YOUNG GROWTH GIANT SEQUOIA RESPONSE TO MANAGEMENT STRATEGIES AT MOUNTAIN HOME STATE FOREST

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By

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ABSTRACT

YOUNG GROWTH GIANT SEQUOIA RESPONSE TO MANAGEMENT STRATEGIES AT MOUNTAIN HOME STATE FOREST

Gary B. Roller

A total of 35, one tenth (0.1) of an acre, plots were established in 1989 on Mountain Home Demonstration State Forest in predominantly young growth giant sequoia stands. This study inventoried, compared, and analyzed overall growth and yield response of young growth giant sequoia (*Sequoiadendron giganteum*) to three management strategies in 2001. The research objective of this study is to answer two main questions: 1) is there a difference between the management strategies of no treatment, thinning only and thinning followed by prescribed burning on the effect of stand growth in young growth giant sequoia and mixed conifer species stands, and 2) is there a difference between the management strategies of no treatment, thinning only and thinning followed by prescribed burning on regeneration response of giant sequoia and other mixed conifer species?

Analysis results reveal a highly significant difference ($p = 0.005$) for cubic foot volume growth over the twelve year period and a significant difference ($p = 0.05$) for board foot volume growth for the same twelve year period for both treatments against the control . Analysis of natural regeneration data for the major conifer species show a highly significant difference ($p = 0.005$) in seedlings per acre on the thinned and burned treatment as compared to no treatment and the thin only treatment, with white fir being the dominant naturally regenerated species (87% of total). No significant difference was observed between the control and thin only treatment themselves.

The results of this study will be useful to forest managers as they develop guidelines for giant sequoia forest structure, density and spacing at Mountain Home Demonstration State Forest. It is nearly impossible to mimic the natural disturbance processes that created the giant sequoia groves of today. Historically, giant sequoia has evolved to its present status with a combination of intense fires creating patchy canopy gaps and bare mineral soil needed for seedling establishment, growth and survival. A combination of various silvicultural strategies such as, prescribed fire, overstory thinning, and planting are needed to manage giant sequoia in perpetuity.

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INTRODUCTION

The giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) is a magnificent tree that grows only in the mixed conifer forests of the California Sierra Nevada. The public holds these trees in high regard and giant sequoia have long been recognized as unique and valuable components of the ecosystems within which they reside (USDA Forest Service 2000). This uniqueness and strong public appeal have placed most of giant sequoia groves in protected, public reserves (e.g., Giant Sequoia National Monument). The protected status bestowed upon the giant sequoia, along with the limited natural range where they occur, has restricted research involving stand manipulation.

The natural range of giant sequoia (Figure 1) is restricted to about 75 groves scattered over a 420-km (260-mi) belt, nowhere more than about 24 km (15 mi) wide, extending along the west slope of the Sierra Nevada in central California (Hartesveldt et al., 1975, Rundel 1972b). The northern two-thirds of the range, from the American River in Placer County southward to the Kings River, take in only eight widely disjunct groves. The remaining groves, including all the large ones, are concentrated between the Kings River and the Deer Creek Grove in southern Tulare County. The limited natural range of these trees suggests a narrow range of environmental conditions suitable for the perpetuation of the species (Rundel, 1972a).

Figure 1. Natural Range of Giant Sequoia.

Paleo-historical research of giant sequoia suggests that the modern sequoia/mixed conifer forest developed only over the past 4500 years and that the unusual distribution of giant sequoia in California can be attributed to changing climatic conditions during the late Holocene period (Anderson, 1992). Within its natural range, giant sequoia is valued primarily for esthetic and scientific purposes. Outside this range, it is highly regarded as an ornamental in several parts of the United States and in numerous other countries (Hartesveldt, et al., 1975). Ongoing research has occurred to manage giant sequoia as a commercially viable species (Heald, et al. 1999-2003).

Stand structure and species frequency vary substantially with elevation, latitude, exposure, soil moisture, and time since fire or other disturbance. In general, protection of groves from fire has resulted in increased prevalence of California white fir (*Abies* *concolor*), reduced regeneration of giant sequoia and pines, and reduced density of shrubs. The age-class distribution of giant sequoia varies widely among groves. Most groves today, however, appear to lack sufficient young giant sequoias to maintain the present density of mature trees in the future. In these groves, giant sequoia regeneration evidently has been declining over a period of 100 to 500 years or more (Rundel, 1972a,b).

Since its discovery in 1852, certain segments of society have seen the potential of this tree as a productive material resource. Others have viewed the logging of these trees as a waste of a national treasure. These views were the beginnings of the conflict over the management of giant sequoia; a natural resource to be preserved for public enjoyment or as a resource utilized for material wealth, or some combination of the two.

Logging of giant sequoia began in the late 1800's and continued through the early 1940's. It has all but ceased, due to the actions of many concerned citizens. Most of the groves of giant sequoias have been placed in protective areas and managed for public, recreational use. Today, 90 percent of the groves are under public ownership. The USDA Forest Service manages 42 percent; USDI National Park Service-34 percent; and the State of California-14 percent. Of the approximately 75 naturally occurring giant sequoia groves, 43 are found on national forests (Rundel 1972b).

American society has voiced its opinion to have giant sequoia placed in areas protected from harvest operations and fire and preserved as a national treasure for all to enjoy. How does this protected status for the ancient trees affect the giant sequoia natural ecosystem? Does this "hands off" approach to management provide for the natural recruitment of new giant sequoia seedlings to become the future ancient trees of tomorrow? Is there any chance that we could use this species as a commercially viable wood resource? There are a few ongoing giant sequoia research and management studies that are trying to answer these questions.

A multitude of management strategies have been proposed over the years to protect current giant sequoia groves and to recruit seedling establishment. Most of these strategies ended up in controversy between the public and professional resource managers and scientists. As a result of this controversy, one agency responsible for the management of most of the giant sequoia groves, the U.S. Forest Service (USFS), entered into the Mediated Settlement Agreement (MSA) in 1990. The MSA provided for a uniform policy regarding management of all naturally occurring giant sequoia groves. It states that all USFS grove areas containing old-growth giant sequoias are to be managed in such a way that will "protect, preserve, and restore the Groves for the benefit and enjoyment of present and future generations" (USDA Forest Service, 1990).

Since the MSA of 1990, the Federal government created the Giant Sequoia National Monument, officially proclaimed by President Bill Clinton in April of 2000. The President used his proclamation power in his discretion, to declare by public proclamation historic landmarks, historic and prehistoric structures, and other objects of historic or scientific interest that are situated upon lands owned or controlled by the Government of the United States to be national monuments, and to reserve as a part thereof parcels of land, the limits of which in all cases, shall be confined to the smallest area compatible with the proper care and management of the objects to be protected (USA 2000). This proclamation and The Giant Sequoia National Monument Draft Environmental Impact Statement (DEIS), have outlined current problems and alternatives for sequoia management. The groves themselves, as well as the ecosystems within the Monument that surround the groves, should provide enriching recreational and social experiences, outstanding landscapes, and an array of rare and endemic species (USDA Forest Service 2002). The USDA Forest Service has since issued the Final Environmental Impact Statement (FEIS) in December of 2003 that lists many alternatives for giant sequoia management at the monument. The proposed action is one that calls for the systematic reintroduction of fire throughout the Monument as one of several tools for giant sequoia management (USDA Forest Service 2003).

There is insufficient research on the management of giant sequoia. Many opinions exist on how giant sequoia should be managed, but unfortunately the research has not adequately met the needs of all who are involved in giant sequoia management. Most Federal and State agencies involved in giant sequoia management have attempted forest thinning or prescribed fire to some degree in giant sequoia groves. These management activities have brought increased criticism and unsubstantiated claims of impending grove destruction hampering research activities (Leisz, 1992). Public education is imperative for the future of giant sequoia grove management. More research on how giant sequoia could respond to these activities is necessary to substantiate all anecdotal evidence.

Management of giant sequoia ranges from custodial protection involving simply putting out fires and controlling recreational impacts to selective removal of trees followed by prescribed burning to prescribed burning only. However, there have been few, if any, comparison studies to track how giant sequoia-mixed conifer stands respond to management activities. There is very little comparison information on how managed stands of young-growth giant sequoia respond to management activities such as selective thinning and prescribed burning (Piirto, 2001).

In 1989, Dr. Robert E. Martin and Mr. Donald P. Gasser initiated a long-term research study with a controlled experiment to investigate the response to management strategies of young-growth giant sequoia at Mountain Home Demonstration State Forest (MHDSF). A study was initiated at MHDSF that would allow stand manipulation in young-growth giant sequoia stands. The lead investigators were fortunate to get this study on the ground considering the limits and restrictions regarding giant sequoia stand manipulation (Martin and Gasser 1989).

OBJECTIVES

In a general sense, there is concern about adequately recruiting regeneration of giant sequoia. There is growing evidence that the approach of preserving stands of this species in reserves does not provide the conditions necessary for regeneration of new stands necessary to sustain the species in perpetuity. Despite good intentions, the "hands off" approach to management practiced in reserves may preclude some of the essential natural disturbances, such as fire and stand openings to allow sunlight at the forest floor, needed to prompt seed fall in mature trees and subsequently, successful establishment and growth of seedlings.

Specifically, the research objectives of this study are to determine the effect of thinning and prescribed burning on: 1.) stand growth of young growth giant sequoia and mixed conifer species stands; and 2.) regeneration response of giant sequoia and other mixed conifer species.

This paper will attempt to give insight to forest managers on the expected growth and yield response of young growth giant sequoia and associated species in response to different management strategies. The management strategies being thinning, thinning and prescribed burn, and control. It will also analyze the differences in new seedling recruitment to the same management strategies.

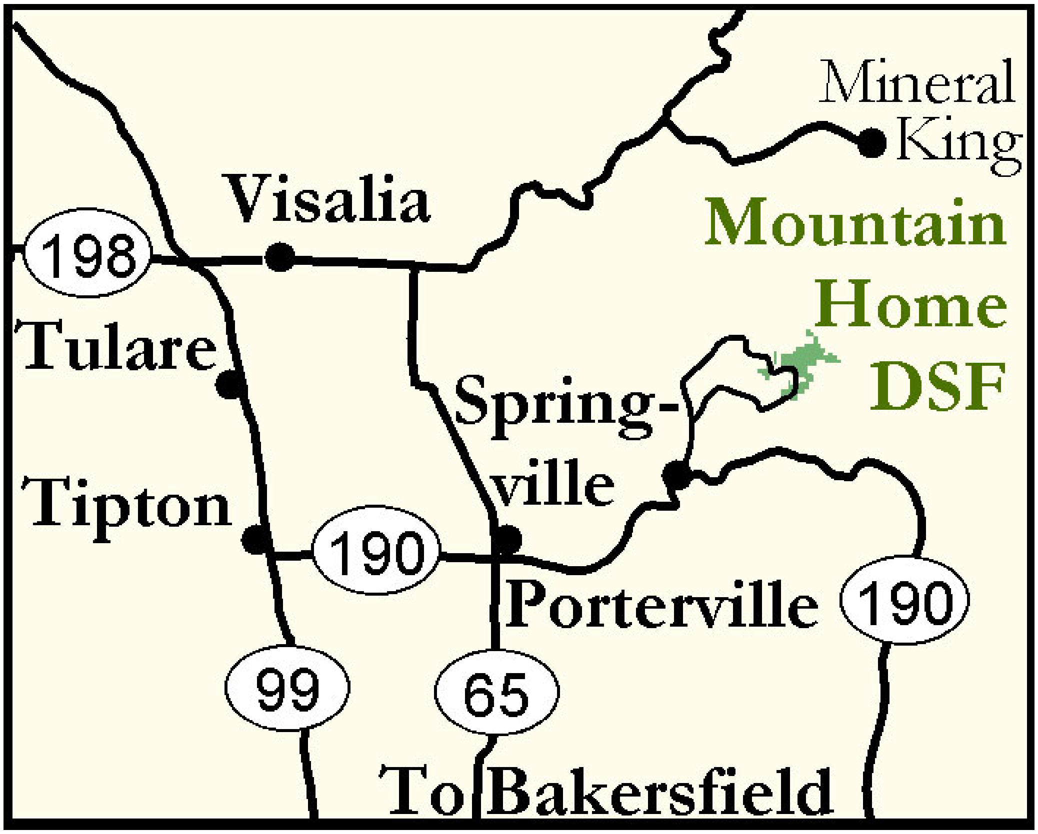
MATERIALS AND METHODS

Study Area

The study area for this project is located at Mountain Home Demonstration State Forest (MHDSF). MHDSF is one of eight Demonstration State Forests currently managed by the California Department of Forestry and Fire Protection (CDF). These forests provide research and demonstration projects on forest management, while providing public recreation opportunities, fish and wildlife habitat, and watershed protection (CDF website 2003). MHDSF is in the southern part of the natural range of giant sequoia.

MHDSF is approximately 4807 acres and elevation ranges from 4800 to 7600 feet. The forest is located in Tulare County in the southern portion of the Sierra Nevada Mountain Range in California (Figure 2). MHDSF is located some 22 air miles northeast of Porterville, CA. The forest is situated in the drainages of the North Fork and the North Fork of the Middle Fork of the Tule River. Climate of the area is characterized by dry, warm summers and cold, wet winters. Average precipitation is estimated to be 40 inches per year. Winter precipitation occurs mostly in the form of snow with occasional warm rains. Average date of the first snowfall is approximately November 1st. Ninety-one percent of the State Forest is classified as Dunnings Site II or better. (CDF, 2003).

Figure 2. Mountain Home Demonstration State Forest



The amended statute under which MHDSF is managed is found in Section 4658 of the California Public Resources Code. Section 4658 states that “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: “the primary purpose of the State Forest program is to conduct innovative demonstrations, experiments, and education in forest management. All State Forest land uses should serve this purpose in some way.” In addition, “timber production will be subordinate to recreation” on Mountain Home Demonstration State Forest (CDF, 2003).

Additionally, MHDSF has a management priority of providing recreation use to its many annual visitors. Its second priority is to provide an optimum volume of timber production while still providing for its first priority. Timber harvest practices should be based on the most economical methods of timber removal while maintaining site productivity through regeneration. Extensive stands of young-growth giant sequoias exist at MHDSF. The primary goal in the management of these stands is the perpetuation of selected trees into the old-growth class (Dulitz, 1992).

Logging history in this forest dates back to 1885. Logging continued through the late 1800's until 1905. Virtually no logging occurred on this forest from 1905 until the late 1930's. In the early 1940's, logging of old growth giant sequoia began in earnest in the southern Sierra Nevada. Many local residents of Tulare County became concerned with the rapid loss of the majestic giant sequoias. Through their various efforts, the State of California was able to purchase the Mountain Home Tract from the Michigan Trust Company for $548,762. It has been State property ever since (CDF, 2003).

Giant sequoia over 60 inches in DBH (diameter at breast height) occurs on approximately 56% of the total acreage of MHDSF. Recent inventory information estimates the total number of these giant sequoia trees at around 4000. Younger giant sequoia trees are present in dense stands ranging in age from 1 to 110 years. The origin of these stands can be traced back to historical site disturbances, mainly logging. Many of these stands average 100 years in age corresponding to the early logging around 1900 (CDF, 2003).

MHDSF contains tree species common to the Sierra Nevada Mixed Conifer type-SAF (Society of American Foresters) forest cover type 243 (Eyre, 1980). In addition to giant sequoia, other dominant tree species include incense cedar (*Calocedrus decurrens* Torr.), white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.), red fir (*Abies magnifica* A. Murr.), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), sugar pine (*Pinus lambertiana* Dougl.), and black oak (*Quercus kelloggii*). Some minor tree species include Jeffrey pine (*Pinus jeffreyi*), canyon live oak (*Quercus chrysolepis*), and white alder (*Alnus rhombifolia*).

Dominant understory species consist of mountain whitethorn (*Ceanothus cordulatus*), mountain lilac (*Ceanothus parviflorus*), Sierra gooseberry, (*Ribes roezlii*), Sierra currant (*Ribes nevadense*), blackcap raspberry (*Rubus leucodermis*), thimbleberry (*Rubus parviflorus*), mountain misery (*Chamaebatia foliosa*), bracken fern (*Pteridium aquilinum*), lotus (*Lotus* spp.), lupine (*Lupinus* spp.), and manzanita (*Arctostaphylos* spp.) (CDF, 2003).

Stand Location/Attributes

The initial step in this study was to identify suitable young-growth giant sequoia stands in MHDSF. This process began in 1989 by the two principal investigators, Dr. Robert E. Martin and Mr. Donald P. Gasser both of the University of California, Berkeley. The selected stands had to meet certain criteria for inclusion in this study. The selections of viable stands were chosen using the following criteria: (Martin and Gasser, 1989, Gasser, 2001).

- contain relatively pure young-growth giant sequoia in composition,
- contain no old-growth giant sequoia trees,
- accessible for the removal of cut trees,
- represent the natural range of variability of growth conditions for MHDSF.

Six stands of young growth giant sequoia were systematically selected using the criteria listed above. The stands names refer to a significant historical or natural features at MHDSF (Figure 3).

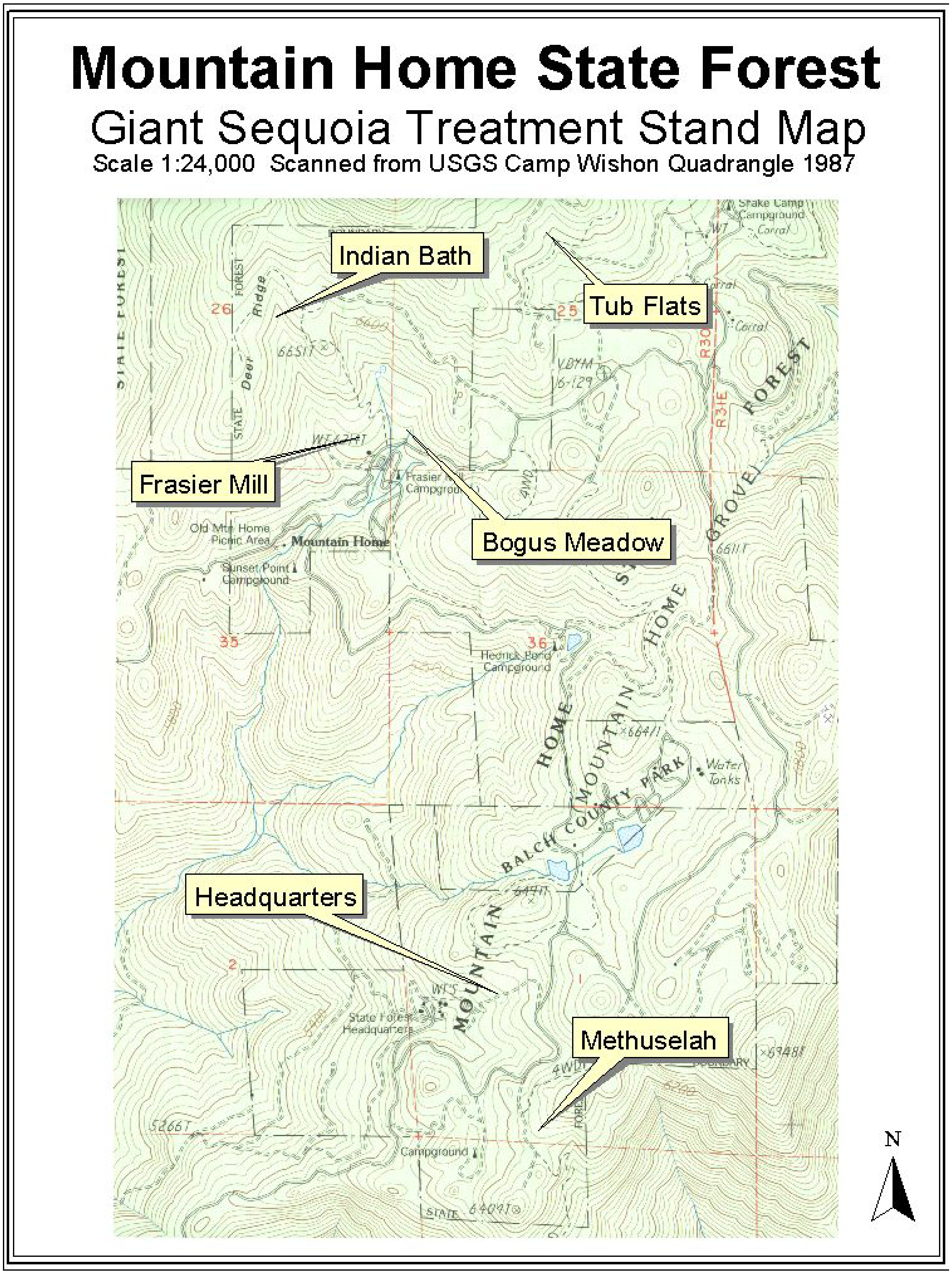
- Bogus Meadow
- Frasier Mill
- Headquarters
- Indian Bath
- Methuselah
- Tub Flats

In each of the six stands, Martin and Gasser (1989) established three treatments Individual plots were then chosen randomly with the restriction that the treated plots be within a practical distance of an existing skid trail to facilitate tree removal.
These treatments are:

- Thinning only (identified by an alphanumerical label A),
- Thinning and underburn (identified by an alphanumerical label B),
- Control (no thinning and no burning, identified by an alphanumerical label C).

Each stand contains at least one plot with each treatment in its boundary. The Headquarters and Tub Flats stands have one plot with each treatment. Bogus Meadow, Frasier Mill, and Indian Bath stands have two plots for each treatment. The Methuselah stand has four plots each of thinning only and thinning with underburn, and three control plots. The fourth control plot on this stand was omitted for unknown reasons. Each of the 35 treatment plots are approximately one tenth (0.1) of an acre (39 foot radius = .1096 acres, 11.88 meter radius = .04 hectares) in size. The numbers of stands and ultimately the number of plots per stand varied because of the different sizes and shapes of the

Figure 3. MHDSF Stand Location Map.



suitable young-growth giant sequoia stands (Martin and Gasser, 1989).

The individual study plots were identified by an alphanumeric code and were permanently monumented with a rebar stake pounded flush to the ground to minimize disturbance and aid in the ability to find them in the future. A five-foot fluorescent orange metal tube was installed at plot center to enable plot identification from a distance. The alphanumeric code assigned to each of the study plots was the first letter of each word in the stand name for the first two digits. The second two digits referred to the treatment letter and the treatment number. For example, IB-A1: this would identify Indian Bath stand, thinning treatment, plot #1; ME-B2 would identify Methuselah stand, thin and burn treatment, plot #2. The names of the stands and number of treatment plots for each of the six stands are as follows:

- Bogus Meadow (BM)-2 Thin, 2 Thin and Burn, 2 Control
- Frasier Mill (FM)-2 Thin, 2 Thin and Burn, 2 Control
- Headquarters (HQ)-1 Thin, 1 Thin and Burn, 1 Control
- Indian Bath (IB)-2 Thin, 2 Thin and Burn, 2 Control
- Methuselah (ME)-4 Thin, 4 Thin and Burn, 3 Control
- Tub Flats (TF)-1 Thin, 1 Thin and Burn, 1 Control

On the Frasier Mill and Indian Bath Stands the plots FM-A2 and IB-A2 were thinned and burned and the plots FM-B1 and IB-B1 were thinned only. This misnaming of the treatment plots was originally done in 1989 for unknown reasons. The misnamed plots were field verified by the author from scorch marks on the residual trees. The analysis for significant differences in growth and yield between plots took this misnaming into consideration and the data was analyzed appropriately.

Each mechanically treated plot was treated by commercial thinning using the classical "thinning from below" approach. This method removes trees of lower crown positions, leaving larger, free-to-grow trees more or less evenly spaced over the area (Nyland, 2002). The trees were harvested to favor the retention of the larger dominant and co-dominant giant sequoia and occasionally a dominant secondary species.

The mechanically thinned and burned plots were burned by a prescribed fire. This is a controlled use of fire under conditions that permit its containment to a predetermined area and still produce a specified intensity of heat and rate of spread to satisfy certain planned objectives. Prescribed burning is the deliberate use of fire to produce the desired benefits with minimum damage and at an acceptable cost (Nyland, 2002). There were some constraints in the actual burning schedule of the plots. All but the Indian Bath plots, were burned in the late fall of 1989 and summer of 1990. Burning of the Indian Bath plots in 1991 was unavoidable due to weather and time constraints. This time difference of a year should have no bearing on results due to an expected lack of response from the trees in this time period (Stephens 2003).

Data Collection

<u>Overstory Sampling</u>

All residual trees on each plot were tagged and measured for diameter at breast height (DBH) and overall height in 1989. These data are the starting point for this long-term study. The same data were collected again in 1994 and the analysis of the differences in diameter growth was done as part of a Master's thesis from U.C. Berkeley in 1998 (Bates, 1998). This thesis was done on the first five years of growth response and showed a significant difference between the treated plots against the control. Bates (1998) reported that trees in the treated plots annually grew three times more in diameter than trees in corresponding control plots. Specifically, trees in the thinning-only and thinning-and-prescribed burned plots grew an average of 0.34 inches in diameter per year compared to 0.12 inches per year in the control plots for similar sized trees. This current study is based on the third measurement of the plots and the response twelve years after the study's inception. This study and the analysis of the data differs from Bates (1998) in that overall growth and volume differences were analyzed as opposed to overall diameter growth. After careful analysis of the original sample design and data it was decided by the author and CDF to analyze volume growth and yield differences as the dominant parameters (Eng 2001, and Robards, 2001).

Each 0.1-acre study plot has a 39 foot (12m) radius from plot center. Every tree within this 0.1-acre plot was tagged and measured for height and DBH. (Diameter at 4.5 ft [1.3m] above ground). A standard diameter tape was used for the stem diameters. All trees were tagged at breast height with blue tags facing towards plot center. The tags were placed at the height where DBH was measured and where DBH should be measured in the future. Height measurements were taken with a Vertex III hypsometer, manufactured by Haglof © Inc.

Since the current measurement was done twelve years after the start, some plots had new in-growth trees that were never measured in any of the previous measurements. All new in-growth trees on the plot were tagged and measured for height and DBH if they had a minimum diameter of 1.0 inch at breast height. This minimum threshold of one-inch diameter was set because it would represent a well-established tree that had some measurable basal area and any tree smaller than this was difficult to tag. There were many other established trees on some of these plots that did not meet this threshold and were not tagged or measured. However, most trees less than 1.0 inch DBH were counted in another portion of this study, the seedling survey, which is discussed later. It will be necessary to add more trees to the database on future measurements as new trees reach this 1-inch DBH threshold.

All height and diameter measurements from 2001 along with the original measurement in 1989 and remeasurement in 1994 and can be found in Appendix A. Any changes in the number of trees per acre that occur are due to either ingrowth or mortality. A few trees were lost due to vandals in the forest cutting them down. These losses were deemed insignificant for purposes of this study. DBH distributions graphs and stand tables are found in Appendix B.

There were some trees that represented a negative growth over the period of twelve years since the first measurement. All the trees that had a negative growth originally were measured again to confirm that they were measured correctly on this third measurement. The Vertex hypsometer was also recalibrated before the remeasurement to ensure that it was reading accurately. Some of the differences in the height growth data can be attributed to the fact that the first two measurements were done with a tape and a clinometer and the new measurements were taken with the Vertex III hypsometer, which is a more accurate measuring device. Other differences could be from the relative inexperience of the measuring crews in the past. Of the 814 trees that were measured, 90 had a negative height growth. A total of 42 of the 90 (5% of the total) negative height growth trees had broken, forked, or deformed tops. Since this study is concentrating on the overall growth and yield response of the residual trees, negative trees are not an issue. Individual trees that appear to be shrinking in height were left in the database. No attempt was made to “correct” the heights. Errors such as these are common and are part of a distribution of measurement errors, including some overestimates and underestimates. If only the underestimates are changed, this could truncate the distribution of measurement errors and cause an upward bias in height estimates (Eng, 2003).

The position of all of the overstory trees, including in-growth in the plot, relative to plot center, was determined for the first time on this third measurement. This section of the data collection was initiated to facilitate production of spatial maps to show where the trees were located and their diameter class, relative to plot center and each other. These data were collected by using the Vertex® III hypsometer to measure the distance from the plot center to the center of the tree. A bearing to each tree was also taken from plot center with a staff compass. This data set could also be used for many other spatial statistical analyses. The maps created from this new data set will also assist in tree location on the next measurement of these plots.

When the measurement of these plots started in 2001, some of the trees had missing tags. At the time the study was initiated, trees were numbered in a clockwise direction from due north. This pattern was critical and allowed the trees with missing tags to be found and properly retagged with the correct number. With this data set and the accompanying stem maps showing location and distance from plot center, there should be no problem finding all of the trees on a given plot, even in the rare instance that all of the tags are missing. Tree location data and stem maps can be found in Appendix C.

By remeasuring the distance to each tree it was found that a total of 5 trees on the 35 plots were actually outside of the 39 foot radius from plot center. These trees were eliminated from the database and were not used in any stand summaries or statistical analyses.

Understory sampling

Within each of the individual sample plots, nine permanent subplots were established to collect data on understory species. These plots were set up in a standard 3 x 3 grid pattern with the center subplot being the center of the 39-foot overstory plot. Refer to Appendix G for grid system layout of understory sample plots.

The nine subplots were originally permanently marked with a rebar stake. An individual understory plot has a 2.6 foot radius for an area of 21.5 square feet (0.8 meter radius, 2.0 square meters in area). A metal detector proved a most valuable tool for this study to locate these subplots. Most of them were buried with litter and would never have been found without the use of the metal detector. Some of the rebar stakes were not found with the metal detector. Missing subplot stakes were relocated by measuring from adjacent stakes and plot center. By doing it in this manner, there is little doubt that the relocated understory plots are at the original position.

The understory vegetation of trees, shrubs, and forbs, at each of the nine subplots, was measured by a total count of each stem per species and by an ocular estimate of percent cover for each species. Grass was also counted by number of stems, not by species. Litter and duff depth were also taken in two random spots within each subplot. Please refer to Appendix D for a list of species found on the plots and the entire database of understory data. The analysis of understory species response to management strategies will follow in a future report.

Downed Woody Material Sampling

The amount of fuel accumulation on the sample plots was measured by using the planar intersect method for inventorying downed woody material (Brown, 1974). Four 33 foot (10 m) transects were laid out in the four cardinal directions from plot center and the woody fuel material was tabulated using a go-no-go gauge. This gauge measures the diameter of downed woody material and classifies them as a 1, 10, 100, or1000 hour fuel based on their respective diameter:

- Twigs under 0.25 inches (.64 cm) diameter are classified as 1-hour fuels,
- less than 1.0-inch (2.54 cm), greater than 0.25 inch are 10- hour fuels,
- less than 3.0 inches (7.62 cm), greater than 1.0 inch are 100-hour fuels,
- greater than 3.0 inches are 1000-hour fuels.

Along the length of each transect, 1 and 10 hour fuels were tabulated from plot center to 6.5 feet (2 m), 100 hour fuels from plot center to 10 feet (3 m), and 1000 hour fuels from 10 feet to 33 feet (10 m). Additionally, all 1000 hour fuels were measured for total diameter and classified as either sound or rotten. Litter depth was also measured along each transect at 10 feet and 33 feet. These measurement protocols can be found in Brown, 1974. See Appendix G for fuel transect layout and Appendix E for downed woody material data. There were no data collected for downed woody materials during the 1994 measurement and the 1989 downed woody materials dataset is incomplete.

Seedling Sampling

The seedling sampling survey was developed to tabulate the number and variety of seedling species on each of the sample plots. The project supervisor, Dr. Douglas D. Piirto, was concerned that an adequate account of the present, new tree seedlings on the plots in response to management strategies was not available (Piirto, 2001). It was decided that to obtain the adequate data, a nested plot would be designed to obtain a 100% count of the tree seedlings. This plot was 19.7 feet (6m) in radius from the plot center of the overstory plot (approximately 0.03 acres (.01 ha) in area). In this plot every seedling was counted by species and by one-foot height classes. All trees were less than 1 inch in diameter at breast height. See Appendix F for seedling data. TPA graphs for regeneration data are in Appendix H.

Photographic Record

Digital photographs were taken of the plots in June 2001 to record the current stand conditions. A photograph was taken in each of the four cardinal directions, from plot center looking towards the outside of the plot. A photograph of the canopy was also taken from plot center by holding the camera parallel to the horizon. These photographs along with pre-treatment photographs from 1989, can be found in Appendix I. The pre-treatment photographs were obtained from Mr. Don Gasser for use in this paper. These photographs tell a story unto themselves and many basic conclusions may be drawn from them regarding changes in the amount of understory, fuel, and light infiltration, in response to the prescribed management strategies. They are also useful as a reference for continued research on this experiment.

Statistical Analysis

One-way analysis of variance (ANOVA) statistical tests were used to determine if significant differences occurred between different years at a significance level of 0.05. Tukey's multiple comparison tests of means was used to indicate significant differences between treatments within ANOVA test results. Tukey's multiple comparison tests provide confidence intervals for all pairwise differences between level means once the hypothesis of overall equality has been rejected. This procedure is sometimes referred to as the Tukey-Kramer multiple comparison procedure or Tukey's Honestly Significant Difference (HSD). Tukey's procedure is based on computing confidence intervals for the difference between each possible pair of means. After all confidence intervals have been computed, each is examined to determine whether the interval includes zero. If it does not include zero the two means are declared significantly different from one another. An interval that does include zero supports the conclusion that there is no significant difference between the means (Devore and Peck, 1997). The critical value is determined from the distribution of the studentized range. The number of means in the experiment is used in the determination of the critical value, and this critical value is used for all comparisons among means. Typically, the largest mean is compared with the smallest mean first. If that difference is not significant, no other comparisons will be significant either, so the computations for these comparisons can be skipped (Lane, 2003).

RESULTS

A primary result of this study is a reestablished and upgraded long-term giant sequoia growth study. This study has now been measured three times. The last measurement (2001), created a digital database of all of the data from the last measurements, photographically recorded the current status of every plot, recorded the position of every tree relative to plot center, and established a new portion of the study regarding natural seedling regeneration. All of the recorded data from the entire 12 year history of this study can be found at CDF headquarters in Sacramento.

All overstory data from this study are analyzed in both board feet/acre and cubic feet/acre parameters as the results are relevant to both timber management and biomass production. Analysis is further broken down into overall stand volume growth and total stand volume yield. Volume was calculated using species specific equations developed for Mountain Home State Forest (Pillsbury et al. 1990, 1991). The regeneration data are analyzed using trees per acre (TPA) per treatment.

Stand attribute summaries by year and treatment are presented in Tables 1-5 (pages 24-28). Please refer to these tables for summaries of tree size, number per acre, basal area, and cubic and board foot volume with changes over time by treatment. No pre-treatment data was collected on the stands. For reference purposes, a 2-inch diameter class distribution, based on the 1989 data, of the control plots in each stand are presented in Figure 4 (pages 29-30). These graphs give an estimate of what the distribution of trees and structure was on all plots per stand before treatment.

Table 1

Stand Attribute Summary for 1989						
	Bogus Meadow	Frasier Mill	Headquarters	Indian Bath	Methuselah	Tub Flats
Elevation	6250 ft.	6240 ft.	6240 ft.	6720 ft.	6840 ft.	6240 ft.
Aspect	SW	SW	SW	SE	NW	SE
# of Thinned Plots (A)	2	2	1	2	4	1
# of Thin and Burn Plots (B)	2	2	1	2	4	1
# of Control Plots (C)	2	2	1	2	3	1
Total Plots	6	6	3	6	11	3
1989 Data Summary						
Avg. Dbh (A plots)	35.1	24.8	18.0	15.9	17.7	11.4
Avg. Dbh (B plots)	27.9	24.2	19.9	13.4	16.6	13.8
Avg. Dbh (C plots)	13.3	15.7	14.4	13.3	12.2	9.5
Max Dbh (A plots)	52.3	46.3	33.7	24.7	28.9	20.9
Max Dbh (B plots)	49.4	35.7	27.1	29.3	28.8	20.5
Max Dbh (C plots)	46.9	52.5	31.4	36.0	31.0	23.5
Avg. Ht. (A plots)	152	118	76	77	65	57
Avg. Ht. (B plots)	120	107	89	77	64	69
Avg. Ht. (C plots)	64	75	68	59	53	47
Max Ht. (A plots)	173	159	129	100	96	92
Max Ht. (B plots)	169	145	112	105	108	86
Max Ht. (C plots)	164	165	108	134	95	103
Avg. Basal Area (A plots)	289	259	175	235	132	139
Avg. Basal Area (B plots)	427	241	207	240	130	139
Avg. Basal Area (C plots)	531	887	521	623	307	368
Avg. Trees per Acre (A plots)	41	64	73	164	82	173
Avg. Trees per Acre (B plots)	77	59	91	223	106	119
Avg. Trees per Acre (C plots)	346	419	328	497	296	583
Average CF Volume (A plots)	10964	8592	4835	5702	2703	2995
Average CF Volume (B plots)	15203	8016	5263	6412	2689	3641
Average CF Volume (C plots)	16547	28454	13360	16647	8852	8195
Average BF Volume (A plots)	68431	49112	25401	26769	11978	13510
Average BF Volume (B plots)	92356	45748	25902	30840	12089	19535
Average BF Volume (C plots)	95084	171775	65109	85145	28255	38203

Table 2

Stand Attribute Summary for 1994						
	Bogus Meadow	Frasier Mill	Headquarters	Indian Bath	Methuselah	Tub Flats
Elevation	6250 ft.	6240 ft.	6240 ft.	6720 ft.	6840 ft.	6240 ft.
Aspect	SW	SW	SW	SE	NW	SE
# of Thinned Plots (A)	2	2	1	2	4	1
# of Thin and Burn Plots (B)	2	2	1	2	4	1
# of Control Plots (C)	2	2	1	2	3	1
Total Plots	6	6	3	6	11	3
1994 Data Summary						
Avg. Dbh (A plots)	37.9	26.0	20.0	16.9	19.9	12.3
Avg. Dbh (B plots)	29.6	25.3	21.4	14.1	19.5	14.7
Avg. Dbh (C plots)	14.1	16.5	15.3	13.9	13.2	9.9
Max Dbh (A plots)	56.0	47.6	37.5	26.2	32.0	22.6
Max Dbh (B plots)	51.1	36.9	29.7	31.3	31.2	22.3
Max Dbh (C plots)	47.2	54.1	33.3	36.4	31.7	24.3
Avg. Ht. (A plots)	164	123	84	79	71	61
Avg. Ht. (B plots)	186	122	102	82	77	71
Avg. Ht. (C plots)	23	78	73	13	60	51
Max Ht. (A plots)	188	164	138	102	98	97
Max Ht. (B plots)	186	158	120	115	111	87
Max Ht. (C plots)	152	175	123	142	101	105
Avg. Basal Area (A plots)	338	282	220	294	165	163
Avg. Basal Area (B plots)	467	235	241	267	149	149
Avg. Basal Area (C plots)	556	965	567	658	354	404
Avg. Trees per Acre (A plots)	41	64	73	182	75	173
Avg. Trees per Acre (B plots)	77	55	91	223	68	119
Avg. Trees per Acre (C plots)	346	419	328	497	298	583
Average CF Volume (A plots)	13607	9642	6567	7162	3561	3636
Average CF Volume (B plots)	18272	9223	6926	7450	3383	3913
Average CF Volume (C plots)	17316	32646	16035	18157	10932	9498
Average BF Volume (A plots)	87860	56062	36167	34039	16447	16817
Average BF Volume (B plots)	115716	54204	36059	36742	16073	20846
Average BF Volume (C plots)	99274	192511	82673	94405	36119	45280

Table 3

Stand Attribute Summary for 2001						
	Bogus Meadow	Frasier Mill	Headquarters	Indian Bath	Methuselah	Tub Flats
Elevation	6250 ft.	6240 ft.	6240 ft.	6720 ft.	6840 ft.	6240 ft.
Aspect	SW	SW	SW	SE	NW	SE
# of Thinned Plots (A)	2	2	1	2	4	1
# of Thin and Burn Plots (B)	2	2	1	2	4	1
# of Control Plots (C)	2	2	1	2	3	1
Total Plots	6	6	3	6	11	3
2001 Data Summary						
Avg. Dbh (A plots)	41.4	28.6	23.0	18.6	22.4	14.1
Avg. Dbh (B plots)	32.2	28.8	24.2	15.6	23.2	17.0
Avg. Dbh (C plots)	15.5	18.0	16.3	15.4	14.4	11.0
Max Dbh (A plots)	59.9	51.2	41.8	28.5	36.3	25.6
Max Dbh (B plots)	54.2	40.3	33.7	33.7	35.7	23.7
Max Dbh (C plots)	48.4	56.8	34.1	38.6	35.7	22.1
Avg. Ht. (A plots)	167	133	94	91	83	66
Avg. Ht. (B plots)	139	126	107	93	91	79
Avg. Ht. (C plots)	74	85	79	72	69	57
Max Ht. (A plots)	189	168	149	117	114	102
Max Ht. (B plots)	200	159	123	129	123	95
Max Ht. (C plots)	187	192	139	156	114	110
Avg. Basal Area (A plots)	400	355	333	353	207	219
Avg. Basal Area (B plots)	550	361	306	314	201	197
Avg. Basal Area (C plots)	659	1052	623	751	419	435
Avg. Trees per Acre (A plots)	46	73	109	187	116	182
Avg. Trees per Acre (B plots)	87	77	91	214	66	119
Avg. Trees per Acre (C plots)	337	433	328	488	340	556
Average CF Volume (A plots)	16092	12604	11056	9630	5126	5200
Average CF Volume (B plots)	21927	12439	8896	9607	5141	5407
Average CF Volume (C plots)	22694	37817	19341	23054	14559	10602
Average BF Volume (A plots)	105380	75052	64486	48473	25419	25277
Average BF Volume (B plots)	141810	73466	47396	49661	26091	28913
Average BF Volume (C plots)	136770	230069	104901	126217	50665	50126

Table 4. Basal Area by Stand

Thin

Stand	1989 Total BA	1989 Sequoia BA	1994 Total BA	1994 Sequoia BA	2001 Total BA	2001 Sequoia BA	Change Total BA 1989-94	Change Total BA 1994-01	Change Total BA 1989-01	Change GS BA 1989-94	Change GS BA 1994-01	Change GS BA 1989-01
BM	289	289	338	338	400	400	49	62	111	49	62	111
FM	259	259	282	282	355	355	23	73	96	23	73	96
HQ	175	175	220	219	333	331	45	113	158	45	112	157
IB	235	235	294	294	353	353	60	58	118	60	58	118
ME	131	117	171	147	207	186	40	37	76	30	39	69
TF	139	124	163	145	219	194	23	56	79	20	49	70

Thin/burn

Stand	1989 Total BA	1989 Sequoia BA	1994 Total BA	1994 Sequoia BA	2001 Total BA	2001 Sequoia BA	Change Total BA 1989-94	Change Total BA 1994-01	Change Total BA 1989-01	Change GS BA 1989-94	Change GS BA 1994-01	Change GS BA 1989-01
BM	427	402	467	440	550	517	41	82	123	38	77	115
FM	226	226	219	219	361	361	-7	141	134	-7	141	134
HQ	207	207	241	241	306	306	33	66	99	33	66	99
IB	240	204	267	227	314	267	28	47	74	22	41	63
ME	130	123	149	147	201	197	19	52	70	24	50	74
TF	139	78	149	88	197	126	10	48	58	10	37	48

Control

Stand	1989 Total BA	1989 Sequoia BA	1994 Total BA	1994 Sequoia BA	2001 Total BA	2001 Sequoia BA	Change Total BA 1989-94	Change Total BA 1994-01	Change Total BA 1989-01	Change GS BA 1989-94	Change GS BA 1994-01	Change GS BA 1989-01
BM	531	431	556	456	659	554	25	102	127	24	98	122
FM	887	847	964	922	1052	1003	77	88	165	75	81	156
HQ	521	460	567	520	623	575	46	57	102	61	55	116
IB	627	545	662	577	758	655	35	96	131	32	79	111
ME	307	238	354	278	419	332	47	66	113	40	55	94
TF	368	309	404	338	435	392	35	31	66	29	54	83

Table 5. Trees Per Acre by Stand

Thin

Stand	1989 Total TPA	1994 Total TPA	2001 Total TPA	Change in Total TPA 1989-1994	Change in Total TPA 1994-2001	Change in Total TPA 1989-2001
BM	41	41	46	0	5	5
FM	64	64	73	0	9	9
HQ	73	73	109	0	36	36
IB	164	182	187	18	5	23
ME	75	75	116	0	41	41
TF	173	173	182	0	9	9

Thin/burn

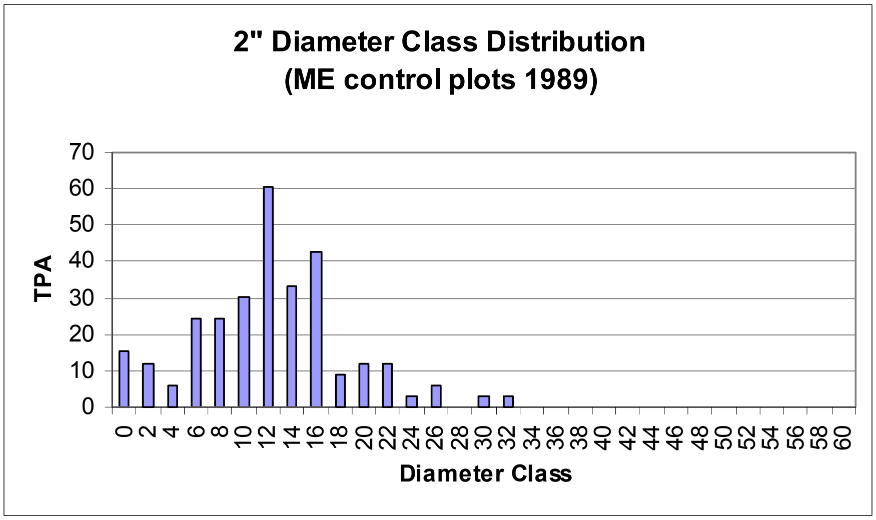
Stand	1989 Total TPA	1994 Total TPA	2001 Total TPA	Change in Total TPA 1989-1994	Change in Total TPA 1994-2001	Change in Total TPA 1989-2001
BM	77	77	87	0	9	9
FM	59	55	77	-5	23	18
HQ	91	91	91	0	0	0
IB	223	223	214	0	-9	-9
ME	68	68	66	0	-2	-2
TF	119	119	119	0	0	0

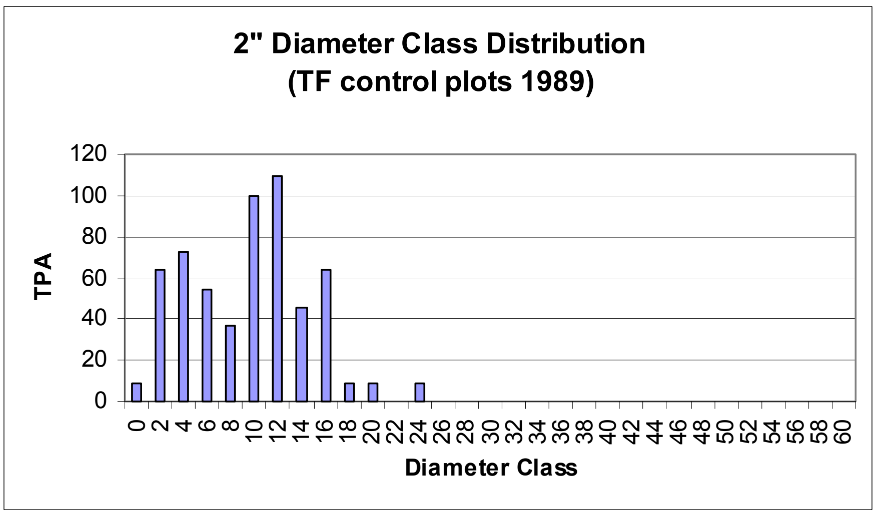
Control

Stand	1989 Total TPA	1994 Total TPA	2001 Total TPA	Change in Total TPA 1989-1994	Change in Total TPA 1994-2001	Change in Total TPA 1989-2001
BM	346	346	337	0	-9	-9
FM	419	419	433	0	14	14
HQ	328	328	328	0	0	0
IB	497	497	488	0	-9	-9
ME	298	298	340	0	43	43
TF	583	583	556	0	-27	-27

***Negative values are due to mortality

Figure 4. Two-Inch Diameter Class Distribution of control Plots in 1989 (pre-treatment)





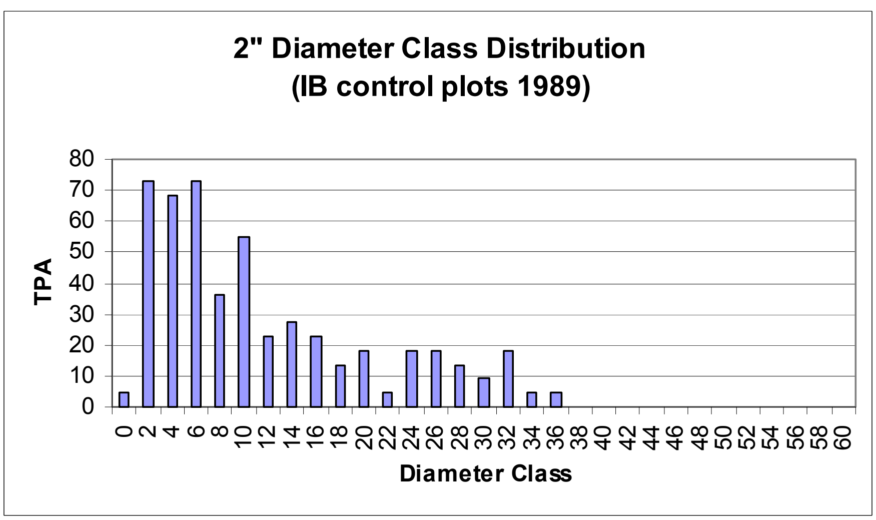
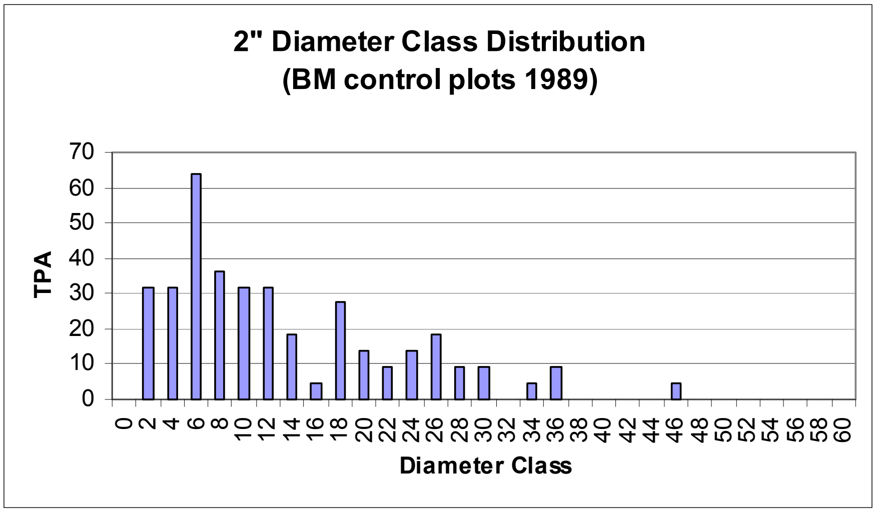
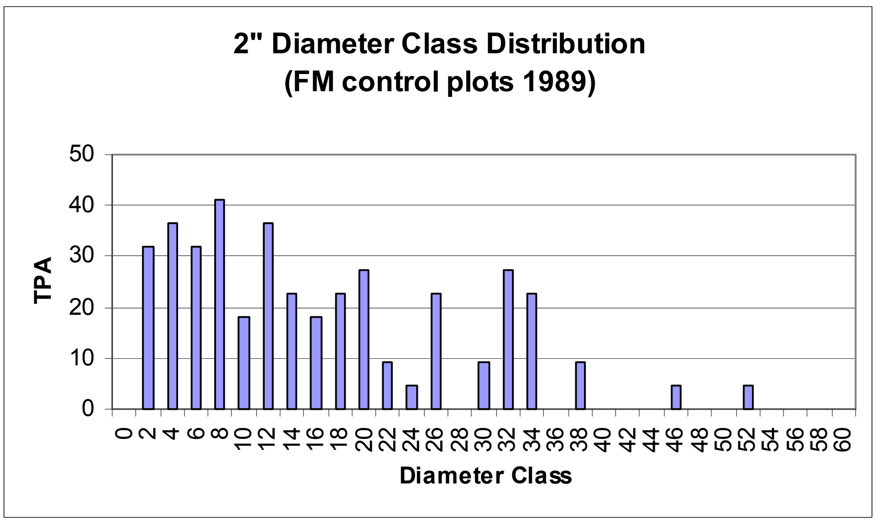
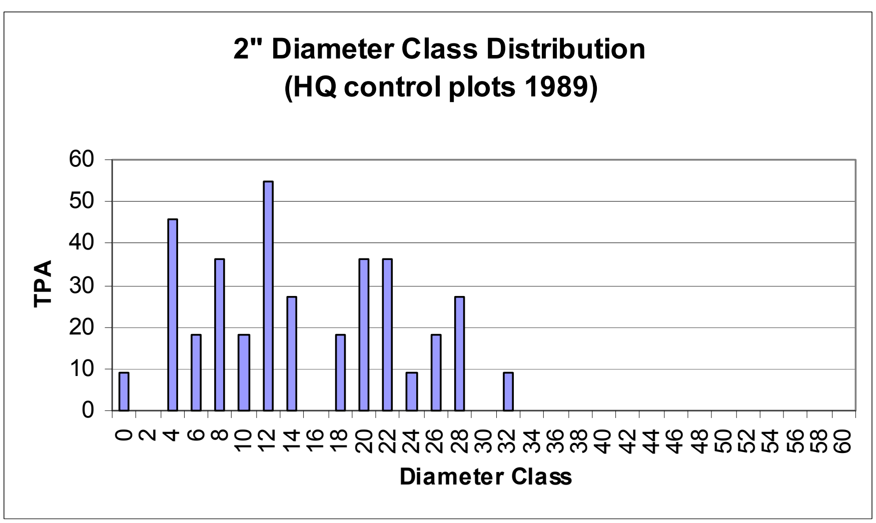


Figure 4. Continued…







The data in this study were analyzed as a completely random design where the experimental units are the forest stands and the sampling units are the inventory plots. This experiment did not control for stand density. This is a possible source of variation. Trying to control for stand density would likely go beyond the level of resolution of the data (Eng, 2003). The following analysis is based on an experimental design, inherited from the original investigators, and is limited in the level of growth dynamics detail. This procedure also allows the examination of differences among means using multiple comparisons. The standard assumptions, listed below for an ANOVA analysis were all met.

- Population of study has a normal distribution.
    - Ho: samples from a normal population-valid
    - H1: samples not from a normal population-invalid
    - Reject if p-value $< \alpha = .05$ (Anderson-Darling normality test)
- Populations have equal variances.
    - Ho: Variances are equal-valid
    - H1: Variances not equal-at least one difference-invalid
    - Reject if p-value $< \alpha = .05$ (Levene's test)
- Samples are drawn randomly-completely randomized design.

For all ANOVA models with statistically significant factors, Tukey's multiple comparison procedure was used to determine which levels of the factors were statistically different from one another. An $\boldsymbol{\alpha} = 0.05$ level was used for all statistical significance tests in this study. Table 6 is a summary of significance for all tests performed across all years and treatments.

Table 6. Parameter Summary of Significance

Parameter	Overall Significance	P-value	Significance Between Treatments: A vs. C	B vs. C	A vs. B
CF Volume Growth 89-94	N	0.198	N	N	N
CF Volume Growth 94-01	Y	0.002	Y	Y	N
CF Volume Growth 89-01	Y	0.005	Y	Y	N
BF Volume Growth 89-94	N	0.641	N	N	N
BF Volume Growth 94-01	Y	0.013	Y	Y	N
BF Volume Growth 89-01	Y	0.05	N	N	N
CF Yield 1989	Y	0.001	Y	Y	N
CF Yield 1994	Y	0.001	Y	Y	N
CF Yield 2001	Y	0.001	Y	Y	N
BF Yield 1989	Y	0.008	Y	Y	N
BF Yield 1994	Y	0.014	Y	Y	N
BF Yield 2001	Y	0.011	Y	Y	N

Cubic Foot Growth

The first analysis is the difference in overall cubic foot volume growth per treatment between measurement year intervals. The three measurement years are 1989, 1994, and 2001. The three treatments are identified in the following tables as; thin only (A), thin/burn (B), and control (C). The cubic foot volume growth results from the first five year interval (1989-1994) show that there is no significant difference ($p = 0.198$) in volume between the three treatments (Table 7). Tukey's pairwise comparisons further show that there is no significant difference between treatments (Table 8).

Table 7. Results of ANOVA for cubic feet growth from 1989-1994.

Source	**DF**	**SS**	**MS**	**F**	**P**
Treatment	2	2717748	1358874	1.70	0.198
Error	32	25506484	797078		
Total	34	28224232			

Level	N	Mean	StDev
A	12	1342	782.2
B	12	1278	943.5
C	11	1908	947.9

Pooled StDev = 892.8

```
Individual 95% CIs For Mean
Based on Pooled StDev
-----+---------+---------+---------+-
 (----------*---------)
(----------*---------)
            (----------*----------)
-----+---------+---------+---------+-
   1000      1500      2000      2500
```

Table 8. Results of pairwise comparisons for cubic feet growth from 1989-1994.

Tukey's pairwise comparisons

Critical value = 3.48

Intervals for (column level mean) - (row level mean)

	A	B
B	-833 961	
C	-1482 352	-1547 287

The cubic foot volume growth results from the second interval, which is seven years, (1994-2001) show that there is a significant difference (p = 0.002) in volume between the three treatments. (Table 9). Tukey's pairwise comparisons further show that there is no significant difference between the thin only and the thin and burn treatments, but that these two treatments by themselves are significantly different than the control (Table 10).

Table 9. Results of ANOVA for cubic feet growth from 1994-2001.

Source	**DF**	**SS**	**MS**	**F**	**P**
Treatment	2	25439212	12719606	7.31	0.002
Error	32	55659390	1739356		
Total	34	81098602			

```
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -----+---------+---------+---------+-
A          12      2345       967   (------*-------)
B          12      2379       850   (-------*-------)
C          11      4198      1935                     (-------*-------)
                                   -----+---------+---------+---------+-
Pooled StDev =     1319              2000      3000      4000      5000
```

Table 10. Results of pairwise comparisons for cubic feet growth from 1994-2001.

Tukey's pairwise comparisons

Critical value = 3.48

Intervals for (column level mean) - (row level mean)

	A	B
B	-1359 1291	
C	-3208 -498	-3174 -465

The cubic foot volume growth results for the entire 12 year length of the study (1989-2001) show that there is a significant difference (p = 0.005) in volume between the three treatments (Table 11). These results mirror the second interval results. Tukey's pairwise comparisons further show that there is no significant difference between the thin only and the thin and burn treatments, but that these two treatments by themselves are significantly different than the control (Table 12).

Table 11. Results of ANOVA for cubic feet growth from 1989-2001.

```
Source      DF         SS         MS        F        P
Treatment    2   44680470   22340235     6.26    0.005
Error       32  114156382    3567387
Total       34  158836852
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N       Mean      StDev   ----+---------+---------+---------+--
A           12       3688       1510    (-------*------)
B           12       3657       1672    (------*-------)
C           11       6106       2415                   (-------*------)
                                       ----+---------+---------+---------+--
Pooled StDev =       1889                3000      4500      6000      7500
```

Table 12. Results of pairwise comparisons for cubic feet growth from 1989-2001.

```
Tukey's pairwise comparisons

Critical value = 3.48

Intervals for (column level mean) - (row level mean)

                 A            B

       B       -1867
                1928

       C       -4358       -4389
                -478        -509
```

Board Foot Growth

The board foot volume growth results from the first five year interval (1989-1994) show that there is no significant difference (p = 0.641) in volume between the three treatments (Table 13). Tukey's pairwise comparisons further show that there is no significant difference between any treatments and the control (Table 14).

Table 13. Results of ANOVA for board feet growth from 1989-1994.

```
Source      DF         SS         MS        F        P
Treatment    2   41922863   20961431     0.45    0.641
Error       32  1.487E+09   46459884
Total       34  1.529E+09
                                      Individual 95% CIs For Mean
                                      Based on Pooled StDev
Level        N       Mean      StDev  -------+---------+---------+---------
A           12       8019       6117  (-------------*------------)
B           12       8570       7665    (-------------*------------)
C           11      10601       6549          (-------------*-------------)
                                      -------+---------+---------+---------
Pooled StDev =       6816                   6000      9000     12000
```

Table 14. Results of pairwise comparisons for board feet growth from 1989-1994.

```
Tukey's pairwise comparisons

Critical value = 3.48

Intervals for (column level mean) - (row level mean)

                 A            B

       B       -7399
                6296

       C       -9583       -9031
                4420        4971
```

The board foot volume growth results from the second interval (1994-2001) show that there is a significant difference ($p = 0.013$) in volume between the three treatments (Table 15). Tukey's pairwise comparisons further show that there is no significant difference between the thin only and the thin and burn treatments, but that these two treatments by themselves are significantly different than the control (Table 16).

Table 15. Results of ANOVA for board feet growth from 1994-2001.

```
Source     DF        SS        MS        F        P
trt2.       2 1.003E+09 501715848     4.94    0.013
Error      32 3.247E+09 101461169
Total      34 4.250E+09
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---------+---------+---------+-------
A          12     14011      7058   (-------*-------)
B          12     14669      6556   (--------*-------)
C          11     25859     14919                  (--------*--------)
                                   ---------+---------+---------+-------
Pooled StDev =    10073                 14000     21000     28000
```

Table 16. Results of pairwise comparisons for board feet growth from 1994-2001.

```
Tukey's pairwise comparisons

Critical value = 3.48

Intervals for (column level mean) - (row level mean)

                 A           B

       B      -10777
                9461

       C      -22194      -21537
               -1501        -844
```

The board foot volume growth results for the entire 12 year length of the study (1989-2001) show that there is a significant difference ($p = 0.05$) in volume between the three treatments (Table 17). Tukey's pairwise comparisons further show that there is no significant difference between any treatments and the control (Table 18). The no significant from the pairwise comparison could possibly be attributed to the ANOVA result of significance at exactly $p = 0.05$ and Tukey's procedure not being a powerful enough test to see significant differences at that minimum level.

Table 17. Results of ANOVA for board feet growth from 1989-2001.

```
Source      DF        SS        MS        F        P
Treatment    2 1.450E+09 725162665     3.30    0.050
Error       32 7.032E+09 219760548
Total       34 8.483E+09
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev -------+---------+---------+---------
A           12     22030     11744 (--------*--------)
B           12     23239     13660   (-------*--------)
C           11     36459     18608             (--------*---------)
                                   -------+---------+---------+---------
Pooled StDev =     14824              20000     30000     40000
```

Table 18. Results of pairwise comparisons for board feet growth from 1989-2001.

```
Tukey's pairwise comparisons

Critical value = 3.48

Intervals for (column level mean) - (row level mean)

                 A           B

       B      -16101
               13683

       C      -29656      -28447
                  798        2007
```

Control plots on this study have substantially more trees per acre (TPA) than the treated plots. It could logically be assumed that more trees are growing more volume on the control plots. The cubic foot volume growth results for the entire 12 year length of the study (1989-2001), by treatment, was divided by trees per acre and these results show that there is a significant difference (p = 0.009) between the three treatments (Table 19). These results mirror the results of the growth by treatment analysis. Tukey's pairwise comparisons further show that there is no significant difference between the thin only and the thin and burn treatments, but that these two treatments by themselves are significantly different than the control just as in the growth analysis (Table 20).

Table 19. Results of cubic foot growth/trees per acre 1989-2001.

```
Source      DF        SS        MS        F        P
trt2.        2      9084      4542     5.48    0.009
Error       32     26518       829
Total       34     35602
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level        N      Mean     StDev  -+---------+---------+---------+-----
a           12     55.04     39.23                      (--------*-------)
b           12     46.67     28.80                  (-------*--------)
c           11     16.96      6.79   (-------*--------)
                                    -+---------+---------+---------+-----
Pooled StDev =     28.79              0        20        40        60
```

Table 20. Results of pairwise comparisons for cubic foot growth/trees per acre 1989-2001.

```
Tukey's pairwise comparisons

Critical value = 3.48

Intervals for (column level mean) - (row level mean)

                a           b

       b      -20.54
               37.29

       c        8.51        0.13
               67.65       59.27
```

Cubic Foot/Board Foot Yield

Current standing cubic foot and board foot yield data was analyzed at each of the three measured years; 1989, 1994, and 2001. Table 21 shows standing volume percent growth over the entire twelve years between treatments. For example; on the thinned only plots, the trees added 64% of the cubic foot volume that was represented on the plots in 1989. ANOVA analyses of standing volume show a highly significant difference between treatments for all three time periods. Tukey's pairwise comparisons reveal that there is no significant difference between the thin only and the thin and burn treatments. Both of these treatments however are significantly different than the control (Table 22).

Table 21. Percent volume growth between treatments from 1989 to 2001.

	Thinned	Thin/Burned	Control
Cubic Feet	64.0	55.6	38.7
Board Feet	72.8	64.6	45.0

Table 22. Cubic Foot and Board Foot Yield Summary of Significance

			Significance Between Treatments		
Parameter	Overall Significance	P-value	A vs. C	B vs. C	A vs. B
CF Yield 1989	Y	0.001	Y	Y	N
CF Yield 1994	Y	0.001	Y	Y	N
CF Yield 2001	Y	0.001	Y	Y	N
BF Yield 1989	Y	0.008	Y	Y	N
BF Yield 1994	Y	0.014	Y	Y	N
BF Yield 2001	Y	0.011	Y	Y	N

Regeneration Analysis

Natural regeneration was analyzed using the one-way analysis of variance test to test for significance between treatment levels. Tukey's multiple comparison procedure was again used to determine which levels of the factors were statistically different from one another if a significant different was detected. There is only one data set of regeneration data and it is from the year 2001. Results from these tests show an overall significant difference ($p = 0.005$) in seedlings per acre between the three treatments (Table 23). Tukey's pairwise comparisons further show that there is no significant difference between the thin only and the control, but that these two treatments by themselves are significantly different than the thin and burn treatment (Table 24).

Table 23. Results of ANOVA for seedlings per acre.

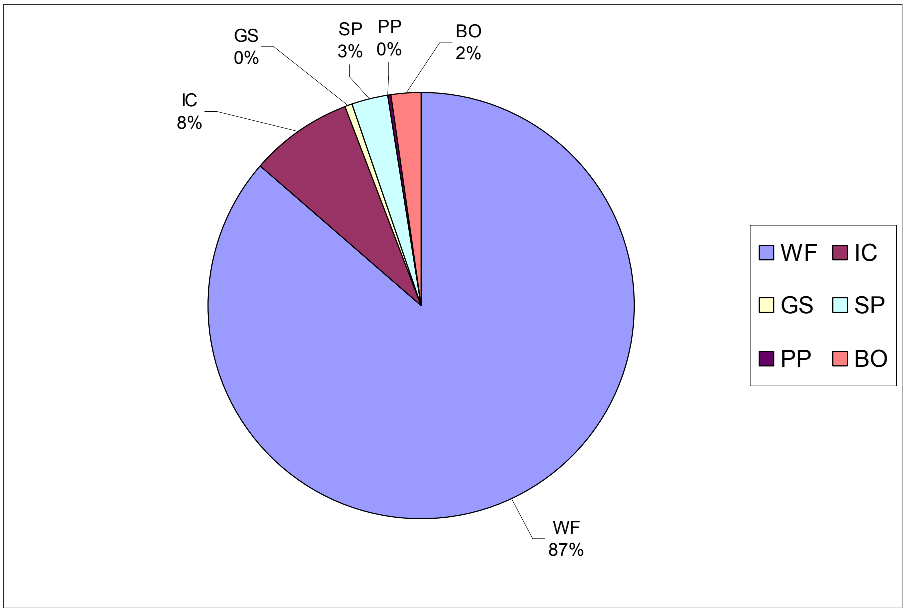
```
Source     DF         SS         MS        F        P
Treatmen    2   53256110   26628055     6.15    0.005
Error      32  138574227    4330445
Total      34  191830337
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N       Mean      StDev  -----+---------+---------+---------+-
a          12        649        587   (-------*-------)
b          12       3262       3379                     (-------*-------)
c          11        678        959   (--------*-------)
                                     -----+---------+---------+---------+-
Pooled StDev =      2081                   0      1500      3000      4500
```

Table 24. Results of pairwise comparisons for seedlings per acre.

```
Tukey's pairwise comparisons

Critical value = 3.48

Intervals for (column level mean) - (row level mean)

                 a           b

       b      -4703
               -522

       c      -2167         446
               2109        4721
```

White fir dominated the species composition of the seedlings with 87% of the total seedlings per acre. This was followed by incense cedar-8%, sugar pine-3%, black oak-2%, and both giant sequoia and ponderosa pine with <1% (See Figure 5).

Figure 5. Percent seedling composition in seedlings per acre.



Figures 6, 7, and 8 show seedlings per acre by species and treatment. White fir dominates the species composition across all three treatments.

Figure 6. Seedlings per acre on thinned only plots.

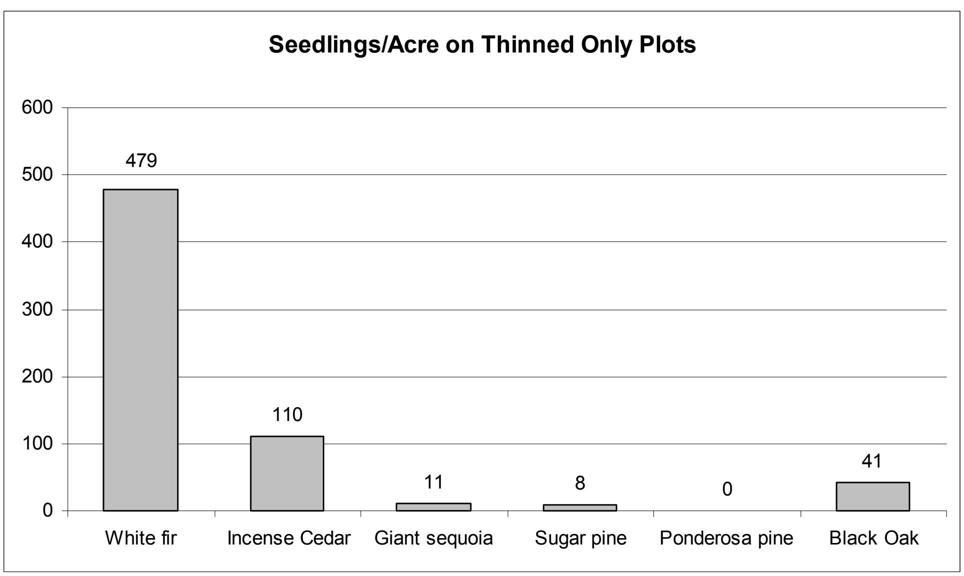


Figure 7. Seedlings per acre on thinned/burned plots.

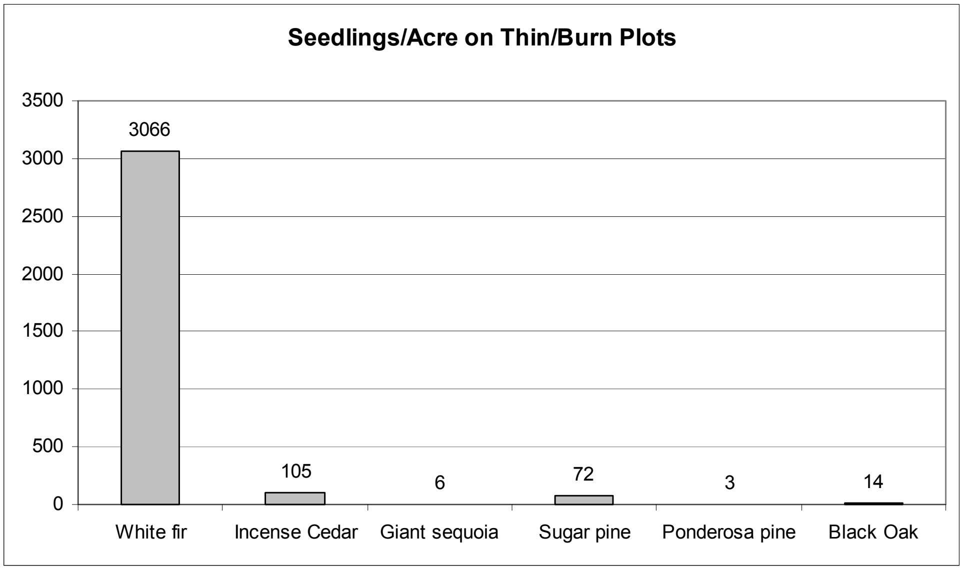
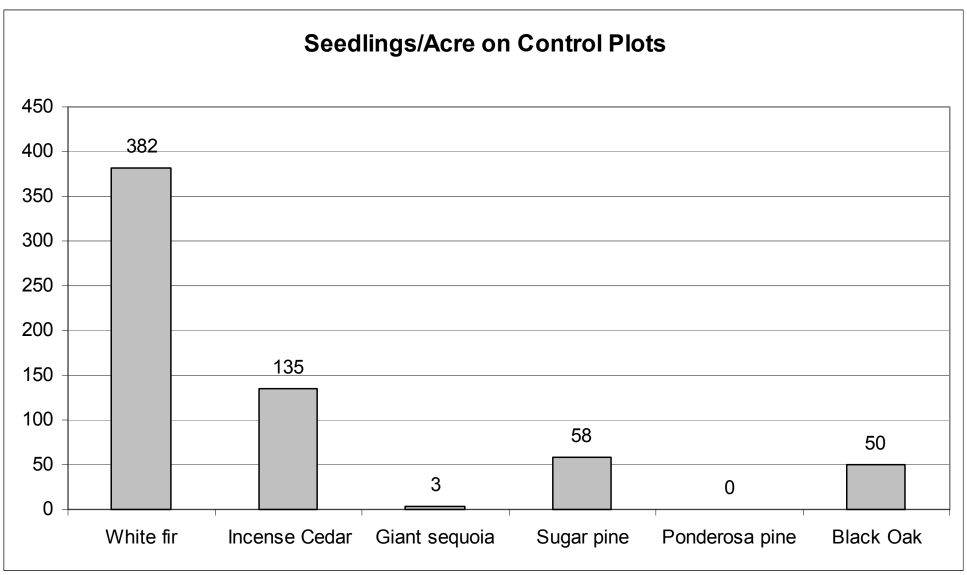


Figure 8. Seedlings per acre on control plots.



Downed Woody Material Analysis

Downed woody material results in tons per acre are presented here across all three treatments (Tables 9, 10, 11, and 12), using Brown's (1974) coefficients. Data is broken down into 1, 10, and 100 hour fuels (activity fuels), 1000 hour fuels, and total fuel in tons per acre. No data on was collected for downed woody materials during the 1994 measurement and there is only an incomplete set of data for the 1989 measurement.

Downed woody material was analyzed using the one-way analysis of variance test to test for significance between treatment levels. Tukey's multiple comparison procedure was again used to determine which levels of the factors were statistically different from one another if a significant different was detected. There is only one data set of downed woody material data and it is from the year 2001. Results from these tests show an overall significant difference (p = 0.000) in activity fuel tons per acre between the three treatments (Table 25). Tukey's pairwise comparisons further show that there is no significant difference between the thin and burned treatment and the control, but that these two treatments by themselves are significantly different than the thin only treatment (Table 26).

Table 25. Results of ANOVA for activity fuel tons per acre.

```
Source     DF        SS        MS        F        P
trt         2     39.37     19.69    12.21    0.000
Error      32     51.58      1.61
Total      34     90.96
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ----+---------+---------+---------+--
a          12     3.942     1.593                      (-----*-----)
b          12     1.550     0.939   (-----*-----)
c          11     1.927     1.182      (-----*------)
                                   ----+---------+---------+---------+--
Pooled StDev =    1.270              1.2       2.4       3.6       4.8
```

Table 26. Results of pairwise comparisons for activity fuel tons per acre.

```
Tukey's pairwise comparisons

Critical value = 3.48

Intervals for (column level mean) - (row level mean)

                 a           b

       b       1.116
               3.667

       c       0.710      -1.681
               3.318       0.927
```

There is no overall significant difference (p = 0.100) in 1000 hour fuel tons per acre between the three treatments (Table 27). Tukey's pairwise comparisons further show that there is no significant difference between any of the three treatments (Table 28).

Table 27. Results of ANOVA for 1000 hour fuel tons per acre.

```
Source      DF        SS         MS         F        P
trt          2      1188        594      2.48    0.100
Error       32      7677        240
Total       34      8865
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean      StDev --------+---------+---------+--------
a           12     16.28      23.04                (---------*--------)
b           12     10.21      12.79          (--------*--------)
c           11      1.93       1.97  (---------*--------)
                                    --------+---------+---------+--------
Pooled StDev =     15.49                    0        10        20
```

Table 28. Results of pairwise comparisons for 1000 hour fuel tons per acre.

```
Tukey's pairwise comparisons

Critical value = 3.48

Intervals for (column level mean) - (row level mean)

                a           b

       b      -9.49
              21.64

       c      -1.55       -7.63
              30.27       24.19
```

Tons per acre for downed woody material on all three treatments and categorized by size class and totals are shown in Figures 9-12.

Figure 9. Downed woody material on thinned only plots in 2001.

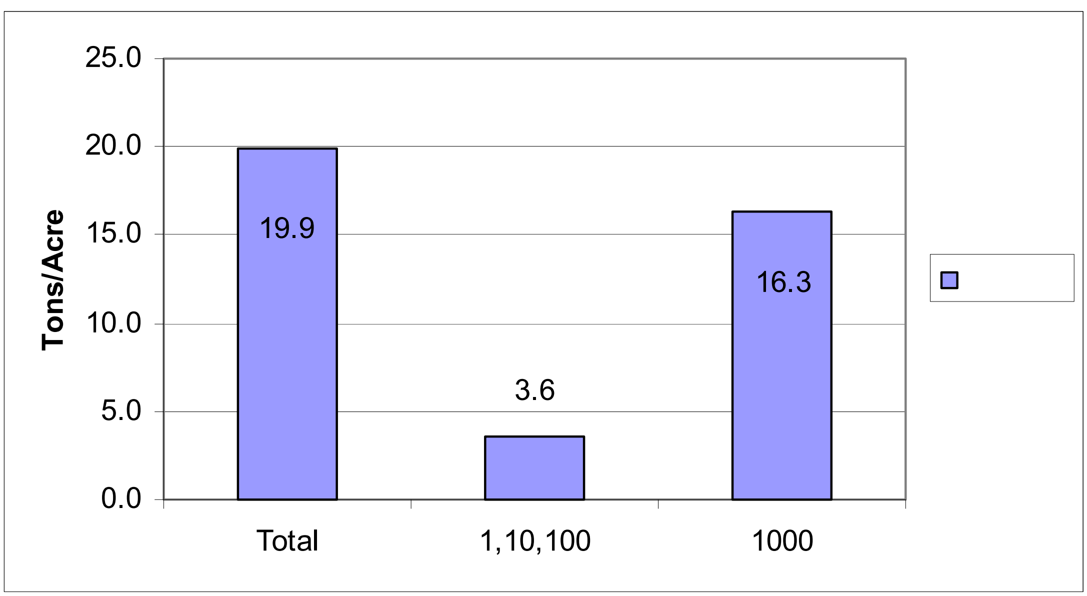


Figure 10. Downed woody material on thinned/burned plots in 2001.

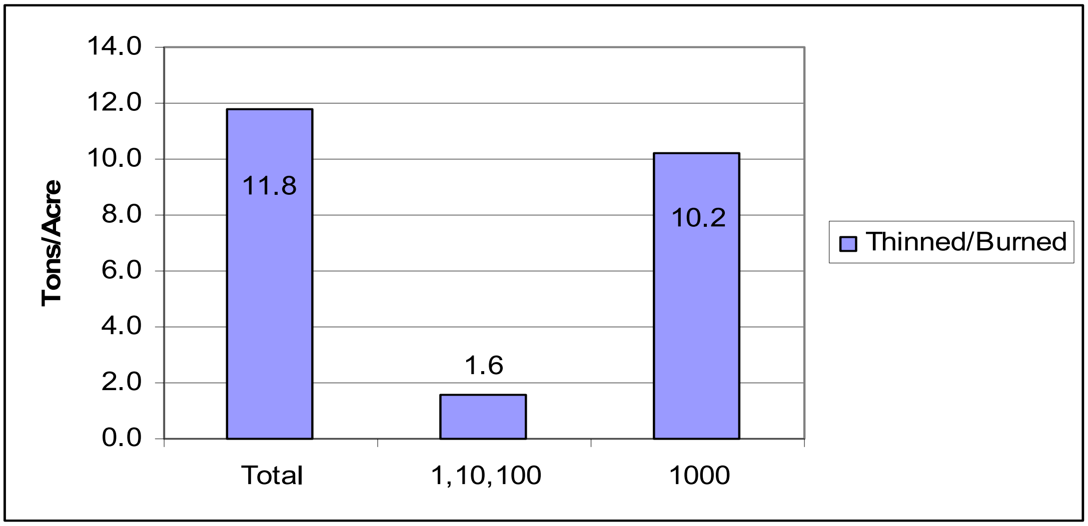


Figure 11. Downed woody material on control plots in 2001.

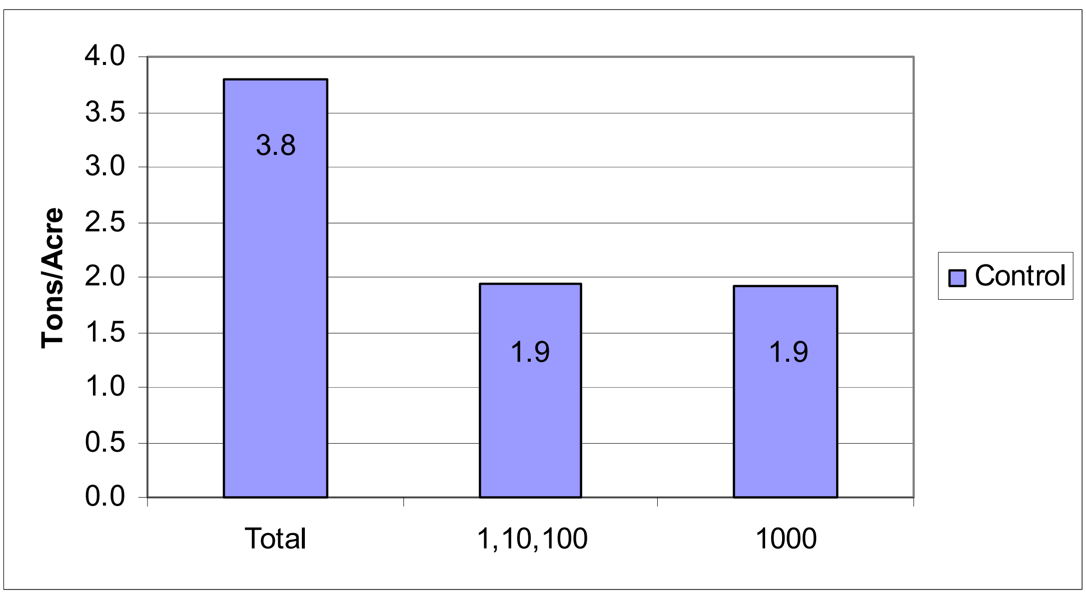
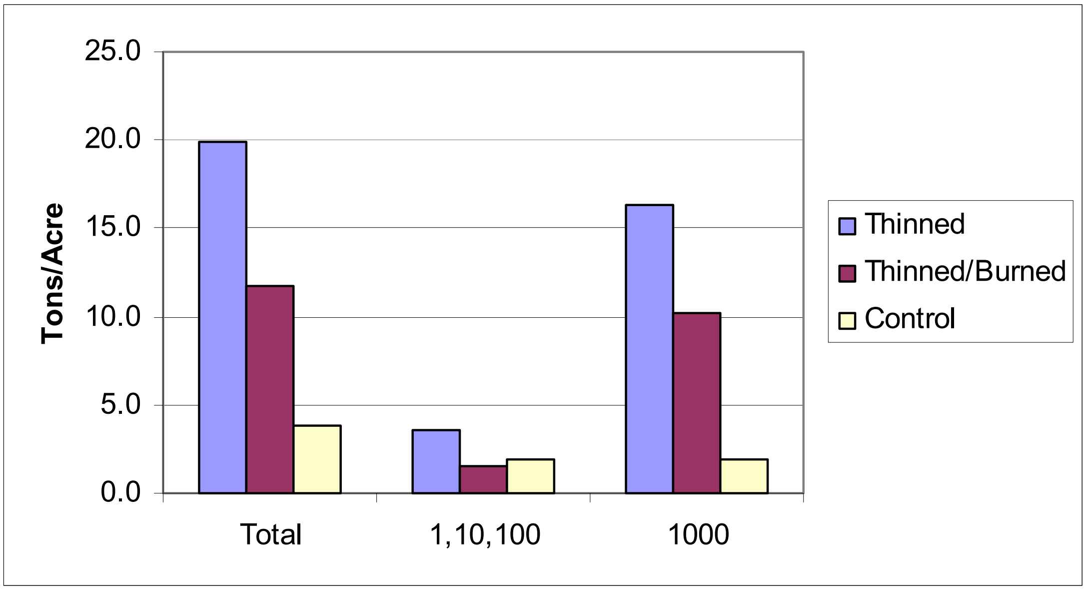


Figure 12. Downed woody material across all three treatments in 2001.



DISCUSSION

The California State Forest system operates under the policy of maintaining state forests as research and demonstration sites for resource management. MHDSF also has a priority to undertake an ongoing program of experimental work with emphasis on reforestation, giant sequoia management, recreation, mitigation of environmental damage from harvesting activities and forest pests. There are a vast amount of young growth giant sequoia groves at Mountain Home, all of which have a management priority to move selected trees into an old growth age class (MHDSF, 2003). The California Department of Forestry and Fire Protection have a unique mandate to protect and restore old growth giant sequoia at Mountain Home. CDF is committed to understand what management tools, in what combination, and application thereof, are the most useful to meet this management goal. We are attempting to understand the entire system from tree establishment to senescence by conducting a variety of regeneration, growth, competition, and mortality studies (Robards 2003). It has been suggested that managers must first identify and examine the key ecosystem elements and their indicators, and how they might naturally occur within and among groves (Piirto and Rogers, 1999). This section will discuss the major findings of this study and their potential effects and influence on future management of giant sequoia groves at MHDSF and other locations throughout the central and southern Sierra Nevada.

The research objective of this study is to answer two main questions: 1) is there a difference between the management strategies of no treatment, thinning and prescribed burning on the effect of stand growth in young growth giant sequoia and mixed conifer species stands, and 2) is there a difference between the management strategies of no treatment thinning and prescribed burning on regeneration response of giant sequoia and other mixed conifer species?

Cubic Foot Volume Growth

Overall cubic foot volume growth was significantly different (p=0.005) between the two treatments and the control for the time period of 1989-2001. Analyzed separately, both treatments were significantly different than the control but not significantly different than each other. This would suggest that either treatment will give more overall cubic foot volume growth versus the control over a 12 year period. These results also suggest that combining a prescribed burn with the overstory thinning did not have a significant effect on the cubic foot volume growth. It can be logically assumed that the thinning of the overstory trees created more growing space for the residual trees. The burning of the surface fuel and litter had no direct effect on the growth of the residual trees. However, prescribed burning has been shown in other studies on ponderosa pine to reduce growth rates of surviving trees. This reduction in growth does not appear to be permanent, and prescribed burning is recognized as a useful management tool to reduce fuel loading and improve forage quality (Landsberg, 1992 and Stephens, 1998).

Overall cubic foot growth between 1989 and 1994 show no significant difference (p=0.198) between any of the three treatments. One possible reason is that the plots are too small. The residual trees did not make use of the small amount of available sunlight created by these small gaps in the canopy. Another possible reason is that the first five year interval is too short for the trees to respond to these management activities.

No measurement of spacing between residual trees was done on these plots. This parameter could affect overall cubic foot growth on the treated plots. Cochran and Barrett (1999), suggest that ponderosa pine cubic volume yield decreases linearly as spacing increased, and board-foot yields vary with spacing. Slash pine (*Pinus elliottii* Engelm.) growth has been shown to follow the same pattern with significant differences in yield as spacing between trees is increased (Bennett, 1963).

Board Foot Volume Growth

Overall board foot volume growth was significantly different (p=0.05) between the two treatments and the control for the time period of 1989-2001. However, there was no significant difference between individual treatments. Considering the borderline significance of the ANOVA analysis (p=0.05), Tukey's pairwise comparisons approach to detect significance between individual treatments is possibly not powerful enough at this borderline level of overall significance. Differences in significance between board foot and cubic foot parameters could possibly be attributed to the variations in the measurement theory and how the equations are derived. There is more board foot cut per unit cubic foot as the scaling cylinder and diameter inside bark increases. More taper tends to make the BF:CF ratio decrease because cubic foot increases while board foot remains the same; so, the denominator of the ratio, BF/CF, increases while the numerator stays constant, which causes the ratio to decrease. Scribner underestimates the scale for all diameters, with the smaller log scales being more underestimated than those of the larger logs. Scribner becomes progressively more accurate for larger logs (Avery and Burkhart , 1994). Many various log rules were created in an attempt to accurately measure board feet, however, none of these rules can accurately predict the mill output of boards, except when near-cylindrical logs are sawed according to rigid assumptions on which the rules are based (Brack, 1999).

Cubic rules are regarded as superior to board foot measurements because they generally give more consistent estimates of log volumes across the range of diameters and lengths (Garland 1984). Log scale and volume relationships, as practiced, are imprecise, inconsistent, and biased. Board foot scales, founded on assumptions about how a log is processed into lumber, offer a poor approximation of reality of board feet (Spelter, 2004). Cubic foot volume is highly, significantly different across all three treatments and time intervals, and in reality is a better measurement due to the increased use of residues from milling in wood products. The cubic rules for volume measure and take into account these residues which are lost in board foot scales.

Regeneration

A highly significant difference (p=0.005) between the number of seedlings per acre was found between the burned plots against the thinned only and the control. It is important to note that the seedling data are only for one year, 2001. There are no other seedling data to compare these data from 2001 against. These data are a starting point and will be useful for the next measurement to perform more robust regeneration analyses. This study found approximately 3500 white fir seedlings out of a total of 3900 mixed conifer and hardwood seedlings in 6-meter openings. A similar study, on the Challenge Experimental Forest in northern California, found approximately 1000 white fir seedlings in 9-meter group openings with a total of 4300 total mixed conifer seedlings (McDonald and Reynolds, 1999). Less than 3% of the total numbers of seedlings found on this study are ponderosa pine or sugar pine. McDonald and Reynolds (1999) found that ponderosa pine saplings were significantly more numerous in 18- and 27-meter openings than in 9-meter openings on that study. That suggests that a 6-meter opening is most likely too small to facilitate growth of shade intolerant ponderosa pine. Giant sequoia regeneration accounted for less that 1% of the total number of seedlings found for this study. Successful regeneration of giant sequoia in shade and in the absence of disturbance is less likely than that of any associated conifer (Harvey et al., 1980). Growths of planted mixed conifer species are negatively influenced by proximity to edge of group openings. Giant sequoia is the most sensitive to the edge environment, and white fir is relatively insensitive. (York et al., 2004). This also suggests that the 6-meter openings are too small for naturally regenerated shade intolerant species.

A similar study at Mountain Home regarding regeneration response to opening size and different fuel treatments show similar results in regards to giant sequoia regeneration. All openings had low giant sequoia seedling density regardless of opening size or fuel treatment and was completely absent from the lop and scatter fuel treatment (Stephens et al., 1998).

The proximity to the edge of a group, as well as the competition of the border tress, are all factors that contribute to natural regeneration of mixed conifer species. Although the general environment of small openings may be similar, the specific environment actually differs, depending on the size of the opening. In general, more light is available in 90-foot openings than in 30-foot openings (McDonald and Abbott 1994). All results from the natural regeneration data and previous literature suggest that the smaller the group or opening, the less natural regeneration response and growth. Development of almost all vegetation was poorest in smaller diameter openings. Small openings are considered inadequate for operational application. Roots of adjacent trees probably extend throughout openings of this size and deny site resources (soil moisture and light) to new conifer and hardwood seedlings (McDonald and Abbott 1994). These results lead to the questions: What is the appropriate opening size? What level of disturbance is required to facilitate natural regeneration in Sierran mixed conifers, especially giant sequoia?

It is commonly known that giant sequoia prefers disturbed, bare mineral soil to facilitate establishment (Burns and Honkala, 1990; Harvey et al., 1980; Schubert, 1957). Soil disturbance and increased availability of light and moisture resulting from past logging in some groves have led to establishment of several fine young-growth stands dominated by giant sequoia. Mechanical seedbed preparation is currently a legitimate regeneration option in some groves, although such treatment is inconsistent with management direction in most of the natural range of the species (Burns and Honkala, 1990). Of the various types of natural disturbances that may remove litter and bare mineral soil, fire is undoubtedly the most significant (Harvey et al., 1980).

Thinning and burning seem to be influencing the natural regeneration per the results of this study. More importantly, thinning alone does not create conditions that favor the development of shade intolerant species in openings of 0.1 acres used in this study.

RECOMMENDATIONS

Future research recommendations

Further research is required to quantitatively state the appropriate level of thinning and what intensity of burning is necessary to create conditions for maximum growth of giant sequoia. This study is a good start to quantify some of the basic factors and results in giant sequoia growth. Future studies need to incorporate a more detailed analysis of diameter and basal area growth in response to management strategies. Unfortunately, there are not a lot of places large enough to implement a study, with an appropriate experimental design, to fully analyze growth response. Robust experiments must be created to adequately develop density and spacing guidelines. The are many studies of this type on plantation giant sequoia occurring at UC Berkeley's Blodgett Forest Research Station in El Dorado County, California. This site, however, does not have any naturally occurring giant sequoia. Giant sequoia is likely to become a valuable commercial species in the future. Young giant sequoia does, however, have favorable wood properties. It is decay-resistant and used as dimensional lumber, veneer, and plywood (Cockrell et al. 1971, Piirto, 1986). The results from this study, as well as the continuing research by the Forest Service and Blodgett Forest, will pave the way to commercial grade use.

Grove restoration and definition of a natural disturbance regime are some of the most researched topics regarding giant sequoia today. Results from this study and continued research can help define and quantify the dynamic disturbance process. Natural regeneration, large tree failure, canopy gap size and distribution, fire intensity and frequency are all valuable and important research topics. It is important to understand what combination and intensity of these disturbance factors is needed to perpetuate giant sequoia groves in the future.

Mountain Home State Forest

Mountain Home has a current policy to manage giant sequoia as a timber resource primarily as a replacement for old growth trees that are lost to natural circumstances and lost to historical logging (MHDSF, 2003). Mountain Home should continue this course as they recognize that lack of disturbance will hinder giant sequoia natural reproduction. It is almost, if not totally, impossible to completely mimic the natural disturbance process that created the sequoia groves that we admire today. Current groves were created by intense fires that created various, and widely distributed canopy gaps that facilitated the growth of new giant sequoias. If the public are willing to accept management practices that less closely mimic natural processes, one could physically cut openings in the forest, following with a light surface fire to prepare a mineral soil seed bed. This would usually require the planting sequoia seedlings, since a light surface fire will induce little seed release from sequoia cones, leading to low seedling establishment (Stephenson, 1992 and Stephens, 1998).

CONCLUSION

It is imperative that Mountain Home Demonstration State Forest and CDF continue this current study into the future. It is one of a very few studies of its kind. This study has proven that there is a significant difference in volume growth and yield of young growth giant sequoia and a significant difference in natural regeneration all in response to the three management strategies used in this study. These results point to the continued research efforts that are needed on giant sequoia silvicultural strategies, natural disturbance processes, and sequoia ecosystem restoration. This study has provided the scientific and management community with one of many tools required to manage giant sequoia in perpetuity.

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