

Vegetation changes in Sequoia National Park, California

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ABSTRACT. Twenty-one vegetation types occurring in Sequoia National Park are described and their changes under western man's influence are documented. Age—population structure of the trees, repeated old photographs, and historical descriptions were the primary evidence for recording and interpreting vegetation changes. These changes are strongly correlated with past land uses. Nineteenth-century livestock grazing is considered to be the primary factor in changes in the blue oak foothill woodland, lodgepole pine and subalpine forests, and various grassland vegetation types. Twentieth-century fire suppression is the primary factor in most changes in the various shrublands and other woodlands and forests. Vegetation changes include increases of introduced species in herb-dominated systems, and increases in cover and density of certain woody plants in tree and shrub-dominated vegetation types.

Introduction

National Parks include preserves in which natural ecosystems are maintained for observation and scientific study. The proper management of these and other natural areas is dependent upon a knowledge of pre-settlement conditions. In the case of Sequoia National Park, the region has been altered greatly since the time of the aboriginal Indians. The primary objective of this study was to develop an overall view as to how and why the vegetation of the Park has changed since western man first came into the area in the 1850s. This has been achieved by research on past land use, by reference to old photographs, and by field research on present vegetation conditions (see Vankat, 1970).

Description of study area

Sequoia National Park is located in Tulare County, California, and includes over 1600 km² of the west slope of the southern Sierra

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Nevada (Fig. 1). It lies between 36° 18' and 36° 42' North latitude and 118° 14' and 118° 55' West longitude. The park is bounded by Kings Canyon National Park to the north, National Forests primarily to the east and south, and privately-owned land to the west.

Standard climatic data are available for two locations, the Park headquarters at Ash Mountain (518 m) and a station at Giant Forest (1954 m). These data reflect the typical mountain-range climatic pattern of increasing precipitation and decreasing temperature with increased elevation; they also show that the regional climate is Mediterranean, with warm dry summers and cool wet winters. Winter precipitation falls as rain in the low elevations and as snow in the middle and upper elevations.

The geological substrate of the Park is mostly Mesozoic granitic rock, typical of the Sierra Nevada batholith, with scattered pre-Cretaceous metamorphic and metasedimentary rock outcroppings (Matthews & Burnett, 1966). The soils reflect these parent materials.

The topography of the Park is mountainous and includes an elevational range from 400 m

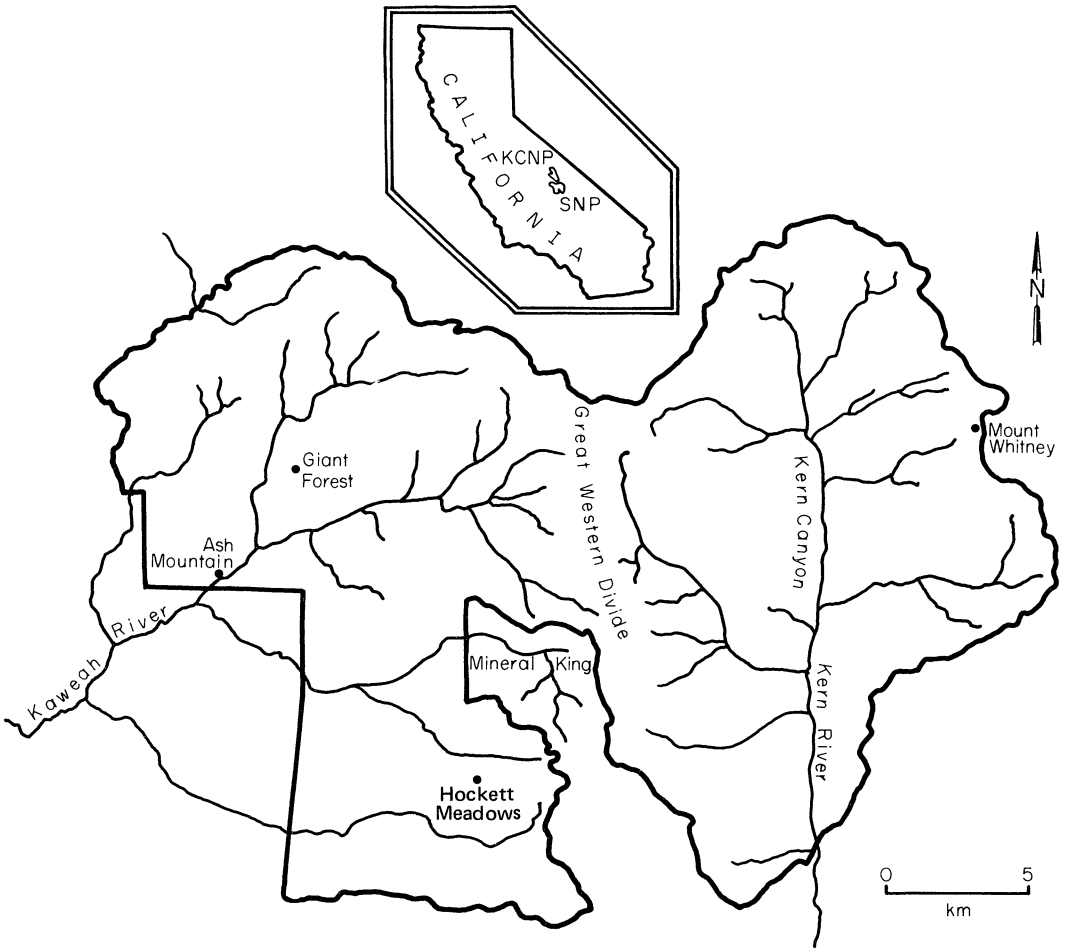


FIG. 1. Map of Sequoia National Park.

on the western boundary to 4419 m at the summit of Mount Whitney on the eastern boundary. The Kaweah River drainage basin of the western half of the Park is a westward-sloping old erosion surface dissected by steep canyons. The Kern River drainage basin of the eastern half is dominated by canyons, plateau-like old erosion surfaces, and glacier-sculptured mountain peaks. To the west lies the San Joaquin Valley, and to the east is the abrupt fault escarpment of the Sierra Nevada and Owens Valley.

Land use history of study area

The history of the Sequoia National Park area can be divided into several periods of differing land use practices. The earliest of

concern to us here was that of the aboriginal Indian tribes. This was followed by several decades of unregulated land use by early Euro-Americans. Federal government management began in the 1890s and emphasized the active protection of resources. Recently the National Park Service has attempted to rely on natural processes in their management practices.

Estimates of the beginning of Indian occupancy range from approximately AD 1000 (Elsasser, 1962) to AD 1400 (Kroeber, 1925). Population densities never became high. Most camp and village sites were in the foothills of the western portion of the Park; mid-elevations were used seasonally, and high elevations were used only infrequently (Elsasser, 1965; Kroeber, 1925). The Indians undoubtedly

altered the abundance and distribution of specific species, but activities such as food gathering probably had little influence on the aspect of the vegetation. The major impact of the Indians resulted from their use of fire in land management. Indian burning practices have been described for a variety of areas in North America (Kozlowski & Ahlgren, 1974; Stewart, 1956), in California (Lewis, 1973), and for the Sequoia National Park region in particular (Driver, 1937; Gayton, 1948; Muir, 1938; Steward, 1933; Stewart, 1927). Such burning aided their hunting and favoured certain wild food crops. The extent of Indian burning in the southern Sierra Nevada is unknown; however, Reynolds (1959) concluded that 'lightning was not the most significant or effective ignition agent operating in the central Sierra Nevada during aboriginal times,' but that 'additional frequency was furnished by the action of aboriginal cultural fires.' Although burning was probably not as common in the less-populated Sequoia National Park region, evidence indicates that it was a major factor affecting the vegetation. Indian land use continued well into the nineteenth century, since the Indians of the Park area were not disturbed by the Spanish exploration and settlement of California (Elsasser, 1965). However, the Indians contracted European diseases, when several homesteads were established along the Kaweah River just outside the present Park boundary; by the mid-1860s, most of the survivors had left the area (Anon., n.d.; Fry, 1925).

There are accounts of Spanish exploration in the region surrounding Sequoia National Park, but there is no proof that western man entered the present Park boundary until the 1850s (Vankat, 1977). The first travellers in the region were explorers and prospectors, but as early as 1861 livestock herders brought cattle into the present-day Park (Farquhar, 1926; Fry & White, 1930). Grazing in the Sierra Nevada rapidly increased, and although cattle were widespread, domestic sheep soon predominated. An extensive investigation of early accounts indicates that all Park areas were subjected to at least some grazing, and that most were utilized intensively (Vankat, 1970). There are many descriptions of the impact of this grazing. For example, King (1926) reported for an area south of the

present Park boundary that 'the Kern Plateau, so green and lovely on my former visit in 1864, was now a gray sea of rolling granite ridges, darkened at intervals by forest, but no longer velveted with meadows and upland grasses. The indefatigable shepherds have camped everywhere, leaving hardly a spear of grass behind them.' And Magee (1885) noted about a trip to Mount Whitney that 'mountain meadows are abundant, but the sheep-herder and his flocks have more largely worked their ruin in the Whitney region than anywhere else in the Sierra that I have visited. Each of these meadows is yearly cropped several times by various flocks of sheep, and the result is that, even where there was a genuine mountain meadow, there are now only shreds and patches. The sod and the verdure are gone — eaten and trodden out; the gravel is now in the ascendant.' In addition to reducing herbaceous cover and accelerating soil erosion, the livestock grazing also increased fire frequency, since the herders burned areas in the fall to promote growth of palatable shoots the following spring. The majority of fires in the second half of the nineteenth century were blamed on sheepherders (Muir, 1877), but later it was acknowledged that the case against them had been overstated (*Report of the Acting Superintendent*, 1897) and that lightning was the chief cause (Barrett, 1935). In retrospect, it seems likely that the frequency of man-caused fires drastically declined with the cessation of Indian burning, and that by the mid-1870s sheepherder fires may have partially replaced those set by the Indians (Vankat, 1977). During the intervening years, tree regeneration may have been sufficient to explain descriptions of sheepherder's fires thinning out the forests (Dudley, 1896; *Report of the Acting Superintendent*, 1892).

When Sequoia National Park was established in 1890, it included only the western portion of the present Park area. The eastern portion, essentially the upper Kern River drainage, was included in the Sierra Forest Reserve created in 1893, and added to the Park in 1926. The Park initially was patrolled by the United States Army; that administration implemented a policy of protecting Park resources from all factors thought to be ecologically damaging, especially sheep grazing

and fires. This policy was continued under the civilian administration which developed into the National Park Service.

With the creation of the Park, sheep grazing was considerably reduced in the Kaweah River drainage, but it remained common in the upper Kern River region until 1900 or shortly thereafter (Vankat, 1970). Cattle grazing was permitted in certain areas in the Kern until 1928, and in the Kaweah until 1930 (*Annual report of the Director*, 1928, 1930). The Army administration also began a fire control programme; by 1910, downed timber had been removed from some sequoia groves, a fire lane had been cut, at least one attempt was made at controlled burning, and the first instructions for the prevention and suppression of fires had been issued (Vankat, 1977). With appropriations for fire protection in the 1920s, the Park appears to have had an effective fire programme by 1930 (Show, n.d.; Strong, 1964). Park fire control has become progressively more efficient with the use of modern technology to locate and suppress fires.

The purely protectionist resource management policy began to be changed in the late 1960s, when the Park administration experimented with prescribed burning and fire management zones (Vankat, 1977). A new period of land use can be recognized as having begun at this time; it followed the recommendation of Leopold *et al.* (1963) that the primary goal of a National Park is the 'maintenance of naturalness' and therefore is based as much as possible on the natural functioning of ecosystems.

This information on past land use practices forms the backdrop for our vegetation studies. The following sections describe both the major vegetation types in the Park and the primary changes in each since the 1850s, and relate these vegetation changes to land-use history.

Materials and Methods

Data on the present state of the Park's vegetation were collected by means of stand surveys and belt transects. The stand surveys were carried out in units of vegetation of variable size, which were considered to be relatively

homogeneous and representative of common plant communities. Data were recorded on woody species presence and estimated cover and on site factors, e.g. elevation, degree of slope, slope exposure, etc. The findings of 106 stand surveys provide a general picture of the vegetation. More detailed information was obtained by the use of ninety-four 2 m × 50 m transects subjectively placed in areas representative of individual stands (additional considerations for placement included availability of old photographs of the site, potential for future relocation, and visual impact on Park visitors); transects were marked with steel stakes at both ends. In addition to site information such as elevation, degree of slope, slope exposure, etc., data were recorded for woody species presence, dbh, height, and position within the transect. Woody plant cover along the centre line of the transect was measured for each species by the simple line intercept method of Andresen & McCormick (1962). Basal areas of all tree species were determined with Bitterlich wedge prisms at both ends of the transects, and the data were corrected by the constant gauge angle technique of Beers (1969). Importance Values were calculated by summing relative frequency, relative basal area (calculated from prism measurements), and relative density values.

Vegetation change was analysed beginning with library research on Park history, including descriptions of the landscape by early travellers, and the details of past land use and management. Over 500 photographs taken in the Park before 1920 were copied, and the exact scenes of 300 were relocated and re-photographed. The point quarter method of Cottam & Curtis (1956) was used to collect data for size class distributions. The dates of vegetation change were determined from increment borings of selected individuals (correction factors based on height of borings were added).

Results and Discussion

The vegetation classification used here is intended to recognize what one can see on the ground; it is physiognomic-floristic, with an emphasis on dominants. It includes more de-

tail than the classifications of Munz (1959) and Küchler (1964). Its use results in the documentation of many of the units recognized by Knapp (1965). Taxonomy and nomenclature follow Munz (1959, 1968). The major vegetation types are as follows:

- Shrublands
 - Foothill
 - Chamise chaparral
 - Mixed chaparral
 - Yucca
 - Montane
 - Montane chaparral
- Woodlands
 - Foothill
 - Blue oak
 - Lowland live oak
 - Low montane
 - Upland live oak
 - California black oak
 - Mid-montane
 - Juniper
- Forests
 - Mid-montane
 - Ponderosa pine
 - Jeffrey pine
 - White fir
 - White fir – giant sequoia
 - High montane
 - Red fir
 - Lodgepole pine
 - Subalpine
- Grasslands
 - Foothill
 - California grassland
 - Montane and alpine
 - Wet meadow
 - Woodland meadow
 - Shorthair meadow
 - Xeric alpine

The determination of elevational ranges was aided by an unpublished vegetation map of the Park.

Shrublands

Foothill chamise chaparral vegetation occurs between 450 and 1700 m on west and south exposures in the drainage of the Kaweah River. It is a sclerophyll type, characterized by a dense canopy of shrubs; total shrub cover is in the 85–95% range, with

Adenosotoma fasciculatum (chamise) accounting for at least 75%. Other common species are *Ceanothus cuneatus* and *Arctostaphylos viscida* (Table 1); Parsons (1976) reported that *Eriodictyon californicum* and *Dendromecon rigida* also were important in young stands. Trees are usually infrequent, but they may be found along intermittent streams or near stand borders. Herbaceous cover may reach 30–50% in the spring, and is dominated by introduced annuals; however, native bunchgrasses still occur in a few stands. A major vegetation change has been an increase in cover and biomass of *A. fasciculatum* as a result of reduced fire frequency. In addition to information from comparison photographs, evidence comes from an anthropological study, which determined that at least one former Indian trail was virtually impassable because of increased shrub densities (von Werlhof, 1961); much the same has been observed for other trails last used in the early part of this century (David J. Parsons, personal communication). Parsons (1976) documented that total woody cover, canopy height, litter, and dominance of *A. fasciculatum* increased in post-fire succession; further, decreases were observed in species diversity and herbaceous cover. Therefore, reduced fire frequency has resulted in this vegetation type now consisting largely of old age stands, instead of a mosaic of different successional stands (Vankat, 1970; Parsons, 1976).

Foothill mixed chaparral vegetation is found in the Kaweah River drainage on north- and east-facing slopes within an elevational range of 450–1700 m, and on other slopes at a higher elevation than chamise chaparral. On more mesic sites, mixed chaparral may be similar to lowland live oak woodland vegetation. Table 1 gives an indication of the greater diversity of the mixed chaparral, as compared to the chamise chaparral. *Aesculus californica*, *Quercus wislizenii* and *Q. chrysolepis* are characteristic tree species. *Pinus sabiniana*, a widespread component of foothill vegetation in California, is inexplicably not present in the Park. *Cercocarpus betuloides*, *Rhus diversiloba*, *Lonicera interrupta* and *Fraxinus dipetala* are common shrub species. This type of chaparral is somewhat similar in general aspect to the chamise type, but trees are much more important. Tree cover is usually between

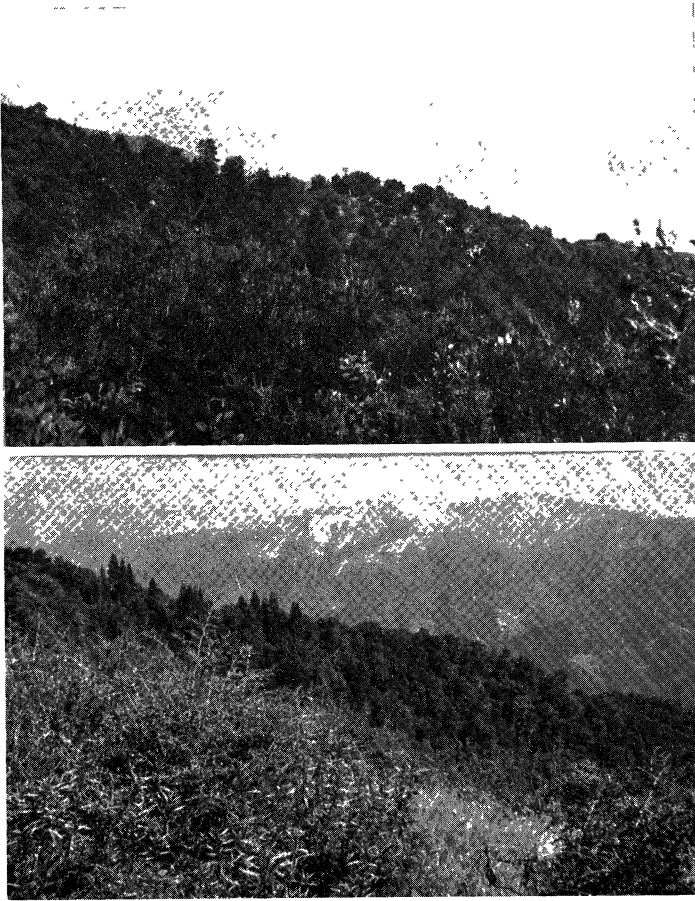


FIG. 2. Comparison photograph set showing an increase of ponderosa pine forest species along a ridge in foothill mixed chaparral vegetation. The old photograph was taken in 1900 by George B. Sudworth and was furnished by the U.S. Forest Service through the National Archives.

40% and 60%, with shrub cover between 30% and 60%, and spring herbaceous cover between 50% and 75%. Little information is available on vegetation change; however, the mixed chaparral is believed to have increased in density and decreased in diversity as a result of reduced fire frequency. In some areas near stands of ponderosa pine forest, there has been an increase in density and cover of forest species (Fig. 2); this is also thought to be related to the lack of periodic burning.

A yucca vegetation type occurs infrequently in the foothill portion of the Park, within an elevational range of 600–1200 m. It is found on steep slopes of metamorphic or metasedimentary rock (parent material is not

correlated with the distribution of the other types of shrublands). It consists of scattered *Yucca whipplei* individuals and a herbaceous layer. With the exception of a change in the composition of the latter, this vegetation probably has not been significantly modified since western man came into the Park region.

Stands of montane chaparral are found scattered throughout the 1200–3350 m elevational range. These stands are dominated by a dense cover of shrubs, comprising one or more of the following: *Arctostaphylos patula*, *A. manzanita*, *A. nevadensis*, *Artemisia tridentata*, *Castanopsis sempervirens*, *Ceanothus cordulatus*, *C. leucodermis*, *Cercocarpus betuloides*, *Holodiscus microphyllus*, *Prunus emarginata* and *Salix* spp. Extensive study would

be required to provide information for floristically-defined vegetation subdivisions within this group. The diversity of stands necessitates the description of several vegetation changes. Some stands have increased in shrub cover and density; depending on the area, this probably has resulted from reduced fire frequency, or recovery from sheep grazing. For example, comparison photographs indicate a regrowth of many *Salix*-dominated stands from the time when 'even the brush along the streams had been eaten' by sheep (*Report of the Acting Superintendent*, 1894). Other stands show a decrease in shrub cover and density. In the case of *Prunus emarginata*, this may be the result of more concentrated grazing by mule deer following reduction of their forage in Forests; Dixon & Herman (1945), in studying their situation in the Park, reported that 'the preferred species of browse, such as snow brush (*C. cordulatus*) and bitter cherry (*P. emarginata*), have been depleted more and more in the area and in many cases actually killed by over-browsing.' Lastly, other stands show an invasion and/or increase in tree cover and density, following the virtual elimination of fires. Wilken (1967) described this for the northern Sierra Nevada, and suggested that the tree increases were temporary, occurring only until the fire-susceptible montane chaparral was burned again. These findings support the hypothesis of Show & Kotok (1924) that stands of such shrubland vegetation are the result of single intense fires, or are the cumulative effect of repeated fires in areas of potential forest vegetation.

Woodlands

Blue oak foothill woodland stands are scattered throughout the western portion of the Park from elevations of 400 to 1100 m. Their appearance is that of an open woodland; tree canopy cover is between 30% and 85%, and herbaceous cover is over 80%. Shrub cover is scarce. This woodland type is much less diverse than the others. *Quercus douglasii* is dominant, and other tree species are of minor importance (Table 2). *Arctostaphylos viscida* is found in most stands, but *Rhamnus crocea* was the only shrub to fall within any of the transects (Table 3).

TABLE 1. Presence values (% stands) for the foothill chaparral vegetation types

Species	Chamise chaparral	Mixed chaparral
Trees		
<i>Quercus wislizenii</i>	25	83
<i>Aesculus californica</i>	13	100
<i>Umbellularia californica</i>	13	33
<i>Quercus chrysolepis</i>		67
<i>Quercus douglasii</i>		17
Shrubs		
<i>Adenostoma fasciculatum</i>	100	33
<i>Ceanothus cuneatus</i>	75	33
<i>Arctostaphylos viscida</i>	50	17
<i>Yucca whipplei</i>	38	17
<i>Ceanothus velutinus</i>	25	50
<i>Cercocarpus betuloides</i>	13	100
<i>Fremontia californica</i>	13	50
<i>Lonicera interrupta</i>	13	83
<i>Rhamus crocea</i>	13	
<i>Rhus diversiloba</i>		100
<i>Fraxinus dipetala</i>		83
<i>Cercis occidentalis</i>		67
<i>Rhus trilobata</i> var. <i>malacophylla</i>		67
<i>Baccharis</i> sp.		50
<i>Eriodictyon californicum</i>		50
<i>Calycanthus occidentalis</i>		17
<i>Philadelphus lewisii</i> ssp. <i>californicus</i>		17
<i>Ribes</i> sp.		17
No. of stand surveys	8	6

Comparison photographs show that there has been a large increase in cover and density of *Q. douglasii* (Fig. 3). Brooks (1967) has concluded that differences between *Q. douglasii* size class distributions of his four stands were the result of dissimilar twentieth century grazing and fire histories. He did not comment on the high percentage of individuals in the two smallest size classes, information which complements the comparison photographs. Age determinations in three stands date the density increase to the 1860s and 1870s, the time of the demise of the Indians and the beginning of livestock grazing (Fig. 4). Either or both of these events could have been the trigger factor; however, grazing is a more likely possibility, since the cultural burnings of the Indians were to a degree continued by the livestock herders. Thus, we hypothesize that intense livestock grazing in the nineteenth century initiated the density



FIG. 3. Comparison photograph set taken in blue oak foothill woodland vegetation just outside the Park boundary along the North Fork of the Kaweah River. Note the increase in cover and density of blue oak (*Quercus douglasii*). The old photograph was taken in the 1880s and was furnished by the Bancroft Library, University of California, Berkeley.

increase by removing herbaceous competition for *Q. douglasii* seedlings and decreasing fuel levels, so that fires were less intense. Griffin (1971) has stated for a different area in California that grasses can be an important factor in oak regeneration, especially in dry years when a heavy grass cover successfully out-competes oak seedlings. For the same

location, White (1966) reported increases in oaks, including *Q. douglasii*, and dated the majority of the new individuals to the period from 1860 to 1890. Livestock grazing peaked in the area from 1860 to 1870; however, since changes in other factors had occurred at about the same time, he did not speculate on a causative factor. White (1966) also reported

TABLE 2. Tree data for three woodland vegetation types: P (presence in % stands), C (cover in % total length of transects), F (frequency in % transects), D (density in individuals per hectare), BA (basal area in m² per hectare), and IV (Importance Value)

Species	Blue oak woodland						Lowland live oak woodland						California black oak woodland					
	P	C	F	D	BA	IV	P	C	F	D	BA	IV	P	C	F	D	BA	IV
<i>Quercus douglasii</i>	100	56.1	100	636	11.85	238	67	17.5	50	100	1.84	52	100	11.3	33	233	2.37	69
<i>Aesculus californica</i>	100	5.8	21	50	1.92	34	89	31.7	50	150	1.95	60	100	4.9	33	33	2.07	34
<i>Quercus wislizenii</i>	100	1.5	14	14	0.39	14	76	73.4	100	400	12.28	188	100	1.3	33	33	0.61	26
<i>Quercus kelloggii</i>	17	4.2	7	7	1.07	13							100	59.6	100	300	12.70	172
<i>Umbellularia californica</i>							56						100					
<i>Quercus chrysolepis</i>							44											
<i>Pinus ponderosa</i>							11											
<i>Samolus caerulea</i>							11											
<i>Staphylea bolanderi</i>							11											
<i>Torreya californica</i>							11											
Total		67.6	142	707	15.23		122.6	200	650	16.07			77.1	199	599	17.75		
No. of stand surveys	6						9						3					
No. of transects			14					3							3			

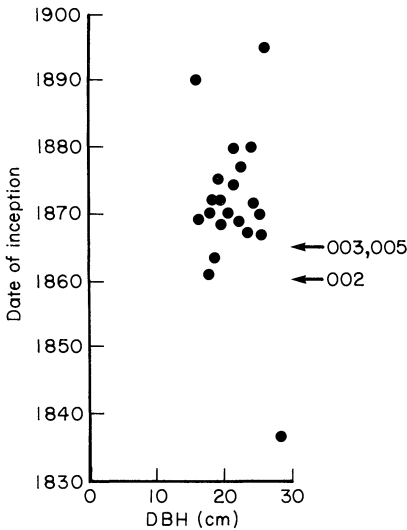


FIG. 4. Age distribution of selected *Quercus douglasii* individuals and dates of density increases in stands of blue oak foothill woodland vegetation.

past changes in the composition of the herbaceous layer; similar changes have occurred in Sequoia National Park, as will be discussed in the section on grassland vegetation.

Lowland live oak woodlands are found in riparian habitats in the western portion of the Park from 400 m upwards to where they intergrade with upland live oak vegetation. This woodland is a broad-sclerophyll type which is dominated by a canopy tree layer with a cover of 30–80%. Its general aspect is much denser than that of the blue oak woodland. *Quercus wislizenii* is the major dominant tree, but *Aesculus californica* and *Quercus douglasii* are also important; the presence of several additional tree species adds to the diversity (Table 2). Numerous shrub species are found in various stands (Table 3). Information on vegetation change is sparse, but several woody species, *Q. wislizenii* in particular, are thought to have increased in cover and density as a result of reduced fire frequency. Formerly, some stands may have been so open as to resemble today's blue oak woodland.

At higher elevations are both the upland live oak and the California black oak woodlands. Stands of the upland live oak type are found on very steep, rocky slopes up to 2300 m in the Kaweah River drainage, and on the

walls of Kern Canyon at elevations of 2150–2600 m. Total vegetation cover is normally around 75%, and is dominated by *Quercus wislizenii* and *Umbellularia californica*. The former is thought to have increased in cover and density in some stands, but it is limited by the high rock cover.

Stands of the California black oak woodland typically occur at elevations of 1000–1550 m, but may extend downslope along streams, and in locations with cold air drainage. The general appearance is that of an open woodland (but more closed than the blue oak type), with a tree canopy cover of 65–80%, a shrub cover of 5%, and a herbaceous cover of 30–65%. *Quercus kelloggii* is the dominant tree species, with *Q. douglasii* of lesser importance (Table 2). *Cercocarpus betuloides* is a common shrub, and is usually associated with several other species (Table 3). The herbaceous layer undoubtedly has been altered (see paragraph on the California grassland); however, with the exception of an invasion of conifers in stands adjacent to the ponderosa pine forest, there does not seem to have been significant changes in the composition of woody species.

Juniper woodland vegetation is found along the walls of Kern Canyon between 2000 and 3300 m. Stands consist of scattered trees and a shrub layer of somewhat greater cover. Dominant tree species are *Juniperus occidentalis*, *Pinus monophylla* and *P. jeffreyi*; the most common shrub species are *Artemisia tridentata* and *Cercocarpus ledifolius*. Vegetation change does not appear to have been extensive; comparison photographs show recovery of shrubs in stands grazed by sheep.

Forests

Stands dominated by yellow pines occur primarily in the western half of the Park, but several are located in or near Kern Canyon. Since the stands are found within a wide elevational range (1400–2800 m) and on a variety of slope exposures, their composition is quite variable. A meaningful division is between those stands with *Pinus ponderosa*, and those with *P. jeffreyi*.

Ponderosa pine forest stands occur only in the western half of the Park. They have a canopy tree cover of 60–95%, an extremely

TABLE 3. Shrub data for three woodland vegetation types (see Table 2 for abbreviations and units)

Species	Blue oak woodland			Lowland live oak woodland			California black oak woodland		
	P	C	F	P	C	F	P	C	F
<i>Arctostaphylos viscida</i>	83	0.4		67			67		
<i>Rhamnus crocea</i>	67	0.1	29	100		50	67	0.5	67
<i>Lonicera interrupta</i>	33			67		50	33		33
<i>Rhus diversiloba</i>	33			100	0.8	50	67	0.7	33
<i>Yucca whipplei</i>	33			11					
<i>Ceanothus cuneatus</i>	17			44					
<i>Cercis occidentalis</i>	17			100			67		
<i>Cercocarpus betuloides</i>	17			89	1.4	50	100	0.1	100
<i>Ribes divaricatum</i>	17								
<i>Fraxinus dipetala</i>				67	0.4	50	33	3.9	33
<i>Rhus trilobata</i> var. <i>malacophylla</i>				78		50	33	5.0	33
<i>Ceanothus velutinus</i>				67					
<i>Fremontia californica</i>				56					
<i>Adenostoma fasciculatum</i>				44					
<i>Calycanthus occidentalis</i>				44					
<i>Eriodictyon californicum</i>				44					
<i>Ribes</i> sp.				44					
<i>Baccharis</i> sp.				22					
<i>Philadelphus lewisii</i> ssp. <i>californicus</i>				22					
<i>Chamaebatia foliolosa</i>				11					
<i>Clematis lasiantha</i>				11					
<i>Dendromecon rigida</i>				11					
<i>Rhamnus californica</i>				11					
Total		0.5	29		2.6	300		10.2	299
No. of stand surveys	6			9			3		
No. of transects			14			2			3

variable shrub cover, and a herbaceous cover of less than 10%. The forest shows a great deal of interstand diversity, including what appears to be a continuum following gradients of slope exposure and recency of fire. Under the most xeric conditions, stands are dominated by mature *Quercus kelloggii*, with scattered mature *P. ponderosa*. On more mesic sites, stands are dominated by mature *P. ponderosa* and *Q. kelloggii*, with scattered mature *Calocedrus decurrens* and an undergrowth of *C. decurrens* and *P. ponderosa*. On the most mesic sites, *P. ponderosa*, *C. decurrens* and *Q. kelloggii* are codominants with an understory of *Abies concolor* and *C. decurrens*. Data on the overall composition and structure of the tree strata are given in Table 4. The most important shrub species are *Chamaebatia foliolosa* and *Arctostaphylos viscida*, but several others occur frequently (Table 5).

The major vegetation change in the ponderosa pine forest has been a great increase in

density of *C. decurrens* and, in the more mesic stands, of *A. concolor*. Size class distributions for stand 050 show that 94% of the *C. decurrens* individuals and 73% of the *A. concolor* individuals had a dbh \leq 0.20 m. Age determinations in this same stand indicate that the increase in density began around 1895–1905, and analyses in other stands give similar results (Fig. 5). Since the date of initial density increase corresponds to the time that a fire control programme was first put into effect in the Park, it is thought that this vegetation change is related to a reduced fire frequency. Another change has been a decrease in shrub species, especially *Arctostaphylos viscida*; possible explanations for this include increased competition, more intense mule deer browsing, and decreased germination of fire-stimulated seeds. These patterns of vegetation change are in agreement with those reported for the Sierra Nevada by Biswell (1959). Neither he nor others published tree age data

to indicate when density increases began, but it has been generally accepted that reduced fire frequency is responsible for the changes. An additional change in some Sequoia National Park stands has been an increase in the density of *P. ponderosa*. This is not thought to be a general trend, since it is observable primarily in areas where the canopy had been opened by the cutting of mature trees for insect control (such disturbance extends back to 1918, according to the *Annual report of the Director*, 1918).

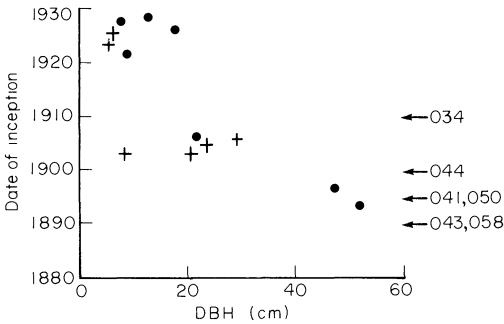


FIG. 5. Age distribution of selected *Abies concolor* (●) and *Calocedrus decurrens* (+) individuals and dates of density increases in stands of ponderosa pine forest vegetation.

Stands of jeffrey pine forest are found in both the Kaweah and Kern regions. They occur at higher elevations than the ponderosa pine forest and are usually on south- and west-facing slopes, scattered within one of the white fir forest types. Vogl (1968) suggested that California jeffrey pine stands occur in areas of high lightning frequency, indicating a dependency on fire. Dominant tree species are *Pinus jeffreyi*, *Calocedrus decurrens* and *Abies concolor* (Table 4); *Arctostaphylos patula* is the only dominant shrub (Table 5). Stands in the Kern Canyon area generally tend to be more diverse than those in the western portion of the Park; they include species such as *Populus trichocarpa*, *P. tremuloides* and *Pinus contorta* var. *murrayana*, probably because of the riparian nature of the canyon, and the proximity of lodgepole pine stands. Generally, herbaceous cover is 20%, shrub cover highly variable, and canopy tree cover between 40% and 60%. Stands in the western half of the Park show little vegetation change,

perhaps in some cases because of a rocky soil surface; there have been only scattered increases in cover and density of the three dominant trees. Comparison photographs show that stands in Kern Canyon have undergone greater changes, involving increases in density and cover of such species as *P. trichocarpa*, *P. tremuloides*, *P. contorta*, *P. jeffreyi* and *A. concolor*. All changes are thought to be related to reduced fire frequency.

White fir forest vegetation is found primarily in the western half of the Park, but a few stands also occur in Kern Canyon. It occurs over a wide elevational range (1250–2600 m), and its composition is variable, containing elements of the ponderosa pine forest at lower elevations, and elements of both the red fir and lodgepole pine forests at upper elevations. This study splits the white fir forest into two divisions, those stands with giant sequoias, and those stands outside of sequoia groves.

White fir forest stands without giant sequoias are dominated by *Abies concolor* and *Calocedrus decurrens* (Table 4). Several shrub species are present in most stands (Table 5). Typically, herbaceous and shrub covers are both less than 25%, and canopy tree cover is over 75%. The major change in the forest has been an increase in density and cover of *A. concolor*, along with *C. decurrens* at low elevations and, to a lesser extent, *Abies magnifica* at high elevations. In stand 051, as an example, 52% of the *A. concolor* individuals have a dbh of ≤ 0.20 m, and age determinations show that the major density increase began around 1895–1915, the period of initial attempts at a fire control programme in the Park (Fig. 6). Data from this and other stands also indicate the possibility of an earlier increase in *A. concolor*, beginning around 1850–70. This corresponds to the date of the demise of the Indians in the region; consequently both periods of increase are thought to be related to reduced fire frequency. The earlier density increase could be expected to be less recognizable than the later, because of the death of seedlings and saplings from natural mortality and livestock herder fires. Recent increases are probably part of an ongoing succession and may reflect years of heavy seed production. A second vegetation change has been a decrease in den-

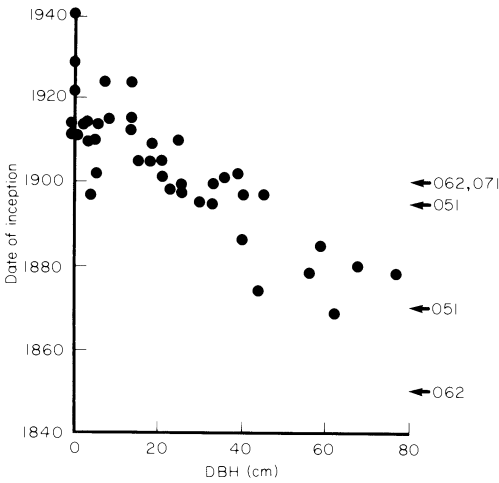


FIG. 6. Age distribution of selected *Abies concolor* individuals and dates of density increases in stands of white fir forest vegetation.

sity and cover of shrubs, especially of *Arctostaphylos* spp. and *Ceanothus* spp. This change is probably related to decreased seed germination of fire-stimulated species, greater mule deer browsing, and an increased density of *A. concolor*.

Giant sequoia groves are scattered in the

Kaweah drainage portion of the white fir forest zone. *Abies concolor* is again the dominant species, while *Sequoiadendron giganteum* is secondary in importance (Table 4). Various shrub species may be present (Table 5). Herbaceous cover is usually 5%, shrub cover less than 10%, and canopy tree cover over 80%. The vegetation changes within the giant sequoia groves are basically the same as those described in the preceding section. For example, Fig. 7 shows an increase in density and cover of *A. concolor* in stand 054 above Log Meadow in Giant Forest, and this is supported by a size-class distribution in which 69% of the *A. concolor* individuals are ≤ 0.20 m dbh. Increment borings date the major increases to 1850–60 and 1910–15; analyses of other stands gave similar results (Fig. 8). A second change has been a decrease in shrub species, especially of *Arctostaphylos patula* and *Prunus emarginata*. These changes in giant sequoia groves are related to the same factors as those discussed for the white fir forest. An additional change has been the lack of reproduction of *S. giganteum*. Most investigators believe this to be a result of a decrease in fires which formerly maintained micro-environments suited to the germination and

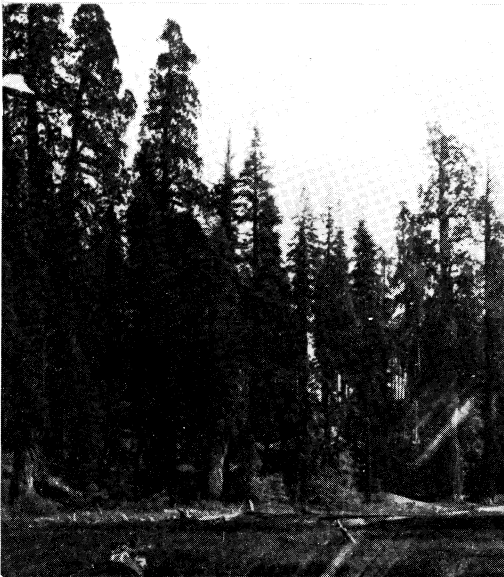


FIG. 7. Comparison photograph set in white fir–giant sequoia vegetation along Log Meadow in Giant Forest. Note the increase in density and cover of white fir (*Abies concolor*). The old photograph was taken in 1900 by George B. Sudworth and was furnished by the U.S. Forest Service through the National Archives.

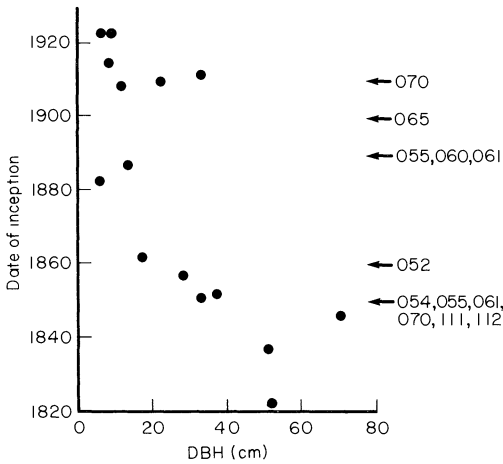


FIG. 8. Age distribution of selected *Abies concolor* individuals and dates of density increases in stands of white fir—giant sequoia forest vegetation.

growth of *S. giganteum* seeds and seedlings; however, Rundel (1971) has stated that low levels of regeneration initially appeared well before the 1850s.

The general vegetation changes observed within both types of white fir coniferous forest have been discussed in many papers, notably Agee (1968), Aley (1963), Biswell (1961), Biswell, Buchanan & Gibbens (1966), Bonnicksen (1975), Hartesveldt (1963, 1964, 1965), Hartesveldt & Harvey (1968), Hartesveldt, Harvey & Shellhammer (1967), Kilgore (1972, 1973a, b), Kilgore & Biswell (1971) and Rundel (1969, 1971, 1972). These and other papers noted the trend of increasing density and cover of *A. concolor* and related it to twentieth-century fire control; there are no other reports of a mid-nineteenth century increase.

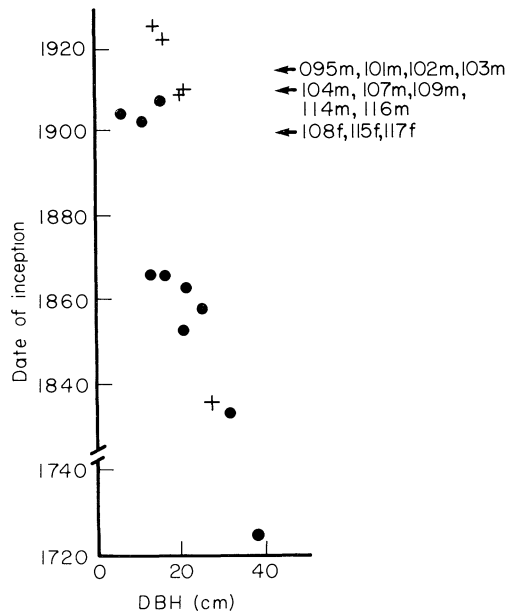
TABLE 5. Shrub data for the mid-montane forest vegetation types (see Table 2 for abbreviations and units)

Species	Ponderosa pine forest			Jeffrey pine forest			White fir forest			White fir—giant sequoia forest		
	P	C	F	P	C	F	P	C	F	P	C	F
<i>Chamaebatia foliolosa</i>	82	27.0	64	20	11.7	20	6		6	7		
<i>Arctostaphylos viscida</i>	64	4.6	36									
<i>Rosa spithamea</i>	45	0.7	36				56		38	21		14
<i>Ceanothus integerrimus</i>	36	0.3	9				6					
<i>Arctostaphylos</i> sp.	18	0.4	9									
<i>Rhus diversiloba</i>	18		9									
<i>Rubus leucodermis</i>	18		18				19		13	7		7
<i>Arctostaphylos patula</i>	9			60	17.6	60				7		
<i>Ceanothus velutinus</i>	9									7		
<i>Cercocarpus betuloides</i>	9											
<i>Lonicera interrupta</i>	9						6					
<i>Rhamus crocea</i>	9	0.3										
<i>Rhus trilobata</i> var. <i>malacophylla</i>	9											
<i>Ribes</i> sp.	9		9				38		6	21		14
<i>Rubus parviflorus</i>	9						13		13	14		
<i>Symphoricarpos</i> sp.							31	1.7	31	29		21
<i>Castanopsis sempervirens</i>							25	2.2	19	50	2.6	21
<i>Prunus emarginata</i>							19		6			
<i>Symphoricarpos acutus</i>							13					
<i>Ceanothus cordulatus</i>							6					
<i>Ceanothus parvifolius</i>							6		6	7		
<i>Ceanothus</i> sp.										7		
<i>Ribes roezlii</i>										7		
Total		33.3	190		29.3	80		3.9	138		2.6	77
No. of stand surveys	11			5			16			14		
No. of transects			12			5			16			14

The red fir forest occurs within an elevational range of 2150–3250 m in the western half of the Park. At the lower and upper portions of this range, stands often contain elements of the white fir and lodgepole pine forests, respectively. Tree cover in red fir stands is variable, but is usually about 80%, shrubs are generally absent, and the herbaceous cover is 5% or less. *Abies magnifica* is the only dominant (Tables 6 and 7). The major vegetation change has been an increase in density and cover of *A. magnifica*. In most stands, this has not involved species replacement; however, where *Pinus contorta* var. *murrayana* is a subdominant, it is becoming less important (*P. contorta* was considered a pioneer species in the expansion of red fir forests by Oosting & Billings, 1943). Most increases in density have occurred in patches of 15–20 m²; Oosting & Billings (1943) reported that dense aggregations occurred under canopy openings. Stands usually contain several patches of different ages, and each patch contains trees of different ages. The size class distribution in stand 110 indicates that *A. magnifica* has increased in density (97% of the individuals were ≤ 0.05 m dbh), and field observations showed the patchiness of this increase. Age determinations in several stands indicate a major increase in density, beginning in 1890–1910. The phenomenon of reproduction in patches is probably natural. In fact, since larger *A. magnifica* individuals usually lie near others of the same size class, red fir forest stands appear to be composed of a series of patches of varied maturity (a similar situation in a stand of white fir–giant sequoia forest was investigated by Bonnicksen, 1975). Kilgore (1971) reported that prescribed burning has decreased the density of *A. magnifica* saplings and *P. contorta*, and increased seedlings of the latter and some shrub species. We propose that under natural conditions recurring fires thin the young patches, leaving scattered trees which may develop into mature individuals; but decreased fire frequency has prevented this from happening, and thus has resulted in denser red fir forests.

The lodgepole pine forest is widespread within an elevational range of 2150–3400 m. Herbaceous cover varies greatly, but generally is around 30%. Shrub cover is 0–15%, and canopy tree cover averages 80%. *Pinus con-*

torta var. *murrayana* is the dominant tree (Table 6), and *Ribes montigeum* is the most common shrub (Table 7). Vegetation change has resulted in an increased density and cover of *P. contorta* in mature stands and on meadow borders. The dates of increase differ between the Kern and Kaweah River drainages, as well as between forests and meadows. A size-class distribution in forest stand 108 in the Kern River drainage shows that 76% of the individuals had a dbh ≤ 0.20 m. Age determinations indicate that reproduction occurred until about 1865–70, and began again around 1900–05; in an adjacent streamside site, meadow stand 107, reproduction took place prior to 1865, and the major portion of the *P. contorta* invasion began around 1910 (Fig. 9). Fig. 10 illustrates the change for both stands. Other forests and meadows in the Kern River drainage show approximately the same dates of *P. contorta* reproduction, as does data presented by A. W. Magill in Hubbard *et al.* (1966). In the Kaweah River drainage, age determinations in meadow stands 078 and 080 indicate that invasion began in about 1900–05 (Fig. 11). Sharsmith (1959) also investigated these and other nearby meadows,



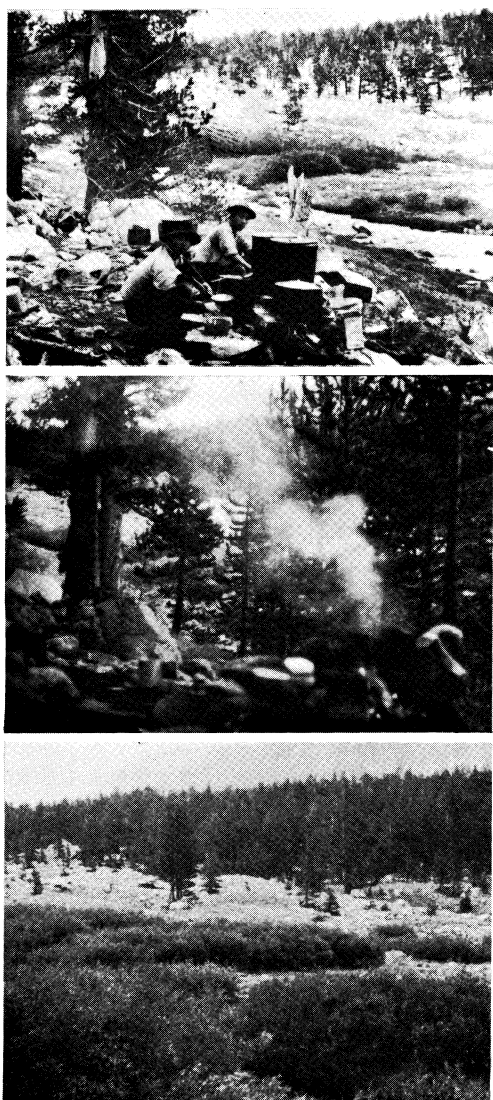


FIG. 10. Comparison photograph set in lodgepole pine forest vegetation in the northern Kern River drainage. The middle photograph shows an increase in lodgepole pine (*Pinus contorta* var. *murrayana*) in the foreground, while the bottom (taken from the other side of these trees) shows an increase in *Salix* along the stream and *P. contorta* in the background. The top photograph was taken in 1912 and was furnished by the Bancroft Library (Sierra Club Collection), University of California, Berkeley.

and found that the trees dated from 1900. However, in contrast to some of his statements, there also has been increased reproduction beneath the canopy of mature individuals. For example, a size-class distri-

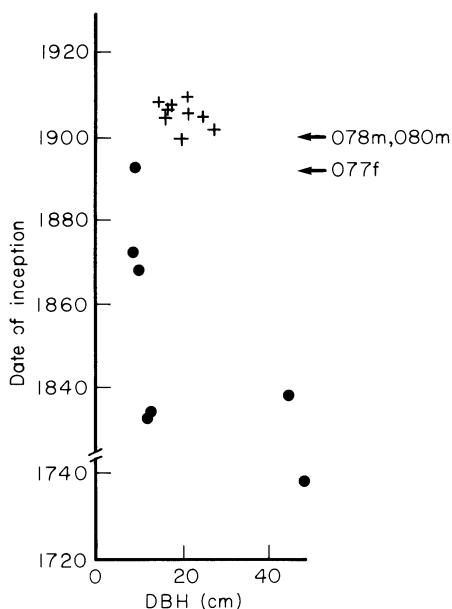


FIG. 11. Age distribution of selected *Pinus contorta* var. *murrayana* individuals and dates of density increases in forest (●) and meadow (+) stands of lodgepole pine forest in the Kaweah River drainage.

bution in forest stand 077 shows that 77% of *P. contorta* individuals have a dbh of ≤ 0.20 m, and age determinations reveal that reproduction occurred prior to 1873 and since 1890, but was not common between those dates (Fig. 11). The 1890 date is tentative, but this estimate would be correct if one assumes the same 10-year lag period between increases in density in the mature stands and the invasion of adjacent meadows that was found in the Kern River drainage.

Of the several hypotheses on meadow invasion, the most commonly held is that grazing resulted in increased precipitation runoff, soil erosion, and stream entrenchment, and that this lowered water tables, drying the meadows and improving conditions for seedling establishment. This is observable in some Sierran meadows, especially in the National Forests where grazing has been more intense. Another hypothesis is that the initial disturbance of ground cover by cattle grazing was the cause of invasion (Armstrong, 1942; Sharsmith, 1959). However, in a later study in Yosemite National Park, Sharsmith (1961) found it difficult to support this latter explanation.

Data presented in this paper show a positive correlation between the lack of sheep grazing and the reproduction of *P. contorta*, suggesting that the elimination of sheep grazing was the trigger factor in *P. contorta* reproduction in Sequoia National Park. The 1890 date of *P. contorta* reproduction in the Kaweah River drainage corresponds to the date of the establishment of the Park. Before 1890 the drainage of the South Fork of the Kaweah River had 'been a favourite grazing ground for sheep and cattle' (*Report of the Acting Superintendent*, 1891), and 'for many years sheep were kept every summer in the Hockett Meadows' of the drainage (*Report of the Acting Superintendent*, 1892). This ended in 1891, when Army troops were first stationed at Hockett Meadow (*Report of the Acting Superintendent*, 1891), near stands 077, 078 and 080. In contrast, sheep grazing in the Kern River drainage was not greatly reduced until around 1900, the initial date of increase of *P. contorta* in this drainage (the variability of the Kern dates probably reflects the fact that the elimination of grazing had not been as abruptly effective as in the Kaweah River drainage). Additional evidence for elimination of sheep grazing as a trigger factor is furnished by the stands which have reproduction dating from prior to 1865 and after 1900, but lack regeneration for the time between, the exact period of the grazing. Muir (in Magee, 1885) and Bradley (1911) reported that sheep ate young conifers, and Sudworth (1900) wrote that trampling prohibited their reproduction. Bradley (1911) also stated that 'what escaped the sheep was killed in the yearly brush and grass fires started by the herders'. Both he and Hutchinson (1900) observed increased reproduction of conifers following the end of grazing in Yosemite National Park. Thus, although stream entrenchment and cattle grazing may serve to explain *P. contorta* invasion of some meadows, the key factor in Sequoia National Park was the elimination of sheep grazing; this allowed survival of *P. contorta* seedlings both in mature stands and in adjacent meadows where intense grazing had improved conditions for reproduction.

The lag period of 10 years between reproduction in mature stands and invasion of meadows may be related to dispersal, germina-

tion, and establishment problems in the meadow environment. Harkin & Schultz (1966) reported that the cutting of *P. contorta* cones by squirrels greatly impeded seed dispersal into meadows. Leonard, Harkin & Zinke (1967) observed that *P. contorta* seedlings in open meadows were usually adjacent to rocks where higher temperature, exposed mineral soil, and the early disappearance of snow cover created a 'more favourable germination and growth environment for lodgepole pine than open or plant covered soil.' Later, Leonard *et al.* (1969) hypothesized that seedling establishment 'is inhibited or prevented at the germination stage by sod, dense meadow vegetation or dense organic surface material, and by saturated soil.'

Although *P. contorta* reproduction began again with the end of sheep grazing, the overall process of increasing densities in mature stands and meadow edges may be a natural cyclic phenomenon. This process is said to involve reproduction until densities become sufficient to carry a fire; Leonard *et al.* (1969) supported the hypothesis of a 200-year interval between fires (Reynolds, 1959, claimed that John Muir first proposed this). Small fires which thinned or destroyed invading stands of *P. contorta* must have been more frequent. Fires were set by Indians in lodgepole pine forests of the central Sierra Nevada (Reynolds, 1959), but without a high population density of Indians such fires in the Sequoia National Park region were probably more often caused by lightning. Large fires also evidently played an important role in determining the meadow-forest boundary, since some meadows (e.g. stand 080) have charred, downed logs and stumps at or slightly ahead of the present edge of invasion.

Subalpine forest is found at the higher elevations of the Park between 2900 and 3700 m. Most timberline stands are dominated by *Pinus balfouriana*, but *P. albicaulis* is common on the Kings-Kern divide, and *P. monticola* is widespread on the ridge east and southeast of the Hockett Meadow region and along the Silliman crest where it occurs with *Tsuga mertensiana* (here at its southern limit, Parsons, 1972). Furthermore, some stands of *P. contorta* var. *murrayana* can be considered to be subalpine in character. Data on composition and dominance are presented in Tables 6 and

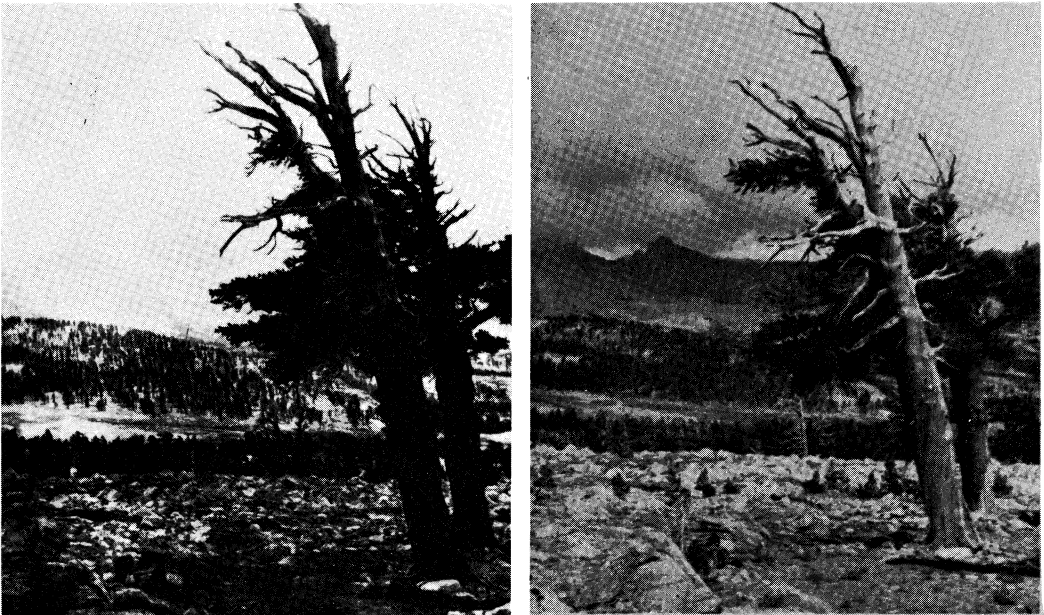


FIG. 12. Comparison photograph set in subalpine forest vegetation north of Mount Whitney. Note the increase in cover and density of foxtail pine (*Pinus balfouriana*) both in the foreground and middle-ground. The old photograph was taken in 1912, and was furnished by the Bancroft Library (Sierra Club Collection), University of California, Berkeley.

7. Usually, herbaceous cover is around 10% (but may be as high as 65%), shrub cover is 0–10%, and tree cover averages 25%. The primary change in these forests has been a slight increase in cover and density of the dominant species, especially *P. balfouriana*, both within and just outside mature stands (Fig. 12). Age determinations of this reproduction date the increase to around 1890–95 (Fig. 13). Such increased densities may be the result of favourable climatic changes; LaMarche (1973) has reported an increased reproduction of high elevation pines during the last 100 years for mountains east of the Sierra Nevada, and has stated that this represents an incipient treeline advance paralleling a warming trend which began in the mid-nineteenth century. Another likely factor is the decrease in sheep grazing which took place in 1890 in the western portion of the Park and began in 1890–95 in the Kern River drainage where, following the destruction of subalpine and alpine forage, ‘the sheep [crowded] around the meadows’ (*Report of the Acting Superintendent*, 1894). The concentration of sheep near the meadows could have allowed increased reproduction of sub-

alpine species at an earlier date than *P. contorta* at lower elevations.

Several stands of dead trees (probably *P. balfouriana*) in the northern portion of the Kern River drainage furnish evidence for another type of vegetation change. These stands are isolated from living stands, and are elevationally slightly higher than the present timberline. Curry (1968) has reported similar

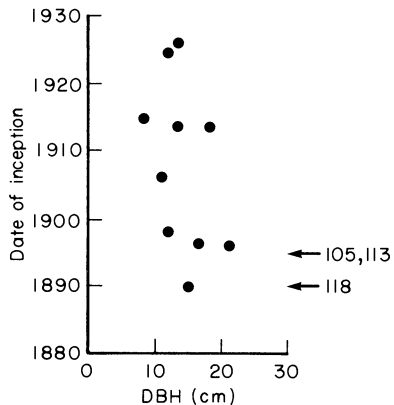


FIG. 13. Age distribution of selected *Pinus balfouriana* individuals and dates of density increases in stands of subalpine forest vegetation.

TABLE 7. Shrub data for the high montane forest vegetation types (see Table 2 for abbreviations and units)

Species	Red fir forest			Lodgepole pine forest			Subalpine forest		
	P	C	F	P	C	F	P	C	F
<i>Symphoricarpos</i> sp.	30	0.2	22						
<i>Castanopsis sempervirens</i>	10						22	0.2	50
<i>Ribes montigeum</i>				67	3.8	44			
<i>Phyllodoce breweri</i>				22	1.1	22			
<i>Ribes</i> sp.				11		11			
<i>Holodiscus microphyllus</i>							22		13
<i>Salix orestera</i>							11		
Total		0.2	22		4.9	77		0.2	63
No. of stand surveys	10			9			9		
No. of transects			10			9			9

dead trees at several locations in the Sierra Nevada, and considered them to be evidence of old timberlines. This movement of treeline probably is the result of climatic change. LaMarche & Mooney (1967) have reported dead stands of the closely-related *Pinus aristata* in the White Mountains of California, indicating a former timberline of up to 150 m higher than present. Their radiocarbon dating and ring counts showed that the dead trees were from the 'altithermal' period, a time of general warming in California which ended roughly 2700 years ago. Later, LaMarche (1973) reported that a higher treeline existed until after about 2200 BC and that a major fall in treeline elevation occurred between AD 1100 and 1500.

Grasslands

The distribution of California grassland vegetation within the Park indicates a close association with the blue oak and California black oak woodlands. The dense herbaceous layers of the grassland and the woodlands are today composed of annual grasses, many not native to California. It is thought that prior to the 1850s these herbaceous layers, like the rest of California's grasslands, were dominated by perennial bunch grasses. Livestock grazing appears to be the primary factor involved in this change; Burcham (1957) concluded for California's rangeland that 'there can no question that [the 1850s-1860s] combination of drought and grazing pressure was to a great extent responsible for the replacement of the perennial plant cover by annuals.'

Wet meadows vegetation is on alluvial parent material at elevations above 1800 m. Bennett (1965) described stands as being 'mostly open and having a cover composed predominantly of perennial sedges, rushes, and grasses that are dependent upon abundant moisture throughout the growing season'. Stands may be subdivided into coarse-leaved and fine-leaved sedge types. The former is composed primarily of *Carex lanuginosa*, *C. rostrata* and *C. nebrascensis*, while the latter has *C. festivella*, *C. spectabilis*, *C. subnigricans*, *Calamagrostis breweri*, *C. canadensis* and *Poa pratensis* (Bennett, 1965). Vegetation changes within these wet meadow types have been characterized by an invasion of introduced species, a decrease in herbaceous cover, and a partial replacement of grasses by unpalatable forbs on meadows subjected to stock grazing. Armstrong (1942), Bennett (1965), Burcham (1957), Hubbard *et al.* (1965, 1966), Sharsmith (1959), Sumner (1941, 1968) and others have reviewed these changes in detail. The invasion of meadows by *Pinus contorta* var. *murrayana* is discussed in the paragraphs on the lodgepole pine forest.

Woodland meadow vegetation also is found above 1800 m. It is composed of a herbaceous layer with scattered trees, including *Pinus contorta* var. *murrayana*, *Populus trichocarpa* and *P. tremuloides*. Bennett (1965) felt that this vegetation represented stands of wet meadow which had dried out, and had been invaded by trees. Most changes in this type would be similar to those of wet meadow vegetation, but there also has been an increase in tree density and cover.



FIG. 14. Comparison photograph set in shorthair meadow vegetation near the southeast boundary of the Park. Note the exposed soil in the foreground of the old photograph, and the partial recovery from this effect of grazing. The old photograph was taken in 1903 and was furnished by the Bancroft Library (Sierra Club Collection), University of California, Berkeley.

Shorthair meadow occurs at the higher elevations, usually above 2450 m. In contrast to wet meadow vegetation, it is found on sites which become dry during the summer. Dominant species are *Carex exserta*, *Calamagrostis breweri* and *Trisetum spicatum* (Bennett, 1965). They usually form dense mats, but grazing has resulted in a breakup of portions of them. There has been some re-vegetation since the elimination of sheep (Fig. 14), but grazing by pack stock has limited recovery.

Xeric alpine vegetation lies above timberline throughout the Park. It is characterized by perennial herbs scattered between the rocks which dominate the landscape. Examples of species found in the Park region are *Carex helleri*, *C. breweri*, *Festuca brachy-*

phylla, *Poa rupicola*, *P. suksdorfii*, *Luzula spicata*, *Eriogonum ovalifolium*, *Oxyria digyna*, *Draba densifolia*, *D. breweri*, *D. lemonii*, *D. oligosperma*, *Phoenicaulis eurycarpa*, *Ivesia shockleyi*, *Potentilla diversifolia*, *Epilobium obcordatum*, *Polemonium eximium*, *Cryptantha nubigena*, *Castilleja nana*, *Penstemon davidsonii*, *Haplopappus macronema* and *Hulsea algida*. The previously-discussed historical accounts of the effects of sheep grazing have led some to claim that the present sparsely-vegetated condition of the alpine zone of the Sierra Nevada is due to erosion following sheep grazing (e.g. Flynn, 1964). However, statements made by Clarence King before the grazing occurred suggest that the alpine region never had an extensive plant cover (except for the areas of shorthair mea-

dow vegetation). He observed (in Whitney, 1865) that from the Kings-Kern Divide toward the Kern River drainage, 'there were a few *Pinus contorta*, visible down the course of the Kern, and quite a grove of *P. breweri* [probably *P. balfouriana*]; these with a few willows [*Salix* spp.] and an Alpine *Ribes*, were all the vegetation we could see, excepting a few carices.' He also reported that in the region from Mount Brewer to the Great Western Divide 'the few *Pinus contorta*, and the groves of our new pine [probably *Pinus balfouriana*] have a peculiar black color, or, rather, dark bluish-green, which rather augments than relieves the desolate, naked aspect of things. The only bits of bright color to break the solemn monotony of granite and snow are the blue lakes, which lie everywhere in the ancient glacier-beds.' Thus, the alpine zone of the Sequoia National Park region was not densely covered with herbaceous vegetation even in its pre-western man condition. However, sheep grazing undoubtedly did result in an overall decrease in herbaceous cover, followed by partial recovery.

Conclusions

The investigation of vegetation change in a region of great ecological diversity is a complex task. In the case of Sequoia National Park, the problems are compounded by past changes in land use and land management practices. A synthesis of the evidence gathered from a wide variety of sources for many vegetation types clearly leads to the conclusion that the primary factor in vegetation change within the Park has been the land use practices of western man. Nineteenth-century livestock grazing nearly completely changed the species composition of the herbaceous layers of the grasslands and the foothill woodlands, and resulted in increased tree densities in the blue oak foothill woodland and the lodgepole pine and subalpine forests. The lack of periodic burning between the end of Indian occupancy and the re-establishment of fire by livestock herders brought about increased tree densities that are still observable in the white fir and white fir-giant sequoia forest types. Park fire control practices, especially during

the effective post-1930 fire suppression programme, reduced fire frequency and increased woody plant density in certain woodlands and most shrublands and forest types. Despite this identification of the dominant factor for each major change, undoubtedly all of the vegetation types in the Park have been affected by both livestock grazing and changes in fire frequency.

The applications of findings of this study to Park management are perhaps obvious. The National Park Service formally recognizes the need to use 'ecological management techniques to neutralize the unnatural influences of man, thus permitting the natural environment to be maintained essentially by nature' (U.S. Department of the Interior, 1970). This study furnishes the Park administration with potential goals for vegetation management and, in some cases, with possible approaches for the achievement of such goals. On a larger scale, the results of this study point to the recognition of the long-lasting, encompassing impact of various land uses. Since the effects of altered burning practices and livestock grazing of 100 years ago are still evident today, there must be concern for the future of the vegetation of the Sierra Nevada, where both private and public land use include the clear cutting and high-grading of marginally productive forest sites with attendant soil destruction, landsliding, forest to brushfield conversion, and loss of genetic quality. The vegetation of Sequoia National Park may have the opportunity to recover from past abuse, but other wildlands must not be irrevocably changed. Ecologically oriented land management must be used to achieve a continuing mix of recreational, aesthetic, and economic benefits.

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