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SEQUOIADENDRON GIGANTEUM-MIXED CONIFER FOREST STRUCTURE IN 1900–1901 FROM THE SOUTHERN SIERRA NEVADA, CA

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ABSTRACT

Historical data collected from eight mixed conifer and four giant sequoia *Sequoiadendron giganteum* (Lindley) Buchholz (giant sequoia)-mixed conifer plots in the southern Sierra Nevada by George Sudworth in 1900–1901 were analyzed to determine historic forest structure. Although it is not possible to document details of the sampling methodology used by this early forest inventory, the plots were dominated by large trees of several species. Average diameter at breast height (DBH) was 110 cm (43 inches) in the mixed conifer plots and 145 cm (57 inches) in *S. giganteum*-mixed conifer plots for trees greater than 30.5 cm DBH. Results indicate that both shade intolerant and shade tolerant species were abundant. Average tree density was low at 278 trees/ha (111 trees/acre) in mixed conifer plots and 272 trees/ha (109 trees/acre) in *S. giganteum*-mixed conifer plots for trees greater than 30.5 cm DBH. The most common size classes are in the medium to large size classes for all *S. giganteum*-mixed conifer species. This is in contrast to published studies of current stands that have determined small size classes of shade tolerant species are occurring at higher frequencies. Early land uses such as logging and grazing at the turn of the 20th century impacted mixed conifer and *S. giganteum*-mixed conifer forests of the southern Sierra Nevada. Information from this study can assist in the characterization of the "natural range of variability" of these forests which could be used in their restoration and management.

The United States Forest Service (USFS) has changed its philosophy of land management. Ecosystem management has been selected and in California it has been defined as the skillful, integrated use of ecological knowledge at various scales to produce desired resource values, products, services, and conditions in ways that also sustain the diversity and productivity of ecosystems (Manley et al. 1995).

Determining which ecosystem structures are sustainable is a complex problem. The USFS has chosen pre-historical (the period before the influence of European settlement) ecosystem structure as the desired future condition but there is presently very little quantitative information in this area for the diverse ecosystems found in California.

Historical and prehistoric information on the structure of mixed conifer and *S. giganteum*-mixed conifer forests is also limited. Information of this type is useful in characterizing the "natural range of variability" that the ecosystems historically operated in and can assist in specifying desirable future conditions in the restoration and management of these forests. Sources of this type of information include early photographs, personal journals, books, forest stand reconstruction from contemporary plot data, fire histories, and analysis of early forest inventories.

Several investigators have examined past forest structure in the southern Sierra Nevada, including sizes of forest aggregations based on tree diameter (Bonnicksen and Stone 1982) and forest structure as determined from tree age (Stephenson et al. 1991). Historic inventory data primarily from the northern Sierra Nevada and the Transverse Ranges of southern California have also been analyzed (McKelvey and Johnston 1992). Results indicate that shade tolerant species such as *Abies concolor* (Gordon & Glend.) Lindl. and *Calocedrus decurrens* (Torrey) Florin have increased in abundance since fire suppression was initiated early in the 20th century (Parsons and DeBendeetti 1979).

Each type of historic or prehistoric data has advantages and disadvantages. Photographs can give excellent visual representations of past landscapes and can assist in the determination of species composition, relative tree size, and density; but it is not possible to derive quantitative inventory data from them for analysis (Vankat and Major 1978). Books and early journals can give descriptions of the past landscapes, but in most cases, lack quantitative information.

Forest stand reconstruction based on sampling the diameter of current *S. giganteum*-mixed conifer forest trees (Bonnicksen and Stone 1982) can

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give information on past and current forest structure but also has limitations. This type of analysis attempts to recreate past landscapes based on tree aggregations and stand structure comparisons. In many cases, diameter at breast height (DBH) is used as a surrogate for tree age which can be inaccurate (Oliver and Larson, 1995). Problems with analysis and interpretation from forest aggregations studies have been reviewed elsewhere (Stephenson 1987).

Fire history investigations can give information on the past fire regime of an ecosystem if appropriate trees are available for sampling (e.g., old, fire scarred trees that are resistant to decay). These histories can give accurate and precise information of the temporal and spatial distribution of the past fire regime, but use of this information to reconstruct past forest structure is difficult because of our limited understanding of the effects of prehistoric fires.

Prediction of the effects and behavior of past fires is difficult when the fuel complexes and forest structures they operated within are fundamentally different than the present. The spatial distribution of prehistoric fires has not been investigated thoroughly making it impossible to estimate how extensive prehistoric fires were. Limited information on the spatial extent of prehistoric fires is available in the southern Sierra Nevada (Kilgore and Taylor 1979; Swetnam et al. 1990; Swetnam et al. 1992; Caprio and Swetnam 1995).

Early forest inventories can provide quantitative information on historic forest structure, however, the results from the analyses of these data can be biased. In most cases, the methods used in the inventory were not carefully recorded and it is not possible to determine how the samples were selected. Reconstruction from early forest inventory data are also limited because so few inventories were conducted.

The objective of this paper is to analyze mixed conifer and *S. giganteum*-mixed conifer forest inventory data acquired in 1900–1901 from the southern Sierra Nevada to further our understanding of forest conditions and their management at the turn of the 20th century.

Study Site and Methods

Forest survey area. The historic data were obtained from the area of the southern Sierra Nevada that is now Sequoia-Kings Canyon National Parks, the southern portion of Sierra National Forest and the northern portion of Sequoia National Forest (Fig. 1).

The mixed conifer forest in this area is composed of *S. giganteum, Pinus lambertiana* Douglas, *Pinus ponderosa* Laws., *A. concolor,* and *C. decurrens.* The inventory also recorded *Abies magnifica* Andr. Murray and *Pinus jeffreyi* Grev. and Balf., but they were relatively rare.

Forest survey. Information on species composition and diameter at breast height (DBH) of the mixed conifer and *S. giganteum*-mixed conifer forests was provided from an early forest inventory (Sudworth 1900a). George B. Sudworth, head of the dendrology project in Washington D.C., collected timber inventory data while employed by the United States Geological Survey (USGS). The purpose of this survey was to inventory the forest reserves of the Sierra Nevada. The original unpublished field notebooks were the source of the inventory data analyzed in this paper.

The field notebooks contain information from many different vegetation types in the southern Sierra Nevada but only plots with *S. giganteum*-mixed conifer or mixed conifer data were used in this analysis. Exact plot locations are not given in the field notebooks but references to rivers, dominant mountains, and landmarks are included. Sudworth may have carried an early USGS map with him during the inventory, but the location of this map is unknown. An incomplete set of photographs associated with Sudworth's forest inventory are also available at the University of California, Berkeley, Bioscience and Natural Resources Library.

Eight mixed conifer plots and four *S. giganteum*-mixed conifer plots were recorded in the 1900–1901 field notebooks (Sudworth 1900a). Locations of plots that were recorded in mixed conifer forests include:

1) Westside of north fork of Kings river, one half way up slope.
2) Bubbs creek near Charlotte creek mouth (tributary Kings river).
3) Near sugar pine mill.
4) One mile west of sugar pine sawmill.
5) Sample area near fish camp. Headwaters of Big creek (tributary Merced river) and near head of Fresno river (Lewis fork).
6) Sample area near fish camp. Headwaters of Big creek (tributary Merced river) and near head of Fresno river (Lewis fork) (similar description used in plot 5).
7) Headwater of Chiquito creek; typical of this area down to the middle fork of the San Jouquin river.
8) Middle east slope, middle fork of San Jouquin river.

Plot locations that were recorded in *S. giganteum*-mixed conifer forests include (only 3 plots had the locations recorded in the field notebooks):

1) North end of giant forest.
2) Near round meadow giant forest.
3) Round meadow giant forest.

Sudworth recorded the species, DBH, and number of 4.9 m (16 ft) logs for each tree greater than 30.5 cm (12 inches) DBH. Plot size was typically 0.1 ha (0.25 acres) with one *S. giganteum*-mixed conifer

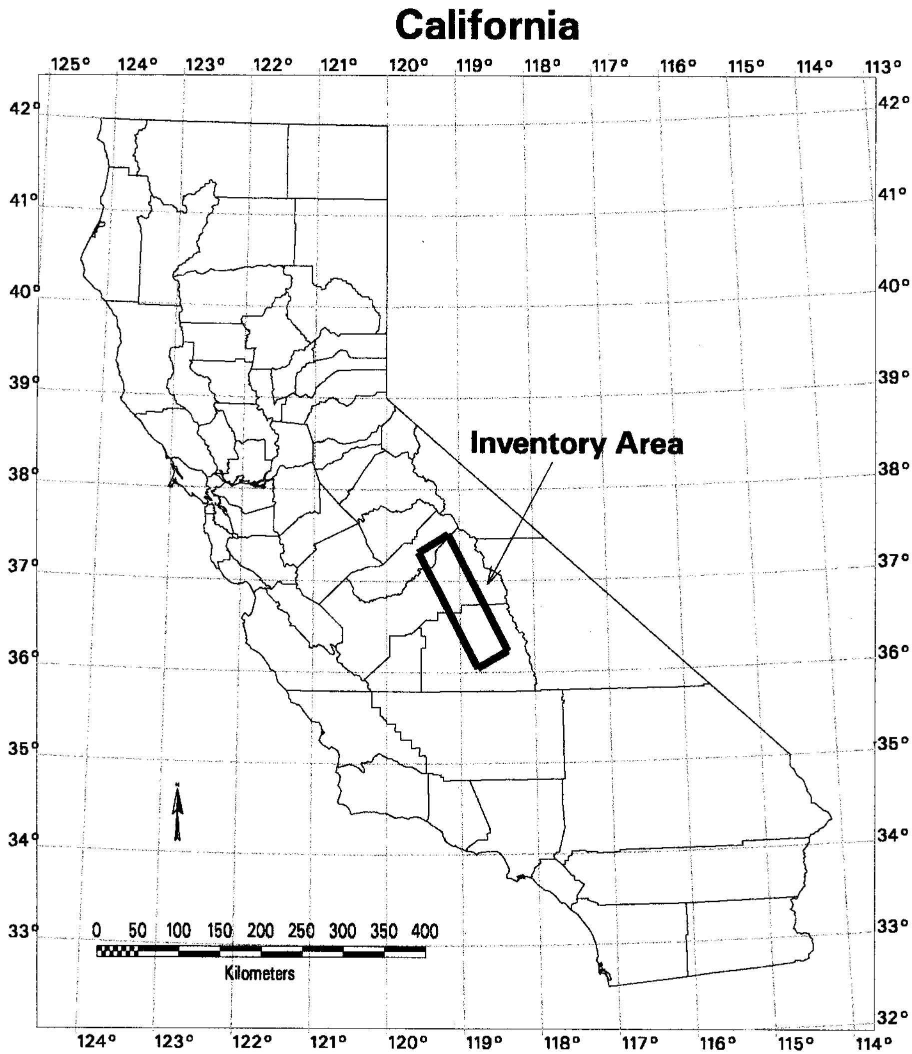

FIG. 1. George Sudworth's Southern Sierra Nevada forest inventory area.

plot of 0.2 ha (0.5 acres) recorded. Only plots with specified sample areas were used in this analysis. Many other much larger plots were recorded in Sudworth's field notebooks in *S. giganteum*-mixed conifer forests, but the area sampled was roughly estimated and were therefore not conducive to quantification.

The following plot values were calculated: average basal area per hectare by species, average number of trees per hectare by species, average quadratic mean diameter by species, average percent plot basal area by species, and average percent plot stocking by species. Histograms of DBH for each species were also produced.

Plot data are summarized and discussed, but a statistical analysis was not performed. Selection of an appropriate analysis method requires information on sampling procedures which are unknown for this early forest inventory.

RESULTS

The smallest tree inventoried in most plots had a DBH of 30.5 cm. No comprehensive inventory data exists for trees below 30.5 cm DBH but the field notebooks had written descriptive observations on regeneration and the impacts from early land uses which are summarized below.

Mixed conifer plots. The eight mixed conifer plots were dominated by large trees of several species. The average quadratic mean diameter at breast height was 110 cm (43 in.) for all trees inventoried. Average tree density was 278 trees/ha or ranged 180–400 tree/ha (111 trees/acre, range 72–160

TABLE 1. SUMMARY OF AVERAGE STAND CALCULATIONS OF GEORGE SUDWORTH'S 8 MIXED CONIFER PLOTS OF THE SOUTHERN SIERRA NEVADA IN 1900–1901. (STANDARD ERROR)

Tree	Basal area (m^2/ha)	Trees/ha	DBH (cm)	Percent basal area	Percent trees/ha
A. concolor	75	113	91	28	40
	(13.5)	(20.7)	(3.5)		
C. decurrens	48	55	114	18	20
	(11.9)	(19.8)	(15.7)		
P. lambertiana	97	53	152	36	19
	(25.3)	(10.7)	(10.5)		
P. ponderosa	33	33	117	12	12
	(16.7)	(15.3)	(21.4)		
P. jeffreyi	14	18	112	5	6
	(8.9)	(10.3)	(20.7)		
A. magnifica	3	8	74	1	3
	(0)	(0)	(0)		

trees/acre) for trees greater than 30.5 cm DBH. Average basal area was 271 m^2/ha (1166 ft^2 /acre). Table 1 summarizes all stand calculations for the mixed conifer plots.

The largest trees in the mixed conifer plots were *P. lambertiana* with an average DBH of 152 cm (60 in.). The largest *P. lambertiana* recorded in the inventory had a DBH of 305 cm (120 in.). *P. lambertiana* made up only 19% of the trees/ha but contributed 36% of the basal area of the plots because of their large size.

Abies concolor was the most common tree found in the plots contributing 41% of the individuals inventoried. *Abies concolor* accounted for 28% of the basal area of the plots, second to *P. lambertiana.* The average DBH of the *A. concolor* trees was the smallest of the species found in the mixed conifer forests.

Pinus ponderosa and *C. decurrens* both have similar average DBH values. *Calocedrus decurrens* was more common contributing 20% of plot stocking compared to 12% for *P. ponderosa. Pinus jeffreyi* also had a similar DBH of 112 cm (44 in.) but was uncommon in the plots contributing 6% of plot stocking. Histograms of DBH by species are given in Figure 2.

The following comments were written by Sudworth in the original field notebooks and include information about regeneration and impacts from early European settlers in the mixed conifer plots (Sudworth 1900a).

September, 1900. Westside of north fork of Kings river, one half way up slope. No reproduction, sheep grazed till 2 years ago and burned over.

September, 1900. Bubbs creek near Charlotte creek mouth (tributary of Kings river), an exceptionally dense stand. No reproduction, complete shade, fire marks.

September, 1900. Near sugar pine mill. Area cut, no reproduction, all timber sound but fire marked.

September, 1900. 1 mile west of sugar pine sawmill. In rich sandy loam, abundant reproduction, 0.5–4 ft of all species. All timber severely fire marked at collar.

October, 1900. Headwater of Chiquito creek; typical of this area down to the middle fork of the San Joaquin river. 60 concolor seedlings 3–6 ft high. No humans, sheep and cattle grazing of long standing.

October, 1901. Heavy shade, no reproduction, humans, 8–10, steep, rocky loam soil, east slope.

Sudworth's notes indicate there were significant human settlement impacts to these ecosystems by the turn of the century. He noted recent evidence of fire in the majority of the plots, and he believed the fires were probably ignited by sheep herders in the area to increase forage production for livestock. In one plot, he noted regeneration of all species was present and in another that only white fir regeneration was found, indicating regeneration was not uniform in the plots. Forests were relatively open during Sudworth's inventory (Fig. 3). Repeat photography has not been attempted because photo points were not permanently marked.

Sequoiadendron giganteum-*mixed conifer plots.* The four *S. giganteum*-mixed conifer plots were dominated by large trees of several species and the average quadratic mean diameter at breast height was 145 cm (57 inches) for all trees inventoried. Omitting *S. giganteum* data, the average DBH of the remaining trees was 111 cm (44 inches) which is similar to the eight mixed conifer plots (110 cm). *Sequoiadendron giganteum* groves were also relatively open during the inventory (Fig. 4).

Average tree density was 272 trees/ha (range 220–290 trees/ha) [109 trees/acre (range 88–116 trees/acre)] for trees greater that 30.5 cm DBH. Average basal area was 2381 m^2/ha (2307 ft^2 /acre). Omitting *S. giganteum* data, average basal area of the remaining trees was 121 m^2/ha (520 ft^2 /acre) which is less than 50% of the average basal area of the eight mixed conifer plots. Table 2 summa-

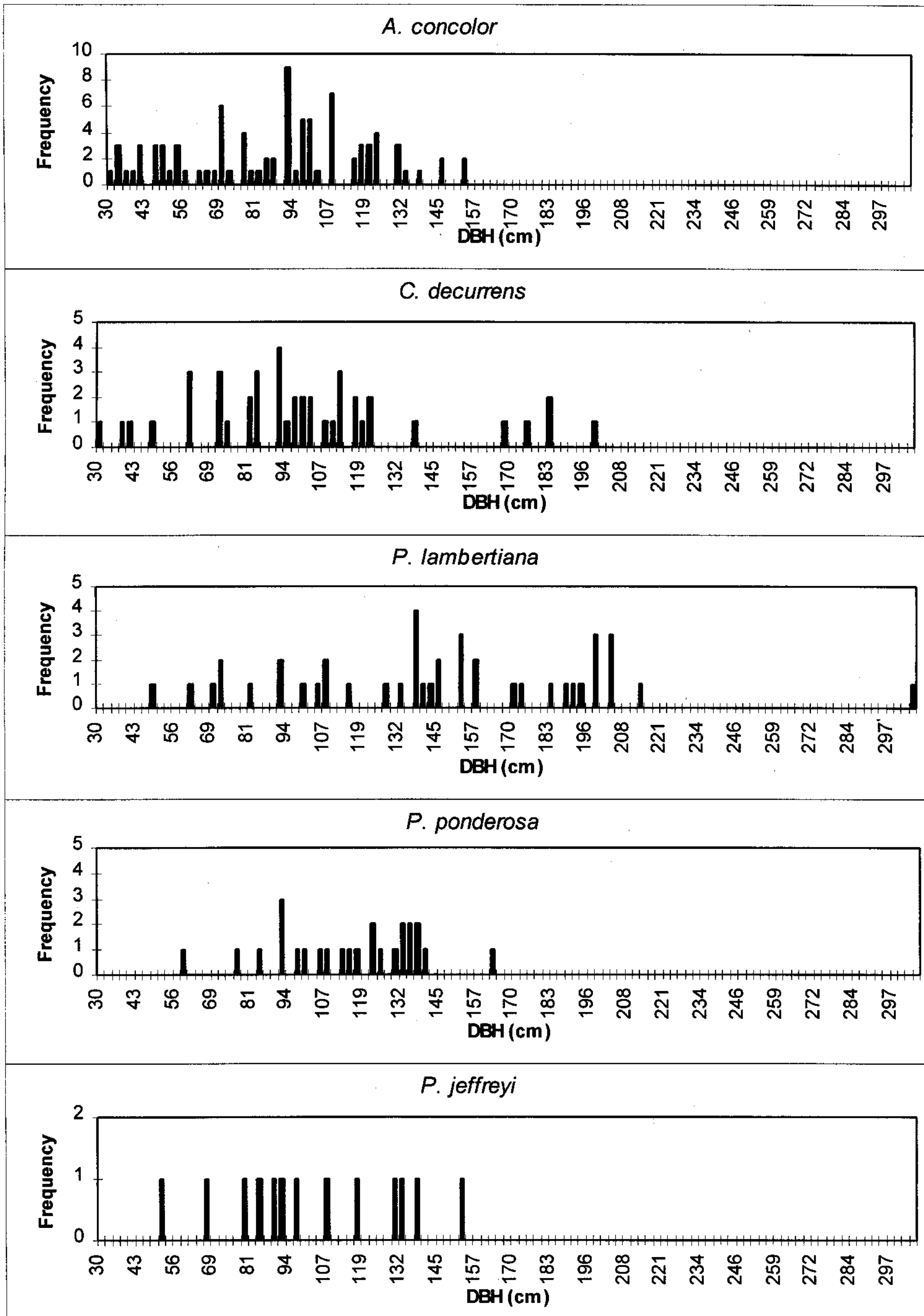

FIG. 2. Histograms of George Sudworth's eight mixed conifer plots of the southern Sierra Nevada in 1900–1901.

rizes all stand calculations for the *S. giganteum*-mixed conifer plots.

Sequoiadendron giganteum were the largest trees in the twelve plots. The largest *S. giganteum* recorded in the inventory had a DBH of 536 cm (211 in.). *S. giganteum* made up only 32% of the trees/ha but contributed 77% of the basal area of the plots because of their large size. Compared to the mixed conifer plots, *P. lambertiana* was a much smaller component in the *S. giganteum*-mixed conifer plots. *Abies magnifica* and *P. jeffreyi* were rare in the *S. giganteum*-mixed conifer

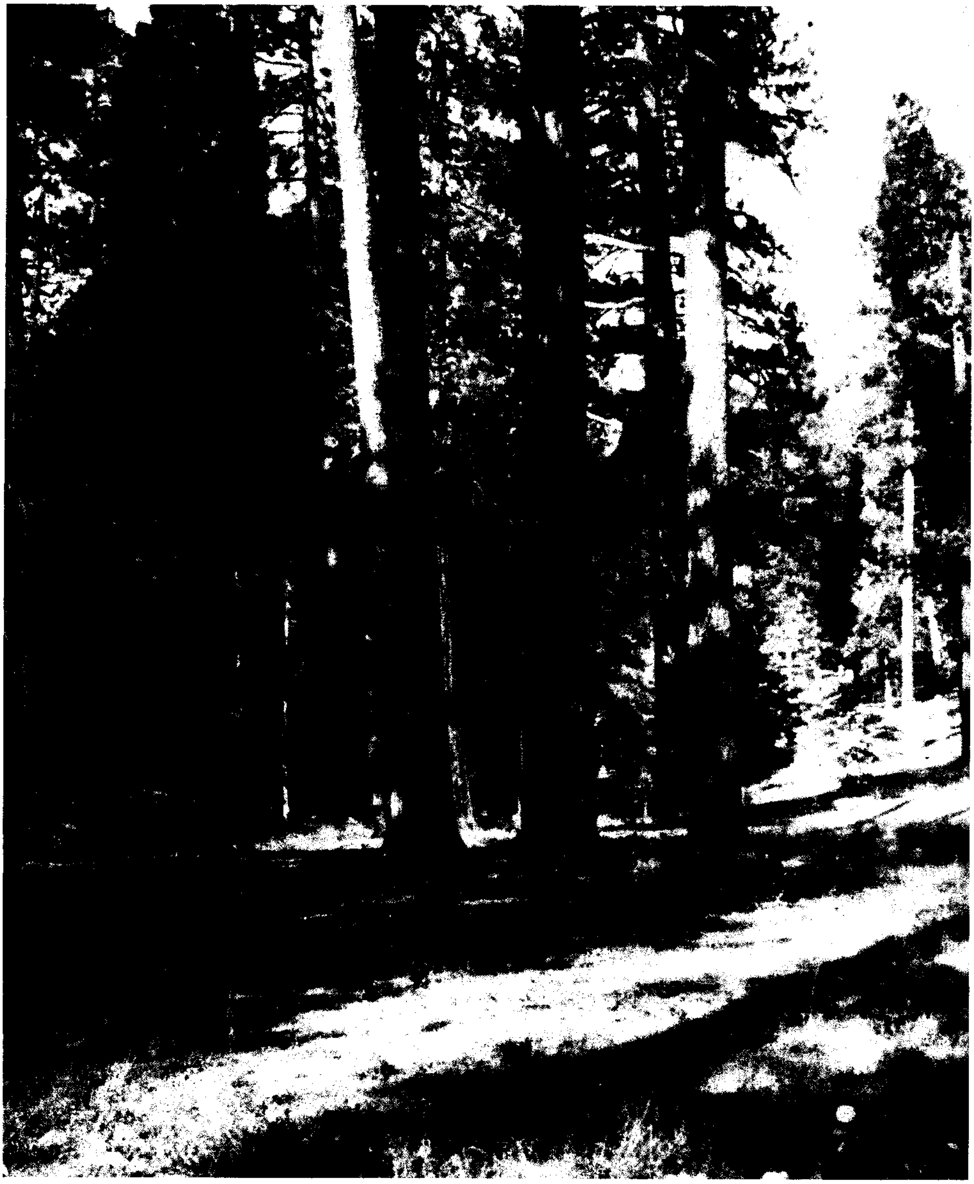

FIG. 3. Tulare county. Interior of forest on bench of Peppermint Meadow, characteristic of east slope of the Kern river at the head of Dry Creek. *Pinus ponderosa, P. jeffreyi, P. lambertiana, Calocedrus decurrens, Abies concolor,* 1901.

plots. Histograms of DBH by species are given in Figure 5.

DISCUSSION

Early land uses have impacted *S. giganteum*-mixed conifer forests of the Sierra Nevada (Stephenson 1996; Elliott-Fisk et al. 1997). Livestock grazing and logging were common in many areas of the Sierra Nevada in the late 1800's (McKelvey and Johnston 1992). In 1900, few *S. giganteum* groves were in government ownership and logging was thought to be a major concern (Perkins 1900). A total of 470 ha (1173 acres) was privately held inside Sequoia and General Grant National Parks (later to become Grant Grove section of Kings Canyon National Park) and the majority of the other groves were in private ownership by people who had every right, and in many cases every intention, to cut them into lumber (Perkins 1900).

Sudworth's field notes recorded that the majority of plots had no regeneration. Regeneration probably occurred pre-historically in these forests with the creation of small canopy gaps. Sudworth verified this by recording that very little reproduction

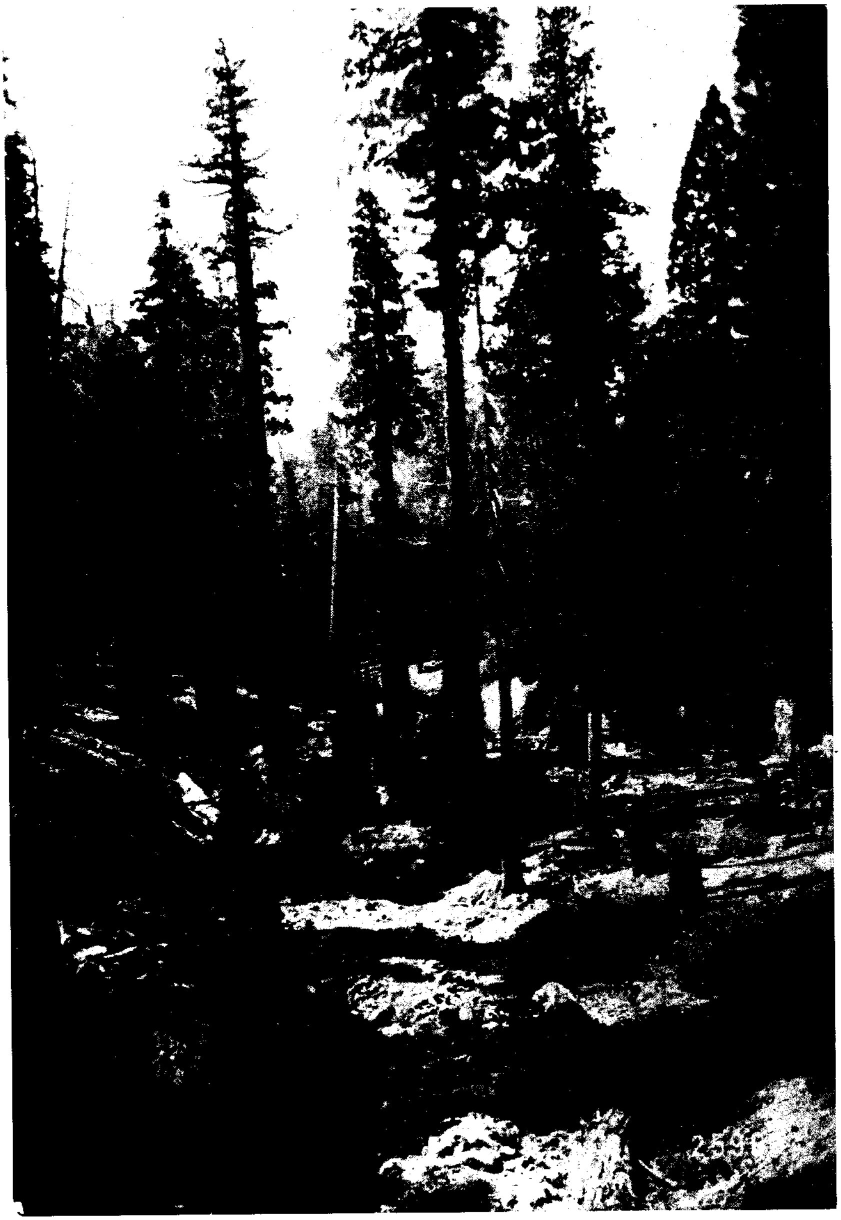

FIG. 4. Tulare county. Freeman Creek canyon with *S. giganteum* forest on north slope of basin. *Sequoiadendron giganteum* 1.75–2.5 meters in diameter and associated species of *P. ponderosa, P. jeffreyi, P. lambertiana, A. concolor, C. decurrens,* and occasional *A. magnifica,* 1901.

occurred in mixed conifer forests except for occasional patches in open spaces (Sudworth 1900a). Patchy, high intensity fires may have created the openings varying in size between 0.1–0.4 ha. in the *S. giganteum*-mixed conifer forests of the southern Sierra Nevada (Stephenson et al. 1991). Areas that had recently burned with a patchy high intensity fire could have abundant regeneration because duff and surface fuels would have been consumed producing a mineral soil seedbed, and resources such as light and water were available because of reduced competition. Since Sudworth apparently did not sample areas that had recently experienced a localized high intensity fire, regeneration was sparse in the sampled plots. The plots, therefore, cannot be assumed to be an unbiased sample of the forest structure of mixed conifer and *S. giganteum*-mixed conifer forests in 1900–1901.

The plots were dominated by large trees of several species. Both shade intolerant and shade tolerant species were abundant in the plots. Age distributions can vary dramatically in stands, often

TABLE 2. SUMMARY OF AVERAGE STAND CALCULATIONS OF GEORGE SUDWORTH'S 4 *S. GIGANTEUM*-MIXED CONIFER PLOTS OF THE SOUTHERN SIERRA NEVADA IN 1900–1901. (STANDARD ERROR)

Tree	Basal area (m^2/ha)	Trees/ha	DBH (cm)	Percent basal area	Percent trees/ha
A. concolor	84 (29.9)	151 (44.7)	81 (5.5)	16	55
P. lambertiana	32 (29.3)	29 (27.1)	127 (37.1)	6	11
P. jeffreyi	3 (0)	2 (0)	114 (0)	0.3	1
S. giganteum	415 (163.9)	88 (40.3)	282 (41.3)	77	32
A. magnifica	3 (0)	2 (0)	122 (0)	0.7	1

with no relation to diameter distributions (Oliver and Larson 1995) making it impossible to make conclusions on the age structure of the plots.

The most common size classes are in the medium to large size classes for all mixed conifer and *S. giganteum*-mixed conifer species. This is in contrast to published studies of current stands in Sequoia National Park that have determined small size classes of shade tolerant species (*A. concolor* and *C. decurrens*) are occurring at higher frequencies relative to larger size classes (Parsons and DeBendeetti 1979). If all trees less than 30.5 cm DBH are removed from the Parsons and DeBendeetti study, the remaining smaller shade tolerant size classes still have much higher frequencies than those Sudworth recorded.

Sudworth's notes indicate there were significant land use impacts on these forests by the turn of the 20th century. He noted recent evidence of fire in the majority of the plots, and believed most of the fires were ignited by sheep herders. Sheep herders burned to increase forage production and to remove

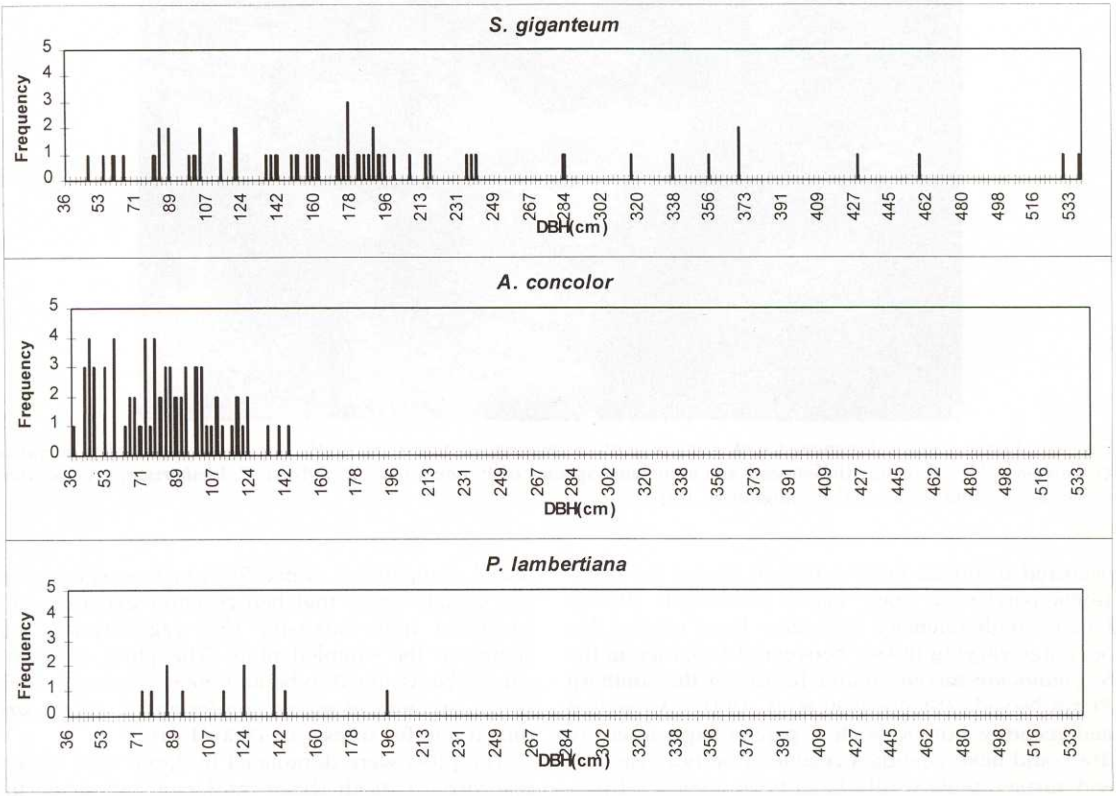

FIG. 5. Histograms of George Sudworth's four *S. giganteum*-mixed conifer plots of the southern Sierra Nevada in 1900–1901.

obstacles from the forest floor which impeded the movement of their livestock (Sudworth 1900b; McKelvey and Johnston 1992).

Sudworth also believed livestock grazing in riparian areas was affecting the hydrology of some *S. giganteum* groves. In a previous inventory, Sudworth believed springs and perennial streams were being effected by excessive sheep browsing which reduced *S. giganteum* regeneration at the "Calaveras" Giant Sequoia grove in the central Sierra Nevada (now part of Calaveras State Park in Calaveras and Tuolumne counties) (Sudworth 1900b).

Some of Sudworth's inventory plots were recently harvested or in the process of being harvested during the survey. He also witnessed the impacts of early logging in *S. giganteum* groves when he camped at the Enterprise Mill in 1901 (Sudworth 1900a). This mill operated two years and harvested many large *S. giganteum* within the present boundaries of Mountain Home Demonstration State Forest, Tulare County.

Most early logging operations in *S. giganteum* groves wasted a great deal of wood. When the trees were felled, the trunk and upper extremities frequently broke into almost useless fragments (Perkins 1900). Additional waste that also occurred at the sawmill resulted in less than half of the standing volume of each harvested *S. giganteum* being converted into wood products (Perkins 1900).

Slash produced by early logging operations in the *S. giganteum*-mixed conifer ecosystems was enormous. It was frequently 2 meters thick and was thought to be a certain source of future fires (Perkins 1900). Early logging operations probably contributed to large, intense wildfires because of increases in surface fuel loads and increased ignitions from field crews.

The absence of trees less than 30.5 cm DBH in Sudworth's plots most likely occurred because they were relatively rare in the sampled plots. The objective of the survey was to assess the timber resources in the Sierra Nevada, and therefore, areas with large dense stands were probably favored. Sudworth sampled areas dominated by large trees and regeneration in these areas would be low since the majority of site resources (light and water) were already being used by the existing mature trees.

The plots sampled by Sudworth represent historic conditions for areas dominated by very large trees in mixed conifer and *S. giganteum*-mixed conifer forests of the southern Sierra Nevada. However, this analysis does not provide information on areas that were dominated by regeneration of trees of smaller size classes. Information from all forest mosaics is needed to completely describe the natural range of variability that occurred in these ecosystems. This analysis gives information only on areas dominated by large trees, and therefore, is incomplete in describing the historic forest structure.

Conclusion

Although it is not possible to document the sampling methods used by this early forest inventory, the mixed conifer and *S. giganteum*-mixed conifer plots sampled by George Sudworth in the southern Sierra Nevada were dominated by large trees of several species. Shade intolerant and shade tolerant species were both abundant in the plots. This contrasts to present forests where small shade tolerant species are more common and represents a structural and compositional shift of forest condition.

Mixed conifer forests were impacted by livestock grazing, fire, and logging at the turn of the 20th century. Some *S. giganteum* groves such as the Converse Basin Grove, now part of Sequoia National Forest in Fresno county, were almost completely clear-cut at this time (Elliott-Fisk et al. 1997). Sheep grazing was intense and fires were frequently ignited by sheep herders to increase forage production and to remove obstacles. Thus, even 100 years ago, these forests were subjected to significant European settlement alteration and do not reflect prehistoric conditions.

Trees less than 30.5 cm DBH were probably rare in Sudworth's plots. This analysis does not provide information on areas that were dominated by regeneration or by trees of smaller size classes. Information from all forest mosaics is needed to completely describe the natural range of variability that occurred in these forests.

Early land use decisions have impacted the present mixed conifer and *S. giganteum*-mixed conifer ecosystems of the southern Sierra Nevada. Knowledge of these practices and their ecological effects is useful in interpreting and understanding current forest structure.

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