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MIXED CONIFER AND RED FIR FOREST STRUCTURE AND USES IN 1899 FROM THE CENTRAL AND NORTHERN SIERRA NEVADA, CALIFORNIA

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ABSTRACT

Historical data collected from five "average" mixed conifer stands, four large mixed conifer stands, and four red fir stands from the central and northern Sierra Nevada by George Sudworth in 1899 were analyzed to determine historic forest structure including diameter distributions, basal areas, and snag and live tree densities. The effects of early logging operations on stand composition and structure is quantified by comparing characteristics of the trees that were harvested versus those unharvested in four mixed conifer stands. Average diameter at breast height (DBH) was 86 cm (34 inches) in the "average" mixed conifer stands, 110 cm (43 inches) in the large mixed conifer stands (this was equal to the average DBH of 8 mixed conifer stands sampled by Sudworth in the southern Sierra Nevada), and 77 cm (30 inches) in the red fir stands for trees greater than 30.5 cm DBH. Shade intolerant tree species dominated the "average" mixed conifer stands, shade intolerant, intermediate, and shade tolerant species were abundant in the large mixed conifer stands, and *Abies magnifica* Andr. Murray dominated the red fir stands. Mean tree density for the "average" mixed conifer, large mixed conifer, and red fir stands was 229 trees/ha, 235 trees/ha, and 433 trees/ha, respectively. Average tree density was higher in Sudworths southern Sierra Nevada mixed conifer stands when compared to the central and northern Sierra Nevada. Snag density averaged 5/ha in the large mixed conifer stands and 17.5/ha in the red fir stands. Early logging operations removed the majority of the *Pinus* spp. and *Pseudotsuga menziesii* (Mirbel) France leaving large amounts of *Calocedrus decurrens* (Torrey) Florin and *Abies concolor* (Gordon & Glend.) Lindley. Information from this study can assist in the characterization of historic stand structure in these forest types.

The absence of fire in the 20th century and past harvesting operations have modified the structure and ecosystem processes in the coniferous forests of the Sierra Nevada. An increase in the density of small shade tolerant trees has been produced in many forest types (Leopold et al. 1963; Hartesveldt and Harvey 1967; Vankat and Major 1978; Parsons and DeBendeetti 1979; Bonnicksen and Stone 1982) and this increase has resulted in a decrease in forest sustainability (Weatherspoon and Skinner 1996; van Wagtendonk 1996; Stephens 1998). Changes in climate over the last centaury may have also contributed to the changes in forest structure (Millar and Woolfenden 1999).

Historical and prehistoric information on the structure (density, size distribution, and species composition) of mixed conifer forests are relatively rare and they have been reviewed elsewhere (Stephens and Elliott-Fisk 1998). One of the methods that can be used to determine prehistoric forest structure is the analysis of data from early forest inventories. These data provide quantitative information on historic forest structure, however, the results from the analyses can be biased because the methods used to select the stands were frequently not recorded (Stephens and Elliott-Fisk 1998).

Analysis of historical data have been done for the Stanislaus and Lake Tahoe Forest Reserves (Sudworth 1900), portions of the northern Sierra Nevada and the Transverse Ranges of southern California (McKelvey and Johnston 1992), and portions of the southern Sierra Nevada (Stephens and Elliott-Fisk 1998). All of these studies discuss early logging operations but no work has been done that quantifies the effects of early logging at the stand level, quantifies the amount of hardwoods present historically in mixed conifer forests, determines historic snag densities and sizes, or differentiates between average and mature mixed conifer stands.

Early logging operations affected the composition and structure of Sierra Nevada forests, especially between 1860 and 1950 (Laudenslayer and Darr 1990). In 1899, approximately 45 percent of the trees harvested in California were either *Pinus ponderosa* Laws (ponderosa pine) or *Pinus lambertiana* Douglas (sugar pine). Most early logging operations in the Sierra Nevada harvested all trees that were considered to be merchantable at the time of the harvest (Laudenslayer and Darr 1990).

The viability of the California spotted owl (*Strix occidentalis occidentalis*) is receiving major atten-

tion in California. The owl prefers to nest in mixed conifer forests with 80 percent of the nesting sites occurring in this forest type followed by 10 percent in *Abies magnifica* Andr. Murray (red fir) and 7 percent in *Pinus ponderosa* hardwood forests (Verner et al. 1992). The remaining 3 percent of nests occur in eastside pine forests and foothill riparian-hardwood habitats in the western Sierra Nevada foothills (Verner et al. 1992).

The habitat requirements of the California spotted owl have been investigated and it nests in old-growth forests with high canopy cover (Gutierrez et al. 1992). A relatively high number of snags and down logs are also correlated to the current nesting sites of the California spotted owl (Gutierrez et al. 1992) but no prehistorical data exist on the abundance of snags or fuel loads in this forest type making it difficult to describe the composition of the prehistorical habitat.

The objective of this paper is to analyze mixed conifer and red fir forest inventory data acquired by George Sudworth in 1899 from the central and northern Sierra Nevada to further our understanding of forest conditions and their management in the late 19th century. Analysis includes snag and live tree densities, basal areas, diameter distributions, and quantification of the effects of early logging operations on stand composition and structure.

Study Site and Methods

The historic data analyzed in this paper were obtained from the area of the central and northern Sierra Nevada that now includes the southern portion of the Tahoe National Forest, the El Dorado National Forest, and northern portion of the Stanislaus National Forest.

Mixed conifer and red fir forests were surveyed in 1899 by George B. Sudworth while employed by the United States Geological Survey. The purpose of this survey was to inventory the forest reserves of the Sierra Nevada. The original unpublished field notebooks (Sudworth 1899) were the source of the inventory data analyzed in this paper.

Sierra Nevada mixed conifer forests sampled by Sudworth were composed of white fir *Abies concolor* (Gordon & Glend.) Lindley (white fir), *Abies magnifica, Pinus ponderosa, Pinis lambertiana, Pinis jeffreyi* Grev. and Balf (Jeffrey pine), *Calocedrus decurrens* (Torrey) Florin (incense cedar), *Pseudotsuga menziesii* (Mirbel) Franco (Douglas-fir), and *Quercus kelloggii* Newb. (California black oak). The red fir forests were composed of *Abies magnifica, Pinus jeffreyi, Pinus monticola* Douglas (western white pine), *Pinus contorta* spp. *murrayana* (Grev. & Balf.) Critchf. (lodgepole pine), and *Tsuga mertensiana* (Bong.) Carrière (mountain hemlock). Red fir forests are widely distributed and they can be found on both the west and east sides of the Sierra Nevada (Rundel et al. 1977).

All stand data recorded by Sudworth in 1899 are analyzed in this paper with the exception of one stand located in a pure *Pinus jeffreyi* forest because of no replication in this forest type. Exact stand locations are not given in the field notebooks but references to rivers, mountains, and landmarks are included (Sudworth 1899).

Five "average" mixed conifer stands, four large mixed conifer stands, and four red fir stands were recorded in the 1899 field notebooks (Sudworth 1899). Mixed conifer stand data were stratified into two classes (average and large) whereas this was not done in the southern Sierra Nevada analysis (Stephens and Elliott-Fisk 1998) because no stands were identified by Sudworth in his notebooks as having "average" characteristics.

Sudworth recorded the species, diameter at breast height (DBH), and number of 4.9 m (16 ft) logs for each tree greater than 30.5 cm (12 inches) DBH (one 28 cm DBH tree was recorded in a red fir stand). Each stand was sampled with one 0.1 ha (0.25 acres) plot. He recorded notes on regeneration (estimate of density by species, not a complete seedling inventory), forest floor depth, and other information such as the revenue generated by early logging operations. He also frequently commented on the effects of early grazing and burning on the Sierra Nevada and his comments are summarized below.

The following values were calculated by averaging all stand data for each of the 3 forest types ("average" mixed conifer, large mixed conifer, red fir): number of snags per hectare, snag basal area, diameter and species of trees removed by early logging operations, basal area per hectare by species, number of trees per hectare by species (density), quadratic mean diameter by species, percent total basal area by species, and percent total stocking by species.

Stand 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 (Stephens and Elliott-Fisk 1998).

Results

"Average" mixed conifer stands. The five mixed conifer stands denoted as "average" by George Sudworth were dominated by moderate sized trees of several species. The average quadratic mean diameter for all trees over 30.5 cm DBH was 86 cm (34 inches). Average tree density was 229 trees/ha (92 trees/acre) (range 150–300 trees/ha). Average basal area was 130 m^2/ha (558 ft^2/acre) (range 94–186 m^2/ha). Table 1 summarizes all stand calculations for the "average" mixed conifer stands.

The largest trees in the "average" mixed conifer stands were *Pinus lambertiana* with an average DBH of 108 cm (42 inches). The largest *Pinus lambertiana* recorded in the inventory had a DBH of

TABLE 1. AVERAGE CALCULATIONS OF GEORGE SUDWORTH'S 5 "AVERAGE" MIXED CONIFER STANDS IN THE CENTRAL AND NORTHERN SIERRA NEVADA IN 1899 (STANDARD ERROR). * Average value for all stands.

Tree	Basal area (m^2/ha) [130]*	Trees/ha [229]*	DBH (cm) [86]*	Percent of total basal area	Percent of trees/ha
Abies concolor	5.3 (5.2)	6.0 (6.0)	105.7 (0)	4	3
Calocedrus decurrens	26.0 (6.6)	54.0 (11.2)	80.6 (10.5)	20	24
Pinus lambertiana	8.8 (4.2)	12 (7.4)	107.8 (22.8)	7	5
Pinus ponderosa	56.6 (23.1)	106.0 (37.0)	83.9 (12.1)	43	46
Pseudotsuga menziesii	30.9 (20.2)	38.0 (24.6)	101.2 (1.8)	24	16
Quercus kelloggii	2.4 (1.4)	13.3 (3.7)	58.0 (7.2)	2	6

152 cm (60 inches). *Pinus ponderosa* was the most common species comprising 46 percent of total stocking and 44 percent of total basal area (Table 1).

Abies concolor was rare in the stands accounting for only 3 percent of total stocking and 4 percent of total basal area. *Calocedrus decurrens* and *Pseudotsuga menziesii* were the next most common species, after *Pinus ponderosa,* respectively. The average DBH of the *Quercus kelloggii* was the smallest of the species found in the mixed conifer stands, the conifer with the smallest average DBH was *Calocedrus decurrens* (Table 1).

Pinus lambertiana, Pseudotsuga menziesii, and *Abies concolor* all had similar average DBH's of approximately 105 cm whereas *Pinus ponderosa* and *Calocedrus decurrens* had average DBH's of approximately 82 cm. *Quercus kelloggii* accounted for an average of 6 percent of stand stocking. No snags were recorded in the average mixed conifer stands (Table 2).

Four of the "average" mixed conifer stands inventoried by Sudworth were in the process of being harvested in 1899. Sudworth's notebooks recorded the diameter and species of all trees harvested and also recorded the same information on all trees that remained after the harvesting operation.

All of the *Pseudotsuga menziesii* trees in these four stands were harvested along with 88 percent of the *Pinus lambertiana* trees (Table 3). The majority of the wood harvested from these stands was from *Pinus ponderosa* trees with an average of 64 m^2/ha (275 ft^2/acre) removed and this was 2.4 times greater than *Pseudotsuga menziesii* which was the next most common species harvested. The amount of *Calocedrus decurrens* and *Abies concolor* trees harvested was low, averaging 13 percent and 33 percent, respectively (Table 3).

The following comments were written by George Sudworth in the original field notebooks and include information about regeneration and impacts from early European settlers (Sudworth 1899).

September 27, 1899. Near Beech Sawmill (above Placerville) on Big Iowa Canyon. No reproduction (manzanita brush) but abundant a few yards distant. Grazed, no humus, all trees fire marked.

September 28, 1899. South of Blair Sawmill (near Sly Park) on summit of ridge. All touched with fire, humus 1–2 inches in spots. Ample reproduction of all species in patches.

September 30, 1899. Sample on big hill south west of Grizzly Flat 0.5 mile. Humus all burned off.

October 5, 1899. 2 miles east of Whitmore's Mill

TABLE 2. CHARACTERISTICS OF SNAGS FOUND IN MIXED CONIFER AND RED FIR STANDS IN THE CENTRAL AND NORTHERN SIERRA NEVADA IN 1899.

Stand type	Average density (snags/ha)	Density range (snags/ha)	Average DBH (cm)	Average basal area (m^2/ha)
Average mixed conifer	0	0	0	0
Large mixed conifer	5	0–10	108.7	4.6
Red fir	17.5	0–60	57.3	4.5

TABLE 3. AVERAGE AMOUNT HARVESTED IN 4 "AVERAGE" MIXED CONIFER STANDS LOCATED IN THE CENTRAL AND NORTHERN SIERRA NEVADA IN 1899.

Tree	Trees/ha cut (percent)	Basal area cut (percent)	Basal area cut (m^2/ha)	DBH of trees cut (cm)
Abies concolor	33.3	48.2	3.9	127
Calocedrus decurrens	12.5	12.5	1.6	88.9
Pinus lambertiana	87.5	92.8	17.1	104.3
Pinus ponderosa	57.9	64.2	64.3	103.3
Pseudotsuga menziesii	100.0	100.0	27.2	101.7
Quercus kelloggii	25.0	38.1	2.9	86.4

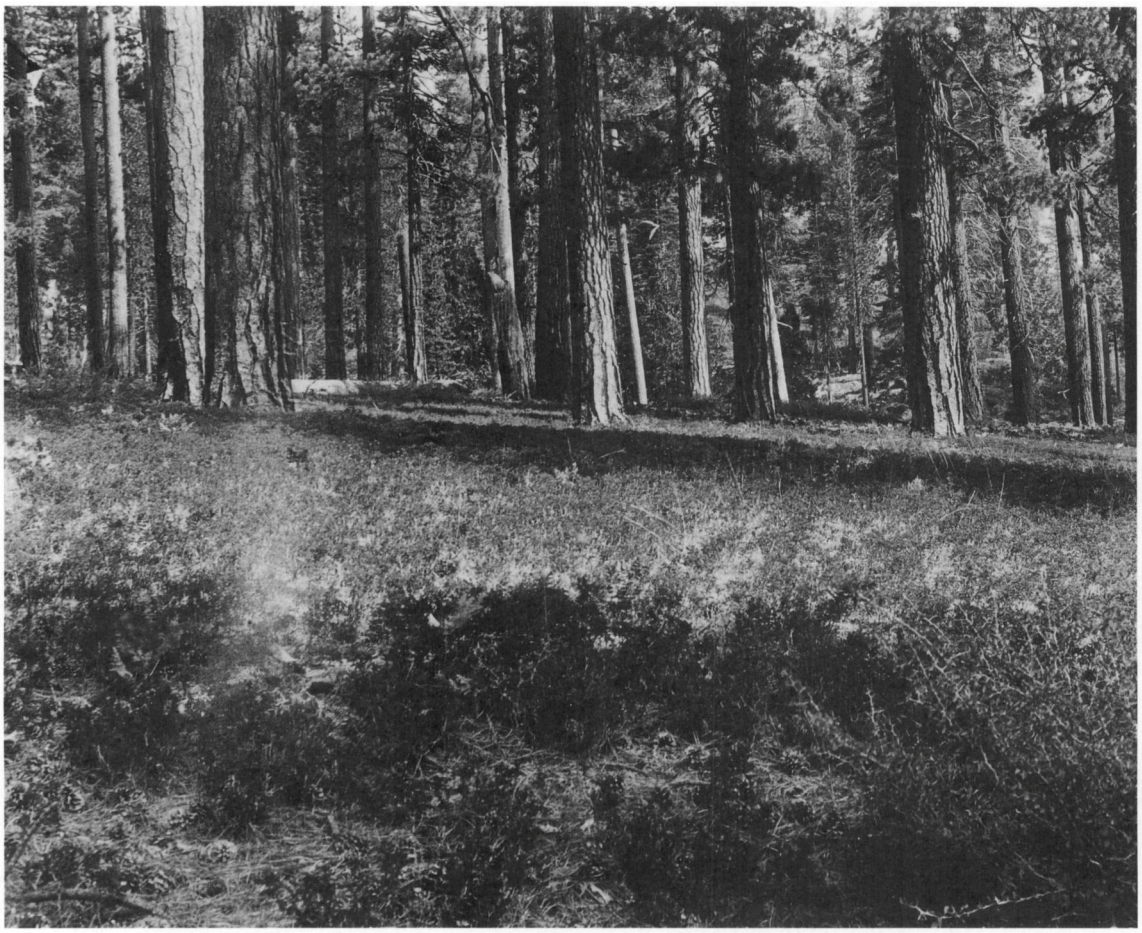

FIG. 1. El Dorado county, 1899. Opposite Snyder and Sherman's Ranch. Yellow pine (mixed conifer) forest on south slope of Silver Fork. Ponderosa pine 91–193 cm (36–76 inches) in diameter, 46–50 m high (150–165 feet), clear 8–11 m (25–35 feet), ten in 0.1 ha (0.25 acre), 3–5 white fir (*Abies concolor*) same size. Cattle grazed.

(Mill Creek, near Volcano), representing no cut stumpage, rolling flat 1000 feet above creek bottom. No humus, frequent burning destroyed all. Abundant reproduction of pines and cedar 5–8 years old, mostly under 4.

October 5, 1899. Near Whitmore's Mill but in shallow ravine. Taken as a whole mill operator estimates output 10–20 thousand per acre. Abundant reproduction of all species. *Taxus brevifolia* Nutt., dogwood, and *Acer macrophyllum* Pursh abundant. Humus in part 3–6 inches.

Large mixed conifer stands. The four large mixed conifer stands were dominated by large trees of several species and the average quadratic mean diameter at breast height was 110 cm (43 inches) for all trees above 30.5 cm DBH. Average tree density was 235 trees/ha (94 trees/acre) (range 160–300 trees/ha). Average basal area was large 215 m^2/ha (923 ft^2/acre) (range 188–232 m^2/ha). The stands inventoried by Sudworth were relatively open and dominated by large trees (Fig. 1). Table 4 summarizes all stand calculations for the large mixed conifer stands.

Abies concolor was the most common species comprising 46 percent of total stocking, but only accounting for 34 percent of total basal area because of their relatively small diameters. The largest tree inventoried in these stands was a *Pseudotsuga menziesii* and it had a DBH of 188 cm (74 inches). *Pseudotsuga menziesii* made up only 16 percent of the trees/ha but contributed 24 percent of the basal area of the stands because of their large size. *Abies concolor* trees were much more common in the large mixed conifer stands when compared to the "average" mixed conifer stands (46 percent stocking versus 3 percent stocking, respectively).

Abies concolor, Abies magnifica, and *Calocedrus decurrens* were the smallest trees with average quadratic mean diameters of approximately 93 cm. *Pinus ponderosa* and *Pinus lambertiana* were larger with average diameters of approximately 112 cm,

TABLE 4. AVERAGE CALCULATIONS OF GEORGE SUDWORTH'S 4 LARGE MIXED CONIFER STANDS IN THE CENTRAL AND NORTHERN SIERRA NEVADA IN 1899 (STANDARD ERROR). * Average value for all stands.

Tree	Basal area (m^2/ha) [215]*	Trees/ha [235]*	DBH (cm) [110]*	Percent of total basal area	Percent of trees/ha
Abies concolor	72.3	107.5	97.3	34	46
	(20.0)	(38.2)	(6.4)		
Calocedrus decurrens	26.7	32.5	92.0	12	14
	(9.5)	(6.3)	(17.4)		
Pinus lambertiana	33.4	27.5	109.1	16	12
	(18.3)	(4.8)	(20.5)		
Pinus ponderosa	10.5	10.0	115.3	5	4
	(10.5)	(10.0)	(0)		
Pinus jeffreyi	13.8	10.0	120.4	6	4
	(11.4)	(7.1)	(21.4)		
Pseudotsuga menziesii	51.8	37.5	123.7	24	16
	(45.4)	(31.2)	(11.8)		
Abies magnifica	6.2	10.0	88.9	3	4
	(6.2)	(10.0)	(0)		

and the largest trees were *Pinus jeffreyi* and *Pseudotsuga menziesii* with average diameters of approximately 122 cm. *Quercus kelloggii* was not recorded in any of the large mixed conifer stands.

Snag density averaged 5/ha with a range 0–10/ha (Table 2). Average snag quadratic mean diameter was 109 cm and snag average snag basal area was 4.6 m^2/ha.

The following comments were written by George Sudworth in the original field notebooks and include information about regeneration and impacts from early European settlers (Sudworth 1899).

September 3, 1899. 12–15 miles west of Bloods, north slope of Mokelumne River. 30 concolor 2–8 inches diameter, 100 under 6 inches. 5 sugar pine under 2 feet high. Thickets of *Acer oblusifobium* (*glabrum*?).

September 8, 1899. South slope of Bear River, one half way up slope. Seedlings of all in spots near blue ceonothus when protected from tramping of cattle. No sheep here, but no humus. Abundant blue ceonothus chaparral.

September 9, 1899. South lower slope of Silver Fork (American River) in rich bottom bench (at point where a little stream enters Silver Fork). Dense fir and cedar on outskirts, no seedlings within. Humus 2–3 inches, cattle grazing and sheep.

September 21, 1899. 1.5 miles south of Merzns, across (west) of Dark and Multon Canyons (where Georgetown road crosses). South slope of South Fork of the Consumnes River (?) (Sudworth included the? mark and was probably referring to the American River). Abundant reproduction of all species 1–12 years old, all fire marked 15 years back. Humus 1.5 inches deep, soil sandy loam with rock.

Red fir stands. Sudworth sampled four red fir stands during this inventory and all stands were dominated by *Abies magnifica.* The average quadratic mean diameter at breast height was 77 cm (30 inches) for all trees inventoried. Average tree density was 433 trees/ha (173 trees/acre) (range 180–610 trees/ha) for trees greater that 28 cm DBH. Average basal area was 202 m^2/ha (867 ft^2/acre) (range 98–286 m^2/ha). Table 5 summarizes all stand calculations for the red fir stands.

TABLE 5. AVERAGE CALCULATIONS OF GEORGE SUDWORTH'S 4 RED FIR STANDS IN THE CENTRAL AND NORTHERN SIERRA NEVADA IN 1899 (STANDARD ERROR). * Average value for all stands.

Tree	Basal area (m^2/ha) [202]*	Trees/ha [433]*	DBH (cm) [77]*	Percent of total basal area	Percent of trees/ha
Pinus jeffreyi	32.2	25.0	128.1	16	6
	(32.2)	(25.0)	(15.1)		
Abies magnifica	136.2	272.5	80.1	67	63
	(55.3)	(93.5)	(10.9)		
Pinus monticola	11.3	30.0	66.4	6	7
	(8.0)	(19.2)	(19.4)		
Pinus contorta	12.6	70.0	47.8	6	16
	(12.6)	(70.0)	(12.0)		
Tsuga mertensiana	9.3	35.0	58.0	5	8
	(9.3)	(35.0)	(14.5)		

FIG. 2. Amador county, 1899. Near sawmill 5–6 km (3–4 miles) below dam on Bear River. Forest fire in fir and pine, killed all seedlings, just started.

The largest trees in the red fir stands were *Abies magnifica* and *Pinus jeffreyi* with DBH's of 160 cm (63 inches). *Abies magnifica* was the most common tree in the stands accounting for 63 percent of all trees inventoried and 68 percent of average stand basal area (Table 5). The next most common tree found was *Pinus contorta* which accounted for 16 percent of all trees but only contributed to 6 percent of basal area because of the smallest DBH of any species in this forest type.

Snag density averaged 17.5 per ha with a range 0–60 per ha (Table 2). Average snag quadratic mean diameter was 57 cm (22 inches) and average snag basal area was 4.5 m^2/ha.

The following comments were written by George Sudworth in the original field notebooks and include information about regeneration and impacts from early European settlers (Sudworth 1899).

September 2, 1899. On foothill (above) Bear Meadow, north fork of Stanislaus River. No grazing, 40 young trees under 10 inches diameter. Humus 4–6 inches deep, no herbaceous growth. 75–100 seedlings 2–10 inches.

September 7, 1899. On south slope 4–5 miles down on Silver Fork (near Silver Lake and Kirkwood). Sheep grazing, no reproduction. Scattered bunches of blue ceonothus. Earth bare, rock and gravel.

September 7, 1899. North side of Thimble Peak (west of Kirkwood Meadow). On volcanic and granite. No humus, grazed by sheep. Dense shade in part, no reproduction. 2 *Abies magnifica* down.

September 13, 1899. On Rocky flat between Lyons and Blakley (south fork Silver Creek, west side of Pyramid Peak). Abundant 1 year fir seedlings, 50 fir under 10 feet, 20 Murr (*Pinus contorta*) pines 2–10 feet, 5 Pimo (*Pinus monticola*) 1–3 feet. Humus 1 inch. Cattle grazed, no sheep within 5 years.

DISCUSSION

Sudworth's noted recent evidence of fire in many stands and believed fires were ignited by sheep herders to increase forage production and by loggers to consume slash fuels (Fig. 2). This burning apparently did not spread extensively because fire scar analysis in the Sierra Nevada have documented the almost complete removal of surface fires in

FIG. 3. Calvaras county, 1899. About 3 km (2 miles) south west of Bloods. Sandy ridge grazed clean and bare by sheep, gullying.

many mixed conifer forests in the 1860–1870's (Kilgore and Taylor 1979; Swetnam et al. 1990; Swetnam et al. 1992; Caprio and Swetnam 1995) at the same time burning was reportedly being used by loggers and sheep herders (Sudworth 1900; McKelvey and Johnston 1992; Stephens and Elliott-Fisk 1998).

Regeneration was noted in the majority of "average" mixed conifer stands. More site resources (light, water, nutrients) were probably available for regeneration in the "average" mixed conifer stands because of their lower stocking and basal areas. Regeneration in mixed conifer forests probably occurred prehistorically when small gaps were created by the interaction of fire and locally high fuel loads (Stephens et al. 1999).

Regeneration was noted in half of the red fir stands and livestock grazing was noted in all stands. Sudworth noted that in some high elevation sites sheep were actually grazing on conifer seedlings (Sudworth 1899). Many photos in the collection show complete bare mineral soils (Fig. 3) and seedlings were reportedly also trampled by livestock.

Early logging operations had a dramatic effect on the species composition and diameter distributions of mixed conifer stands sampled by Sudworth (Table 3). The majority of the *Pinus* spp. and *Pseudotsuga menziesii* were harvested in the stands leaving large amounts of *Calocedrus decurrens* and *Abies concolor* (Fig. 4). This type of logging operation has been described as "high-grading" because of the preference for large trees of particular genera. In this period it was common for all merchantable trees to be removed during logging operations (Laudenslayer and Darr 1990). *Abies concolor* and *Calocedrus decurrens* were therefore left because they were of relatively low economic value late in the 19th centaury.

Early logging operations coupled with a national fire suppression policy that began in the early 20th century favored shade tolerant species such as *Calocedrus decurrens* and *Abies concolor.* Climate changes over this period (wetter than average) may

FIG. 4. El Dorado county, 1899. Forest logged out 5–6 years ago. Sugar pine (*Pinus lambertiana*), large ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*) taken out, Kellogg oak (*Quercus kelloggii*) and incense cedar (*Calocedrus decurrens*), 12–25 per ha., remain (5–10 per acre). Reproduction of incense-cedar, ponderosa pine, white fir, and Douglas-fir abundant 2–9 m high (6–30 feet), 2–8 years old. Ground grazed. Half mile south of Blairs Mill at Sly Park. Humas 4–10 cm deep (2–4 inches). Soil deep brown, sandy loam.

have also led to an increase in tree densities in Sierra Nevada forests.

The management of *Quercus kelloggii* is receiving increased attention in the Sierra Nevada Framework Project (SNFP) Environmental Impact Statement because several rare species such as the California spotted owl and Pacific fisher use this species for foraging and denning habitat (USDA 2000). *Quercus kelloggii* is shade intolerant, and therefore, would have difficulty living in areas dominated by large mixed conifers because it can be over-topped and killed which is one explanation of why it was not recorded in any large mixed conifer stands. *Quercus kelloggii* did contribute to 6 percent of average stand stocking on the less stocked "average" mixed conifer stands because these stands were composed by smaller trees, and therefore, more site resources were probably available for the oaks.

There was a great deal of variability in snag densities in the stands, particularly in the red fir forest type. Tree density was also much higher in the red fir forest type when compared to the mixed conifer forests. Snag basal area was almost identical in the large mixed conifer stands and red fir stands (4.6 m^2/ha and 4.5 m^2/ha, respectively). Snag densities found in the large mixed conifer stands are on the lower end of the current requirements for California spotted owls (Verner et al. 1992). Very little snag information exists for red fir forests making it difficult to compare this historic data to contemporary data.

The average basal area recorded in the mixed conifer stands is high, even for those labeled as "average." The SNFP Environmental Impact Report is defining desired conditions in mixed conifer forests as having basal areas below 70 m^2/ha (300 ft^2/acre). The large mixed conifer stands Sudworth inventoried had over three times this basal area and the "average" mixed conifer stands had double the

basal area. Some areas of mixed conifer forest in the Sierra Nevada have the ability to produce much larger trees.

The average quadratic mean diameter of the large mixed conifer stands from this study (110 cm) is equal to those recorded in the 8 mixed conifer stands in the southern Sierra Nevada (110 cm) for all trees greater than 30.5 cm DBH. (Stephens and Elliott-Fisk 1998). Omitting *Sequoiadendron giganteum* (Lindley) Buchholz (giant sequoia) data from the four *Sequoiadendron giganteum* –mixed conifer stands in the southern Sierra Nevada produced an average DBH of the remaining trees of 111 cm which is also very similar to those recorded above.

Average tree density was higher in the southern Sierra Nevada when compared to the central and northern Sierra (278 trees/ha compared to 235 trees/ha, respectively). Average stand basal area was also higher in the mixed conifer stands from the southern Sierra Nevada when compared to the large mixed conifer stands from this study (271 m^2/ha versus 215 m^2/ha, respectively). Since the average DBH was equal in the mixed conifer stands the increase in basal area is a result of increased stocking in the southern Sierra Nevada (18 percent higher).

Abies concolor was very rare in the "average" mixed conifer stands but was the most common tree in the large mixed conifer stands. Low amounts of *Abies concolor* in the "average" mixed conifer stands may have occurred because these stands were probably less developed (younger) or they may have been in drier locations which would have favored pines over true fir species. In the southern Sierra Nevada *Abies concolor* contributed to 40 percent of average stand stocking and 28 percent of average stand basal area (Stephens and Elliott-Fisk 1998). In the large mixed conifer stands in this study, *Abies concolor* contributed to 46 percent of average stand stocking and 34 percent of average stand basal area indicating that *Abies concolor* was slightly more common in the central and northern Sierra Nevada stands sampled by George Sudworth.

Pinus lambertiana was much more common in the southern Sierra Nevada when compared to the central and northern Sierra Nevada (19 percent of stocking, 36 percent of basal area versus 12 percent of stocking, 16 percent of basal area, respectively). This difference can be partially explained by the presence of *Pseudotsuga menziesii* in relatively large amounts (16 percent of stocking, 24 percent of basal area) in the northern Sierra Nevada whereas *Pseudotsuga menziesii* is not native to the southern Sierra Nevada. Both *Pseudotsuga menziesii* and *Pinus lambertiana* are classified as shade intermediate (in between shade tolerant and shade intolerant) and therefore, *Pseudotsuga menziesii* may have occupied areas that *Pinus lambertiana* could have also dominated.

Conclusion

The mixed conifer stands sampled by George Sudworth in 1899 were dominated by large trees at relatively low densities. Shade intolerant species, particularly *Pinus ponderosa,* dominated the "average" mixed conifer stands whereas the large mixed conifer stands were composed of shade tolerant, intermediate, and shade intolerant species.

Early harvesting operations removed the majority of the economically viable species (*Pinus* spp. and *Pseudotsuga menziesii*) and left a large amount of *Calocedrus decurrens* and *Abies concolor.* This practice coupled with fire suppression policies initiated at the beginning of the 20th century promoted the establishment and growth of shade tolerant species.

There was a large amount of variability in snag densities, particularly in the red fir stands. The red fir stands had the highest tree densities and *Abies magnifica* dominated in these stands.

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