnation. The control plots for the study described below on Mountain Home Demonstration State Forest show levels between 500 and 600 square feet of basal area.

It is instructive to note that in a 100 percent survey of old-growth giant sequoia in the National Parks, giant sequoia consistently carries about 200 square feet of basal area per acre, and it is a major portion of these stands (Stohlgren 1991). This study measured almost 161,000 giant sequoia trees in 35 groves. The findings show that over half of the basal area rests on only 5 percent of the trees.

Response to Manipulation

Bob Martin and Don Gasser on the Mountain Home Demonstration State Forest are conducting a study to quantify the development of different forest responses that are encountered following thinning and burning. Begun in 1989, a total of six stands have been thinned to different basal area levels (130 and 240 square feet per acre). Half of the thinned stands were burned following harvest, while one third of the area acts as a control and has not been thinned or burned. Permanent plots have been set up and these are being followed and measured through time. Forest stand dynamics have developed to reveal patterns of ecological succession which may be important to future development and growth, as well as management activities. While still early in the life of this study, it is clear that giant sequoia responds quickly to new growing space, and the thinned stands are showing a growth spurt that is not evident in the control areas. Understory dynamics are being measured as well, so that the growth and regeneration of tree, shrub, and other portions of the forest can be reported under different management regimes.

Yield

Questions as to yield of the growing forest come about when the trees are harvested. A recent study at Mountain Home Demonstration State Forest has brought the two existing volume measures into question (Pillsbury, De Laissoe, Dulitz 1992; Wensel, Schoenheide 1971). In the thinning of the plots discussed above, the measured differences in log volumes were occasionally 20 percent separate. Sufficient tests are needed throughout the range to determine the site specific nature of taper and shape as they influence volume and value.

Wood Quality

The findings of numerous studies indicate that the quality of second-growth redwood is vastly different from the old-growth of the same species. The brashness for which the old-growth tree is so well known is the factor that caused many of the large old trees to splatter upon hitting the ground, and chunks can still be found in Converse Basin, on Redwood Mountain, and in other areas that show this phenomenon.

Wood quality of young-growth giant sequoia was first detailed in California in 1971 and various work since then has confirmed the earlier information (Cockrell, Knudson, Stangenberger 1971). In this early research, the qualities of old- and young-growth redwoods, both coastal and interior, were compared and contrasted. Young-growth giant sequoia proves to be a species with qualities that meet or exceed those of young-growth coastal redwood, at least in terms of important wood properties of specific gravity, most mechanical properties, extractive content and decay resistance (*fig. 3*).

Piirto and Wilcox (1981) found that the wood of young-growth giant sequoia is both stronger and heavier than that in old-growth, and that this is the reverse of coastal redwood. This is shown also to be true for those giant sequoia grown out of native range (Keylworth 1954; Liubirescu, Guriianu, Lonescu 1972). Knigge and Lewark (1982) were cautious in recommending giant sequoia for European demands, as wood density is an issue in some applications.

The comparison of giant sequoia to coastal redwood is important, in that the latter is recognized as a superior species, and regularly sells at the top end of the coniferous board and product market. Without management, giant sequoia solid wood product value is very low relative to its inherent qualities because of the numerous persistent branches. These branches are a serious detriment to the production of wood of high quality, and early pruning is necessary to ensure that the full value of the solid wood product is realized.

With the substantially superior volume growth shown for giant sequoia, the value for biomass chips should not be ignored, and a mixed stand of conifers which includes giant sequoia may be managed from the start for a variety of products. The ability of giant sequoia to initially colonize and capture the site may be combined in a product-oriented strategy that includes pruning only a portion of the stand designated as crop trees. With advancing age, some trees may be removed to make room for the high quality growing crop, while still providing for a high biomass yield.

Operations

The California Forest Practices Act and numerous rules give protection to the potentially affected resources, but soil, as the basic resource, deserves special consideration. Most stands within the native range of giant sequoia are on deep soils which have access to deep water on a year-round basis. Careful planning and control of the placement of tractive

Mechanical property	Giant sequoia*		Coast redwood+	
	Old-growth	Young-growth	Old-growth	Young-growth
Specific gravity#	0.30	0.35	0.38	0.34
Static bending				
Modulus of rupture (psi)	5200	6670	7500	5900
Modulus of elasticity (million psi)	0.56	1.14	1.18	0.96
Work to maximum load (in-lb/cu in)	5.3	6.7	7.4	5.7
Compression parallel to grain-maximum crushing strength (psi)	2700	3510	4200	3110
Compression perpendicular to grain-fiber stress at proportional limit (psi)	230	380	420	270
Maximum shearing strength parallel to grain (psi)	730	740	800	890

*Cockrell (1971).

+USDA Wood Handbook (1974).

#Specific gravity is based on oven-dry weight and green volume.

Figure 3-Mechanical properties (green condition): giant sequoia and coast redwood.

equipment is important to ensure that neither displacement nor compaction take place in the area of the watercourses.

Despite the above proviso that current operations follow, it is more than interesting to note that the finest stands of young-growth giant sequoia exist in those areas which were treated the most harshly and with the least sensitivity a century ago. Giant sequoia at Whitaker's Forest, Big Stump, Converse Basin, and numerous other locations which were virtually clearcut, have impressive young-growth trees reaching seven feet in diameter and two hundred feet in height. Huge stumps give testimony to what was there before, and which will be again, despite primitive logging efforts which undoubtedly displaced soil following logging and burning. As described elsewhere in these proceedings, it is these conditions that give rise to the dense regeneration which characterizes giant sequoia cut areas.

Current commercial operations within existing groves are commonly controversial. The soil and water regimes in many existing groves may limit operations designated for scenic and aesthetic areas. In these groves, dry season operation with low ground pressure equipment is prudent. Post-harvest stump cutting to ground level, or even stump grinding, would be desirable, due to the longevity and the visual nature of these stumps. Burning following logging has been shown to promote a forest floor that is safer from wildfire, and which may provide regeneration benefits as well.

Operations in most existing stands will have to contend with the extreme branchiness and the tendency for significant taper in open stands. Both of these factors will probably cause commercial forests to be grown at a higher density and

thinned later than other species in order to minimize these effects. Early pruning of branches may yield significant returns to the landowner.

In looking at the response of thinning of giant sequoia on other resource values, minor thinning and understory manipulation has had little impact on avifauna within the giant sequoia forest (Kilgore 1971), while a long-term study by Marshall (1988) details the changes in bird and small mammal habitat that has occurred on Redwood Mountain in a 50-year period. Despite low levels of logging in the immediate area of the sequoias, some bird species have disappeared from the area. These data suggest that larger scale harvest of trees from areas outside of the groves may have a greater affect on bird populations than does minor manipulation within the groves. A half century of growth and development of the forest in the absence of operations also appears to have had an impact on certain wildlife abundance. Revitalization of deer habitat has resulted in an increase in deer utilization following thinning and understory cleaning at Whitaker's Forest (Lawrence, Biswell 1972). Clearly, manipulation of the forest results in habitat change favoring some animals but detrimental to the existence of others.

Conclusion

For a species to be a candidate for management, it needs several characteristics such as growth, value, and responsiveness to manipulation. If the purpose of management is to allow for goals to be brought to fruition, than the species must be able to fulfill objectives through manipulation or other activity.

Even for parks or those areas which are dedicated to aesthetic purposes, giant sequoia management is a viable alternative. The fast initial growth and the development of a substantial bole size makes it a natural for these purposes. In existing redwood groves, trees may be removed with the assurance that growth response to manipulation will reward the landowner with speedy recruitment into the larger size classes. Low stump cutting will promote the appearance of old-growth forest characteristics, as stump rotting appears to be a very slow process.

Proper giant sequoia management can yield useful products by combining tremendous growth potential, a wide range of density options, and very responsive reaction to manipulation. When combined with the high value that the redwood markets enjoy, it is surprising that so little management effort has heretofore taken place. A society which consumes so much should take advantage of a species where such broad potential exists.

References

- Blank, V.R.; Buck-Gramcko, A.; Knigge, W. 1984. Physikalische holzeigenschaften des mammutbaumes (*Sequoiadendron giganteum* (Lindl.) Buchholz) aus europaischen versuchsanbauten. Forstarchiv, 55,Jahrgang.
- Cockrell, R.A.; Knudson, R.M.; Stangenberger, A.G. 1971. Mechanical properties of southern sierra old- and second-growth giant sequoia. Bulletin 854. California Agricultural Experiment Station, Division of Agricultural Science Univ. of California; 14 p.
- Dulitz, D. 1988. Forest statistics. Mountain Home Demonstration State Forest. 16 p.
- Hartesveldt, R.J.; Harvey, H.T.; Shellhammer, H.S.; Stecker, R.E. 1975. The giant sequoia of the Sierra Nevada, U.S. Department of the Interior, National Park Service, Washington, D.C.; 180 p.
- Heald, R.C. 1989. Compartment statistics for Blodgett Forest Research Station. Unpublished draft supplied by author.
- Keylwerth, R. 1954. Das holz der Sequoia gigantea. Holz als Roh-und Werkstoff 12(3): 105-107.
- Kilgore, B.M. 1971. Response of breeding bird populations to habitat changes in a giant sequoia forest. American Midland Naturalist 85: 135-152.
- Knigge, V.W.; Lewark, S. 1982. Untersuchungen von holzeigenschaften kalifornischer mammutbaume (*sequoiadendron giganteum* (Lindl.) Buchholz) aus weitwuchsbesanden, Forstarchiv. 55, Jahrgang.
- Knigge, V.W.; Pellinen, P.; Schilling, T. 1983. Untersuchungen von zuwachs, astigkeit, verkernung und rindenstarke westeuropaischer anbauten des mammutbaumes (*Sequoiadendron giganteum* (Lindl.) Buchholz). Forstarchiv, 54, Jahrgang.
- Lawrence, G.; Biswell, H. 1972. Effect of forest manipulation on deer habitat in giant sequoia. Journal of Wildlife Management 36(2): 595-605.
- Libby, W.J. 1981. Some observations on Sequoiadendron and Calocedrus in Europe. Calif. For. and Forest Prod. 49. Berkeley: Univ. of California; 12 p.
- Libby, V.J. 1992. Personal communication.
- Liubirmirescu, A.; Guruianu, M.; Lonescu, R. 1972. Physical and mechanical properties of the wood of Sequoia gigantea. Revista Padurilor 87(12):613-616.
- Marshall, J.T. 1988. Birds lost from a Giant sequoia forest during fifty years. Condor 90:359-372.
- Metcalf, W. 1951. Tree planting and Whitaker's Forest. Agriculture and Home Economics, State of California.
- Piirto, D.D.; Wilcox, W.W. 1981. Comparative properties of old- and young-growth giant sequoia of potential significance to wood utilization. Bulletin 1901. Berkeley: Univ. of California; 26 p.
- Pillsbury, N.; De Laissoe, M.; Dulitz, D. 1992. Young growth Sierra redwood forest volume equations for Mountain Home Demonstration State Forest. Forest Note 103, California Department of Forestry and Fire Protection.
- Stohlgren, T.J. 1991. Size distributions and spatial patterns of giant sequoia (*Sequoiadendron giganteum*) in Sequoia and Kings Canyon National Park. Davis: Univ. of California; 214 p.
- Wensel, L.C.; Schoenheide, R. 1971. Young growth gross volume tables for Sierra redwood. Hilgardia 41:4.
- Weatherspoon, C.P. 1985. Management of giant sequoia. Pacific Southwest Forest and Range Experiment Station, Berkeley, CA: Forest Service, U.S. Department of Agriculture; 47 p.

The Sequoia Forest Plan Settlement Agreement as It Affects *Sequoiadendron giganteum*: A Giant Step in the Right Direction¹

Julie E. McDonald²

Abstract: Due to agitation, litigation, and prolonged mediation instigated by environmentalists, the Giant Sequoia groves of the Sequoia National Forest have been declared by the Sequoia National Forest to be a "unique national treasure." There will be no commercial logging within the groves, and the Forest will over time prepare a management plan for each grove aimed at restoration and regeneration.

A lawsuit over Forest Service logging in Giant Sequoia groves, and much outcry over the Sequoia National Forest Plan to commit most Giant Sequoia groves to logging operations, spurred the Forest Service to change its Giant Sequoia management policy quite dramatically. Under the Forest Plan Settlement Agreement, which was signed by a diverse range of parties, Giant Sequoia groves will be preserved at least for the next decade "as a unique national treasure."

The Agreement contains lengthy details on how Giant Sequoia grove boundaries and buffer zones will be established and managed. But the more recent scientific and agency trend toward "ecosystem management" must call into question whether identifying and protecting grove boundaries (rather than broader ecosystems) will actually perpetuate the species, and the ancient giant specimen trees, for the enjoyment and awe of future generations.

History

In the mid-1980's, timber managers on the Sequoia National Forest decided it was time to log within the uncut groves of Giant Sequoias.³ Specimen redwoods were not marked for logging, but essentially all the surrounding trees, including ancient giants of other species, were marked for sale. (The Forest Service referred to this as "nonintensive management.") Timber sale documents stated that the logging would improve chances for Giant Sequoia regeneration. But that was not the primary goal of the logging operations. Rather, logging was scheduled within the groves because it was one more place from which the Forest could attempt to meet its target for commercial timber production.

The Forest did not publicize to the citizenry at large its decision to sell timber within Giant Sequoia groves. When

local citizens who discovered logging operations within the groves became extremely upset, Forest Service employees seemed genuinely surprised. These local citizens rallied the Sierra Club, which filed suit.⁴

The result was a victory for environmentalists in *Sierra Club v. United States Forest Service*, 843 F.2d 1190 (9th Cir. 1988). The Sierra Club challenged nine timber sale contracts, five of which involved logging in Giant Sequoia groves, alleging that the Forest violated the National Environmental Policy Act (NEPA) (42 U.S.C. 4332). The Court of Appeal found that the individual environmental assessment reports (EAs) on the timber sales wrongly concluded that no environmental impact statement (EIS) was required. The sales were "highly controversial" in the sense that there was a genuine dispute among experts over the impact of logging on the groves. They also raised questions about cumulative watershed and wildlife effects, and whether the sales might cause violations of state water quality standards.

The Court in April of 1988 issued a preliminary injunction against further logging of the nine sales until the trial court could determine whether the newly-completed EIS on the Forest Plan (EIS, February 25, 1988) sufficed to meet NEPA's requirements with respect to the nine challenged timber sales.

Meanwhile, however, numerous persons and organizations, including plaintiff Sierra Club, appealed the Forest Plan on a wide variety of issues. With respect to Giant Sequoias, the Plan at least tentatively divided the Forest's 13,200 acres of groves into two categories: 3,900 acres would be preserved, while 9,300 acres would be subject to logging of species other than Giant Sequoia (EIS Table 4.3). The Sierra Club and others objected to any further logging in the groves.

The Forest Service hired a mediator to conduct what turned out to be about a year-and-a-half of negotiations, culminating in the multi-party Forest Plan Settlement Agreement of July 1990. During the course of the Forest Plan negotiations, the lawsuit over the nine timber sales was settled. (*Sierra Club v. United States Forest Service*, No. CVF-87-263-EDP [E.D. Cal.], Stipulation for Entry of Judgment, December 16, 1989.) The Forest Service agreed to withdraw two timber sales altogether, not to allow further logging in units containing Giant Sequoias, and to reforest logged Giant Sequoia units so as to restore them as nearly as

¹An abbreviated version of this paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

²Public Interest Lawyer, Sierra Club Legal Defense Fund, 180 Montgomery Street, Suite 1400, San Francisco, CA 94104-4230.

³Converse Basin, part of the Hume Lake Ranger District, was cut over about a century ago, Giant Sequoias and all. Otherwise, the Forest's Giant Sequoia groves were mostly intact.

⁴The individuals most responsible for inspiring action to stop grove logging were Ms. Charlene Little and Ms. Carla Cloer. I think the public owes them a debt of gratitude. Julie E. McDonald, Public Interest Lawyer

possible to their former natural state. Relatively more Giant Sequoia seedlings were to be planted than the proportion represented in the logged stands, seedlings were to be planted at a minimum spacing of fifteen feet (farther apart than normal for stands replanted for future commercial timber production), and a reforestation report would be prepared after five years.

Description of Mediation--Four Crucial Points:

1. The mediation was a huge endeavor. It expanded from a projected six to eighteen months. Meeting attendance ranged from approximately eight to 45 people, with each meeting including at least three lawyers and three Forest Service representatives. We spent countless hours in strange hotel rooms and coffee shops reviewing our positions and negotiating.

2. The full range of views about forest management was fiercely advocated. Sometimes the mediator would separate us so that we could rethink and calmly state our positions. After a while we got to know each other and could lapse into teasing and humor. A long field trip helped us get out of a stalemate.

3. A key premise of our negotiations was that no agreement on any issue would be final until the total package was approved.

4. The final agreement was controversial within (at least) both the environmentalist and timber communities. But after so much negotiation, the parties were running out of time and money: the agreement had to be either signed or abandoned. To the credit of the Forest Service (James A. Crates, Forest Supervisor, and Paul F. Barker, Regional Forester), the agency decided to sign the agreement even though some of the environmental and timber appellants decided not to sign.

Settlement Agreement Requirements

The Forest Plan Settlement Agreement marked a decided turn-around in the Forest's position on grove management. The provisions relating to the Giant Sequoia groves were hard-fought, line by line; but they eventually were accepted by signatories that included local timber companies, the Tule River Indian Tribe, the California Cattlemen's Association, various off-highway vehicle and other recreational user groups, environmental organizations, the Attorney General, and, of course, the Forest Service.

The Agreement accomplishes the following (pp. 6-27):

1. Policy: The Agreement declares the Forest's groves to be "a unique national treasure that shall be preserved." The management goal "shall be to protect, preserve, and restore the Groves for the benefit and enjoyment of present and future generations" (p. 6). The objective of regenerating cutover Giant Sequoia groves "will be to restore these areas, as nearly as possible, to the former natural forest condition" (p. 27).

The Agreement excepts from these goals most of the 3,000-acre Converse Basin. Having been logged in the last century, the Basin will "continue to be available for commercial logging" (p. 6). However, logging will require an environmental impact statement, and no clearcutting will be allowed. Also, 600 acres of the Basin previously identified for preservation by the Forest Plan, plus an additional 240 acres to be selected where 70- to 100-year-old Giant Sequoias are abundant, will be managed for preservation (p. 26).

2. Grove Boundaries: The Agreement recognizes that Giant Sequoia grove boundaries "have not yet been precisely identified" and that Giant Sequoias occur naturally in scattered locations outside the "traditional" groves identified by Rundel (p. 12). It establishes a process for the Forest Supervisor to determine grove boundaries based upon: (a) recommendations of a Grove Boundary Team consisting of representatives of the Sierra Club, Save-the-Redwoods League, the timber industry, and the Forest Service, and (b) if necessary, the advice of a panel of experts (pp. 11, 23-24).

The boundary process was supposed to be completed in 1991; however, it has turned out to be a more complicated and expensive process than the parties anticipated. It is still far from completion.

Under the Agreement, a grove includes (subject to Boundary Team adjustments), in addition to areas identified by Rundel, "[a]ny naturally occurring giant sequoia (1 foot or larger dbh) which is located within 500 feet of at least 3 other giant sequoias (each 1 foot or larger dbh)" (p. 13). A grove also includes, with smaller protective boundaries, "[a]ny detached naturally occurring group (10 or more giant sequoia trees with at least 4 trees with a 3 foot or larger dbh) located outside the Grove Influence Zone" (see below) (p. 21).

The interim boundary for each grove (pending the Supervisor's decision) includes a 500-foot buffer around the outermost Giant Sequoia trees (p. 7). Beyond the grove there is also a 500-foot Grove Influence Zone (p. 8).

Boundaries are subject to ongoing modification if more Giant Sequoia trees are later discovered (p. 22).

3. Management Restrictions:

a. All groves (interim and final) are removed from the "suitable land" base that is subject to commercial timber operations. Mechanical entry is restricted (e.g., to existing roads) (p. 7). The Forest must begin to inventory and evaluate each grove for fuel load build-up, and set priorities for treatment. There can be no logging in a grove within the period covered by the Forest Plan except "for the limited and specific purpose of reducing the fuel load ... pursuant to a Grove specific fuel load reduction plan and Grove specific EIS" (p. 10). The objective must be "to preserve, protect, restore and regenerate the Giant Sequoia Groves, without unnecessary damage to any old-growth trees in the Grove" (pp. 10-11).

b. Grove Influence Zones can only be logged using single-tree or small group uneven-aged silviculture (pp. 8, 25).

c. The Forest Service must also use "every reasonable effort" to protect naturally occurring individual Giant Sequoia trees (pp. 20-21).

d. Cutover groves are to be managed so as "to restore these areas, as nearly as possible, to the former natural forest condition" (p. 27).

4. Special Management of Specific Groves and Vicinity: The Agreement establishes special requirements for certain groves and nearby areas (pp. 16-19). For example, some small groves are combined into a larger single grove, and the Freeman Creek Grove is designated a Botanic Area (p. 17).

5. Special Notice: The Agreement requires that parties to the Agreement be given specific notice, with opportunity for comment and field review, of any proposed logging, either upslope of a grove or within 1,000 feet of an interim or final grove boundary (pp. 23, 25).

The Future

While the Agreement protects Giant Sequoia "groves," current knowledge, as well as recent Forest Service direction at the Regional and national levels, highlight the need to protect whole ecosystems.

There is a need to determine what the Giant Sequoia ecosystem is, and how it can best be managed so as to assure the future health of Giant Sequoia and other associated plant and animal species.

One thing that is certain is that people are deeply moved in the presence of living things as mighty and beautiful as ancient Giant Sequoias. There will always be people willing to fight for whatever it takes to preserve the ancient trees, the Giant Sequoia species, and the Giant Sequoia ecosystem. It should be public policy to do all of this.

Reflections on Management Strategies of the Sequoia National Forest: A Grassroots View¹

Carla A. Cloer²

Abstract: In 1986, local citizens discovered that giant sequoia (*Sequoia-dendron giganteum* [Lindl.] Buchholz) groves were being intensively logged by modified clearcutting which removed all vegetation around specimen sequoias in areas each up to 50 acres. After logging, the groves were to have plantations established in them. More than 1,000 acres in various groves had been approved for such treatment. When an administrative appeal to Sequoia National Forest failed to stop these projects, a lawsuit was filed, resulting in an injunction stopping the logging. Today, U.S. Department of Agriculture, Forest Service, policy precludes such intense logging, however groves on Forest Service lands remain unprotected by law. Logged-over groves need study to determine how best to restore them; thousands of seedlings planted in recently logged groves will result in crowded even-aged plantations; logging roads within groves need to be restored to natural conditions. It will take centuries to evaluate consequences of recent activities; intact portions of groves must have strictly minimum management so as to preserve options for future generations.

At the turn of the century, logging abuses in groves of giant sequoia caused a public outcry which led to the formation of National Parks to protect many of the groves (Hartesveldt and others 1975). Most groves unprotected by National Parks were within Sequoia National Forest. The Forest's 38 groves were generally left alone until the Forest Service initiated a prescribed burn in the Bearskin Grove in 1975 (Rogers 1986). This initial experimental management of one small area of one grove was quickly followed by several decisions in rapid succession between 1982 and 1986 to intensely log within over 1,000 acres within giant sequoia groves (Cloer and Little 1987). For the most part, these decisions were made without public input. Beginning in 1987, following the lawsuit to stop such logging, public awareness and news media attention of logging activities in groves of giant sequoia has intensified. Articles in such magazines as *Audubon* (Green 1990), *National Geographic* (Findley 1990), *Sierra*, *The San Diego Tribune* (Levin 1987), as well as articles in the *San Francisco Examiner* (Kay 1992), and the *Sacramento Bee* (Knudson 1991) have raised public awareness that their favorite tree and the groves of which it is an integral part are not protected throughout their range; the groves in the National Forests have no statutory protection. This paper will describe the local citizens' battle to stop intense logging in groves and explain their insistence that the groves be legislatively protected.

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²Co-founder of Sequoia Forest Alliance; member, Executive Committee of the Kern-Kaweah Chapter of the Sierra Club, Boards of the Rule River Conservancy and the Sequoia Forest Citizens Coalition; litigation committee of Tulare County Audubon. Address: 182 East Reid Avenue, Porterville, CA 93257.

Forest Service Policy

In the southern Sierras, between the extremes of the granitic high country and the southern terminal ending in the Mojave Desert, lies the narrow Sierran conifer forest. Here the mixed-conifers including ponderosa, Jeffrey, and white pine, incense cedar, red and white fir, are reigned by the monarch of the Sierra, the giant sequoia, whose glowing red bark and magnificent size has inspired so many.

In the early 1980's, local citizens, particularly those in the Kern Valley Wildlife Association, became alarmed by Sequoia National Forest's increase in using clearcutting in non-grove areas as a method of logging. This harsh treatment of the forest resulted in thousands of 10 to 40 acre patches where virtually no vegetation or wildlife remained after logging. The forest was being logged much too fast to meet the legal mandate for a sustained yield, and this logging was being done at a financial loss to the taxpayer (Rice 1991). The replanted pine seedlings often died in the hotter, dryer "clearcuts." The forest was becoming fragmented, stream sediments increased, riparian zones became damaged, ponderosa and Jeffrey pine plantations replaced true fir forests, and recreation and visual qualities were degraded. Soon the local Sierra Club became involved in logging issues, and local citizens formed Sequoia Forest Alliance.

Although it was obvious that overlogging the forest adjacent to giant sequoia groves would eventually affect the groves themselves, there was no immediate concern for logging within giant sequoia groves. Not only was there the assumption that logging within groves was prohibited, many groves were posted with yellow signs which declared:

Type I
Redwood Grove
Area Back of This Sign
Established Under Reg U-3
by Regional Forester

According to 1970 Region V Guidelines this meant that "...no major activities such as campground or road construction, or timber cutting, will be permitted within any Type I Grove." This was the first specific Forest Service Manual direction for management of giant sequoias (Rogers 1985). Sequoia National Forest documents written between 1970 and 1984, including District Multiple-Use Plans, refer to various groves as being Type I.

Then in the Fall of 1986, Charlene Little saw a timber sale ad which offered a "marginal amount of Giant Sequoia..." In response to her letter of concern Regional Forester, Zane G. Smith, Jr., wrote, "We have not changed our long standing Regional Direction for the management of the Sierra Redwood Groves" (Smith 1986).

Any reassurance from the above statement was short lived. One day in summer of 1986, while looking at non-grove areas, Charlene Little stumbled into a logged-over portion of the Long Meadow Grove. Roads had been pushed through the grove, large roots had been severed (Pintek 1987b), huge swaths of earth had been piled, all vegetation had been removed except for giant sequoias eight feet in diameter and larger; to the observers it appeared to be disastrous "nuclear" logging.

What had happened to the Type I protection? The official response was, "Some grove boundaries were posted with Grove Type signs, but no groves were approved as Type I by the Regional Forester" (Crates 1987). They had no idea who had posted hundreds of signs. "Recent conversations with individuals that worked on the Forest during the 1960's and 1970's have indicated that much of the posting was probably done during the 1960's. We have no record of what the policy was prior to the May 1970 direction" (Crates 1987). Now there was a new grove designation system (USDA 1985). This new designation system had a category for preservation, but none of the logged groves were in that category. There was no law prohibiting logging in the groves, no law protecting the giant sequoias.

When the Type I policy changed, apparently in 1985, the only written record available was an electronic mail transmittal sheet. There was no public involvement and no environmental studies which preceded the decision to change policy. Even if the policy had been changed in a proper manner, the following sales which allowed logging in groves had Decision Notices issued prior to the new policy transmittal date of 3/28/84: Red Sale (1982), Ridge 2 Sale (1982), Huckleberry Sale (1983), Eagle Sale (1983), Buck Sale (1983), Gauntlet Sale (1983), Wind Sale (1984) and sales in the Alder Creek Grove.

Attempts to Stop the Logging

Between August 1986 and March 1987, concerned citizens sent letters and petitions to the Supervisor of Sequoia National Forest, James A. Crates. He agreed not to approve any new projects within groves until a forest-wide giant sequoia management plan was written, but he would not stop sales already under contract (Crates 1987). This meant that two proposed sales which would have logged in the Freeman Creek Grove were stopped. However, over 457 acres (not including areas in Alder Creek Grove) had already been logged in groves; Mr. Crates was reaffirming his decision to log an additional 593 grove acres (Fisk 1986).

Supervisor Crates' decision to not stop logging in groves was appealed to the Regional Forester; the appeal was rejected as "untimely." The only recourse available was to file a lawsuit and to request an injunction.

In *Sierra Club vs. The United States Forest Service* [also described by Julie McDonald in these Proceedings (McDonald 1992)], the Sierra Club sought an injunction on nine timber sales, five of which involved logging in giant sequoia groves. A major issue was Sequoia National Forest's

failure to have an Environmental Impact Statement on any portion of its timber program.

Sequoia National Forest argued that the logging was actually "grove enhancement" and was being done to release the sequoias from a buildup of non-sequoia species which were causing a fire hazard and inhibiting sequoia reproduction. During the lawsuit discovery process, however, Sequoia National Forest was unable to produce even a single study, map, or document which indicated that the specific areas approved for logging had been determined to have such conditions. There was a contradiction in their contention that the logging was to enhance sequoia reproduction because all of the stand prescriptions called for planting 75 percent pine and 25 percent sequoia at 10 by 10 foot spacing, creating an even-aged plantation. In actuality, they were committing those grove acres to the perpetual production of timber with its repeated cycle of logging, release, planting, thinning, and relogging.

Why did they do this? Possibly some personnel actually believed that the logging would help the groves; however, an interview with former Regional Forester, Zane G. Smith, Jr., now retired, indicates that Sequoia National Forest was pressed to meet inflated logging volumes (Green 1990). Giant sequoias typically occupy the better timber growing sites (Rogers 1985); and about this same time Sequoia National Forest initiated clearcuts in other sensitive areas such as important viewsheds and very steep slopes.

Conservation groups were convinced that any sequoia seedling that might become established after logging would in turn become logged during the next re-entry. Natural restoration occurred in the Converse Basin, where there was once the largest grove of giant sequoias known in the Sierra Nevada before the turn-of-the-century logging (Harvey 1985). Sequoias which had germinated from the natural seed bed had grown to considerable size, up to six feet in diameter. In the Cabin Sale (1985), however, not only were non-sequoia trees logged, but the sequoias that were replacements for their logged ancestors were also cut. Sequoia Forest explained that these trees were "second growth" and therefore they did not qualify for sparing. By the same logic, any sequoia tree which was established after the more recent logging would also be "second growth" and available for logging.

Experts found that the type of logging occurring in the groves could cause significant environmental impacts (Rundel 1987 and Stephenson 1987). While waiting for the judge to rule, logging continued in the groves. Local citizens watched as survey stakes were replaced by bulldozed roads and then every living thing was removed from the units except for the largest giants.

About 16 months after the lawsuit was filed, the Ninth Circuit Court of Appeals granted us an injunction. The case was won, not because it was illegal to log in groves, but because of the lack of an Environmental Impact Statement. Because of court delays, only four units in groves were saved: two in the Peyrone Grove and two in the Red Hill Grove. The precedent was set, however, that the groves were not to be treated the same as any ordinary piece of the forest.



Planted pine seedlings line up in shadow of the 150- to 300-year-old trees they replace in a unit of the Black Mountain Grove, Tule River Ranger District of Sequoia National Forest, logged in 1988. This type of logging in groves is termed "non-intensive" management; in 1986, 9,300 acres within groves were assigned to "non-intensive" management (Fisk 1986).

Even after the injunction was in place stopping the project, Sequoia National Forest continued with the site preparation and planting. During the course of site preparation, many smaller giant sequoias, up to eight inches in diameter (some 60 years old), were accidentally cut, piled, and burned. These stumps are evidence that the grove was indeed regenerating itself before the "treatment," and evidence that young sequoia reproduction was not a priority to Sequoia National Forest.

While the contract provided for penalties for damaging any giant sequoia, Sequoia National Forest did not penalize the industry for cutting these trees, explaining, "The original Environmental Analysis Report ... designated the protection of specimen 'reserve' giant sequoia trees. Because of the fact that the giant sequoias cut were not of specimen 'reserve' size as defined in the original Environmental Analysis and not designated as reserve trees as indicated in C2.3# - Reserve Trees in the timber contract no action was taken" (Crates 1989).

Land Management Plan

After the injunction was in place, and Sequoia National Forest was clearly aware of public sentiment favoring grove preservation, the Land Management Plan, issued in 1988, called for similar treatment of 9,300 acres of giant sequoia groves. The Sierra Club and others appealed the Land Management Plan on this and other issues.

As late as 1990, Environmental Assessments were listing the goals to "manage groves with objectives of perpetuating the species, preserving old-growth specimen trees, and providing timber." Please note that throughout all the controversy, no one has suggested that there is a shortage of individual giant sequoia trees; the concern has been for the natural processes of the ecological entity called a "grove." Persuading the Forest Service to protect "groves" instead of merely protecting unique large specimen trees while doing tree-farm management around them has been a continuing battle.

Settlement Agreement

The July 1990 Settlement of the Sierra Club's administrative appeal (McDonald 1988) of Sequoia National Forest's Land Management Plan calls for an amendment to the Forest Plan which would manage most groves for preservation of natural processes. The Settlement takes the majority of grove acres out of the "suitable timber base," but logging is allowed in groves to remove fuel loads which might pose a fire threat. To some environmentalists, this language is too similar to some of the arguments justifying recent harsh logging. Another of the Settlement Agreement's weaknesses is that its definition of "grove" does not take into account those environmental factors upon which the groves may depend. It defines groves as small, unconnected islands with narrow buffers; Settlement provisions call for placing grove boundaries 500 feet from the outermost sequoia. In many cases this

will be insufficient for long-term protection. For example actions far above groves can interrupt or change surface and/or subterranean water flow upon which the groves depend. The Settlement is also deficient because it does not require that all sequoias be in a grove; it allows for "naturally occurring giant sequoias outside of groves." Another failing of the Settlement Agreement is that it allows logging in the historical Converse Basin Grove. Remember, the giant sequoia provisions of the Settlement Agreement were not based on scientific grove biology. The Settlement was a compromise bargained between environmental groups, the Forest Service, and the timber industry. Proposals made during negotiations were screened by first running them through the computer to check how they would affect logging volumes.

Even should the Settlement Agreement provisions be satisfactory, it leads to an amended Forest Plan which will provide protection by Forest Service policy. Remember the Type I policy which protected the groves and which was changed with so little notice! We may have policy protection once again, but now many of our finest groves are greatly damaged. Local citizens feel that significantly stronger protection is needed, and that the areas to be protected need to be connected and buffered in a large giant sequoia reserve.

Enforcement of Policy

No projects are supposed to be approved in groves until scientific study has been completed and until specific grove management plans are written. But constant public monitoring is necessary. Last June, a timber sale was sold and even marked on the ground within the Alder Creek Grove (Tule Helicopter Sale 1991). This past April a supposed hazard tree removal project in the McIntyre Grove (USDA 1992) resulted in the logging of several non-hazard trees (Key 1992) with much unnecessary bulldozing; while investigating that sale, we found that other areas of the grove had been logged and bulldozed in the 1990 Nelson Tractor Sale.

Many salvage timber sale boundaries take in portions of giant sequoia groves; while decisions state that no logging will occur in groves, there are no indications of grove boundaries on sale maps so grove intrusion is quite possible.

Problems in the Logged Groves

Giant sequoia grove ecologists need to take a hard look at the recently logged groves. While studies and surveys of groves will cost money, it is important to note that the timber sales within the groves cost taxpayers hundreds of thousands of dollars more to administer and reforest than the income received for the logged timber. If fuel load reduction had been the prime purpose of all the logging, a much more cost effective way for achieving that purpose could have been found (O'Toole 1988).

Potential problems exist in these logged groves which may need remediation in the near future. One evident problem is that many of the specimen sequoias had trenches dug



This 15-acre unit of the Black Mountain Grove, cable logged in 1987, contains the three isolated "specimen" sequoias named "The Three Sisters." The fire set to "broadcast burn" logging slash on the 50 percent slope burned much too hot.

around them to protect them from fire during the burning of logging slash. These trenches, some on very steep slopes, act to concentrate the increased water run-off coming down from freshly denuded slopes. Over time many of these huge trees may become undercut, lose their balance and fall over. It is possible that this effect could be mitigated if work is begun soon.

Before the lawsuit was settled, Sequoia National Forest replanted 75 percent pine and 25 percent giant sequoia seedlings at 10 by 10 foot spacing up to the drip lines of the remaining giants. The lawsuit settlement required recently logged groves to be restored to natural conditions; that

requirement was interpreted to be the planting up to five seedlings of various conifer species in 12 inch circles at 15 by 15 foot spacing up to the drip line of remaining giants. If the growing sites are as good as predicted, soon there will be an overcrowded conifer thicket in all of these groves.

Ostensibly, the groves were stripped of their trees to reduce fire hazard, yet in many cases the fire ladder is still in place. And worse than before, at the bottom of the fire ladder, waiting like an incendiary bomb, is the most flammable item in the forest: an even-aged plantation. In established plantations such as in the Alder Creek Grove, it may be too late to initiate a natural-like fire regime; hand



This aerial view of logging on Sequoia National Forest shows a clearcut harvest unit in both grove and non-grove areas: the spared giant sequoias in the Long Meadow Grove stand newly vulnerable to the elements in a modified clearcut.

thinning may be necessary. In the recently planted groves, a corp of volunteers could relieve the area of excess non-natural seedlings.

In the groves there are many temporary roads, landings, and firebreaks, compacted and pouring increased runoff and sediment into the streams; these need to be restored back to a natural state. Some logging roads cut across subterranean water flow that used to seep across a wide area, sustaining the groves. Now, because the flow has been interrupted by road cuts, the water is collected, channeled into culverts, and

concentrated into narrow surface streams. This loss of sub-surface water could have catastrophic impacts on the future of certain groves.

Many of the groves have cattle grazing in them. The cumulative impacts of grazing need to be studied in addition to all of the other impacts already occurring in the groves. As for the supposed problem of lack of sequoia reproduction, how many recruitment trees are optimum? Many of the Black Mountain sites contain plentiful sequoias in many age classes. This is the same grove that had the smaller Sequoias

removed by accident. I believe that short-lived human beings lack perspective when looking at a species that can live 3,500 years and still be fertile. Even one recruitment per acre every century might be too many if you consider that other tree species also grow in a natural grove. While it is certain that fire has a natural role in all areas of the Sierra, certainly some grove areas did not burn for extended periods of time, perhaps even several hundred years. The trees targeted for recent logging from groves were old-growth pine ranging from 150 to 350 years of age (stump evidence). As for recent logging emulating fire, it is difficult to imagine a natural fire regime which would totally consume the ancient pines and leave the giant sequoias intact. If the recent logging emulated fire in any way, there should have been no need to artificially replant sequoia; clearly, despite agency rhetoric, the replanting of pine was not intended to imitate nature.

We need to change the timber production mentality which refers to stocking standards; a natural grove in most cases does not consist of pure sequoia, but rather is a mixed-conifer forest with a diversity of age classes. In a natural grove there are some areas which do not contain sequoias, perhaps even for centuries; we must enlarge our vision in order to understand a species which exceeds our concept of time.

Probably the greatest threat to the groves involves the continuous degradation and fragmentation of the adjacent forests. While the Settlement Agreement calls for some constraints on logging, and while recent studies on the plight of old-growth dependent species are calling for a reduction of clearcutting and logging volumes, Sequoia's timber program, to date, appears to be unchanged. Sequoia National Forest's Five Year Sale Plan shows a continuation of what local involved citizens believe is an unsustainable and destructive amount of logging and clearcutting.

The Future

The giant sequoia tries human beings' lack of patience and humility; as so many have noted, in our short lifetimes we cannot know but a small portion of the sequoia story. It may be centuries before the consequences of this generation's actions can be evaluated. In the past century and a half nearly every impact imaginable, from subdivisions to clearcuts, has occurred in one grove or another. The few groves or portions of groves that have been spared must, to the greatest extent possible, have minimum intrusion. As long as a grove contains seed bearing trees, there will be options. The danger is not in doing too little, but in doing too much.

Not only do scientists need the remaining untouched groves for baseline comparison, we must not foreclose the options of future generations who will better understand Sequoia ecology. We must continue to gather information about this fascinating species and trust that our children and their children will value these magnificent creations, build upon our knowledge, and continue our work.

I urge all who study and love giant sequoias to visit and hike in the forest and see how it is being managed. Defend

these places, refuse to let research findings be misapplied, and don't trust agencies to always do the right thing. Tell Congress that the natural world matters to you; indeed we cannot exist without it. Tell them that the sequoia groves will be safe only if the entire forest which sustains them is healthy. Insist on legislative protection for a generous reserve connecting and buffering the groves.

My favorite giant sequoia is the Wishbone Tree in the Wheel Meadow Grove. I first met it when I was about five years old. As sequoias go, it's not terribly big, but it looks like a wishbone because of the opening at its base. The trail goes through that opening, and I can ride my horse through without ducking my head. The tradition is that as you pass through the tree you touch it and make a wish. Today, instead of my former teenage wishes for fame or fortune, my wish is much more serious; it is for life on earth to continue; it is a wish that countless future generations of children will be able to reach out and touch this tree with wonder and awe as they make their own wishes.

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References

- Cloer, Carla; Little, Charlene. 1987. Administrative appeal, timber harvesting within giant sequoia groves, on behalf of the Sierra Club and Forest Alliance. Unpublished draft supplied by authors.
- Crates, James A. [Letter to Charlene Little]. 1987 February 10. 1 leaf. Located at: U. S. Department of Agriculture, Forest Service, Sequoia National Forest, Porterville, California.
- Crates, James A. [Letter to Carla Cloer]. 1989 February 14. 1 leaf. Located at: U.S. Department of Agriculture, Forest Service, Sequoia National Forest, Porterville, California.
- Crates, James A. [Letter to Charlene Little]. 1987 February 20. 1 leaf. Located at: US. Department of Agriculture, Forest Service, Sequoia National Forest, Porterville, California.
- Crates, James A. [Letter to Carla Cloer]. 1987 February 23. 1 leaf. Located at: U.S. Department of Agriculture, Forest Service, Sequoia National Forest, Porterville, California.
- Findley, Rowe. Will we save our own? National Geographic. 1990 September.
- Fisk, Ken. [Memo to Management Team]. 1986 September 8.
- Green, Lee. They are raping the giant sequoias, Audubon Magazine, 1990 May.
- Hartesveldt, R.J. The "discoveries" of the giant sequoia. Journal Forest History 1975.
- Harvey, Thomas H. Evolution and history of giant sequoia. 1986. In: Weatherspoon, C. Phillip; Iwamoto, Y. Robert; Piirto, Douglas D., tech. coords. Proceedings of the workshop on management of giant sequoias; 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; 1-3.

- Kay, Jane. Logging threat to sierra giants. San Francisco Examiner. 1992 May 24.
- Key, Sandra. [Letter to John Rasmussen]. 1992 April 29. Located at: U.S. Department of Agriculture, Forest Service, Sequoia National Forest, Porterville, California.
- Knudson, Tom. The Sierra in peril. Sacramento Bee. Series, 1991 June 9-13.
- Levin, Ann. Sharp words cut deep in logging war. San Diego Tribune. 1987 Nov. 11.
- McDonald, Julie E. Appeal to the Chief of the U.S. Forest Service, Sequoia National Forest Plan and EIS, Statement of Reasons and Exhibit Volumes I, II, and III, 1988 July 20.
- McDonald, Julie. The Mediated Settlement: Proceedings of the symposium on giant sequoias, their place in the ecosystem and society, Visalia, California. 1992 June 25-27.
- O'Toole, Randall. Review of the Sequoia Forest Plan and Final EIS, CHEC, 1988 Aug.
- Pintek, Steve. Affidavit, 1987a June 8.
- Pintek, Steve. [Memo to contracting officer]. 1987b May 21. 1 leaf. Located at: U. S. Department of Agriculture, Forest Service, Sequoia National Forest, Porterville, California.
- Rice, Richard E. Taxpayer Losses from National Forest Timber Sales, FY 1990, Wilderness Society, 1991 May.
- Rogers, R.R. Management of giant sequoia in the National Forests of the Sierra Nevada, California. In: Weatherspoon, C. Phillip; Iwamoto, Y. Robert; Piirto, Douglas D., tech. coords. Proceedings of the workshop on management of giant sequoias; 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; 32-36.
- Rundel, Philip W. Affidavit in support of complaint for declaratory and injunctive relief, unpublished, 1987 May 17.
- Sierra Club, et al. Mediated Settlement Agreement of Sequoia National Forest Land Management Plan Administrative Appeals, 1990 July.
- Sierra Club vs. United States Forest Service, 843 F. 2d 1 190 (9th Cir. 1988).
- Settlement, Sierra Club, giant sequoia lawsuit, 1989 December 28.
- Smith, Zane G., Jr. [Letter to Charlene Little]. 1986 December 12. Located at: U.S. Department of Agriculture, Forest Service, Sequoia National Forest, Porterville, California.
- Stephenson, Nathan L. Affidavit in support of complaint for declaratory and injunctive relief, unpublished, 1987 May 23.
- U.S. Department of Agriculture, Forest Service. 1992. Sequoia National Forest Tule River Ranger District. Human Hazard Tree Removal Environmental Assessment.
- U.S. Department of Agriculture, Forest Service. 1991. Sequoia National Forest. Tule River Ranger District. Nelson Tractor Sale Environmental Assessment.
- U.S. Department of Agriculture, Forest Service. 1970. Forest Service Manual Title 2400, Timber Management, Sierra Redwood Groves, R-5 Supplement No. 91.
- U.S. Department of Agriculture, Forest Service. 1985. Forest Service Manual. Title 2400, Timber Management, Giant Sequoia Groves, R-5 Supplement No. 28.
- U.S. Department of Agriculture, Forest Service. 1988. Sequoia National Forest Land and Resource Management Plan.

Perspectives of the Forest Products Industry on Management Strategies¹

Glen H. Duysen²

Abstract: Past history indicates a wide range of management strategies in the giant sequoia groves of Tulare and Fresno counties. The variation in management is a result of grove ownership, Federal and state regulations and policies, and public sentiment. When the West was developing in the late 1800's, lumber from the giant sequoia was a highly desired product. Private groves were harvested. These lands now are stocked with second-growth sequoia, pine, fir, and cedar. Management activities since the 1930's on Forest Service, state, Native American, and private properties have been confined to the removal of the white wood species. Management of sequoia groves on Federal park lands has been limited to control burning for fire protection. Regardless of the management strategy applied during the past 120 years, the giant sequoia specimen tree is a most hearty "soul," maintaining a defiant stance against old age, fire, wind, drought, and man's activities. Current management strategies on Federal lands are mandated by law, regulation, or management plans, and basically provide only for fire protection for the sequoia groves. Selective harvesting of white wood species in sequoia groves on state land has resulted in healthy, esthetically pleasing, timber stands, which the forest products industry strongly supports. Management strategies for all ownerships should provide for the reproduction of the giant sequoia species. As a fast growing tree adaptable to the local climate, the establishment of giant sequoia reproduction for future national lumber requirements on state, private, and Forest Service lands is a worthy goal.

My comments today are based on my observations as a licensed professional forester, working in and around both public and private giant sequoia groves for the past 25 years in Tulare and Fresno counties.

We can learn much about the giant sequoia species by examining three different management strategies practiced over the past 120 years. As California developed in the 1880's, the first strategy involved the demand for redwood lumber. Many small sawmills were constructed on private property. A major species milled was specimen size giant sequoias. Evidence of this practice can be found in the Converse Basin, Dillonwood, and Mountain Home. Although generally regarded as a poor management practice today, these lands currently support a well-stocked stand of second-growth sequoias, with a mixture of the other native conifer species.

Since the 1930's, the harvesting of specimen size giant sequoias has been very minor, but logging of the white wood species (pine, fir, and cedar) has occurred within sequoia groves on both Federal, state, and private lands. This management strategy varies from a very light selective harvest to removing all white wood trees. A wide range of other practices have been found within and around the Sequoia

National Forest. On Tule River Native-American land and within their groves, there has been harvesting of the conifer species. The Sequoia Crest grove is an example of summer home development within a grove, which required the removal of the white woods and some second-growth sequoias. Mountain Home State Demonstration Forest has selectively harvested within their groves, resulting in an excellent stand of second-growth sequoia intermixed with pine, fir, and cedar. However, because of Federal laws and regulations, sequoia groves within the USDI National Park boundaries have had limited physical activity. Road construction has been minor, and fire protection management and regeneration has been conducted through control burns.

So then what have we learned from these management strategies? There are widely divergent opinions concerning how the entire stand structure should be managed in a grove, but the forest products industry strongly supports the protection and preservation of specimen giant sequoia trees.

Fire Management and Regeneration Strategies

Exposed mineral soil and sunlight are requirements for the regeneration of the species. These two conditions do not occur in the nondisturbed grove. In order to perpetuate the species, we believe manipulation of the surrounding vegetation is essential to attaining the proper seed bed.

We do know that although some people believe the giant sequoia tree is a fragile, near-extinct species, there are sufficient examples which indicate the hearty nature of the tree. Major fires over the past 1,000 years have not been able to destroy these magnificent giants. Winter storms, while eliminating an occasional tree, have not caused major damage to the groves. Recent studies have found the giant sequoia to be a very windfirm species throughout the world. Human activities, whether through road construction, logging, or land development, apparently have not affected the longevity and health of the species. Ground disturbances have not occurred for 120 years at the Converse Basin and at Dillonwood, with later activity on the Tule River Native- American Reservation, Camp Lena, and Sequoia Crest. The remaining specimen trees in these groves appear to have remained thrifty and windfirm when compared to groves that have not been entered. The forest products industry emphatically believes our giant sequoia groves should be managed carefully and skillfully, but not treated as an endangered species. Giant sequoia groves do not need or require wide buffer strips or entire drainages set aside as protection measures.

¹An abbreviated version of this paper was presented at the Symposium on Giant Sequoias: Their Place in Ecosystem and Society, June 23-25, 1992, Visalia, California.

²Resource Manager, Sierra Forest Products, Terra Bella, CA 93270.

Protection from wildfires has been a high priority for many years in the management of giant sequoia groves on both National Park Service and USDA Forest Service lands. This protection has created problems and becomes more difficult over the years because of the elimination of periodic ground fires, and the rapid growth of understory stands of the conifer species. To reduce the fire hazard to the groves in recent years, two methods have been used: controlled ground fires and mechanical removal.

The National Park Service has taken the lead in the use of controlled ground fire to reduce the catastrophic wildfire potential. The forest products industry, while realizing the limitations under which the Park Service operates due to laws and regulations, has the following general concerns in the use of control burning:

- Difficult to control intensity of burn;
- Creates additional air pollution;
- End product is not esthetically pleasing;
- Site preparation is often not adequate for regeneration;
- Destroyed conifer resource not utilized.

The Forest Service has advocated mechanical methods to remove the fire potential in their groves and to promote regeneration. With the signing of the Mediated Agreement for the Sequoia National Forest in 1990, mechanical entry into the Sequoia groves is not permitted except for the specific purpose of reducing the fuel loads, after analysis through a grove Environment Impact Statement. Mechanical entry has several advantages:

- Method can be controlled;
- Removed white woods can be utilized;
- Sites quickly heal esthetically;
- An adequate seed bed can be prepared;
- Visibility of specimen trees can be enhanced.

A Multiple-Use Strategy

Another land management practice worthy of discussion can be found on the Mountain Home State Demonstration Forest (this strategy was also used on selected areas of the Sequoia National Forest). Selective and small group harvesting of white wood species within giant sequoia groves in the State Forest has been the practice for many years. A multi-age stand of healthy pine, fir, and cedar co-exist with the specimen size giant sequoias. The timber stand has been

opened sufficiently to permit the establishment of second-growth sequoias. Specimen trees are visible to the visiting public. Recreation is the first priority in the management of the State Forest, and the numerous campgrounds are heavily used. This is living proof that timber management, even in giant sequoia groves, can be in harmony with recreation and wildlife. The forest products industry strongly supports the multiple-use concept as exemplified on Mountain Home State Demonstration Forest. Their managers over the years are to be praised for their progressive and dedicated approach to managing this natural resource.

Diverse ownership and management strategies are supported by the forest products industry. We are aware that on Federal lands the strategies are often dictated by law, regulation, and mediated management plans. State, Native-American, and private lands are managed under different circumstance. We also recognized the reasons for the differences. We do not advocate the same strategy for all ownerships. We strongly reject the view that a single management strategy for all giant sequoia groves, whether National Park, National Forest, state or private, is in the best long-term interest of the groves or the American people. We also reject the non-management concept. Non-management is bad management.

The development of second-growth commercial stands of giant sequoia on USDA Forest Service, state, and private land should also be pursued. As a fast growing and desirable commercial species, second-growth giant sequoias may help to supply the need for wood products for our future generations.

Conclusion

This symposium has presented different views on Sequoia grove management; presenting these different strategies is a constructive problem-solving method. Only through open dialog and the sharing of information will we be able to do the best job in managing our respective natural resources.

The use of misinformation and broad accusations in order to influence the public has no place in sound resource management. It is evident from the quality of speakers that the giant sequoia is in no danger of extinction or is being mismanaged in any ownership. All participants at this symposium have the responsibility to speak honestly and professionally with the public and our elected representatives. If we do not tell the whole story, then we should not consider ourselves professionals.

Reflections of the Audubon Society Giant Sequoias: Their Place in the Ecosystem and Society¹

Daniel Taylor²

Abstract—The giant sequoia is one of the world's most awe-inspiring creations. It is an important element of the west's ancient forest habitat that was once widespread, but has been reduced to one-tenth of its former extent due to a century of intensive logging. Decisions about the management of these groves must reflect our best science together with a sensitivity for the social and aesthetic importance of the species. Audubon believes the plight of the sequoia must be viewed within the overall context of the Sierra Nevada. The Sierra without the sequoia would be a tragically lessened place. But so would a sequoia grove without many of the other older forest-dependent wildlife considered at risk in the Sierra. Audubon's vision for the sequoia and for the Sierra Nevada is one of *forests that work*, producing effective biodiversity protection, clean water, clean air, and needed recreational opportunities: and *working forests* in which ecologically sustainable quantities of high quality forest products can be produced. Audubon supports a scientifically-based management and protection strategy for the sequoia. We call on the Forest Service and the political leaders of that agency to heed the public call for the increased protection and careful stewardship of the sequoia and the Sierra Nevada.

It is indeed a privilege to be with you today, participating in these important discussions concerning one of our planet's most awe-inspiring creations. We are pleased to be both a contributor to, and a sponsor of this event. I regret that my time here has been too limited and that I was not able to join with you on a field trip yesterday. But I took my own sequoia field trip this past Father's Day. With my wife and eight year old son, I packed a small picnic lunch and drove up to the Placer County sequoia grove on the Tahoe National Forest.

As you know, this grove composed of six ancient trees and two downed logs is the northernmost grove of the sequoia. It is also one of my favorite places in the Sierra. Only 2 hours from downtown Sacramento, it offers the opportunity to experience the majesty of the giant sequoia, accompanied by the sugar pine, ponderosa pine, and Douglas-fir, all far older than our republic. This seemed a good place to spend a Father's Day. When I think of my own father, I recall his strength, and his stability, his patience, and his seeming permanence in my life—all of these attributes symbolized in a different way by these trees. He was old when I was young.

The largest tree in this grove is the General Pershing Tree. My own son walked up to this tree, and against it he appeared tiny and ephemeral. I reflected for a few moments how temporary we are when compared to the sequoia. This tree was a sapling at the time of Christ. It will outlive me, and outlive my son. If he is privileged to have children, it

will outlive them too for generations to come. So there, in this natural cathedral, I experienced the sequoia, and the azaleas still in flower, and dogwoods now passed their peak. When a hermit warbler flew by, giving us a great look at a bird more often heard than seen, the day was complete.

My assignment today is to share my observations with you regarding the giant sequoia and its place in the ecosystem and our society. I accept this challenge readily, both as a representative of a large environmental group, and as an environmental staff person of 15 years, the last eight of which have been devoted with ever greater intensity to the management and protection of our forests. It is my lot, either good or bad, to be one of the few members in the California forest protection community to be active in the debate over forest management on both the public lands and the private lands. Today, I wish to focus most of my remarks on the public lands, in accord with our theme of the giant sequoia.

The National Audubon Society's mission is to conserve and restore natural ecosystems, focusing on birds and other wildlife for the benefit of humanity and the earth's biological diversity. With 550,000 members and 600 local chapters throughout the Western Hemisphere, Audubon applies its expertise in science, education, habitat management, political action and grassroots involvement to accomplish its goals. National Audubon's top environmental objectives include the protection of America's ancient forests.

Audubon's Vision: Forests Which Work

The ancient forests of the Pacific Northwest and California are the last survivors of vast primeval forests that covered much of America when the first colonists arrived. After a century of intensive logging, less than a tenth of the western ancient forests remain, nearly all on public land. These publicly-owned forests are to be managed for multiple use. Yet, the agencies in charge, have historically put the needs of the timber industry first in making important decisions about management. Today, the legacy of this imbalance is a forest environment in which biological diversity is at severe risk.

The giant sequoia plays a key role in Sierra Nevada forest ecology. It also occupies a special place in American culture and legend, and is considered by many to be the "king" of the plant world. In the past, Audubon has severely criticized specific management decisions which have harmed the giant sequoia. Many here are more expert than I in the history and management of the sequoia, and the Sequoia National Forest. Place names like Converse Basin, Starvation Creek, and Long Meadow evoke powerful feelings between

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²Western Regional Representative, National Audubon Society, 555 Audubon Place, Sacramento, CA 95825

people and their government of deep controversies, mistrust, alienation and possibly regret.

Audubon believes the plight of the sequoia must be viewed within the overall context of the Sierra Nevada. The Sierra without the sequoia would be a tragically lessened place. But so would a sequoia grove without the spotted owl, great grey owl, Sierra Nevada red fox, fisher, goshawk, and the California condor. The sequoia cannot truly be protected when it alone is the focus of society's consideration. What's at stake is more important: the health of an entire regional ecosystem. It is accurate to call the giant sequoia one of the crown jewels of the Sierra Nevada. But what purpose are crown jewels without a crown in which to place them?

Audubon's vision for the sequoia and for the Sierra Nevada is one of *forests which work*, producing, through scientifically sound management and protection strategies, effective biodiversity protection, clean water, clean air, and needed recreational opportunities for an expanding human population.

This vision is far from reality today. In the United States, the environmental community has attempted to change the timber first philosophies of our forestry agencies. We have gone to the courts and asked at least that the laws be obeyed. Conservative judges have enforced the law, and this has stopped some timber sales which threaten ecological values. In many respects, the collective memory of agency promises made, but not kept, are powerful. When the Chief of the U.S.D.A., Forest Service embraced "ecosystem management" for the national forests and grasslands earlier this month, his announcement was greeted with deep skepticism from the environmental community. Faith in words alone is no longer enough. Because there is no longer faith in words alone. Practical, enforceable, on-the-ground management directives are needed.

We also want *working forests* in which ecologically sustainable quantities of high quality forest products can be produced. We recognize that California ranks as one of the world's largest consumers of forest products. Each year, we use in the form of dimensional lumber, plywood, paper and wood by-products about 10 billion board feet. And both public and private forests of California have been producing about 4 billion board feet of these products. Therefore, each year we import 60 percent of the wood products we use. Audubon takes no comfort in merely shifting the overcutting of California's forests to some other part of the country, or worse yet to another country in which logging is done with even fewer environmental regulations. However, all human uses of our natural resources including logging must be scaled to the land's ability to provide timber, soil, water, fish and wildlife in perpetuity, not to a mere abstract socio-economic perception of what these uses ought to be.

Forest Protection Strategies

I would like to discuss some specific initiatives which Audubon supports to bring life to our vision on forestry. In

the midst of the forest policy crisis now gripping our region, several opportunities for solutions exist.

Audubon supports legislation now being considered in the Congress to protect and restore National Forest ecosystems. The bill, House Resolution 4899 is being actively debated in both the House Agriculture Committee and Interior Committee. We urge the Congress to pass this important bill provided it continues to carry levels of forest protection which help ensure the long-term existence of old-growth and late seral stage forest ecosystems. Included in the bill are powerful incentives for worker retraining and community stability. This is a good bill which will help us protect and mend our forests while being mindful of the human costs involved. Contrary to claims made by certain environmental opponents, we do not seek a new religion which worships trees and sacrifices people.

Our political system depends on the promise of compromise. But the issue of ancient forest protection is one where it is not possible to simply "split the difference" between competing factions. Solutions must be based on strong science. Compromises which ignore science are doomed to fail. Species and ecosystems will continue to decline, ushering forth petition after petition for new endangered species and the rigid regulations which follow.

We also strongly support the provisions in HR 4899 for a comprehensive study and interim protections for the national forest lands in the Sierra Nevada. The need to protect the few remaining blocks of unroaded habitat still existing in the range is crucial. So is the need for an objective, ecologically-based study to help guide long-term management. The Sierra is a complex area. It is largely an altered landscape that for almost 150 years has been impacted by grazing, unwise logging, mining, population growth, road building, hydro-electric development, and fire suppression. Only through a comprehensive, scientific study done by competent, unbiased, recognized authorities can we hope to find credible answers to the challenges of maintaining and restoring a Sierra Nevada rich in wildlife and forests, and suitable for appropriate, sustainable development.

We support the adoption of interim direction proposed by the California Spotted Owl Technical Team in its May 8, 1992 report. This report represents the best scientific statement to date on the status of the California spotted owl. The recommendations contained in this important report will maintain needed options to protect the owl over the long term. We urge that its recommendations be implemented.

We support a forest protection strategy for the giant sequoia. Management within groves must be ecologically driven, reflective of the best, most accepted scientific understanding, and only be aimed at improving forest health. Sequoia groves should remain removed from the timber base, and any volume produced should not be counted toward timber targets for a forest or ranger district. The incentives to cut in order to satisfy timber targets must never again exist. In the case of the sequoia, we are stewards of a resource of planetary significance.

We are working hard to pass state legislation to reform private land forest practices. Currently, a package of bills commonly known as the "Grand Accord" (Senate Bills 300 and 854, and Assembly Bills 641 and 714) enjoys support from responsible voices in the timber industry and the environmental community. Sadly, the Grand Accord finds itself stuck in the California State Assembly. If passed it would help assure a sustainable private forest industry in California. It would accomplish the difficult goal of integrating public resource protection and private investment in forest land, people, and equipment which this state needs.

Future Goals

In conclusion, any discussion about the future of the sequoias, or the Sierra Nevada requires reflection on the future of the Forest Service. It is well reported that the agency finds itself mired in crisis, and stuck between changing management paradigms. As we ponder a future for this agency, we should take lessons from its past. The Forest Service of 1905 was a small agency with spirit, pride, and idealism. In his autobiography Pinchot wrote, "Every member of the Service realized that it was engaged in a great and necessary undertaking in which the whole future of their country was at stake. The Service had a clear understanding of where it was going, it was determined to get there, and it was never afraid to fight for what was right."

Perhaps it is only at times of crisis that courage and leadership emerge. Sadly, our nation's forest policy leadership has provided an object lesson in both delay and denial

in its management of forest lands. It is my personal hope, and that of Audubon, that the Forest Service, and those political leaders who oversee it will heed the emerging public land values of the 1990's: clean air, clean water, wildlife habitat, sustainable economic development, and recreational opportunities.

I am impressed with today's generation of leadership of the Forest Service in California and the California Department of Forestry and Fire Protection. Their desire to move forward with a more ecologically sensitive management philosophy is encouraging. We welcome this trend, and we want to work with the agencies, the industry and our political leadership to help accomplish a new, sustainable management paradigm for our forests. But we don't have much time.

Society would be well served if this conference helped usher forth a new beginning in the management of the sequoia and the Sierra Nevada. A renewed stewardship commitment based on strong science would help heal the anger and alienation brought forth by decisions of the past. Such a shift would be an appropriate gift to future generations of people and sequoias alike.

References

- Pinchot, Gifford. 1947. *Breaking new ground*. New York: Harcourt Brace.
- Verner, Jared; McKelvey, Kevin S.; Noon, Barry R.; Gutierrez, R.J.; Gould, Gordon I., Jr.; Beck, Thomas W., technical coordinators. 1992. *The California spotted owl: a technical assessment of its current status*. Gen. Tech. Rep. PSW-GTR-133. Albany, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 285 p..

Mitigating Some Consequences of Giant Sequoia Management¹

William J. Libby²

Abstract: There are recognized financial and opportunity costs associated with the reduction or elimination of timber harvest on productive forests. It has recently become clear that there are additional costs associated with harvest foregone, which range from increased pollution to species extinction at distant sites. Appropriate mitigation of these unwanted costs is to link harvest foregone at some sites to increased productivity of the renewable wood resource at other sites.

At trailhead to South Grove, Calaveras, a sign quotes John Muir: "The Sierra redwood is nature's forest masterpiece, and so far as I know, the greatest of living things. It belongs to an ancient stock, and has a strange air of other days about it."

Our ancient giant sequoias are a national treasure. While we may disagree as to the best way to manage these giant trees, there seems to be broad agreement on the following three points. The very large sequoias should not be logged. The very large sequoias should, to the extent possible, be kept in a natural and healthy state. The ecosystems of the giant sequoia groves should be managed in the long run such that, as these old giants eventually die, they will be replaced by young sequoias that will grow to equally majestic sizes and live equally long lives.

If we achieve these goals, we do so not only for ourselves, but for all people on Earth, so that they can visit these groves, or at least know that such magnificent trees are here. More important, we do this for all our children, for the hundred human generations that will occur during the life span of a single sequoia tree, and for the thousands of human generations that will occur in the future of these groves.

In pursuing these fine goals, we encounter an ethical conflict that did not exist 20 years ago, and that very few of us predicted. The actions contemplated at this Symposium have both positive and negative consequences. As responsible members of Earth's human community, we should and can mitigate the negative consequences while securing the positive consequences. I'll now try to identify some of the problems, and suggest possible solutions.

Tropical Rainforests

Tropical rainforests contain about four-fifths of Earth's species. If a tropical rainforest is wholly cutover, even though much of it promptly regenerates following logging, it is estimated that a quarter or more of its species will have

become extinct as a direct result of such habitat disturbance (Lugo 1988, Appendix Note 1).

Figure 1 shows selective logging in a tropical rainforest. The photo was taken in Venezuela, but it could well be of selective logging in a tropical rainforest almost anywhere. A track has been bulldozed to the valuable tree at its end. Only this one tree will be removed from the immediate area for sale. Many other trees have been destroyed or damaged as a result of this selective harvest, and the ecosystem has been disturbed. In some tropical forests, the logging roads open the forest to either legal or illegal entry by farmers, who then cut and burn the remaining forest and attempt to convert it to crop or pasture lands.



Figure 1-Selective logging in the Orinoco rainforest in Venezuela. This practice results in about 2 cubic meters of harvestable wood per hectare per year. Photo by author, 1991.

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²Professor of Forestry, University of California, Berkeley 94720.

New Zealand

When the Maori came to the large islands they called Aotearoa, less than a millennium ago, about three-quarters of the land was covered by forest. When Europeans came, less than two centuries ago, the Maoris had cleared about a third of the native forest and only half of Aotearoa was forested. The European colonists soon renamed it New Zealand, and they and the Maoris accelerated forest clearing; nonetheless, by 1990, 23 percent of New Zealand still had old-growth native forest (Appendix Note 2).

If the 20th-Century peoples of New Zealand had attempted to satisfy their needs for wood and wood products from these remaining native forests, while simultaneously managing them to maintain their native old-growth character, New Zealand would now almost certainly be a net importer of wood and wood products.

Primarily because of a farsighted concern about future wood supplies, but also to create employment, substantial areas of marginal farmland, open grassland (and later small areas of some cutover native forest) have been planted with non-native tree species, mostly radiata pine from California.

When intensively managed, these forests are sometimes called "fiber farms" (*fig. 2*), a term that in some circles has been given a pejorative connotation. Such forested fiber farms are simplified and highly productive ecosystems. They are, in general, less complex than are native forests, but they are biologically and physically more diverse ecosystems than are typical agronomic crops. In this sense, it is ecologically more desirable to grow and harvest fiber from a eucalypt or pine fiber farm than it is to grow and harvest an alternative source of fiber from a bagasse or kenaf fiber farm.

These exotic-tree plantations and fiber farms now supply all of New Zealand's net requirements for wood and wood products. In addition, for every unit of wood used in New Zealand, another unit is exported to other countries on the Pacific Rim. And, most importantly for our discussion, most of New Zealand's remaining native forest is now reserved, with logging still permitted on only a small area. Because of these exotic plantations and highly productive fiber farms, occupying only five percent of New Zealand's land area (i.e., increasing New Zealand's forested land area by 22 percent), except for some specialty woods, there is no need to cut timber in any of New Zealand's remaining native forest.

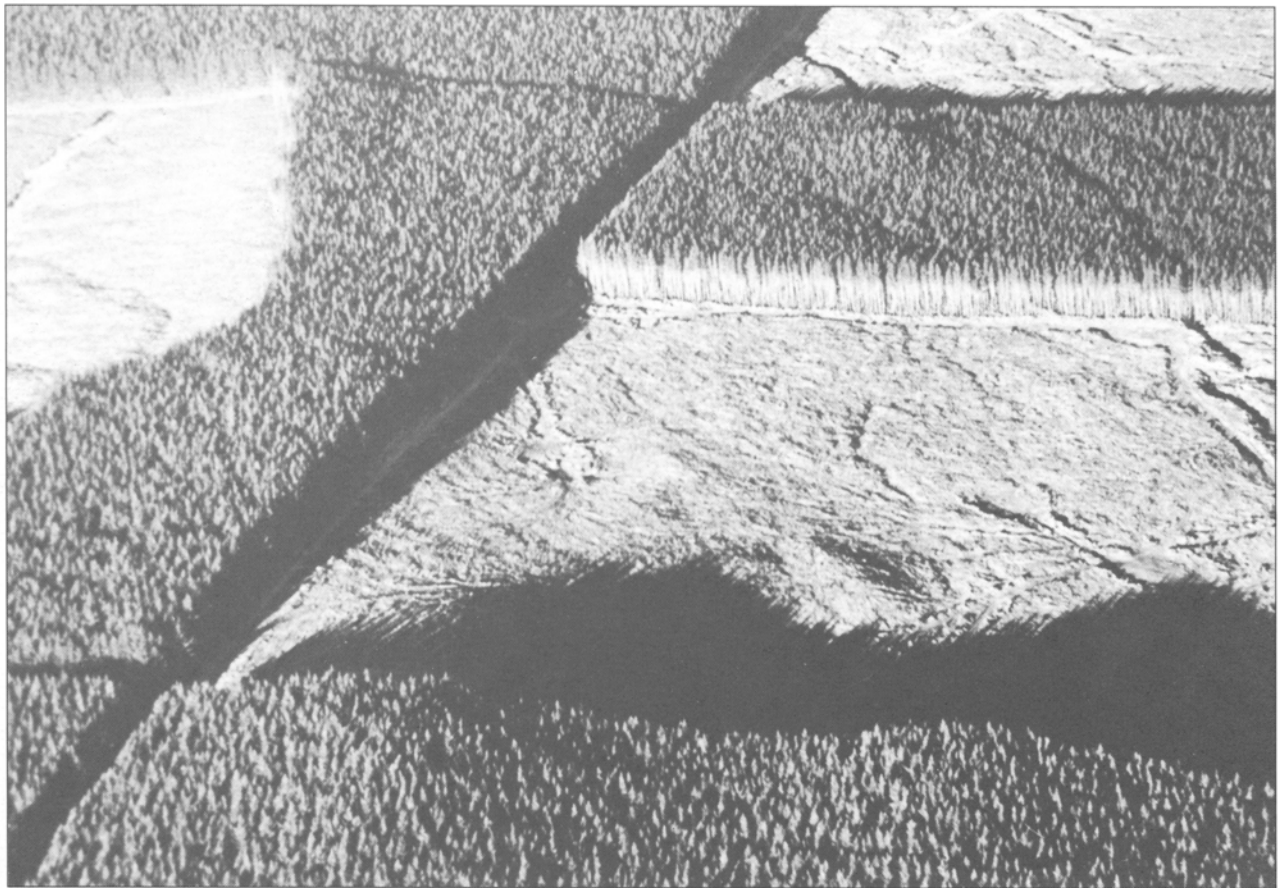


Figure 2—Harvest cuts in a New Zealand radiata pine fiber farm. Such plantations, when managed intensively, produce in excess of 27 cubic meters of usable wood per hectare per year. Photo from J. H. Johns, 1963, courtesy New Zealand Forest Research Institute (Forest Service) and New Zealand National Archives, Wellington.

California

California has the best species, the best sites and the best climate for growing wood of any temperate or subtropical region in the world. Add to that the closeness of its forests to major markets and to good ports, and it is not surprising that it is and has been a major producer of wood and wood products. In 1947, shortly after World War II, California was wood self-sufficient, exporting about as much wood as it imported. Thirty years later, in the mid-1970s, California had become a net importer of 40 percent of the wood and wood products that it consumed. Henry Vaux, then Chair of the State Board of Forestry, noted this disturbing trend and made the following projections.

First, he projected that a combination of population growth and increased per-capita use of wood and wood products would double the demand for harvested wood in California by the year 2020. That prediction is reasonably on schedule.

Second, he projected that if California's "timber-growing lands" could be effectively managed, their combined wood productivity could be tripled. (The term "timber-growing lands" means lands growing or capable of growing wood economically. They may be publicly or privately owned. Parks and other no-harvest reserves are not "timber-growing lands" even though they might be highly productive forests.)

Vaux asked for nothing heroic. He was not asking for the intensity of management practiced with California species on New Zealand fiber farms, but just for reforesting potentially productive forest areas that are understocked and better managing those areas presently growing trees for harvest. (Many of California's non-industrial private forest owners, in the present political and economic climate, consider such timber-oriented management activities difficult.) He calculated that if tripled productivity could be achieved, even with doubled demand, California would again be wood self-sufficient in 2020. However, Vaux's full projection is not on schedule. In 1988, California had become a net importer of 60 percent of the wood and wood products it consumed (Appendix Note 3), and that figure is probably even higher in 1992.

It is tempting to scapegoat Japan as a major contributor to world and Pacific-rim exploitation of old-growth forests. Like California, Japan imports about sixty percent of the wood and wood products it consumes. Thus both California and Japan contribute similarly to the problem. But unlike California, Japan has a national forestry policy and program with a goal of increasing domestic wood production, thereby reducing net imports to 20 percent of consumption by the year 2020 (Appendix Note 4).

The goal of reversing or eliminating California's net importation of wood does not exist, either in Sacramento, or in the United States Forest Service's Headquarters for the California Region. California is perhaps Earth's worst unnecessary wood imperialist. Let me comment on the basis for these harsh "unnecessary" and "imperialist" terms. As a

contrasting example, the climate in Kansas neither produced major natural forests nor would it now allow sufficiently productive forest plantations for Kansas to be wood self-sufficient. It is both reasonable and necessary for Kansas to be a net importer of wood and wood products. That is not, as indicated above, the situation in California. Rather than grow most or all of our own wood, which California could surely do, this rich state uses its political and economic power to obtain somebody else's wood.

Pacific Rim Trade and Species Extinction

Many of our leading conservation thinkers have noted variations on the theme that "everything is connected to everything" (see, for example, Commoner 1991, page 8). John Muir said something like that over a century ago. The connections were very loose when he said it, and they were still loose in the middle of this century. In the late 1940s, when California was wood self-sufficient, protecting the trees on some of our productive land by transferring ownership to a park or reserve had little effect beyond our borders. We just cut the wood we needed from somewhere else in California.

In the 1970s, the connectedness had expanded. When land was withdrawn from wood harvest in California in that decade, we bought wood from Oregon and Washington, where there was a substantial surplus of available wood. The effect of this 1970s demand shift was thus absorbed in the American west, and few effects were felt elsewhere.

By 1992, this connectedness had become longer and stronger. Like a guitar string, a perturbation at one end resonates over some or all of its length, depending on where the frets are pressed. The wood-demand notes keep getting lower and louder.

Now, when Californians choose not to harvest their own forests, this logically results in a three-step demand shift to the Pacific Northwest, diverting wood from being sent to the Far East, resulting in increased cutting in tropical forests in Malaysia, the Philippines, Indonesia and elsewhere to satisfy needs for wood in the Far East. For every substantial area taken out of wood production in California, some number of hectares will be cut, or will be cut sooner, somewhere else. For every 10,000 of these hectares cut in tropical rainforests, on average, one plant species and 48 total species will become extinct, somewhere, as a linked result of this three-step demand shift (Appendix Note 5).

Is Using Wood Environmentally Appropriate?

There are three parts to this issue: consumption without effective use, needed use, and recycling.

One response to California's enormous demand for imported wood is to reduce unnecessary consumption of wood and wood products. A good case has been made for

this course of action, and I hope it continues to be effectively made. One of my favorites is reducing the "cover your tail" proliferation of multiple-copy reports and memos practiced in or imposed by many of our bureaucracies lately. A second is the Sunday edition of many newspapers. I'm curious about what proportion of the typical Sunday edition is effectively used, or needed, by most subscribers.

The response must be different when resources are needed for appropriate uses. It is occasionally suggested that, in order to preserve more of our forests, we can satisfy these appropriate needs by using alternatives to wood. In some cases this is environmentally near-neutral or even beneficial, for example substituting surplus bagasse for wood fiber. But most of the substitutes for wood are environmentally more harmful than using wood (Appendix Note 7). In short, rather than reduce the proportion of wood used for appropriate human needs, strong arguments can be made to increase the proportion of wood in such uses (Appendix Note 9).

Recycling of solid wood and paper are both environmentally and economically preferable to adding them to landfills. Recycling is clearly appropriate for wood and wood products used well. However, recycling has high environmental costs as well as financial costs, and it is a poor second choice to that of reducing unnecessary consumption.

Costs and Mitigations

The term "mitigations" as used here refers to procedures or actions intended to reduce some of the harm caused as a side-effect of accomplishing some desired goal.

We can now consider some costs, in terms of average maximum likely extinctions, resulting from proposed alternatives for managing our giant sequoia groves. I present as examples four alternatives from a longer list under consideration: (a) Full timber production from the Forest Service giant sequoia groves; (b) A timber yield/amenity combination, with emphasis on visual quality, maintaining current giant sequoia percentage cover and tree size-class distribution; (c) Maximum amenity, with a 30-year cycle of selective logging, harvesting only three-fourths of the anticipated mortality; and (d) Transfer to park and monument status, with no logging.

Full timber production from the groves, including removal of the specimen trees to make room for vigorous young-growth, is clearly not an acceptable option. Yet, the full productivity of the site must be calculated as a mitigation baseline. Giant sequoia grows on sites high in productivity. Estimated average productivity of these giant sequoia groves is 11 cubic meters of usable wood per hectare per year, and there are about 6,000 hectares under consideration (Appendix Note 11).

The following numbers indicate some costs and possible mitigations under alternative (d) above, the no-wood-harvest option. Using 2 m³/ha/yr as a reasonable average for rainforest productivity (Appendix Note 12), and 25 m³/ha/yr as the likely productivity of California fiber farms, means that we

could replace the wood-production foregone on 6,000 hectares of giant sequoia groves by harvesting 33,000 hectares of tropical rainforest (estimated extinction of 160 species), or by substituting (mostly environmentally harmful) alternatives, or by dedicating 2,640 previously non-productive hectares as fiber farms (preferably in California, but elsewhere could also work). Increasing wood production on a larger number of hectares already growing wood for harvest is another possible mitigation, the number depending on the increase in wood production thereby achieved.

Interestingly, alternatives (b) and (c) result in wood productivity figures similar to each other (both a bit under 5 m³/ha/yr) and they can be treated together. The wood production foregone in options (b) or (c) could be replaced by harvesting about 18,600 ha of tropical rainforest (estimated extinction of 90 species), or by substituting (mostly environmentally harmful) alternatives, or could be mitigated by dedicating 1,500 previously non-productive hectares as fiber farms, or by increasing the intensity of management for wood on a larger number of hectares.

Some of us at this Symposium have publicly indicated a willingness to accept the extinction of as many as 90 or even 160 tropical species as part of the price to pay for modifying aesthetic perception on 6,000 hectares containing full-sized giant sequoias. An acceptable price, perhaps, but most of us here have indicated that the extinction of even one species by the actions we contemplate today is not a trivial price.

The extinction costs calculated above were made under the scenario that all of the wood demand shift from California's forests will result in increased cutting in tropical rainforests. To the degree that the supply of wood from fiber farms and other forests can be (sustainably) increased, the number of tropical rainforest hectares cut will be proportionally decreased.

If our actions today contribute to an increase in the world price of wood, this will also result in some substitutions for wood. Let me pursue one last example that has received much attention. If today's wood-supply connectedness resonates to Europe and results in substitutions for wood there, that is likely to cause an increase in emission damage to central European forests. It should be noted that such substitutions will result in fewer species extinctions in those dying European forests than would result if no substitutions were made, given that the substituted European wood demand had been satisfied in part by cutting in tropical rainforests. This is because the European forests, being temperate, contain fewer species than do tropical forests. It is also because these European forests passed through an extinction episode during recent glaciations, and their tough surviving species are likely to survive current environmental insults as well.

This last example was presented to indicate the complexity of connected tradeoffs. Such price-driven substitutions for wood in Europe will increase pollution, including emissions that will sicken and kill more forest. But while a few species may as a result become extinct in those affected European forests, it will be a much smaller number than

would go extinct in the tropics if that wood had been inappropriately obtained in native tropical forests. Is that a good tradeoff?

Concluding Comments

The estimates of 160 or 90 species becoming extinct as costs of altering the aesthetic perception of our sequoias are probably high, because the full effect of this perturbation will not resonate to the tropical rainforests. However, it seems highly likely that some of it will, and that the real number of resulting species extinctions is substantially larger than one. We should find ways to mitigate that cost, and thus to avoid that loss of species from Earth.

I close with a quote, not from John Muir, but of a rule I learned as a Boy Scout. "Always leave a campground in better shape than you found it." So, if we are going to dedicate a 2,600 ha fiber-farm to save the species we would have caused to go extinct by placing 6,000 productive hectares in parks, why not dedicate an additional 2,600 ha. of fiber farm? This extra step would take a bite out of California's current net imports of wood. Doing so would thereby save a similar number of species that would otherwise have gone extinct due to actions in California that have nothing to do with management of the giant sequoia groves.

References

- Anonymous. 1988. Forestry in Malaysia. Ministry of Primary Industries. Malaysia. 68 p.
- Commoner, B. 1991. Making peace with the planet. New York: Pantheon Books.
- Holmen, H.; Kolare, I; Lundberg, G., eds. 1992. International evaluation of energy forestry. Joint publication of the Swedish National Board for Industrial and Technical Development and The Swedish Council for Forestry and Agricultural Research. Stockholm. 44 p.
- Johnson, R., ed. 1991. Tomorrow's energy. Swedish National Energy Administration. Stockholm. 68 p.
- Koch, P. 1992. Wood versus nonwood materials in U.S. residential construction: some energy-related global implications. *Forest Products Journal* 42:31-42.
- Lugo, A. E. 1988. Estimating reductions in the diversity of tropical forest species. In: Wilson, E. O., ed. Biodiversity. Washington, DC, National Academy Press; 58-70.
- Poffenberger, M. 1992. Sustaining Southeast Asia's forests. SE Asia Sustainable Forest Management Research Network Report 1. Berkeley. CA: 17 p.

Appendix Notes

1. Based on conversations with Drs. Peter Raven, Missouri Botanic Garden, and James Hamrick, University of Georgia, in 1990. A wider range of estimates had previously been reviewed by Lugo (1988).

2. Forest history, wood use and forest productivities in New Zealand are from the Plenary Address by Dr. Wink Sutton to the National Meeting of the Society of American Foresters, San Francisco, August 1991; from 1992 corre-

spondence with Dr. Sutton; and from information obtained by the author in New Zealand in 1992.

3. Estimates of import/export balances were obtained from Professor William McKillop, University of California Berkeley, and from the California Forestry Association, Sacramento, 1990.

4. Information on Japanese forest policies and programs was obtained from Dr. H. (Joe) Josephson, retired. United States Forest Service Economics Research Division. Washington D.C., 1990.

5. Calculation of tradeoffs between forest productivity in California and extinctions in tropical rainforests: The development below is based in part on a conversation with Peter Raven, Missouri Botanic Garden, on 9 April 1990, and on several conversations with Russ Henly, William McKillop, Jeff Romm, Henry Vaux (all University of California Berkeley) and others during 1989-1992.

Estimates of current cutting rates in tropical forests, and the time to harvest trees in 100 percent of them at that rate, are:

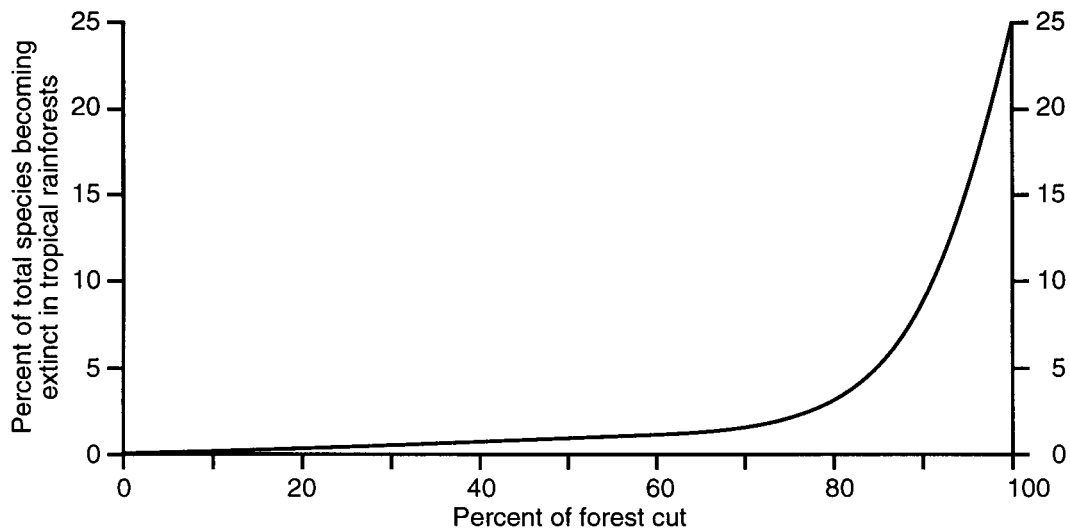
140,000 square kilometers per year = 14,000,000 ha/yr
30 years to 100 percent cutover at that sustained rate.

A similar estimate, 11.3 million hectares cut per year, was used by Lugo (1988), leading to a 36-year estimate of time to 100 percent cutover beginning in 1988. Lugo nicely reviewed the substantial uncertainties in making such estimates.

Not all of the resident species will have become extinct when the rainforests are 100 percent cutover. About a quarter (perhaps a low estimate) of the native biota is expected to become extinct in any given region as a direct result of disturbance and destruction in 100 percent of that region's rainforest.

Some extinctions occur during early stages of ecosystem disturbance, as species with local distributions are by chance included in early percentiles of cutting, or as species with fragile requirements have such requirements compromised. Most extinctions occur as the last vestiges of an ecosystem are disrupted or destroyed. Appendix figure 1 presents a likely progression of extinctions with time and with area cut; this relationship no doubt varies in detail from one forest region to another.

The horizontal axis of appendix figure 1 indicates that it is important for conservationists to be given time to secure adequate reserves before 90 percent or so of a region's forest is cutover; or for local organizations to be given the time to first recognize the need, and then be empowered, to modify destructive forest practices. See Poffenberger (1992) for examples of the latter. If our actions can slow the rate of cutting in tropical rainforests, that is a positive result. But, even though relatively few species are driven to extinction by a particular harvest during early stages of harvesting a forest, anything that hastens the time to reach the last decile of cutting is harmful if it thereby forecloses the possibility of modifying practices or creating adequate reserves.



Appendix Figure 1-An example of the progression of species extinctions caused by logging and subsequent disturbance in a tropical forest. The lower axis may be viewed as having a time dimension as well as an area dimension.

The figures developed below are for an average rate of extinction over a 30-year period. As indicated above, the proportional rate will be less per hectare and per year when the early deciles of any given forest are being logged or cleared, and the extinction rate will be much greater as cutting or clearing occurs in the final 10 percent of the old-growth forest. In locations such as the Philippines, the old-growth forests are nearly gone and species extinctions per area cut are reflected in the high rates near the right edge of appendix Figure 1. Locations such as Indonesia are earlier in the progression toward the final percentiles of cutting, and species extinctions will, for a while, be at the lower rates in the left part of appendix Figure 1.

Peter Raven and others have estimated, fairly accurately, that there are about 250,000 living plant species now on Earth. About 170,000 of these occur in tropical rainforests and, if a quarter of them are at risk due to forest clearing and disturbance, 42,500 will be made extinct over the 30-year period it will take at recent cutting rates to cut over our tropical rainforests. That's an average of 1,417 per year. The average number of extinctions per year and the area cut per year can be used to calculate the average number of hectares cut per extinction: (hectares cut per year)/(average extinctions per year) = hectares cut per plant species extinction.

$$14,000,000/1,417 = 9,880$$

Raven and others have estimated, with much less accuracy, that there may be about 10,000,000 living species of all kinds now on Earth. These include many fungi, insects, other invertebrates, bacteria, protozoa, etc. that haven't even been characterized and named as yet. Of these, perhaps 8,000,000 occur in tropical rainforest ecosystems. Using similar reasoning as with plant species, above, 2,000,000 are at risk of becoming extinct due to forest harvesting and

clearing in the next 30 years, an average of 66,667 per year. The calculation of hectares cut per species extinction is:

$$14,000,000/66,667 = 210$$

As noted by Norman Myers (Appendix Note 6), there are many other costs besides species extinction when tropical rainforests are deforested. These include such things as the intensified flood-drought cycles in southern Asia, and reductions in hydropower generation due to sedimentation above the approximately 200 major dams built since 1940 in affected regions.

Please also note that some of the worldwide demand for wood will be filled by wood from the pine plantations in the southeastern United States, the radiata pine fiber farms in New Zealand, the eucalypt fiber farms in Brazil, and perhaps from the great wood mine in northern Russia. With the possible exception of wood from the Russian wood mine, the importation and use of wood from these sources is environmentally near neutral, and beneficial to the economies of these wood-growing regions. As wood from old-growth forests has become scarce, wood from fiber farms has recently been preferred to wood from tropical rainforests as sources of imports, both because of the more consistent technical qualities of the fiber-farm wood and because of the increasingly recognized environmental costs of harvesting rainforests. At recent import levels in Europe and the Far East, these sources of supply are already largely committed. Thus, additions to import demand are likely to result in increased harvesting in rainforests, both legally and illegally.

6. From Myers' 30 April 1991 manuscript: Environment and development: the question of linkages. Paper for the United Nations Conference on Environment and Development.

7. Some of the information on the environmental and economic costs of recycling, and on alternatives to wood, was provided by Professor Wayne Wilcox of the University of California Forest Products Laboratory, during 1990-92. See also Koch (1992).

Aluminum, for example, is sometimes called "solid energy" because of the high energy requirements for its manufacture. Other metals often leave surface mining scars, and CO₂, and toxic materials may be emitted during their manufacture. Cement releases fossil CO₂ as calcium carbonate is converted, at high energy costs, to cement powder. Coal, oil and natural gas are mostly non-renewable, and all produce fossil CO₂ and/or fossil methane when vaporized, biodegraded or burned. Many of the products made from the above alternatives to wood are not biodegradable when their use is completed. While the possibility of increasing species extinctions strikes a responsive emotional chord, the increased environmental degradation due to substituting the above materials for wood may actually be more important.

The distinction between fossil CO₂ and current-budget CO₂ is a subtle one. Once they are released, you can't tell one from the other. But the carbon and some of the oxygen that produces fossil CO₂ was sequestered in limestone, coal and oil many millions of years ago, when Earth was a warmer place. Our ecosystems are now adapted to the levels of current-budget CO₂. In recent years, CO₂ entering the atmosphere has been about 94 percent current-budget CO₂ and six percent newly-released fossil CO₂ (Appendix Note 8). That additional six percent doesn't seem like much, but it is cumulative. Two years of such releases adds a total of about 12 percent over baseline budget, three years about 18 percent, and in not too many years the CO₂ in the atmosphere is doubled. Some is resequenced, but there is no doubt that, in recent years, atmospheric CO₂ levels have been rising sharply and steadily. This relationship also holds for methane, a perhaps more-important component of atmospheric "greenhouse gases."

8. The figures on fossil CO₂ release are from the United States Department of Energy, provided by Dr. Patricia Layton, Oak Ridge National Laboratory Biofuels Development Program, 1991.

9. An outstanding example of such environmentally appropriate increased use of wood may be found in Sweden. In the mid-1970s, it was recognized that Swedish farmers were producing more grain than could be used in Sweden or sold abroad. Subsidizing the farmers not to grow crops, or

buying the surplus and storing it in government granaries, were not considered acceptable long-term solutions. A program was begun to develop woody biomass as an alternative crop.

In 1979, an incident occurred at Pennsylvania's Three-Mile Island nuclear power plant. Sweden responded to this incident with a national referendum to shut down their twelve nuclear power plants by the year 2010. These supply about 45 percent of Sweden's electrical power. The first was scheduled for shutdown in 1997.

Shortly after this referendum, the Swedish government declared that Sweden's four remaining free-flowing rivers would not be dammed to replace nuclear power with hydro power.

Sweden then made a national commitment to reduce sulphur and NO_x emissions, and to hold CO₂ emissions to 1988 levels. The willow crops being grown for energy biomass help in these latter goals. Willow wood emits little sulfur when burned, and the growing willows sequester one cutting cycle's (about 8 years) worth of CO₂, before being burned, rather than cycling it annually (as would annual crops) or not sequestering it at all (as would fallow or paved fields).

To get the economics right, the Swedish biomass program is hoping to pass a tax on fossil CO₂ emissions, thus making the wood-produced electricity less expensive than electricity produced by oil, coal or natural gas.

Finally, wood fuel provides more Swedish jobs than does imported coal, oil and gas. The wood is harvested in winter, reducing the potential for soil compaction, increasing nutrient cycling from the deciduous leaves, and providing gainful employment when it is most needed in rural communities (Johnson 1991, Holmen, Kolare and Lundeberg 1992, Appendix Note 10).

10. Personal communication from Dr. Irene Kolare, August 1992. The need to remain competitive on world markets has recently caused the plans for shutting down the Swedish nuclear plants to be postponed, and the Swedish electrical industry has been specifically protected from the tax on fossil CO₂.

11. Data from Robert Rogers, Sequoia National Forest, 1992.

12. Data from Hato la Vergareña for the Orinoco rainforest, 1991; personal communication from D. O. Ahmad, Forest Research Institute, Kuala Lumpur, Malaysia, 1991; and from pages 34-35 (Anonymous 1988).

Symposium Results: Views from the Agency Leadership¹

Richard A. Wilson²

My response to this Symposium centers around our activities at Mountain Home Demonstration State Forest. We practice multiple use management with an emphasis on recreation.

A forest requires manipulation. It is not like a corn crop. Ground disturbance is necessary for giant sequoia regeneration. How the disturbance occurs is subject to review. Tractor and fire are both tools that are useful in disturbing the site.

Mountain Home Demonstration State Forest is an ecosystem of diversity. It is no longer the turf of foresters alone. We need to involve other resource disciplines. What goes on under the ground is important. There is much more involved than just getting trees to grow on the soil.

We are very proud of our work at Mountain Home Demonstration State Forest. We have preserved the big

trees; we have excellent regeneration; we provide high use recreation. These benefits are provided through ecosystem manipulation while incorporating what we have learned from research projects.

Mountain Home Demonstration State Forest doesn't represent all the answers on giant sequoia management, but the public is pleased. We will continue to share our knowledge.

In California we live with four words: fire, flood, earthquake, and drought. Lightning doesn't call in for a burning permit or to check if it is a burn day. We need to reduce fuels in an environmentally safe manner. If we do not, fire will create some huge clearcuts.

I appreciate the opportunities this Symposium has created and we look forward to participating in future meetings on giant sequoia.

¹This paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

²Director, California Department of Forestry and Fire Protection, 1416 Ninth Street, P.O. Box 944246, Sacramento, CA 94244-2460.

Management Perspective of the Symposium on Giant Sequoia¹

J. Thomas Ritter²

Abstract: Management of the giant sequoia must recognize that our society has strong emotional support for protection of this species. However, future decisions must be based on the ecosystem rather than the species or individual trees. All agencies must work on a cooperative basis for development of research, management strategies, and education. Greater understanding of long-term effects of management programs is needed. Decisions must give greater emphasis to the significance of future generations of the species, of the giant sequoia ecosystem and of our society.

Giant Sequoias-Their Place in the Ecosystem and Society is a very appropriate title and theme for this symposium. This concept links two important components in the debate over the future of the giant sequoias: the ecosystem and people.

During the past two days, extensive and diverse information has been provided from each conference participant. Field trips have also been offered in order to inspect and observe several contrasting management strategies. An analysis of this information can be summarized by the following five concepts: giant sequoias-the objects of our affection, the value of the ecosystem, the role of science, and the preservation of the giant sequoias for future generations.

Objects of Our Affection

The giant sequoias are the objects of our affection. These trees are a unique resource to most people and this cannot and should not be ignored. The value of the sequoias has been verified by common ideas appearing in each presentation at this symposium: "Sacred Object, National Treasure, Cathedral, Shrine of the Sierra, Big Trees, Monarchs, Hero Tree, King Plant." Clearly this species has special status. We must recognize and accept that any discussion, any study, and any examination of the giant sequoia stimulates extensive emotion and inspiration. We must always recognize that the sequoia is not an ordinary species, regardless of the abundance or rarity of these trees. The history of human involvement with the sequoia consistently records strong emotional support. Our challenge is to remember that while emotions are strong, we must always make our decisions and base our actions upon scientific information and recommendations.

¹An abbreviated version of this paper was presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

²Superintendent, Sequoia and Kings Canyon National Parks. Three Rivers, CA 93271 (209) 565-3101.

What is the Value of the Ecosystem?

With the strength of this emotion, it is easy to focus our attention upon the species and fail to base management decisions upon this important question: what is the value of the ecosystem? We all know that there are many significant components of an ecosystem and that each plant and animal species has an important function. We also know that soils, water, and air are critical to this ecosystem. As we debate the function and the future of the giant sequoia, we must never forget that basic ecologic principles govern and control our lives and the future of the giant sequoias. We may not agree on the role and the relative importance of each component, but we must agree that ecosystem analysis and management should dominate.

As we work together at this symposium to exchange information, we must work together each day, recognizing that each of us has a role. Bio-regional coordination and interagency cooperation are crucial to the success of the giant sequoia. Most of the participants at this symposium have reported that ecosystems do not know political boundaries. Effective use of limited funding and resources clearly depends upon cooperation. We know that the bio-regional boundaries will change depending upon the specific resource under consideration. Factors such as management of air resources and soil resources must be evaluated differently.

There has been extensive cooperation in the past, but this must become more intense and with stronger direction. Interagency cooperation and coordination must be improved and focused. This means that each agency must dedicate funds and staffing to support strong and active interagency cooperative programs.

The USDI National Park Service, the USDA Forest Service, the California Department of Forestry, and Universities must enhance these specific functions:

- information exchange,
- research design,
- ecosystem change monitoring,
- ecosystem impacts,
- management strategy development.

The relationship between agencies and all people in our society is the same as the relationship between all components of the sequoia ecosystem. We must interact with each other on a constant basis simply because we are dependent upon each other and cannot function alone. This is the basis and the fundamental requirement of cooperation. We have the choice to compete or to cooperate.

Impacts affecting sequoia groves are accumulative and have a major effect upon the species. The effects are even more important upon the systems that support the giant sequoia. Some impacts are universal such as air pollution. Other impacts are localized and are generally related to agency activities and policies. These include fire suppression, controlled fire management, constructing communities within sequoia groves, mechanical disturbance and logging activities. To understand and exchange information about the effects of various disturbances, we must develop a comprehensive and coordinated program to expand research and to exchange scientific information. We must also design comprehensive programs to inventory and monitor changes to groves that are managed under various strategies and for different objectives.

This comprehensive program, founded upon interagency cooperation, will provide excellent guidance to resource managers in the future. However, we must be cautious not to assume that scientific information will provide clear and perfect information for all decisions. Scientific information must be combined with solid and logical decisions made by resource managers.

Who Needs Science?

This need for input from resource managers evokes a basic question that we need to examine: what is the value of research and who needs science? At Sequoia and Kings Canyon National Parks, the contributions of science to the decision-making process are impressive and a strong demonstration of the value of science. Some examples include a better understanding of fire effects upon the sequoia, understanding of the effects of human activities such as air pollution on the sequoia and development of communities, roads, and trails in the groves. This research has resulted in modification of the prescribed fire programs and has been the basis for removal of large campgrounds and visitor facilities in the Giant Forest area of Sequoia National Park.

Research is critical as a basis for management decisions. We must not wait for research to provide all the answers, but we must have adequate knowledge to make sound management decisions. It is important to remember that any management plan is not doctrine, but is a collection of hypotheses that managers must constantly test and examine. Strong and well designed research programs linked with consistent interagency management cooperation will improve the opportunities for protection of giant sequoia ecosystems.

Giant Sequoia and Future Generations

With these basic principles established, we must never forget the critical importance of future generations. The fundamental and most important guidance we must follow is that our decisions and actions must consider the future. Do we really think about the long-term? It is reasonable to think and to plan in terms of the life span of a giant sequoia, to make our decisions in terms of 2,000 years. If this is our time frame, then our decisions will vastly improve the future vitality of the sequoia as a resource and as a species.

The inclusion of future generations as a component of ecosystem management is not limited to issues involving the giant sequoia. We must also remember that the resource systems must be strong and vital in the future if they are to support the sequoia species. The future of the giant sequoia depends upon our emotions as we view this species as the object of our affection. We must always make decisions based upon the value of the ecosystem. To succeed in management of the sequoia, we must constantly cooperate because we are all in this together. We must have good data and solid recommendations founded upon scientific research. Our decisions and actions must consider future generations. These principles are essential to each of us and to the future generations who will inherit the giant sequoia.

Giant Sequoia Management in the National Forests of California¹

Ronald E. Stewart

Sandra H. Key

Bruce A. Waldron

Robert R. Rogers²

Abstract: The USDA Forest Service is one of six public agencies that manage giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz). The history and biology of the species and the increasing national interest define this agency's present management philosophy. Today's management objectives are to protect, preserve, and restore the existing giant sequoia groves and to extend the range of the species. Future management complexities include responding to the technical silvicultural needs of the species and the public preference for esthetic values.

The National Forests in California are responsible for the conservation of 41 groves of giant sequoia. To redeem this responsibility, after nearly a century of fire suppression, the agency is exploring ways to restore the groves to a natural condition when fire played a major role in their ecology. If the conditions created by fire are not reestablished in the groves, giant sequoia could be replaced by other species. Specifically, fuels build-up has progressed to dangerously high levels in some groves and must be reduced. The bare mineral soil and open canopy required for reproduction must also be re-created.

To deal with these problems, in the past 30 years the Forest Service has observed and participated in giant sequoia research conducted by other agencies. Drawing from this information, National Forest management of giant sequoia has centered on working with the species in its different stages of growth, and in developing strategies to mitigate the adverse conditions created by fire exclusion within the groves.

Currently, the Forest Service is exploring research opportunities in giant sequoia groves and mapping naturally occurring giant sequoia groves and establishing plans for each. It is also developing strategies to continue to incorporate public values and concerns in giant sequoia management. This paper chronicles the parallel evolution of grove management and public values, and points toward a future where grove management will be guided jointly by biology and by clear societal preference for preservation of esthetic values.

¹An abbreviated version of this paper was presented at the Symposium on Giant Sequoia: Their Place in the Ecosystem and Society, June 23-25, 1992, Visalia, California.

²Regional Forester, Pacific Southwest Region, 630 Sansome Street, San Francisco, CA 94111; Forest Supervisor, Sequoia National Forest, 900 West Grand Ave., Porterville, CA 93257; District Ranger, Hume Lake Ranger District, 35860 E. Kings Canyon Rd., Dunlap, CA 93621; Silviculturist, Sequoia National Forest, 900 West Grand Ave., Porterville, CA 93257--all with USDA Forest Service.

Giant Sequoia Locations

Giant sequoia are found naturally only at elevations of 4,500 feet (1,365 meters) to 7,500 feet (2,275 meters) in a narrow 15-mile (24 kilometer) by 260-mile (420 kilometer) range in the west-side Sierra Nevada of central California (Weatherspoon 1986).

The sequoias typically form groves as they grow among a mixture of conifer species including white fir (*Abies concolor*), sugar pine (*Pinus lambertiana*), incense-cedar (*Calocedrus decurrens*), ponderosa pine (*Pinus ponderosa*), California black oak (*Quercus kelloggii*), and often Douglas-fir (*Pseudotsuga menziesii*) (Harvey 1980). Areas covered by the groves range in size from 1 acre (0.4 hectare) to 4,000 acres (1,600 hectares). In total, the groves occupy a combined area of about 36,000 acres (14,400 hectares) within a range that covers an estimated 2,500,000 acres (1,000,000 hectares). The locations of the groves are influenced by the interaction of temperature, soil moisture, and site-disturbing events such as fire (Weatherspoon 1985).

Giant sequoias are found in 75 areas on land administered by private owners, the USDA Forest Service, Tulare County, the National Park Service, the Bureau of Land Management, the State of California, and the Tule River Indian Reservation. Roughly one-half of the naturally occurring groves and one-third of the acres are found in the Sequoia National Forest. Most of the remaining groves are located within the boundaries of Sequoia and Kings Canyon National Parks.

Groves Under National Forest Stewardship

The Forest Service manages both the extreme northern and southern extensions of the giant sequoia's range. The northernmost grove, the Placer County Grove, is located in the Tahoe National Forest, near Sacramento. The southernmost grove, Deer Creek, is located in the Sequoia National Forest, near Bakersfield.

The Sequoia National Forest manages 38 giant sequoia groves throughout the sequoia's southern range (Rundel 1972). According to data in a 1981 forest vegetation inventory, these groves cover about 13,200 acres (5,280 hectares). Of these acres, only 3,400 acres (1,360 hectares) are dominated by an estimated 8,600 specimen trees with a diameter of 8 feet (240 centimeters) or greater. The remaining acres are characterized as a mixed-conifer forest with young giant sequoias present. No one has estimated the number of smaller

giant sequoias, but on the basis of field observations, it is reasonable to assume they number in the tens of thousands.

The Sierra National Forest has two groves, the Nelder in a northern section of the forest, and the McKinley at the southern edge. The Sierra National Forest Land and Resource Management Plan recommends historical area designation for the Nelder Grove because of its early-day logging record. Current recreation amenities in that grove include a campground, the Shadow of the Giants National Recreation Trail, and a trail to the Bull Buck Tree, one of the largest giant sequoias in the National Forests. The Sierra plan also recommends botanical area designation to promote research and ecological study in the McKinley Grove.

The Tahoe National Forest has one grove that has been designated the Placer County Big Tree Grove Botanic Area. This is the northernmost grove in the giant sequoia range. Six giant sequoias grow here. The largest is 12 feet (360 centimeters) in diameter.

In addition to preserving specimen old-growth giant sequoias, the Forest Service is planting giant sequoia seedlings outside established groves. These young trees will increase biodiversity, contribute to the esthetic quality of the forest, and to some extent provide wood and wood products for the future.

Within the groves, the agency also manages about 3,000 acres (1,200 hectares) of second-growth giant sequoias that are between 60 and 90 years old.

This young second-growth is managed for restoration of the groves.

Developing an Approach to Giant Sequoia Management

The history of disturbances of the giant sequoia by Europeans can be documented as far back as their announced discovery in 1852 by early settlers (Hartesveldt and others 1975). Logging began almost immediately, but did not reach a large scale until about 1890.

Between 1890 and 1925 at least nine of the then privately owned groves were logged for nearly all the giant sequoias, as well as the more valuable pine and fir. A few of the smaller giant sequoias were also cut in the Nelder grove. Both the state and federal government recognized the value of these unique trees and sought to protect them by acquiring land containing the largest and best-known groves. Between 1936 and 1975, the Sequoia National Forest acquired all or portions of the Little Boulder, Converse, Bearskin, Lockwood, Black Mountain, Long Meadow, Deer Creek, and Peyrone groves. The largest, Converse, had been completely logged over around 1900 for both giant sequoia and other conifers.

Early Federal Activities

After acquiring privately owned groves, the Forest Service generally limited activities within them. The primary exceptions in the Sequoia National Forest centered on

the removal of dead or dying trees and the development of a campground and summer home tract in the McIntyre Grove. Other National Forests usually restricted their activities to trail and road development.

Some of the most visible recreation development took place in the National Parks. The Park Service developed administrative, commercial, residential, and recreational facilities in some of the giant sequoia groves at Yosemite and Sequoia National Parks. The most extensive developments were at Giant Forest, in Sequoia National Park.

From the time the groves were acquired, Federal agencies followed a policy of quickly suppressing all wild fires. As early as 1955, Herbert Mason, a professor at the University of California, writing in the *Sierra Club Bulletin*, recognized that fire exclusion was changing the composition of species in the Sierra Nevada (Mason 1955).

In the 1950's and 1960's, both the Forest Service and Park Service began to notice the effects of the competing vegetation on giant sequoias. A greater number of trees were growing in association with giant sequoias than would have been expected before wildfires were suppressed. Most of the additional trees were shade-tolerant white fir and incense-cedar, and natural giant sequoia reproduction was lacking in most of the groves. Also, large amounts of ground fuels such as duff, brush, and downed logs had developed, increasing the potential for fire.

Vegetative Changes and Reproduction

The Sequoia National Forest contains many examples of the connection between vegetative changes and giant sequoia reproduction. The main causes of change in vegetative structure and diversity are wildfire and historic logging. Based on Sequoia National Forest fire records, fires within the Forest Service's giant sequoia groves occur at a frequency of three to four fires per year. Virtually all are less than an acre or half a hectare. The interval of larger fires, 3,000 acres (1,200 hectares) or larger, such as the Daunt Fire (1910-Freeman Grove), Deadman Fire (1928-Black Mountain Grove), and the McGee Fire (1955-Converse Basin), occur on the average every 20 to 30 years.

Nearly all the young-growth giant sequoias that exist on private and Federal land resulted from removing the competing trees and digging down to bare mineral soil during early-day logging. A primary example was Converse Basin where the Forest Service acquired land that had been clear-cut while in private ownership.

Dense stands of second-growth giant sequoias grew on most of the old logging sites. In 1955, the 17,580-acre (7,032-hectare) McGee Fire burned through some of this area. After the fire, giant sequoia seeds quickly germinated and grew, creating additional vigorous young growth.

The areas of historic logging and the McGee Fire have extensive aerial photography dating from 1940. These aerial photos and others taken at periodic intervals offer a pictorial record of the extensive new growth that occurs among giant

sequoias in response to extreme changes. In contrast, other groves that had not been disturbed either by major fires or by early logging do not have this natural reproduction.

Photographs and on-the-ground observations showed that the giant sequoia is more than a barely-surviving relict species; it regenerates and grows well when the surrounding ground is disturbed, allowing seeds to fall on bare mineral soil in open, sunlit areas. Research over the past 30 years has sought methods to re-create these conditions.

Developing Management and Restoration Strategies

Because of its proximity to the adjacent National Parks, the Sequoia National Forest was in an ideal position to observe and participate in the research conducted within the Park Service groves.

Initial studies within the Park Service focused on the effect visitors might have on giant sequoias. In 1956, Richard Hartesveldt and a team from San Jose State University began field studies to observe the human impacts on the giant sequoia environment in Yosemite National Park. In 1962, their studies shifted to Sequoia and Kings Canyon National Parks, and giant sequoia reproduction was added to the study at Whitaker Forest and Redwood Mountain (Harvey and others 1980).

Fire As a Tool

These studies evaluated ground-disturbing activities, such as prescribed fire, to improve the growing conditions for giant sequoias. In the 1960's and 1970's, the Park Service, Forest Service, and the California Department of Parks and Recreation all experimented with using prescribed fire in their groves as a way of controlling competing vegetation and reducing the menace of damaging wildfires. While the various agencies were able to coordinate their information, their differing missions enabled them to use a variety of approaches when working with giant sequoias.

The Park Service first used prescribed fire as a tool among giant sequoias in the mid-1960's. Later the University of California at Berkeley completed related studies at Whitaker Forest. The Forest Service worked closely with these agencies by supplying crews for prescribed burning and by helping to evaluate the prescribed fire results.

After studying these results, the Sequoia National Forest, in 1975, planned and conducted its first low-intensity, prescribed fire in the Bearskin Grove. Also that year, the Sierra National Forest started some prescribed burning in a test area of the Nelder Grove (Harvey and others 1980).

The original objectives in the Bearskin Grove, to reduce the threat of wildfire and to encourage giant sequoia reproduction, were not fully realized by use of low-intensity prescribed fire. At Bearskin, the first-year seedlings grew well, but very few survived after that. As results were evaluated, it became apparent that long-term successful reproduction

required more bare ground and a more open tree canopy to allow sunlight to reach the bare ground.

The Sequoia National Forest management team also reviewed the work in the grove and concluded that neither objective was met to the degree needed to recommend continuation. While some fuel was consumed, more potentially hazardous fuel remained. Also, the fire burned at such a low intensity that very few of the shade-tolerant trees were killed. The full forest canopy was left, creating too much shade for successful sequoia reproduction.

Similar observations were made by the Park Service, when they found that the distribution of surviving giant sequoia seedlings in burned areas was spotty. Thickets of sequoia saplings were growing where the burn was very hot and extensive enough to open the canopy. Few seedlings survived elsewhere (Harvey and others 1980). The Park Service used repeated prescribed fires on the same site over several years to reduce the fuel loading and to open up the area for successful giant sequoia reproduction.

The Forest Service began to explore other options to secure sequoia reproduction and to reduce fuel loading, without repeated multi-year burning. Regional Forester Doug Leisz reviewed the Bearskin project on the ground. He recommended treatments be intensified to improve conditions for giant sequoia regeneration. These treatments included opening the stand to allow more sunlight to reach the forest floor and increasing the intensity of the prescribed fires.

Prescribed Cutting and Fuels Treatment

In an effort to bolster seedling survival rates, the Forest Service began to consider prescribed cutting followed by actions to remove slash accumulations. When considering cutting for fuel reduction and sequoia reproduction, the Sequoia National Forest was able to draw on previous experience of cutting within giant sequoia groves. In 1975, the agency permitted white woods to be cut when part of the Converse Grove was commercially thinned to encourage more vigorous growth. Some of the larger second-growth giant sequoia trees were designated as potential specimen trees and were given special protection during the cutting.

Between 1981 and 1986, 13 areas within the giant sequoia groves were analyzed for opportunities to use prescribed cutting followed by prescribed fire to reduce fuel loading and to improve giant sequoia reproduction. Based on this analysis, about 1,000 acres (400 hectares) within 11 giant sequoia groves were marked for cutting, primarily to remove competing white fir. The other 12,200 acres (4,880 hectares) within the 38 groves in the Sequoia National Forest were not entered.

One-third of the prescribed cutting was designed to improve the vigor of the existing stand by removing individual trees that were in poor health. About two-thirds of the prescribed cutting was designed to create conditions favorable for giant sequoia reproduction by clearing the forest floor and opening the canopy. This also reduced the fuel available for wildfire.

Actions to reduce fuels after cutting have included chipping, under burning, and piling and burning. In 1981, the first combination of cutting and prescribed fire was accomplished in the Little Boulder and Redwood Mountain Groves. From 1983 to 1989, approximately 40 to 80 acres were burned annually using prescribed fire.

Commercial timber sales were the means of accomplishing the prescribed cutting. None of these sales permitted the removal of large, old giant sequoia trees, living or dead. A few large giant sequoias, that had already fallen to the ground, were removed. Some smaller young second-growth trees, none larger than about 48 inches (122 centimeters) in diameter at breast height, were removed for road clearing, logging access, and stand health.

To start a new generation, natural seeding was used for reproduction. The Forest Service also planted giant sequoia seedlings to ensure satisfactory survival where additional giant sequoias were desirable but were not occurring naturally. Seeds used to grow the seedlings were generally collected in the same grove where they were to be planted. By 1990, about 600 acres (240 hectares) within groves were planted with giant sequoia seedlings.

Prescribed Cutting and Specimen Tree Survival

Prescribed cutting within the groves has permitted the Forest Service to observe the effect that cutting has had on surrounding trees. Critics of this logging have claimed that the removal of other trees exposes the shallow-rooted giants to greater mortality from wind blow-down. What is normal, and how do undisturbed groves compare?

Research in Sequoia National Park found that the natural rate of wind mortality for trees larger than 7 feet (210 centimeters) in diameter is 1.1 trees each year per 1,000 trees (Lambert and others 1988). A 1991 review in the Sequoia National Forest of trees within 100 feet (30 meters) of a cutting unit showed that only four out of 916 such trees had either blown over or were broken off by wind since 1981. This is equivalent to 0.4 trees each year per 1,000 trees. The mortality rate associated with cutting is actually less than that experienced under preservation conditions in the National Park. This does not imply that cutting extends the life of giant sequoia, but neither does it suggest that removal threatens giant sequoias exposed by cutting.

Extending the Range of Giant Sequoias

In addition to working with established groves, the Forest Service is the only agency in the United States that actively seeks to expand the natural range of the sequoias. Starting in the 1970's, the Sequoia National Forest planted giant sequoias outside the natural groves in all ranger districts. In 1990 alone, that forest planted more than 40,000 giant sequoia seedlings. To date, nearly 800 acres (320 hectares) outside of groves have been planted with a mixture of seedlings that includes the giant sequoia species. Other National Forests also have planted sequoias. These out-plantings provide an opportunity to study the species and its response to environmental effects over a much wider area.

The sequoia's range also has been expanded in other countries. Although native only to a small area in California, giant sequoias have been planted successfully world-wide. They thrive in at least 25 European countries where they are valued for possible timber production, and for park and landscape trees (Libby 1982).

Public Response

The Forest Service now realizes that it went too far, too fast in implementing its management activities in the groves. Almost from the time of their discovery, people have reacted strongly to try to protect giant sequoia (Hartesveldt 1975). Logging in the sequoia groves near the end of the 19th century created a public outcry that was largely responsible for the creation of Sequoia National Park and later public acquisition of privately owned sequoia groves. When seen in its historical context, logging activity in National Forest giant sequoia groves in the 1980's clearly rekindled a concern that had lain dormant for several decades.

In the wake of the prescribed cutting and fuel treatment, the Sierra Club and others protested that the Forest Service was destroying that which it was supposed to protect. In 1988, on procedural grounds, the Sierra Club filed for and received a preliminary injunction against planned prescribed cutting in several groves.

In pursuing giant sequoia management, however, the Forest Service followed all requirements of the National Environmental Policy Act as they were practiced at that time. Even so, the management activities were done without making absolutely certain that the public, interest groups, and other agencies fully understood and supported these activities. This became especially crucial outside of the academic world where the research data was not as well known.

The Forest Plan and Mediated Settlement Agreement

Management of giant sequoias was also one of the issues considered during the 1980's as the Sequoia National Forest developed its Land and Resource Management Plan. The comment period, after a draft of the plan was released in 1986, provided the forum for the public to express its concerns about the way the Forest Service was managing giant sequoia groves. The forest supervisor, Jim Crates, responded on October 9, 1986, by suspending further management activities in all giant sequoia groves pending completion of the forest plan.

The final plan, released in 1988, continued the suspension pending completion of a forest-wide grove management implementation plan and environmental impact statement. This provision of the plan did not resolve the public's concerns about the sequoias. In response to this concern and to other forest management issues, a total of 22 administrative appeals were filed against the final plan.

Because the claims of the various appellants were wildly conflicting, the forest supervisor decided to attempt resolu-

tion of the appeals using a formal mediation process. This option was discussed with the appellants, and most agreed to try mediation using a professional mediator.

The Sequoia National Forest went to the negotiating table many times between March 1989 and June 1990, to work with groups such as the Sierra Club, recreation users, the timber industry, Save-the-Redwoods League, and the California State Attorney General. A settlement agreement embodying a balance of public and resource management values was signed in July 1990.

The Mediated Settlement Agreement established this overriding goal for the giant sequoia groves:

The goal for the administration of the Groves shall be to protect, preserve, and restore the groves for the benefit and enjoyment of present and future generations (USDA Forest Service 1990).

Given this statement of intent, the Mediated Settlement Agreement changed the Sequoia National Forest's management emphases to grove protection, enhancement of esthetic values, and restoration of natural ecosystem functions.

The settlement agreement also included these additional requirements:

- Mapping of all grove boundaries and grove buffers using the agreed-to criteria for boundary delineation. This will be done by a four-person team representing the Forest Service, Sierra Club, timber industry, and Save-the-Redwoods League.

- Interim protection of groves and grove buffers while boundaries and restrictions on mechanical or motorized use are determined.

- Inventory of all giant sequoias (3 feet or larger diameter at breast height) in each grove by size and approximate location.

- Development of grove-specific fuel load reduction plans and Environmental Impact Statements formulated to "preserve, protect, restore, and regenerate the Giant Sequoia groves..."

- Exclusion of the groves from the commercial timber land base except for part of a second-growth portion of the Converse Basin Grove.

- Logging pursuant only to fuel load reduction based on a specific plan and Environmental Impact Statement, removal of safety hazards to the recreating public, and maintenance of current utility rights-of-way.

Since the signing of the Mediated Settlement Agreement, public interest regarding Forest Service management of giant sequoias has remained high. A diverse range of interest groups have become involved with ground-level forest management and have stayed involved.

Giant Sequoia and the Old-Growth Issue

In the two years since signing the settlement agreement, stories, both national and international in scope, appeared in magazines like *National Geographic*, *Audubon*, and *Sunset*,

and on the CNN television network. In many cases, these stories tied the giant sequoia issue to the old-growth or "ancient forest" issue. Some even went so far as to imply, erroneously, that the Forest Service was cutting specimen, old-growth trees. The overwhelming majority of letters and media stories have supported the management of giant sequoia groves for recreational and spiritual values, and those ecological values associated with old-growth forests. It is fair to say that, for some, the giant sequoias have come to symbolize the "ancient forest" issue.

In September 1991, all the national attention culminated in Congressional Oversight Hearings held by Congressmen Richard Lehman and Calvin Dooley in Visalia, California. The Congressmen heard testimony from a variety of academic, public agency, general public, and industry speakers regarding research and management objectives and practices in the giant sequoia groves.

Regional Forester Ron Stewart, representing the Forest Service, extended many of the policies of the Mediated Settlement Agreement to groves in the Tahoe, and Sierra National Forests. He formally withdrew all giant sequoia groves in California from the commercial timber land base so that the Forest Service would not count the giant sequoia groves when determining how much commercial timber harvest the land will support. He further instructed that all groves be mapped and that management plans to preserve, protect, and restore the groves be prepared. These plans are to be done in consultation with the scientific community and with full public participation.

Finally, Stewart announced the convening of an international giant sequoia symposium in June 1992. The purpose of the symposium would be to share knowledge about the giant sequoia groves and to set priorities for future research.

Current and Future Management

The Mediated Settlement Agreement established specific work to be completed in relation to the giant sequoia groves. Future management will be determined after the grove boundaries are established and basic inventory information is collected.

Grove Mapping

The Sequoia National Forest has started to map the precise location of giant sequoia grove boundaries. Preliminary photo-interpretation work on this project has been completed. Field verification to validate photo-interpretation has begun and should be finished by 1994. This is an arduous, time-consuming task because some of the groves lack distinct boundaries and the total perimeters cover hundreds of miles. Final grove boundaries on the Sequoia National Forest will be confirmed by a team composed of representatives from the Sierra Club, Forest Service, Save-the-Redwoods League, and the timber industry, according to the Mediated Settlement Agreement. The boundaries will encompass not

only the location of giant sequoia trees, but will include surrounding areas that exert ecological influences on the groves as defined in the Mediated Settlement Agreement.

As an interim protection measure pending completion of mapping on the Sequoia National Forest, a buffer has been established around each grove. This interim buffer extends 1,000 feet (303 meters) beyond the outermost giant sequoia trees until final mapping of the groves and associated buffer zones is completed.

According to the Mediated Settlement Agreement, only activities designed to meet stated grove objectives will be allowed within the groves and the first 500 feet (152 meters) within the buffer. These activities will be conducted to reduce the fuel loading; to maintain existing utility lines; to preserve, protect, and regenerate the groves; or to remove trees posing a safety hazard to the recreating public.

Within the next 500 feet (152 meters) of buffer, known as the "grove influence zone," activities designed to meet other forest plan objectives are permitted, provided that physical disturbance is not severe and the grove ecosystem is not adversely impacted. When grove and grove influence zone mapping is completed, it is estimated that about 30,000 acres (12,000 hectares) to 35,000 acres (14,000 hectares) will be designated to protect the 13,200 acres (5,280 hectares) where giant sequoias are present (USDA Forest Service 1990).

Grove Management Plans

After grove mapping is completed, the Forest Service will complete a fuel load reduction plan and Environmental Impact Statement specific to each grove. The Forest Service is fully committed to bringing social, esthetic, and biological factors together when developing these plans. All planning will be done with full public participation to ensure that ecological, recreational, spiritual and old-growth values are conserved.

The current condition of groves varies greatly, ranging from groves that are in congressionally designated wilderness to groves that were totally cut over before coming into Forest Service ownership. Some of the groves have roads in and through them. Others have recreation improvements, power lines, and water lines.

Plans for groves in designated wilderness will continue to emphasize natural processes wherever possible. Outside of wilderness, the grove plans will indicate if, where, and when a fuels reduction prescription will be needed to meet the management objectives of protection, esthetics and natural ecosystem functions.

Fuels reduction prescriptions must also take into account air quality regulations. The increasingly high standards for air quality, especially near Class I airsheds, reduce the periods available for using prescribed fire. Visitors also generally object to the smoke because it is unpleasant to smell and obliterates the view from vista points.

Each plan will also contain a monitoring strategy to periodically evaluate the results. Other agencies and interested publics will help evaluate and monitor these plans.

Research Opportunities and Needs

As the Forest Service develops management plans for the groves, the agency will evaluate broad research needs, as well as the research opportunities within each grove. One of the primary opportunities for research rests in the sheer range of giant sequoias under Forest Service management. The extremes of the natural giant sequoia range are within the National Forests. These groves provide a unique opportunity for additional research into possible conditions that may have limited the natural occurrence of the species.

Converse Basin offers another unique research opportunity. The stumps from the late 1800's logging provide the longest record of climate and fire occurrence history available. Natural reproduction that occurred from this early logging is now about 100 years old. The events that allowed such extreme logging should not have happened and will never happen again; nevertheless, the outcomes can provide valuable information for the future of the giant sequoia species. These research efforts will incorporate other studies and will be shared with all other owners and managers of giant sequoia as well as the general public.

In coordination with other agencies, the Forest Service will continue to examine the possibility of expanding the sequoia's range. This also gives an excellent opportunity to study the possibility of growing giant sequoia for wood production outside the natural groves. Preliminary studies by the Pacific Southwest Research Station show that young giant sequoias grow rapidly and are highly resistant to disease and pollution. The extended range also gives the chance to study the effects of different growth sites.

The multiple agencies and private owners who manage giant sequoia groves provide a unique opportunity to do broad-based research using different management strategies. They also provide additional protection for the species because no one management strategy is likely to be 100 percent correct. Coordinating all of these opportunities for new research and ensuring that the results are widely published will be a major effort. All persons who manage, or who are interested in giant sequoia management, must be fully aware of the most current knowledge about the species to be able to provide the best management.

Giant Sequoia Management Staff Officer

Because the Pacific Southwest Region is placing such a heavy emphasis on giant sequoia management, the Regional Forester will seek to establish a giant sequoia management staff officer to coordinate all activities relating to the species. This person also will serve as the liaison with other agencies, private land owners, interested publics, the Sierra Club, other organizations, educational institutions, and the Save-the-Redwoods League.

The giant sequoia management staff officer will design, coordinate, and conduct a workshop to identify and prioritize giant sequoia research needs and to coordinate future research efforts. The Pacific Southwest Research Station of the Forest Service will emphasize giant sequoia research and will coordinate activities with the National Forests. The giant sequoia management staff officer will also establish partnerships with universities for specific research projects. These could be international in scope since sequoias have been planted throughout the world.

Interpretation of giant sequoia ecology will be emphasized. In the past, information about sequoias has primarily been made available to visitors while they stopped at the groves. This should be broadened so information about giant sequoia can be made available nationwide and even worldwide.

Ongoing Public Participation in Grove Management and Restoration

Regardless of the activity, any action involving giant sequoias will be conducted with full public participation. The Forest Service will fully cooperate with all of the other managers of giant sequoia and persons engaged in giant sequoia research. A steering committee, composed of researchers and managers working with the species, should be established to guide giant sequoia research. Because the species is of such great interest to persons throughout the world, research efforts must be coordinated and publicized.

The continuing effort of conducting research and working with the public and other agencies will help ensure the protection, preservation, and restoration of the 41 giant sequoia groves now managed by the Forest Service. All groves will benefit from the variety of agencies now working with them, and the individual agencies will be able to draw from the expertise and research of each other organization.

Collectively, this work may dispel the mistaken notion that the sequoias are a barely surviving relic of the past. With research and caring management, they should be a mighty species of the future.

References

- Hartesveldt, Richard J.; Harvey, H. Thomas; Shellhammer, Howard S.; Stecker, Ronald E. 1975. The giant sequoia of the Sierra Nevada. Washington, DC: National Park Service, U.S. Department of the Interior; 180 p.
- Harvey, Thomas H.; Shellhammer, Howard S.; Stecker, Ronald E. 1980. Giant sequoia ecology. Scientific Monograph Series No. 12. Washington, DC: National Park Service, U.S. Department of the Interior; 182 p.
- Lambert, Sherman; Stohlgren, Thomas J. 1988. Giant sequoia mortality in burned and unburned stands. *Journal of Forestry* 86(2): 44-46.
- Libby, William J. 1982. Some observations on sequoiadendron and calocedrus in Europe. *California Forestry and Forest Products* 49. Berkeley, CA: University of California, Dept. of Forestry and Conservation; 12 p.
- Mason, H. L. 1955. Do we want sugar pine? *Sierra Club Bulletin* 40(8): 40-44.
- Rundell, Phillip 1972. An annotated check list of the groves of *Sequoiadendron giganteum* in the Sierra Nevada, California. *Madrono* 21: 319-328.
- U.S. Department of Agriculture, Forest Service. 1992. The Sierra National Forest Land and Resource Management Plan. Clovis, Calif.
- U.S. Department of Agriculture, Forest Service. 1990. The Sequoia National Forest Land Management Plan Settlement Agreement. Porterville, Calif.
- Weatherspoon, C. Phillip. 1990. *Sequoiadendron giganteum* (Lindl.) Buchholz Giant Sequoia. In: Burns, Russell M.; Honkala, Barbara H., tech. coords. *Silvics of North America. Volume I. Agric. Handb.* 654. Washington, DC: U.S. Department of Agriculture, Forest Service; 552-562.
- Weatherspoon, C. Phillip. 1986. Silvics of giant sequoia. In: Weatherspoon, C. Phillip; Iwamoto, Y. Robert; Piirto, Douglas D., tech. coords. *Proceedings of the workshop on management of giant sequoia*; May 24-25, 1985; Reedley, California. Gen. Tech. Rep. PSW GTR-95. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 4-10.

The Natural Giant Sequoia (*Sequoiadendron Giganteum*) Groves of the Sierra Nevada, California-An Updated Annotated List

Dwight Willard¹

Abstract: Giant sequoias naturally occur in the Sierra Nevada, California, in 65 groves, described in an annotated list. The grove list significantly differs from prior published giant sequoia grove lists, primarily as a result of more consistent application of objective criteria of geographic isolation and minimum giant sequoia group size in grove identification. The grove list also reflects significant gains in knowledge of giant sequoia natural distributions during recent years.

Giant sequoia (*Sequoiadendron giganteum*) naturally occurs in the Sierra Nevada, California, primarily in isolated concentrations traditionally known as groves. Sequoia locations are most easily described by reference to named groves, though a relatively few giant sequoias occur apart from recognized groves, in the same localities.

Significant additional giant sequoia location research since the early 1970's makes the following updated annotated grove list appropriate. The list clarifies, corrects, and adds new information to current grove lists. The list was also prepared more consistently on the basis of objective criteria of geographic isolation and minimum giant sequoia group size.

"Grove" is not a term of art. "The concept of the grove has little biological reality," observed Rundel, the most frequently cited grove list authority in recent decades (Rundel 1972). I concur with Rundel's recognition that it is difficult to conceive of a satisfactory operational definition of a grove, when one considers the locally complex patterns of giant sequoia distribution. The following grove list, like any other, is partially subjective.

The grove list should not be considered as a final definitive list, considering the still incomplete state of giant sequoia inventories. As of January 1994, possible giant sequoia locations have not been fully surveyed in some remote areas of Sequoia National Forest. It is possible that further study could lead to recognition of a new grove. But the list better reflects the current state of knowledge than prior grove lists.

Groves have been named by Caucasians since the mid-19th century. Often several names have been used for the same grove or for different sections of the same grove. (Rundel [1972] appended a catalog of multiple historical grove names that he excluded from his final list of grove

names.) In contrast, many groves became known by single, accepted names by the early 20th century. Sequoia National Park groves were comprehensively and systematically listed by the 1930's. However, comprehensive grove lists for the entire Sierra Nevada were unsystematic prior to 1969.

The first comprehensive and more systematic grove list for the entire Sierra Nevada was in Rundel (1969, 1972). Rundel's list was more closely based on geographic distinction than any prior list, and it reflected his scientific study of actual sequoia distribution. Rundel's list is the basis for the familiar post-1972 descriptions that giant sequoias occur in "75 groves." His grove list used historical tradition as the basis for some grove identifications, and he did not consistently apply an identification criterion of minimum sequoia group size.

Flint (1987) included a grove list which consolidated several contiguous giant sequoia concentrations which had been separately listed by Rundel under single grove names, producing a list more consistently based on geographic isolation. Flint's list highlighted that fewer than 75 groves had significant geographic separation. The following grove list adopts Flint's practice of consolidating contiguous giant sequoia distributions in grove identification.

In general, the updated grove list reflects the perspective that the list is best conceived as an effort to consistently identify and briefly describe the geographically distinct groves of significant giant sequoia group size, rather than as an exhaustive attempt to list every geographically distinct giant sequoia occurrence.

Several natural criteria are used to determine grove identity. The foremost criterion for separate identity is substantial distance isolation from other giant sequoia concentrations. Conversely, giant sequoia groups which are known to be essentially contiguous are always identified as a single grove. If sequoias grow beside one another, historical tradition, different owners, or an intervening political boundary do not make them farther apart.

In the absence of substantial distance isolation, other criteria were applied, such as watershed isolation and the subjective sense of the propriety of either distinction as separate groves or of identification as multiple units of a single grove (regarding isolated sequoia concentrations which are close to one another). Numerous groves have two or more separate but geographically close units of giant sequoia occurrence, such as when sequoia concentrations in moist drainages are separated by dryer divides without sequoias.

¹ This paper was not presented at the Symposium on Giant Sequoias: Their Place in the Ecosystem and Society, but has been included as supplemental material.

² Attorney and author of a reference book on giant sequoia groves.

The grove list was generally prepared in a manner that maintains the sense of a grove having noteworthy geographic distinctiveness and a minimum historic number of mature giant sequoias (e.g., more than 10). The only exceptions are Placer County Grove and Surprise Grove, which now have less than 10 mature sequoias, but which are sufficiently isolated from other groves to affirm their traditional identification as separate groves. This is a departure from prior grove lists which selectively identify several isolated, very small sequoia groups as groves, while inconsistently excluding numerous other comparable, isolated, small giant sequoia groups from grove identification.

Single giant sequoias and clusters of very few giant sequoias that are substantially isolated from larger giant sequoia aggregations are not identified as groves in the below list (except for Placer County and Surprise Groves). This exclusion covers some giant sequoia "outliers" that have been named as groves in the past, such as the very few giant sequoias in "Clough Cave Grove" and "Squirrel Creek Grove," as well as numerous isolated single giant sequoias or very small clusters of giant sequoias without names. If all isolated sequoias or tiny sequoia clusters, often separated from listed groves by more than 1,000 feet and/or drainage divides, were separately identified as groves, the total of listed groves would probably exceed 100. By that practice, the "grove" concept would lose its usual informative meaning of a group of giant sequoias that is particularly noteworthy because of location and grove size.

The minimum group size criterion is for the purpose of making the most useful grove list, and it should not be interpreted as a depreciation of the value of giant sequoias outside of listed groves.

Sequoias have also been planted singly or in groups in numerous locations outside of the natural groves. Some of these sites have acquired "grove" names. The following grove list excludes sites where sequoias occur only as a result of planting.

Some well-known multiple names for single groves are retained in the list either by hyphenating grove names, or in description of a grove unit or section. It would probably be more confusing than useful to not incorporate the established use of some familiar multiple grove names. However, the revised name usage in the below grove list avoids giving the misimpression that a single grove is more than one grove.

Giant Sequoia Grove List

Notes regarding grove annotations: Grove location descriptions by surveyed township, range, and section number refer to the recognized area of sequoia aggregation known as the grove. Surveyed sections with sequoia outliers only, or a tiny edge of a larger grove are not all described. The form of describing location by land survey description follows the practice of Rundel (1969 and 1972), though the location descriptions have been significantly amended as a result of better grove location information in recent times.

Only the primary land ownerships and grove watersheds are described. Described private ownership is as of January 1994.

Groves are listed alphabetically within four regional groups, except for the groves north of the Kings River, which are listed in order from north to south.

A. Groves north of the Kings River

1. Placer County Grove: T. 14 N., R. 13 E., Sec. 19; Middle Fork of the American River watershed; Tahoe National Forest; the tiny, most northern grove.
2. North Calaveras Grove: T. 5 N, R. 15 E., Sec. 14, 15, 22; Big Trees Creek, Calaveras Big Trees State Park.
3. South Calaveras Grove: T. 5 N., R. 16 E., Sec. 28, 29, 30, 31, 32, 33; North Fork of the Stanislaus River watershed, Calaveras Big Trees State Park.
4. Merced Grove: T. 2 S., R. 19 E., Sec. 23; Moss Creek, Yosemite National Park.
5. Tuolumne Grove: T. 2 S., R. 20 E., Sec. 7, 18; North Crane Creek, Yosemite National Park.
6. Mariposa Grove: T. 5 S., R. 22 E., Sec. 6, 7, 8, 18; headwaters of Big Creek, Yosemite National Park.
7. Nelder Grove: T. 6 S., R. 22 E., Sec. 4, 5, 6, 7, 8; California and Nelder Creeks, Sierra National Forest; a few miles south of Mariposa Grove.
8. McKinley Grove: T. 10 S., R. 26 E., Sec. 26, 35 Dinkey Creek watershed, Sierra National Forest.

B. Groves south of the Kings River in the Kings River watershed

9. Agnew Grove: T. 13 S., R. 29 E., Sec. 13; Rattlesnake Creek, Hume Ranger District (Monarch Wilderness), Sequoia National Forest.
10. Bearskin Grove: T. 13 S., R. 28 E., Sec. 34, 35; Bearskin Creek and Tenmile Creek watershed, Hume Ranger District, Sequoia National Forest.
11. Big Stump Grove: T. 14 S., R. 28 E., Sec. 7, 8, 18; Mill Creek, Kings Canyon National Park and Sequoia National Forest.
12. Boulder Creek Grove: T. 13 S., R. 29 E., Sec. 26, 35; near Boulder Creek, Hume Ranger District, Sequoia National Forest.
13. Cherry Gap Grove: T. 13 S., R. 28 E., Sec. 19; Mill Flat Creek headwaters just west of Cherry Gap, Hume Ranger District, Sequoia National Forest.
14. Converse Basin Grove: T. 13 S., R. 28 E., Sec. 4, 5, 6, 7, 8, 17, 18; T. 13 S., R. 27 E., Sec. 1, 2, 11, 12, 13; Converse, Cabin, and Verplank Creeks, Hume Ranger District, Sequoia National Forest.
15. Deer Meadow Grove: T. 13 S., R. 29 E., Sec. 24; Boulder Creek, Hume Ranger District, Sequoia National Forest.
16. Evans Grove: T. 13 S., R. 29 E., Sec. 9, 15, 16, 17, 21, 22; Redwood, Windy Gulch, and Evans Creeks, Hume Ranger District, Sequoia National Forest.

17. Grant Grove: T. 13 S., R. 27 E., Sec. 36; T. 13 S., R. 28 E., Sec. 31; Mill Flat Creek watershed, Kings Canyon National Park and Sequoia National Forest.
18. Indian Basin Grove: T. 13 S., R. 28 E., Sec. 4, 8, 9, 16; Hume Ranger District, Sequoia National Forest.
19. Kennedy Grove: T. 13 S., R. 29 E., Sec. 22, 26, 27, 28; Kennedy Creek, Hume Ranger District, Sequoia National Forest.
20. Landslide Grove: T. 13 S., R. 29 E., Sec. 30, 31; Landslide Creek; Hume Ranger District, Sequoia National Forest.
21. Little Boulder Creek Grove: T. 13 S., R. 29 E., Sec. 27, 34; Little Boulder Creek, Hume Ranger District, Sequoia National Forest.
22. Lockwood Grove: T. 13 S., R. 29 E., Sec. 7, 8, 17; Lockwood and Barton Flat Creeks, Hume Ranger District, Sequoia National Forest.
23. Sequoia Creek Grove: T. 14 S., R. 28 E., Sec. 6; T. 14 S., R. 27 E., Sec. 1; Sequoia Creek, Kings Canyon National Park.

C. Kaweah River watershed groves

24. Atwell-East Fork Grove: T. 17 S., R. 30 E., Sec. 1, 2, 9, 10, 11, 12, 13, 14, 15, 24; T. 17 S., R. 31 E., Sec. 7, 18; East Fork of the Kaweah River watershed, Sequoia National Park. The Atwell unit of the grove has the highest elevation giant sequoia.
 - Atwell unit (generally north of the East Fork of the Kaweah River)
 - East Fork units (generally south of the East Fork of the Kaweah River)
 - Redwood Creek unit (along Redwood Creek, north of the East Fork of the Kaweah River)
25. Board Camp Grove: T. 18 S., R. 30 E., Sec. 9, 10, 15, 16; just east of Homers Nose Grove north of the South Fork of the Kaweah River, Sequoia National Park.
26. Cahoon Creek Grove: T. 17 S., R. 30 E., Sec. 27, 34; Cahoon Creek, Sequoia National Park.
27. Case Mountain Grove: T. 17 S., R. 29 E., Sec. 26, 27, 35, 36; Salt Creek, Bureau of Land Management land just west of Sequoia National Park.
28. Castle Creek Grove: T. 16 S., R. 30 E., Sec. 22, 23, 24, 26, 27; Castle Creek, Sequoia National Park.
29. Coffeepot Canyon Grove: T. 17 S., R. 30 E., Sec. 32; Coffeepot Canyon Creek, Sequoia National Park.
30. Devils Canyon Grove: T. 18 S., R. 30 E., Sec. 31; Devil's Canyon Creek, Sequoia National Park.
31. Eden Creek Grove: T. 17 S., R. 30 E., Sec. 28, 32, 33; T. 18 S., R. 30 E., Sec. 5; Eden Creek, Sequoia National Park.
32. Garfield-Dillonwood Grove (in the watersheds of both the Kaweah and Tule Rivers): T. 18 S., R. 30 E., Sec. 20, 21, 22, 28, 29, 33, 34; T. 19 S., R. 30 E., Sec. 1, 2, 3, 4, 9, 10, 11; Sequoia National Park, Sequoia National Forest, and substantial private ownership in the Dillonwood section.
 - Garfield section (within Sequoia National Park)
 - Dillonwood section (south of Sequoia National Park in the Tule River watershed)
33. Giant Forest: T. 15 S., R. 29 E., Sec. 36; T. 15 S., R. 30 E., Sec. 31, 32, 33; T. 16 S., R. 29 E., Sec. 1, 12; T. 16 S., R. 30 E., Sec. 4, 5, 6, 7, 8; Giant Forest plateau, Sequoia National Park.
34. Homers Nose Grove: T. 18 S., R. 30 E., Sec. 9, 16; North of the South Fork of the Kaweah River, west of Board Camp Grove, Sequoia National Park.
35. Horse Creek Grove: T. 17 S., R. 30 E., Sec. 26, 27, 35; Horse Creek, Sequoia National Park.
36. Lost Grove: T. 15 S., R. 29 E., Sec. 3, 4; Dorst Creek headwaters, Sequoia National Park.
37. Muir Grove: T. 15 S., R. 29 E., Sec. 8, 9, 16, 17; North Fork of the Kaweah River watershed, Sequoia National Park.
38. New Oriole Grove: T. 17 S., R. 30 E., Sec. 17; just south of Oriole Grove, Sequoia National Park.
39. Oriole Grove: T. 17 S., R. 30 E., Sec. 4, 5, 8, 9; Squirrel Creek, Sequoia National Park.
40. Pine Ridge Grove: T. 15 S., R. 29 E., Sec. 17, 18; northwest of Pine Ridge, North Fork of the Kaweah River watershed, Sequoia National Park.
41. Redwood Meadow Grove: T. 16 S., R. 30 E., Sec. 13; T. 16 S., R. 31 E., Sec. 17, 18, 19, 20; Middle Fork of the Kaweah River watershed, Sequoia National Park.
42. Redwood Mountain Grove: T. 14 S., R. 28 E., Sec. 10, 13, 14, 15, 16, 20, 21, 22, 23, 24, 25, 26, 27, 28; Redwood, Eshom, and Pierce Creeks, Kings Canyon National Park, Sequoia National Forest, and the University of California's Whitaker Forest section; generally considered to be the largest grove in area and the grove with the largest surviving total population of mature and old-growth sequoias.
43. Skagway Grove: T. 15 S., R. 29 E., Sec. 16, 17, 20; north of Pine Ridge, North Fork of the Kaweah River watershed, Sequoia National Park.
44. South Fork Grove: T. 18 S., R. 30 E., Sec. 14, 15, 16, 21, 22; South Fork of the Kaweah River, Sequoia National Park.
45. Surprise Grove: T. 18 S., R. 30 E., Sec. 7; Bennett Creek, Sequoia National Park.
46. Suwanee Grove: T. 15 S., R. 29 E., Sec. 26, 35; just west of Suwanee Creek, Sequoia National Park.

D. The most southern groves (watersheds of the Tule and Kern Rivers and Deer Creek)

47. Alder Creek Grove: T. 20 S., R. 31 E., Sec. 8, 9, 16, 17; South Fork Alder Creek, Sequoia National Forest and substantial private ownership.
48. Black Mountain Grove: T. 21 S., R. 31 E., Sec. 5, 6, 7, 8, 9, 16, 17, 18, 19, 20, 21; T. 21 S., R. 30 E., Sec. 1, 12; T. 20 S., R. 31 E., Sec. 31; Wilson, Deadman, Long Canyon and Miner Creeks, Sequoia National

Forest, Tule River Indian Reservation, and substantial private ownership.

49. Burro Creek Grove: T. 19 S., R. 31 E., Sec. 28, 32 (probable but unconfirmed), 33; Burro Creek, Sequoia National Forest.
50. Cunningham Grove: T. 22 S., R. 32 E., Sec. 30, 31; Long Meadow Creek, Sequoia National Forest.
51. Deer Creek Grove: T. 23 S., R. 31 E., Sec. 2, 3; Deer Creek, Sequoia National Forest; the most southern grove.
52. Dennison Grove: T. 18 S., R. 30 E., Sec. 31; Kramer Creek, southwest corner of Sequoia National Park.
53. Freeman Creek Grove: T. 20 S., R. 32 E., Sec. 28, 29, 32, 33, 34, 35; T. 21 S., R. 32 E., Sec. 2, 3; Freeman Creek, Sequoia National Forest; the most eastern grove.
54. Long Meadow Grove: T. 22 S., R. 31 E., Sec. 26, 27, 35; Sequoia National Forest.
55. Maggie Mountain Grove: T. 19 S., R. 30 E., Sec. 20; Galena Creek, Sequoia National Forest.
56. McIntyre Grove: T. 20 S., R. 31 E., Sec. 34, 35, 36; T. 21 S., R. 32 E., Sec. 6, 7; T. 21 S., R. 31 E., Sec. 1, 2; Middle Fork of the Tule River watershed, Sequoia National Forest.
 - McIntyre unit (Middle Fork of the Tule River)
 - Carr Wilson unit (on Bear Creek)
57. Mountain Home Grove: T. 19 S., R. 30 E., Sec. 13, 25, 26, 27, 35, 36; T. 19 S., R. 31 E., Sec. 7, 13, 18, 19, 30, 31; T. 20 S., R. 30 E., Sec. 1, 2, 12; T. 20 S., R. 31 E., Sec. 6; on the Mountain Home plateau and in the canyon of the North Fork of the Middle Fork (also known as the Wishon Fork) of the Tule River, Mountain Home State Forest and Sequoia National Forest.
58. North Cold Spring Grove: T. 22 S., R. 30 E., Sec. 36; near North Cold Spring Peak, west of Parker Peak Grove, Tule River Indian Reservation.
59. Packsaddle Grove: T. 23 S., R. 31 E., Sec. 13, 14, 23, 24; Packsaddle Creek, Sequoia National Forest.
60. Parker Peak Grove: T. 22 S., R. 31 E., Sec. 29, 30, 31, 32; Redwood Creek, Tule River Indian Reservation.
61. Peyrone Grove: T. 21 S., R. 31 E., Sec. 34; T. 22 S., R. 31 E., Sec. 2, 3, 4; Windy Creek watershed, Sequoia National Forest and Tule River Indian Reservation.
62. South Peyrone Grove: T. 22 S., R. 31 E., Sec. 10; Cedar Creek watershed, Sequoia National Forest.
63. Red Hill Grove: T. 21 S., R. 31 E., Sec. 22, 23, 26, 27, 28; South Fork of the Tule River watershed, Sequoia National Forest, Tule River Indian Reservation and private owners.
64. Silver Creek Grove: T. 19 S., R. 31 E., Sec. 29; Silver Creek, Mountain Home State Forest and Sequoia National Forest.
65. Starvation Creek Grove: T. 23 S., R. 31 E., Sec. 9, 15, 16; Starvation Creek (Deer Creek watershed), Sequoia National Forest.

Supplementary Notes

1. Differences between this grove list and the "75 groves" list in Rundel (1972) are described below. Grove names in the updated list follow Rundel, unless otherwise explained. Grove names in quotes below are Rundel grove identifications not followed in the updated grove list.

Groves listed by Rundel that are omitted:

- "Abbott Creek Grove" (At present only two isolated sequoia clusters are known to occur in the Abbott Creek watershed, both of which are too small to qualify as a grove.)
- "Squirrel Creek Grove" (This refers to a few isolated outlier sequoias, too few in number to qualify as a grove.)
- "Tenmile Grove" (No sequoias are known to naturally exist in Rundel's described section location apart from Bearskin Grove. "Tenmile Grove" is apparently nonexistent.)

Added grove not listed by Rundel:

- South Peyrone Grove (See note 3, below.)

Consolidation of Rundel grove identifications (14 groves named by Rundel are identified as 6 groves on the updated list):

- Contiguous "Atwell," "East Fork," and "Redwood Creek" Groves are named Atwell-East Fork Grove.
- Contiguous "Belknap," "McIntyre," and "Wheel Meadow" Groves are named McIntyre Grove.
- "Burton Grove" is considered to be an included part of Kennedy Grove. (There is not a separate grove unit west of Kennedy Grove in the area sometimes mapped as "Burton Grove.")
- Contiguous "Garfield" and "Dillonwood" groves are named Garfield-Dillonwood Grove.
- "Middle Tule Grove" is a contiguous part of Mountain Home Grove.
- "Powderhorn Grove" is a distinct grove unit included in Starvation Creek Grove. (This unit is in the northwest quarter of T. 23 S., R. 31 E., Sec. 15. The unit is west of the sometimes mapped "Powderhorn Grove" location in Sec. 14 and 15 near Powderhorn Meadow, which has only a few isolated sequoias.)

Renamed groves, otherwise listed by Rundel (not a consolidation of Rundel grove identifications):

- "Putnam-Francis Grove" is renamed Board Camp Grove (to conform to National Park Service name usage)
- "Case Mountain Groves," "Castle Creek Groves," and "Redwood Meadow Groves" are each described as a single grove in the updated list (with the recognition that they contain multiple grove units).

2. Groves which include two or more geographically distinct but close units include Agnew, Atwell-East Fork,

Bearskin, Black Mountain, Case Mountain, Castle Creek, Kennedy, Lockwood, Mariposa, McIntyre, Nelder, Peyrone, Pine Ridge, Redwood Meadow, and Starvation Creek Groves, as well as probably others.

3. South Peyrone Grove is on Sequoia National Forest land in the Cedar Creek watershed, east of the Tule River Indian Reservation, about one mile south of Peyrone Grove. The author's identification of this grove in the June 1992 version of this paper was the first known identification of this grove on a publicized grove list. The grove name was chosen by the author. It is conceivable that official sources might adopt a different grove name in the future.
4. The grove list reflects numerous interpretive decisions on grove identification concerning giant sequoia concentrations which are geographically distinct enough to suggest a possible separate grove identity, but close enough in distance to other giant sequoia concentrations to be considered as separate units of a single grove. Some of the reasoning behind these decisions is described below.

Northern and Kings River Watershed Groves

Agnew and Deer Meadow Groves: These very close groves are distinguished because they are in separate drainages, separated by a well-defined ridge.

Big Stump and Sequoia Creek Groves: These very close groves are distinguished because they are in separate drainages, separated by a well-defined ridge.

Evans and Kennedy Groves: These groves are relatively close in distance, but they were identified as separate groves because there is marked terrain change between the two giant sequoia groups; they are in separate watersheds; and the nearest Kennedy Grove sequoias are a tiny northern grove unit (rather than the main grove unit).

Evans and Lockwood Groves: These groves are close in distance, but they were distinguished as separate groves because there is a ridge between the groves; they are in separate watersheds; and they have previously been consistently described as separate groves.

Nelder Grove: This is a particularly problematic grove identification. The grove has four distinct units, two of which are about .5 mile from the nearest other unit. This grove could reasonably be considered as three groves. I identify them as units of a single grove because of their relative proximity in the context of the groves north of the Kings River, because one of the more isolated units is very small, and in recognition of the consistent tradition of recognizing a single Nelder Grove.

Groves South of the Kings River Watershed

Atwell-East Fork Grove: The traditionally distinguished "Atwell" and "East Fork" Groves were consolidated because lobes of these major giant sequoia grove areas extend to within a few hundred feet of each other in the same drainage. Similarly, the previously distinguished "Redwood Creek Grove" was consolidated into Atwell-East Fork Grove because part of that giant sequoia group is probably less than 500 feet from giant sequoias of the "Atwell" unit of the grove which extend into the eastern edge of the Redwood Creek drainage.

Case Mountain Grove: The grove has three distinct clusters of surviving old-growth sequoias, separated by distances of about .6 to .9 miles from the nearest cluster. However, these are considered part of a single grove because scattered small groups of sequoias reportedly occurred in intermediate small drainages before 1950's sequoia logging. Since then intermediate private land areas have also been extensively planted with sequoias, which disguises the natural sequoia regeneration which probably occurred after logging. Originally, the grove had numerous scattered stringer units. None was so remote from others as to warrant separate grove identification.

Homers Nose and Board Camp Groves: These very close groves are distinguished because they are in separate watersheds, separated by a ridge.

Horse Creek and Cahoon Creek Groves: These very close groves are distinguished because of a well-defined ridge between them.

McIntyre Grove: The distinct "Carr Wilson Grove" unit was identified as part of large McIntyre Grove because it is downstream in the same drainage from some sequoias of the McIntyre unit.

Peyrone Grove: This grove has several units, including two main units that are about .4 miles apart and in separate drainages. However, the units are identified as one grove because there are scattered sequoias between them.

Redwood Meadow Grove: This grove contains two isolated units of significant size, in separate drainages about .3 miles apart, as well as a third distinct unit which is too small to identify as a separate grove. The units were consolidated as a single grove because the area is remote from other groves; the units are relatively close; and the second largest unit (sometimes described as "Little Redwood Meadow Grove") is less than 35 acres.

Starvation Creek Grove: This grove has a main unit along Starvation Creek and a unit about .3 miles away (sometimes described as "Powderhorn Grove"). These units were considered to be a single grove because of their proximity, and because part of the eastern unit is in the same watershed as the Starvation Creek unit.

Acknowledgments and Unpublished Data Sources

Wendell Flint was particularly helpful in discussions of the concepts and factual content of the grove list. Robert Rogers, silviculturist, Sequoia National Forest, assisted me in researching miscellaneous historical and modern unpublished data, maps, and aerial photographs on file at Sequoia National Forest, Porterville, California. Numerous other persons supplied me with bits and pieces of unpublished information which helped in my preparation of the updated grove list.

References

- Flint, Wendell D. 1987. To find the biggest tree. Three Rivers: Sequoia Natural History Association; 116 p.
- Hammon, Jensen, Wallen and Associates. 1964, 1970, 1975, 1976. Sequoia tree inventory. Hammon, Jensen and Wallen Mapping and Forestry Service, Oakland, CA. Report to the National Park Service. Unpublished reports and maps concerning giant sequoia inventories in Sequoia and Kings Canyon National Parks, on file at Ash Mountain offices, Sequoia National Park.
- Rundel, Philip W. 1969. The distribution and ecology of the giant sequoia ecosystem in the Sierra Nevada, California. Durham, NC: Duke University; 204 p. Ph.D. dissertation.
- Rundel, Philip W. 1972. An annotated checklist of the groves of *Sequoiadendron Giganteum* in the Sierra Nevada, California. Madrono 21 (5):319-328.
- Western Timber Service, Inc. 1970. Sequoia tree inventory. Western Timber Service, Inc., Arcata, CA. Report to the National Park Service. Unpublished reports and maps concerning giant sequoia inventories in Sequoia and Kings Canyon National Parks, on file at Ash Mountain offices, Sequoia National Park.

Appendix

Symposium Program

Tuesday, June 23, 1992

8:00	Introductions and Welcome of Keynote Speakers	Andrew Leven <i>USFS, Pacific Southwest Region</i>
8:05	Welcome to the Visalia Area	Peter Carey <i>Mayor of Visalia</i>
8:25	Keynote Speech	Douglas Leisz <i>Former Associate Chief, USFS</i>
8:55	Panel: Natural Values, Public Values, and Public Perceptions	Bob Jasperson <i>Save-the-Redwoods League, Moderator</i>
	A Botanist's View of the Big Trees	Robert Ornduff <i>University of California</i>
	Sequoia Grove Preservation: Natural or Humanistic?	William A. Croft <i>University of Michigan</i>
	Public Perceptions of Giant Sequoia Over Time	William Tweed <i>Sequoia National Park</i>
10:15	Break	
10:40	Panel: Natural Perspectives, Genetic Characteristics, and Ecological Considerations	Bill Libby, <i>University of California, Moderator</i>
	Perspectives on the Giant Sequoia Groves	Dwight Willard <i>Author and Attorney</i>
	Paleohistory of Giant Sequoia in the Sierra Nevada	Scott Anderson <i>Northern Arizona University</i>
	Genetics of Giant Sequoia	Lauren Fins <i>University of Idaho</i>
	Giant Sequoia in the Mixed-Conifer Ecosystem	Philip Rundel <i>UCLA</i>
12:00	Lunch	
	Lee Stetson will present his dramatic interpretation of John Muir: Giant Sequoia in the Sierra Nevada	
1:30	Panel: Giant Sequoia in a Disturbance-Driven Environment	Dave Parsons, <i>Sequoia National Park, Moderator</i>
	Giant Sequoia in a Disturbance-Driven Environment: Integrating Science and Mgt	Norman Christensen <i>Duke University</i>
	Fire and Climate History in Giant Sequoia Stands	Thomas Swetnam <i>University of Arizona</i>

Long-Term Stand Dynamics of Sequoia Groves Nathan Stephenson
*Sequoia National
Park*

Fire Ecology: Implication for Managing
Giant Sequoia Ecosystems.....Jan van Wagtendonk
*Yosemite National
Park*

Air Pollution Effects on Giant Sequoia Ecosystems Paul Miller
USFS, PSW Riverside

3:15 Break

3:45 Panel: Management Strategies Joseph Fontaine,
Sierra Club, Moderator

US Forest Service Sandra Key
Sequoia National Park

US Park Service David Parsons
Sequoia National Park

California Department of Forestry and Fire Protection Dave Dulitz
Mt. Home State Forest

4:45 Poster Session

6:00 End of Poster Session

7:00 Banquet
Giant Sequoia in Europe Prof. Wolfgang Knigge
University of Göttingen, Germany

Wednesday, June 24, 1992

All day field trips

Thursday, June 25, 1992

8:00 Announcements

8:05 Panel: Influences on Grove Development Julie Allen,
USFS Sequoia National Forest, Moderator

Soils and Nutrients Relationships in the Development
of Giant Sequoia Groves Paul Zinke
University of California

Microbiology: The Spice of Life in Mixed-Conifer Forests Randy Molina
USFS, PNW Corvallis, Oregon

Faunal Relationships in Sequoia /Mixed-Conifer Forests David Graber
Sequoia National Park

Insect and Disease Relationships Douglas Piirto
*Cal Poly State University
San Luis Obispo*

Visual Ecology in Giant Sequoia Kerry Dawson
University of California, Davis

9:45 Break

10:15	Panel: Native Values and Public Agency Management Strategies	Janet Wold, <i>Stanislaus National Forest, Moderator</i>
	Native American Views and Values of Giant Sequoia	Floyd Franco, Jr. <i>Chairman, Tule River Tribal Council</i>
	Management Strategies by the Tule Indian Reservation	Brian Rueger <i>Consulting Forester Tule River Indian Reservation</i>
	Management Strategies by California Department of Parks and Recreation	Wayne Harrison <i>Calaveras State Park</i>
	Management Strategies by the Bureau of Land Management	Russell Lewis <i>Caliente Resource Area, BLM</i>
	Private Land Management	Dave Reed, <i>Owner, Dillionwood Company</i>
	Young Growth Management	Donald Gasser <i>University of California</i>
	Mitigating Some Consequences of Giant Sequoia Management	William Libby <i>University of California</i>
12:00	Lunch	
1:15	Panel: Reflections on Management Strategies	Kenneth Delfino, <i>California Dept. of Forestry and Fire Protection, Moderator</i>
	The Mediated Settlement	Julie McDonald <i>Sierra Club</i>
	Perspectives of the Forest Products Industry	Glen Duysen <i>Sequoia Forest Products, Inc.</i>
	A Grassroots View	Carla A. Cloer <i>Sequoia Forest Alliance and Involved Citizen</i>
2:15	Audience Response: What Should the Future Be?	Alana Knaster, <i>Mediation Institute, Moderator</i>
3:30	Break	
3:50	Symposium Results: Views from the Agency Leadership	Philip Aune, <i>USFS, Pacific Southwest Research Station, Moderator</i>
	California Department of Forestry and Fire Protection	Richard Wilson <i>Director</i>
	Sequoia Kings Canyon National Park.....	Thomas Ritter <i>Superintendent</i>
	US Forest Service, Pacific Southwest Region	Ronald Stewart <i>Regional Forester</i>
4:40	California Congressional Delegation	To Be Announced
4:55	Final Comments and Future Actions	Ronald Stewart
5:00	Close of Symposium	

Speakers List

Julie Allen
US Forest Service
Sequoia National Forest
900 W. Grand Avenue
Porterville, CA 93257

Scott Anderson
Northern Arizona University
Bilby Research Center
Flagstaff, AZ 86011

Philip Anne
US Forest Service
Pacific Southwest Research Station
2400 Washington Avenue
Redding, CA 96001

Peter Carey
Visalia City Council
707 Acequia
Visalia, CA 93291

Norman L. Christensen
School of Forestry Duke
University Durham, NC 27706

Carla A. Cloer
182 E. Reid Avenue
Porterville, CA 93257

William A. Croft
Program in Linguistics
University of Michigan
Ann Arbor, MI 48109-1285

Kerry Dawson
Environmental Design
University of California
Davis, CA 95616

Kenneth Delfino
California Dept. of Forestry and Fire Protection
1416 Ninth Street
Sacramento, CA 95814

Dave Dulitz
Mt. Home Demonstration State Forest
PO Box 517
Springville, CA 93265

Glen H. Duysen
Sierra Forest Products, Inc..
PO Box 10060
Terra Bella, CA 93270

Lauren Fins
University of Idaho
Department of Forestry
Moscow, ID 83843

Joe Fontaine
Sierra Club PO Box
307 Tehachapi, CA
93581

Floyd Franco, Jr.
Tule River Tribal Council
PO Box 589
Porterville, CA 93258

Donald Gasser
Department of Forestry and Resource Mgmt.
145 Mulford Hall
University of California
Berkeley, CA 94720

David Graber
Sequoia and Kings Canyon National Parks
Three Rivers, CA 93271

Wayne Harrison
Calaveras State Park
PO Box 120
Arnold, CA 95223

Bruce S. Howard
Save-the-Redwoods League
621 Miner Road
Orinda, CA 94563

Bob Jasperson
Save-the-Redwoods League
114 Sansome Street
Room 605
San Francisco, CA 94104

Sandra Key
US Forest Service
900 W. Grand Avenue
Porterville, CA 93257

Alana Knaster
Mediation Institute
22231 Mulholland Hwy. Suite 207 A
Woodland Hills, CA 91364

Wolfgang Knigge
Institut für Forstbenutzung
Büsgenweg 4
3400 Göttingen
GERMANY

Richard Lehman
2115 Kern Street, Suite 210
Fresno, CA 94721-2682

Douglas Leisz
2399 Kingsgate
Placerville, CA 95667

Andrew Leven
US Forest Service
Pacific Southwest Region
630 Sansome Street
San Francisco, CA 94111

Russell Lewis
Bureau of Land Management
4301 Rosedale Highway
Bakersfield, CA 93308

William Libby
Department of Forestry and Resource Management
145 Mulford Hall
University of California
Berkeley, CA 94720

Julie McDonald
Sierra Club Legal Defense Fund
2044 Fillmore Street
San Francisco, CA 94115

Paul Miller
US Forest Service
Pacific Southwest Research Station
Forest Fire Laboratory
4955 Canyon Crest Drive
Riverside, CA 92507

Randy Molina
US Forest Service Pacific
Northwest Region Forest
Science Laboratory
3200 SW Jefferson Way
Corvallis, OR 97701

Robert Ornduff
Department of Integrative Biology
Mulford Hall
University of California
Berkeley, CA 94720

Davis Parsons
Sequoia and Kings Canyon National Parks
Three Rivers, CA 93271

Douglas Piirto
Cal Poly University
Natural Resources Mgmt. Dept.
San Luis Obispo, CA 93407

Dave Reed
Dillionwood
170 La Joya Drive
Nipomo, CA 93444

Thomas Ritter
Sequoia National Park
Three Rivers, CA 93271

Brian Rueger
Tule River Indian Reservation
Hammon, Jensen, Wallen & Associates
39173 Bear Creek Drive
Springville, CA 93265

Phil Rundel
Laboratory of Biomedical and Environmental Sciences
900 Veteran Avenue
University of California
Los Angeles, CA 90024

Mike Srago
US Forest Service
630 Sansome Street
San Francisco, CA 94111

Nathan Stephenson
Sequoia and Kings Canyon National Parks
Three Rivers, CA 93271

Lee Stetson
Wild Productions
Box 811
Yosemite, CA 95389

Ronald E. Stewart
US Forest Service
Pacific Southwest Region
630 Sansome Street
San Francisco, CA 94111

Thomas Swetnam
Laboratory of Tree Ring Research
University of Arizona
Tucson, AZ 85721

Dan Taylor
Audubon Society
555 Audubon Place
Sacramento, CA 95825

William Tweed
Sequoia and Kings Canyon National Parks
Three Rivers, CA 93271

Jan van Wagtendonk
Research Scientist
Yosemite National Park
El Portal Office
El Portal, CA 95318

Dwight Willard
1074 Neilson Street
Albany, CA 94706

Richard Wilson
California Dept. of Forestry and Fire Protection
1416 9th Street
Sacramento, CA 95814

Janet Wold
US Forest Service
Stanislaus National Forest
19777 Greenley Road
Sonora, CA 95370

Paul Zinke
Department of Forestry and Resource Management
145 Mulford Hall
University of California
Berkeley, CA 94720



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- Protection and management of resources on 191 million acres of National Forest System lands
- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands
- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

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